Retrofit Pathways to Decarbonisation

11th January 2023

Supporting our recent article 'Retrofit, is Fabric First Really the Best Strategy?' let's have a more detailed look at some example pathways to decarbonisation, to clearly demonstrate how a 'fabric first' approach is no longer the best way forward for retrofitting a standard home.

We have utilised our proprietary energy model 'Hedgehog', to project how a 1955 semi-detached home with unfilled cavity walls and a combi boiler that requires replacing in 2023, would be affected by a number of different retrofit strategies. In order to model impacts out to 2050 we have used these emissions factors, based on National Grid's Future Energy Scenario (without BECCS) and these rates. There is obviously significant uncertainty about what will happen to rates in particular, depending on how the market evolves. These numbers should be taken as indicative only.

Pathways modelled

We modelled the following options:

Solar PV only	• 6 kW solar PV • Replace existing gas combi boiler with a similar model
Heat pump only	• 7kW Vaillant Arotherm at a max flow temperature of 45°C • 7 triple convector radiators • Smart hot water cylinder
Heat pump and solar	• As 'Heat pump only' plus • 2.6 kW solar PV
+ CWI, loft insulation, airtightness and dMEV	• 5kW Vaillant Arotherm at a max flow temperature of 45°C • 5 triple convector, 1 double convector radiators • Smart hot water cylinder • 6 kW solar PV • Loft insulation top up to 0.11 W/m^{2}K (400mm) • Cavity wall insulation (CWI) 0.7 W/m^{2}K • Party cavity wall insulation 0 W/m^{2}K • Airtightness works 12 m^3/m^2/hr @ 50Pa • Decentralised mechanical extract ventilation (dMEV) in the kitchen and both bathrooms

+ Windows and doors	As above but with the following adjustments/additions: • 5kW Vaillant Arotherm at a max flow temperature of 45°C • 2 triple convector, 4 double convector radiators • High-performance double-glazed windows 1.2 W/m^2K and doors 1.4 W/m^2K improving air tightness to 7 $m^3/m^2/hr$ at 50Pa
+ EWI and floor insulation	As above but with the following adjustments/additions: • External wall insulation (EWI) 0.25 W/m^2K • Solid floor insulation 0.25 W/m^2K • 3 double convector, 3 single convector radiators

The detailed inputs and results for each pathway are shown in Appendix Table 1.

Doing everything all at once

For an initial comparison of the options, we modelled the impact of doing all of the retrofits, all together at the start of 2023, then calculated the costs and savings relative to the baseline case of simply replacing the gas combi boiler with a similar model every 15 years.

Figures 1 and 2 shows the results of this comparison, with % bill savings, % carbon savings, upfront costs and investment net present value (NVP) of each option calculated up to 2050. The upfront cost and investment NPV values do not include any grants. The investment NPV is calculated using a discount rate of 5%. Carbon and bill savings are shown as a percentage saving relative to not upgrading the building at all.

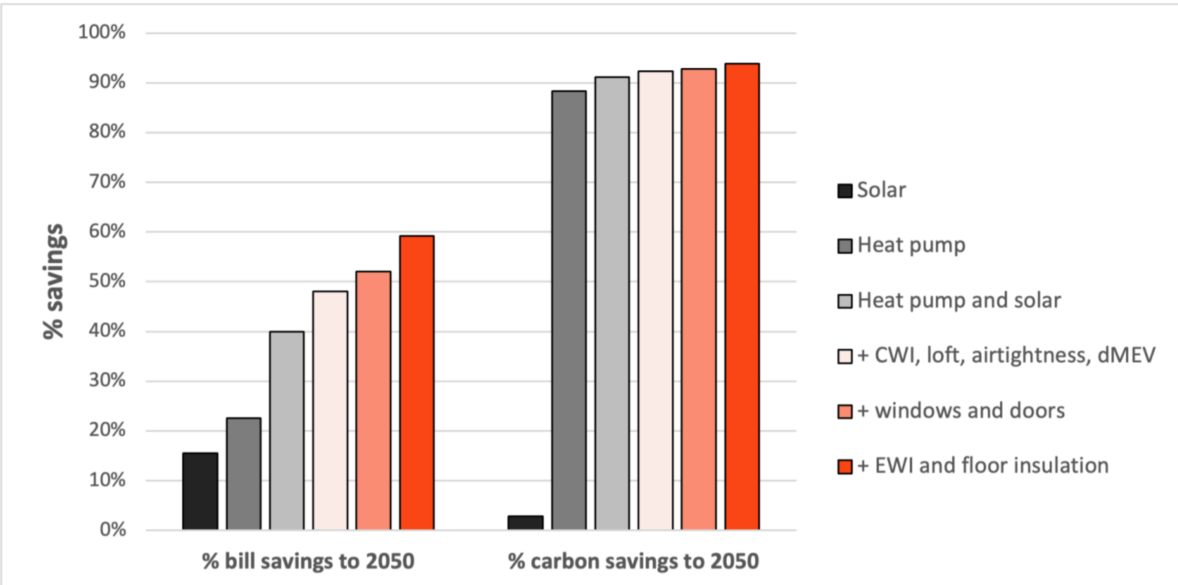


Figure 1: *Bill and carbon savings out to 2050 relative to gas boiler replacement at end of life*

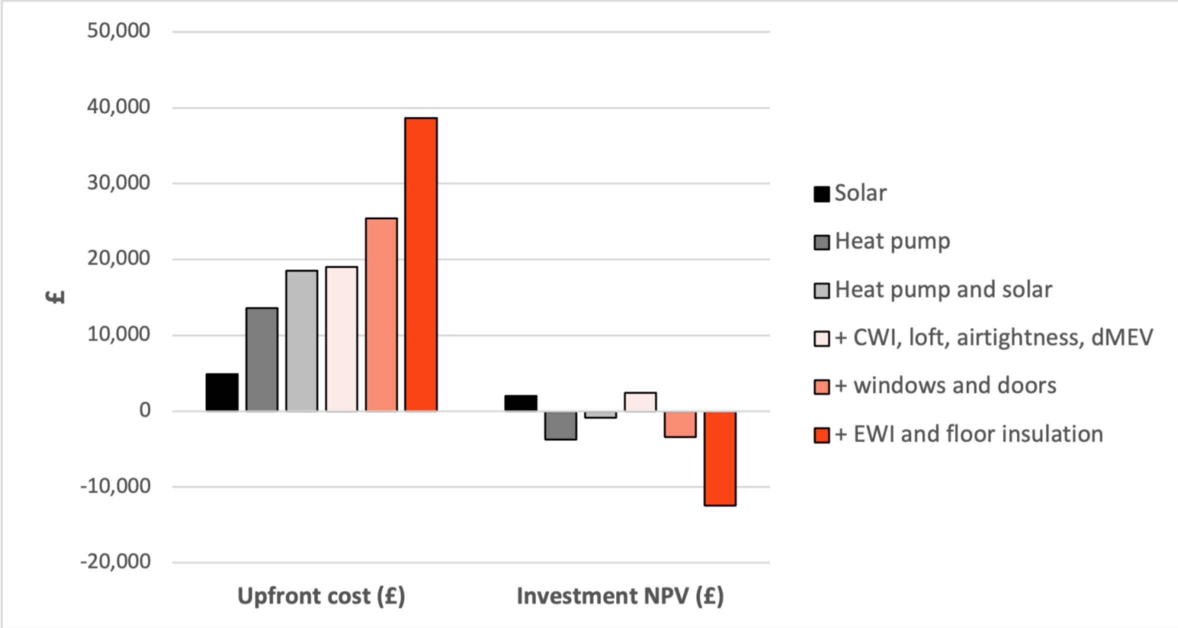


Figure 2: *Upfront cost and Net Present Value of each retrofit option. Calculated relative to gas boiler replacement at end of life, using a 5% discount rate*

Perhaps the most striking result is that the heat pump delivers massive carbon savings (88% reduction in lifetime emissions to 2050) all on its own. Upgrades beyond the heat pump only slightly increase this (to at best 94% with the deepest retrofit). This is because, as the grid decarbonises, the emissions associated with electricity tend to zero, so increasingly saving electricity only saves very small amounts of carbon. For similar reasons, the carbon impact of solar PV is very small (3% lifetime saving up to 2050) because it displaces electricity from an increasingly clean grid.

From an economic perspective however solar PV is a great investment, with an NPV of £2000 for this particular home. The heat pump alone delivers bill savings, but not enough to offset the capital costs (the difference would be more than offset by the current Boiler Upgrade Scheme grant of £5000, but we haven't modelled that here as it is not available to social landlords). The heat pump + solar PV combination is the best of both worlds, giving higher bill and carbon savings than either solution in isolation.

Adding CWI, loft insulation, airtightness works and dMEV only marginally increases carbon savings (to 92%), but these relatively cheap retrofits reduce the cost of the heat pump installation by reducing the need for radiator upgrades. As such the total capital cost of this pathway is only a few hundred pounds more than for the solar PV and heat pump only pathway. This option significantly increases bill savings at a small additional cost, leading to the biggest net saving. This highlights that, when easy fabric upgrades are available, it is absolutely worth doing them.

Adding high performance windows and doors brings carbon savings up to 93%, but significantly increases capital costs, whilst increasing savings to a much lesser extent, making the NPV of the overall investment negative.

Adding external wall insulation and insulating the solid floor brings carbon savings up to 94%, increases capital costs even further whilst increasing bill savings to a lesser extent, further reducing the NPV.

Acknowledging budget constraints

In the absence of budget constraints, you might reasonably design policy to push for the deepest retrofit case presented above, arguing that the system benefits in terms of reduced infrastructure build out would make up for the cost difference, as system costs are not well reflected by customer rates.

However, this is counterproductive in the face of real-world budgetary constraints, especially with ever increasing interest rates. The real implication of pushing for a deep fabric approach is likely to delay heat pump installations. To quantify this impact, we modelled two further options for implementing the deepest retrofit case, with 2 stages of retrofit 15 years apart:

Year	Fabric first	Easy insulation + heat pump first
2023	Loft insulation, cavity wall insulation, airtightness, dMEV, Solar PV + • EWI • High performance windows and doors, • Solid floor insulation • Gas combi boiler	Loft insulation, cavity wall insulation, airtightness, dMEV, Solar PV + • Heat pump • Cylinder • Radiators
	Upfront costs ~ £34,000*	**Upfront costs ~ £19,000***
2038	• Heat pump • Cylinder • Radiators	• EWI • High performance windows and doors, • Solid floor insulation
	Upfront costs ~ £7,800*	**Upfront costs ~ £23,000***

*prices shown are at current costs.

The capital cost, NPV, bill savings, and carbon savings are shown in the figures below, with the 'Everything all at once' case included for comparison. The incremental impact of the second step is hashed to allow you to differentiate.

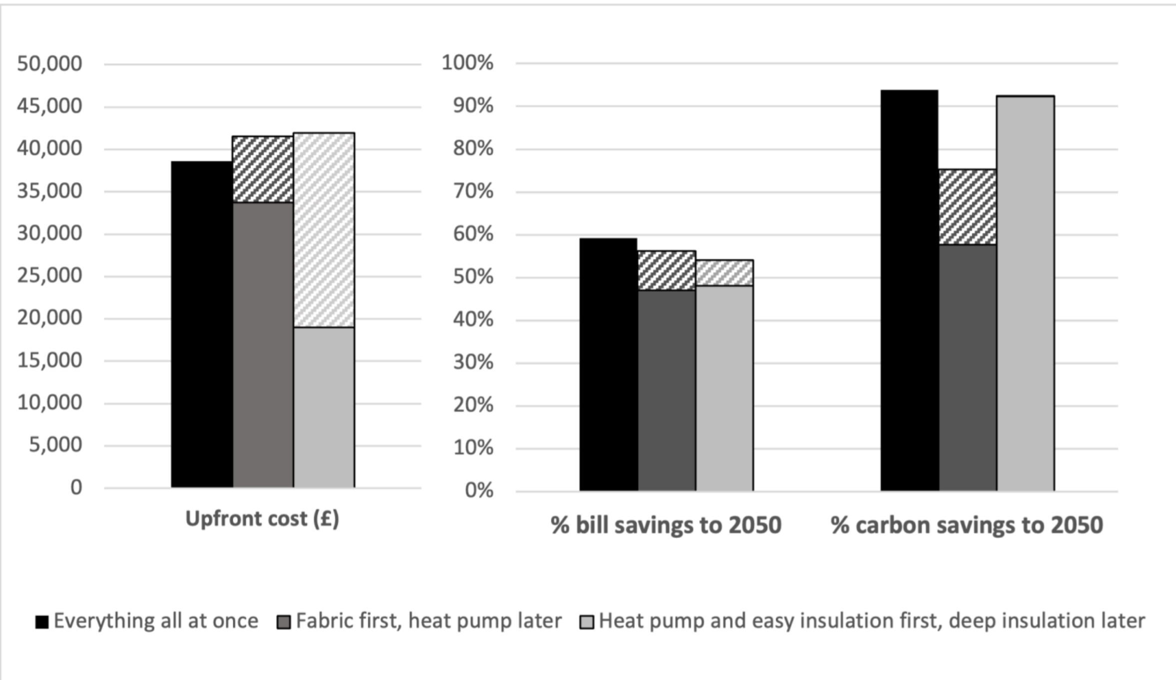


Figure 3: *The impact of ordering: costs, bill savings and carbon saving comparison. In the "Fabric first, heat pump later" case, a deep fabric retrofit occurs in 2023 with a heat pump is installed 15 years later (impact shown in the hashed area). In the "Heat pump and easy insulation first" case, a light fabric retrofit occurs in 2023 alongside a heat pump install, and the deep fabric measures happen 15 years later.*

The upfront cost and bill saving benefits of insisting on a fabric first approach are very small, and the carbon downside is very significant. The fabric first approach only delivers a 74% saving to 2050 whereas the heat pump first approach delivers a 92% saving. Putting the heat pump in first slightly increases the overall capital cost as you spend more on radiators and a larger heat pump. The bill savings are also slightly lower in the heat pump first approach, but not significantly. Importantly the heat pump first approach delivers on carbon savings now and leaves you the option of doing expensive deep fabric retrofits later, whereas the fabric first approach keeps you burning gas, whilst leaving the bulk of the carbon savings contingent on future action.

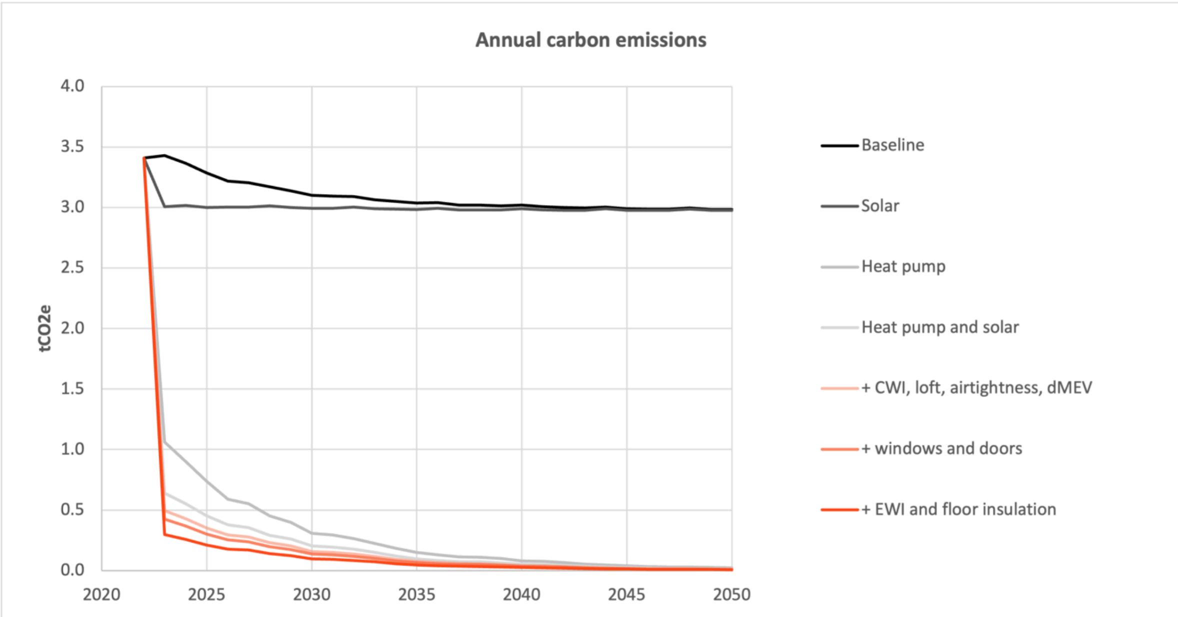
Finally, the heat pump first approach has significantly lower upfront costs, making it more affordable for both landlords and homeowners, therefore all the more likely to actually happen. In a world that needs us to rapidly reduce emissions, we should seize this compelling decarbonisation option with both hands, not put barriers in its way.

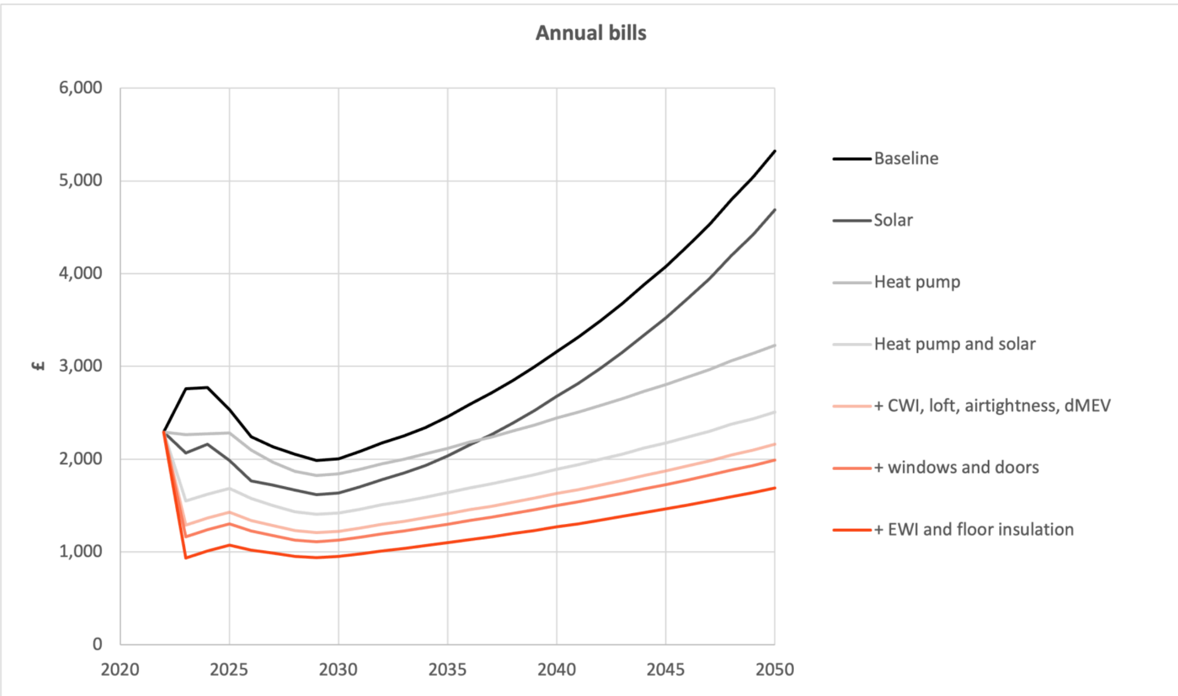
Author: *Steph Willis is one of Sero's dedicated data scientists and our resident heat pump expert, with a wealth of experience in maximising the potential of this innovative technology.*

Appendix

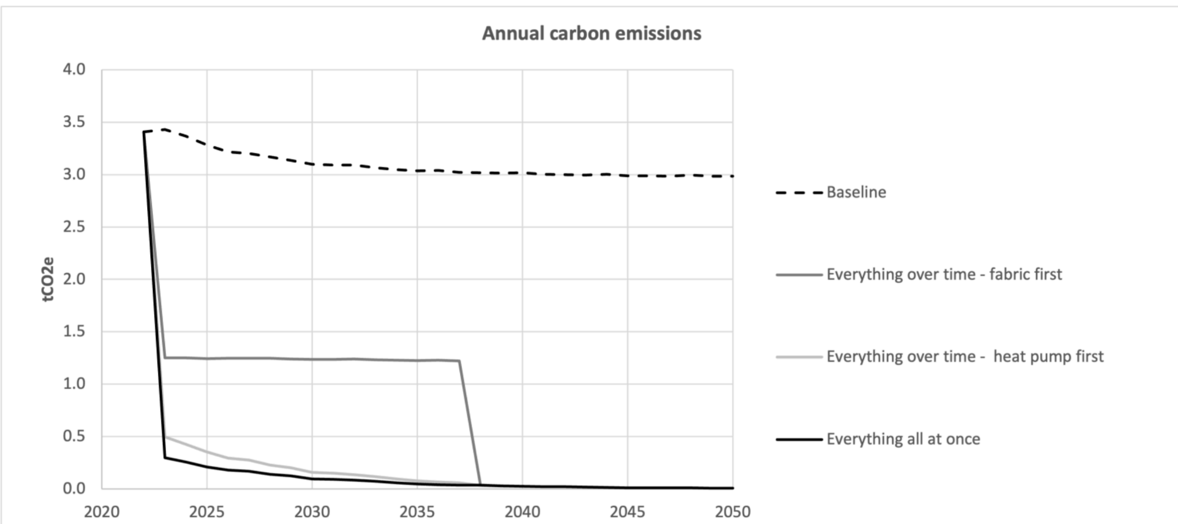
Time series graphs

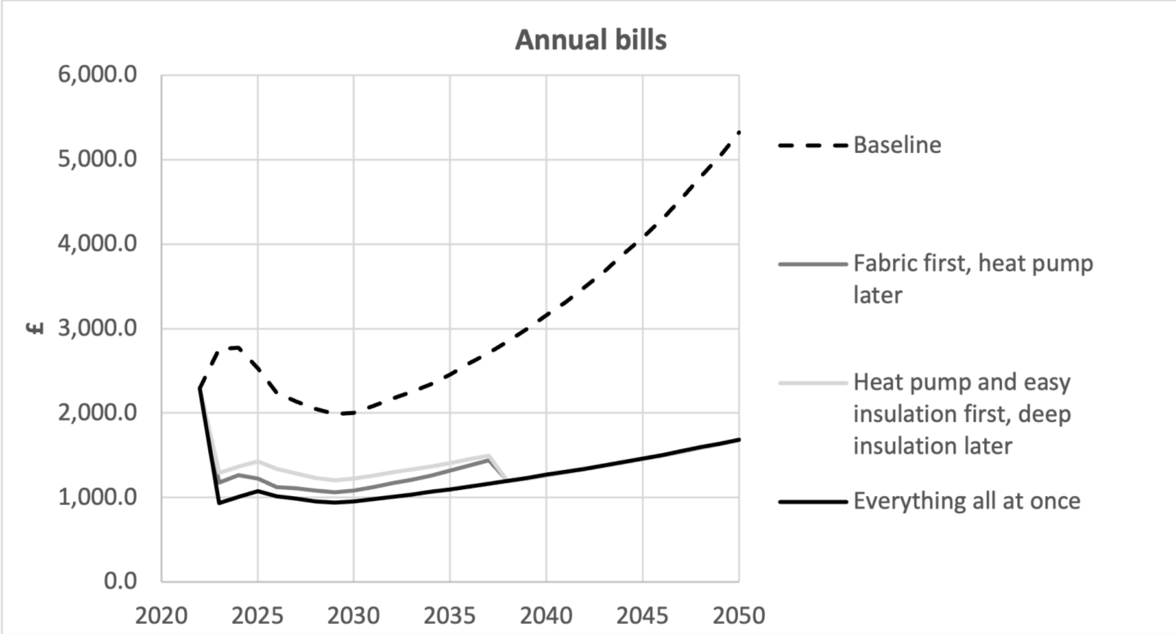
Everything all at once





A phased approach





Detailed inputs

Variable	Baseline	Solar only	Heat pump only	Heat pump and solar	+ CWI, loft, airtightness dMEV	+ windows and doors	+ EWI and floor insulation
Roof U value (W/m2K)	0.4				0.11	0.11	0.11
Wall U value (W/m2K)	1.5				0.7	0.7	0.25
Party Wall U value (W/m2K)	0.5				0	0	0
Floor U value (W/m2K)	0.62						0.25
Window U value (W/m2K)	2.8					1.2	1.2
Rooflight U value (W/m2K)	3.1					1.5	1.5
Door U value (W/m2K)	2.8					1.4	1.4
Infiltration m^3/m^2hr @ 50 Pa	15				12	7	5
Ventilation System	Intermittent extract				dMEV	dMEV	dMEV
Space Heating System	Condensing gas combi, > 1998, auto ign.	Condensing gas combi, > 1998, auto ign.	ASHP	ASHP	ASHP	ASHP	ASHP
Heat pump capacity (kW)			7	7	5	3.5	3.5
Flow temperature	70		45	45	45	45	45
Space Heating Efficiency[1]	0.84		3.91	3.91	3.77	3.65	3.65
Water Heating Efficiency	0.84		3.00	3.00	3.00	3.00	3.00
Cylinder volume (l)	0		210	210	210	210	210
PV Capacity (kWp)	0	2.6		2.6	2.6	2.6	2.6
Radiators	2 double convectors and 4 single convectors		7 triple convectors	7 triple convectors	5 triple convectors, 1 double convector	2 triple convectors, 4 double convectors	3 double convectors and 3 single convectors

[1] *These efficiencies are based on Vaillant arotherm specification data at a flow temperature of 45C. The radiators included at each step were sized to meet the home's heat load at the flow temperature. In reality the heat pump would run at a lower flow temperature than that for most of the year because it would run with weather compensation, which would improve efficiency. The efficiencies are lower in the better fabric cases because the smaller heat pump models have lower rated efficiencies.*

Detailed outputs

Variable	Baseline	Solar only	Heat pump only	Heat pump and solar	+ CWI, loft, airtightness dMEV	+ windows and doors	+ EWI and floor insulation
EPC	D	C	D	B	B	A	A
SAP	62	77	67	83	89	92	99
EIR	57	71	70	84	90	93	99
Space heating demand (kWh/m2)	170	170	169	169	116	89	48
HLP (W/m2K)	4.0	4.0	4.0	4.0	2.8	2.3	1.5
Upfront cost (£)	2,900	4,900	13,600	18,500	19,000	25,400	38,700
NPV capital costs to 2050 *(5% discount rate)*	4,100	9,300	15,900	21,100	21,500	29,100	41,300
NPV bill savings to 2050 *(5% discount rate)*		7,200	8,000	16,100	19,700	21,500	24,700
Investment NPV (£) *(5% discount rate)*		2,000	-3,700	-900	2,400	-3,400	-12,400
Abatement cost (£/tonne) *(5% discount rate)*		-1,041	91	21	-55	78	277
% carbon savings to 2050		3%	88%	91%	92%	93%	94%
% bill savings to 2050		16%	23%	40%	48%	52%	59%

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