Options appraisals for heat pump retrofit in 15 London buildings

A Carbon Trust report for the Greater London Authority (GLA)

August 2020














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Contents

Introduction

Replacing fossil fuel boilers and direct electric heating with heat pumps is fundamental to the Mayor of London's ambition for a net zero carbon, low pollution city.

To better understand the potential role of heat pumps in decarbonising buildings, the Greater London Authority (GLA) commissioned the Carbon Trust to write a report on **Heat Pump Retrofit in London.**

To inform the analysis in the main report, we undertook heat pump retrofit options appraisals for 15 example buildings in London that are typical of common building types in the London stock.

For each building, we assessed the technical potential for different retrofit options such as the potential locations for different heat pump systems and the potential for improving heat emitters and thermal fabric of the building. Based on this assessment, we selected a range of packages of measures (encompassing heat pumps, upgraded heat emitters and energy efficiency improvements) and modelled the costs and impacts of each package.

Information provided in each Options Appraisal

For each scenario we assessed the following factors, details of which are provided in this report:

- **CAPEX**: The up-front capital costs of the retrofit package, the anticipated lifetime of the measures and the CAPEX over a 30-year period[1].
- **OPEX:** The annual heating bills and costs associated with associated with service and maintenance.
- **Lifetime costs:** The combined CAPEX and OPEX over periods of 10, 20 and 30 years. We did not adjust lifetime costs for inflation and we did not apply a discount rate[2].
- **Lifetime costs including grants and other financial variables**: In addition to the baseline financial calculations, we have provided lifetime costs including current RHI rates (as of April 2020), the proposed £4,000 Clean Heat Grant and scenarios including flexible time of use tariffs.

[1] CAPEX over a 30 year period was calculated by assuming a lifetime for each of the measures installed. For example, for air source heat pumps this was typically 15 years, whereas for ground source heat pumps this was typically 20 years. For gas condensing boilers the lifetime was assumed to be 12 years. Upon replacement, we calculated the proportion of original up-front costs that would need to be spent again on a replacement. For example, for heat pumps, are a proportion of installation costs associated with installing new pipework would not be applicable on subsequent installations. For ground source heat pumps, it was assumed that ground loops would not need replacing until 50 – 100 years. However, we did not account for potential changes in the cost of heat pump capital equipment over time. Research for BEIS in 2016 suggest that a ~20% cost reduction in heat pump installations could be possible when the market reaches full maturity. We included a scenario that looks at an overall 20% reduction in capital costs to give an indication of the impact of this potential reduction. Our heat pump capital costs include the full cost of installing associated hot water cylinders or thermal stores and associated pipework.

[2] Whilst it would be common practice to apply a discount rate in 30 year financial calculations, for the purposes of this study we felt that it was more transparent and accessible to show real costs in 2020 terms.

- **CO_2 savings:** We looked at CO_2 savings cumulatively over a 30-year period.

- **Heat pump efficiency:** based on the core parameters of the heat pump design and using specific makes and models deemed suitable for each scenario, we estimated the efficiency of the heat pump in use.

- **Thermal Energy Demand Intensity (TEDI) in kWh per m^2 per year:** For each building we assessed the predicted thermal demand for space heating, based on the levels of heat loss from the property and predicted space heating requirements.

- **Flow temperatures**: In each case we assessed the flow temperatures required to deliver comfortable temperatures for the building. These were calculated as a function of the building heat loss and the capacity of the heat emitters and are quoted for a design day of -1.8°C external temperature and 20°C internal temperature.

Methodology and data

A full methodology is available in the final chapter of this document. In summary:

- Detailed energy use, energy survey and other information on buildings was provided by a combination of supportive London Boroughs and private individuals.

- For each building, we undertook heat loss calculations, an assessment of current annual energy use and an assessment of the capacity of current heat emitters. For a number of cases, we used existing half hourly metered data to help understand the likely peak heating load.

- To determine appropriate heat pump systems for each building and their costs, we engaged with heat pump manufacturers and installers who provided high level system specifications and indicative costings.

- Require energy efficiency measures were determined by a combination of recommendations from Energy Performance Certificates and existing energy surveys of buildings. The costs for energy efficiency measures were based on a combination of secondary research sources and primary research on material and labour costs in the London market.

- To determine the likely performance of the heat pump in-situ we utilised the Building Research Establishment's (BRE) tool: Domestic Annual Heat Pump System Efficiency (DAHPSE) calculator.

- To determine the impact of energy efficiency measures in each building we used a combination of data from heat loss calculations undertaken to BS EN 12831 and the SAP 10.1 methodology.

- We used marginal CO_2 emissions factors from 2020 – 2060 from the Treasury Green Book.

- We used estimated gas and electricity tariffs from the Treasury Green Book Domestic and Commercial Central scenarios for 2020 – 2060.

The importance of demand reduction to achieving net zero carbon emissions

The scenarios for each building were chosen to highlight the relative costs and benefits of different combinations of heat pump, heat emitter and energy efficiency measures. For example, different scenarios were chosen to understand the relative costs and benefits to the building owner of packages involving energy efficiency and not involving energy efficiency.

However, as discussed in the main report, at the energy system level, energy efficiency and thermal energy demand reduction are essential components for the wide-spread transition to heat pumps in buildings. Therefore, the scenarios presented here should not be interpreted as recommended packages of measures for each building. Rather they are an exploration of the relative costs and benefits under current market conditions, from the building owners point of view.

Business As Usual is not an option

For each building, a Business as Usual (BAU) scenario was developed (scenario A) against which all of the other scenarios were compared. In the majority of cases, the BAU scenario was the replacement of the existing gas heating system with a modern, efficient gas boiler replacement. The BAU scenario was chosen as the most typical example of current practice in the real world. However, in the context of this report it is crucial to note that the BAU scenario fails to deliver the carbon, air pollution and fuel poverty reductions required.

Rather, the BAU scenario is included as a useful comparator to help identify where the heat pump retrofit options offer the most compelling financial cases in the immediate term and, on the other hand, the buildings that will require further regulatory and fiscal support to make the case for heat pump retrofit compelling.

This report provides a detailed summary of each of the 15 buildings used in the analysis and the results of the options appraisal for each one. Whilst the information provided here is unique to the circumstances of each individual building, each appraisal provides useful transferable information for other building owners, local authorities or social landlords exploring the potential to retrofit existing buildings with heat pumps.

Similarly, in our analysis we have assumed that the cost of energy efficiency measures is fully additional to the BAU costs. However, in order to meet net zero carbon objectives, energy efficiency is essential under all technology choices and so this cost could be considered essential under all scenarios. Also, a level of spending on the building fabric is likely to necessary under any BAU scenario, for example through replacing windows and roofs within the 30-year lifetime analysed here. This spending is not included in our BAU calculations. Again, our intention here is to identify the relative merits of different retrofit packages from the building owners' perspective, in the context of making a choice about a replacement heating system in 2020.

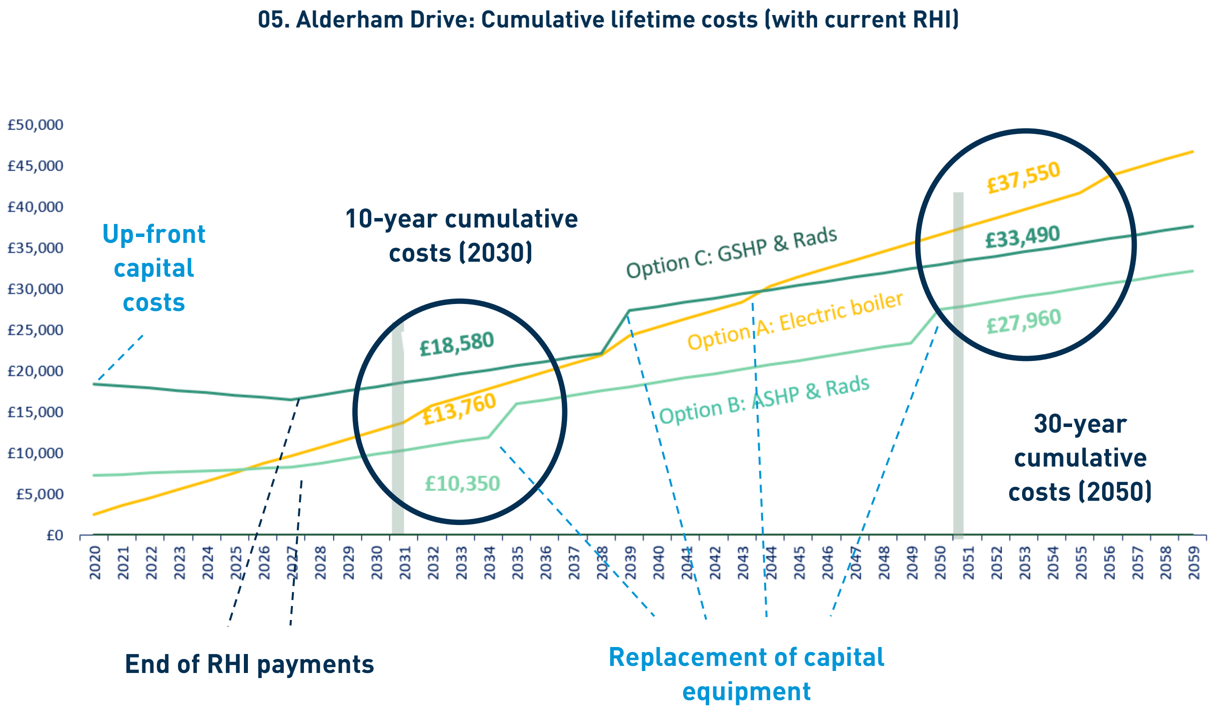
Buildings used for analysis

The 15 Buildings are broadly representative of a range of common building types in London. Whilst they are not intended as an exhaustive or statistically representative sample of buildings in London; they provide valuable insights in to the challenges and opportunities of heat pump retrofit in London. GLA analysis indicates that the 11 domestic buildings are broadly representative of around a quarter of London's homes.

Domestic									
No.	Street	Borough	Beds	Floor area	Type	Age	Heating fuel	EPC Rating	(kWh per m² pa)
1	Lymington Road	Camden	1 Bed	49m2	Ground floor, flat	1970s	Gas	C	69
2	Cavendish House	Barnet	2 Bed	75m2	Mid floor, flat	1980s	Gas	B	26
3	Sherwin House	Lambeth	2 Bed	53m2	Ground floor, flat	1930s	Gas	C	74
4	Northcote Road	Wandsworth	3 Bed	114m2	Top floor, maisonette	Victorian	Gas	D	105
5	Aldenham Drive	Hillingdon	2 Bed	60m2	Terraced house	1980s	Electric boiler	C	66
6	Surrey Road	Southwark	3 Bed	93m2	Semi-detached house	1960s	Gas	C	72
7	Mowbray Road	Croydon	3 Bed	133m2	Detached house	1930s	Gas	D	123
8	Albany Road	Newham	3 Bed	94m2	Terraced house	Pre 1919	Gas	D	94
9	Tradescant Road	Lambeth	5 Bed	142m2	Terraced house	Victorian	Gas	E	156
10	Ernest Dence Estate, Greenwich		95 Flats	~5,700m2	Block of flats	1930s	Gas (Communal)	C - E	116
11	Enfield Tower Block	Enfield	50 Flats	~2,900m2	Block of flats	1960s	Electric heating	C - E	52
Non-domestic									
12	Gifford House	Merton		~800m2	Small office	1983	Gas	D	110
13	Billet Road	Waltham Forest		2413m2	Medium office	1970s	Gas	C	90
14	Docklands Road	Newham		37,544m2	Very large office	2000s	Gas (electric cooling)	D	90
15	Wimbledon Library	Merton		500m2	Library	Victorian	Gas	D-E	130

Interpreting the lifetime costs charts

Each of the lifetime costs charts presents a cumulative analysis of the combined capital and operational costs under each scenario. The following graph is an example from the cumulative lifetime costs analysis.



Each graph contains:

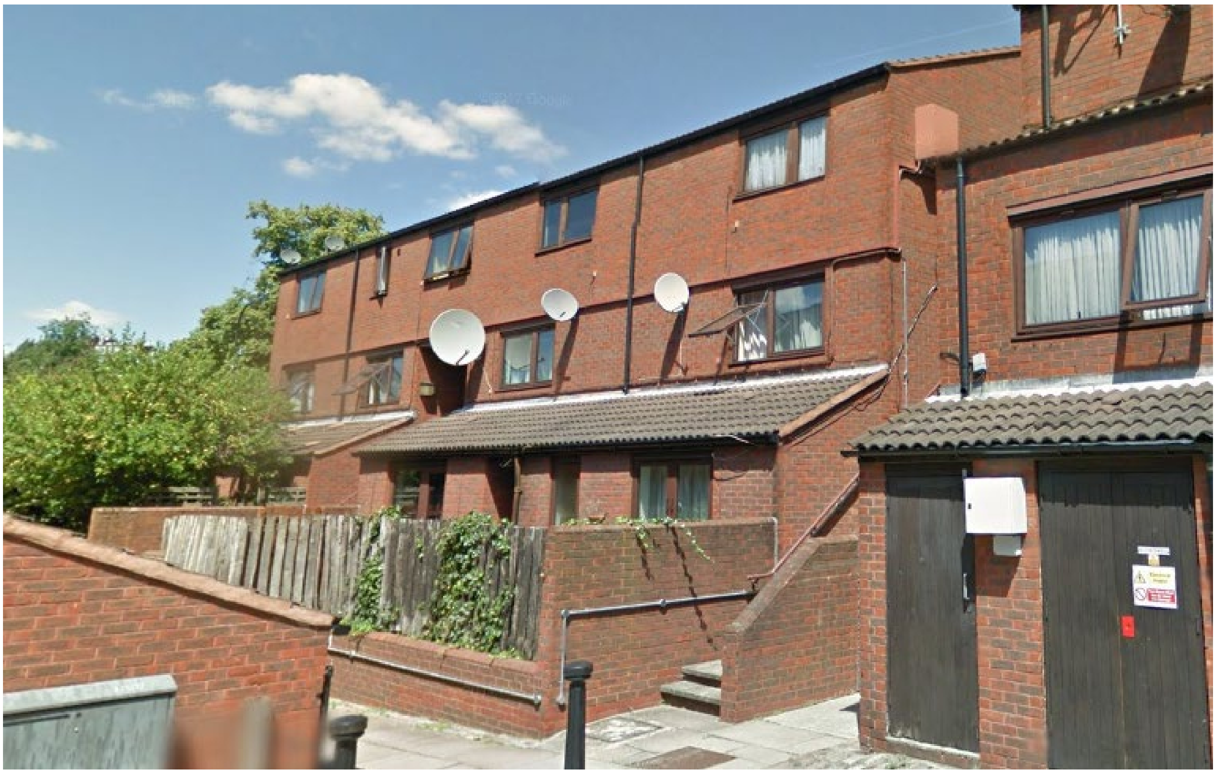
- Lines showing the total cumulative cost of ownership for each scenario over a 40-year period
- Figures for the cost of ownership at 10 years (left hand side)
- Figures for the cost of ownership at 30 years (right hand side)
- Within each line it is possible to see developments such as the replacement of capital equipment and the end of RHI payments (RHI payments as of April 2020).
- All costs are un-discounted and do not apply a rate of inflation. Predicted future energy prices are taken from the Treasury Green Book central forecasts for gas and electricity prices.
- Each graph accounts for the full capital installation costs (including all heat emitters, hot water cylinders and ancillary works) as well as any energy efficiency improvements where these are part of the scenario package.

- Our typical assumptions for the replacement of capital equipment were that gas boilers would need replacing every 12 years; air source heat pumps every 15 years; ground and water source heat pumps every 20 years.

- The initial costs of installation for heat pumps were typically higher than the subsequent replacement costs. This is because certain ancillary works (such as the installation of new pipework) are often necessary on the first installation of a heat pump that are not needed when the heat pump is replaced.

- We did not take in to account the potential depreciation of heat pump capital equipment over time. In reality, there is scope for heat pump prices to fall relative to gas boilers. We also did not take in to account potential future changes in taxation on gas and electricity.

01. One bed ground floor flat, EPC C: Lymington Road, Camden



Age	Type	Floor area (m^2)	EPC rating
1980s	1 bed ground floor flat	52	C (70)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
3,596	2,317	5,913	NA
Space heating demand (kWh per m^2 pa)	Current space and water heating system	Secondary heating	Current flow temperature
69	Gas combi-boiler and radiators (Double panel) No cylinder)	None	Unknown
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators ($^{\circ}$C)
2.6	4.8	1.83	51^{0}C
Monthly indicative gas usage (kWh) 2019			
Jan	807	Jul	162
Feb	825	Aug	174
Mar	676	Sep	282
Apr	505	Oct	473
May	281	Nov	748
Jun	162	Dec	818

Assessment of retrofit potential: 01. Lymington Road.

<table>
<tr><th colspan="3">Potential for air source heat pump (external unit)</th><th colspan="2">Potential for individual GSHP</th></tr>
<tr><td rowspan="5">Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?</td><td>Rear garden</td><td>Yes</td><td>Available & accessible space for ground trench</td><td>No</td></tr>
<tr><td>Balcony</td><td>No</td><td>Available & accessible space for bore hole</td><td>Maybe*</td></tr>
<tr><td>External walkway</td><td>No</td><td colspan="2">Potential for shared ambient loop</td></tr>
<tr><td>Roof terrace</td><td>No</td><td>Space for boreholes within building curtilage?</td><td>Yes</td></tr>
<tr><td>Wall mounted</td><td>No</td><td>Available service ducts for internal pipework?</td><td>Unknown</td></tr>
<tr><td colspan="3">Potential for heat pump (internal unit)</td><td colspan="2">Other source potential</td></tr>
<tr><td colspan="2">Suitable space for internal ASHP?</td><td>Limited</td><td>Available water source</td><td>No</td></tr>
<tr><td colspan="2">Suitable space for hot water cylinder?</td><td>Limited</td><td>Waste heat, tube, sewer, other</td><td>No</td></tr>
</table>

Energy efficiency upgrades considered

The flat already has double glazing and cavity wall insulation although the quality and performance of both is unconfirmed. EPC recommends solid floor insulation. However, for the scenarios for this property we assumed that the property was capable of achieving low flow temperatures without further upgrades to the thermal fabric. Before going ahead with the work we would recommend that a heat transfer co-efficient test is undertaken to ensure that levels of thermal efficiency are as good as is suggested by the EPC.

Heat emitter upgrades considered

Existing radiators are a mixture of double panel and single panel with a total output of 3.9kW at Delta T 50. Current flow temperatures (50°C) could be met with a low temperature heat pump but better efficiency would be achieved with enlarged radiators or underfloor heating.

Heat pump options considered

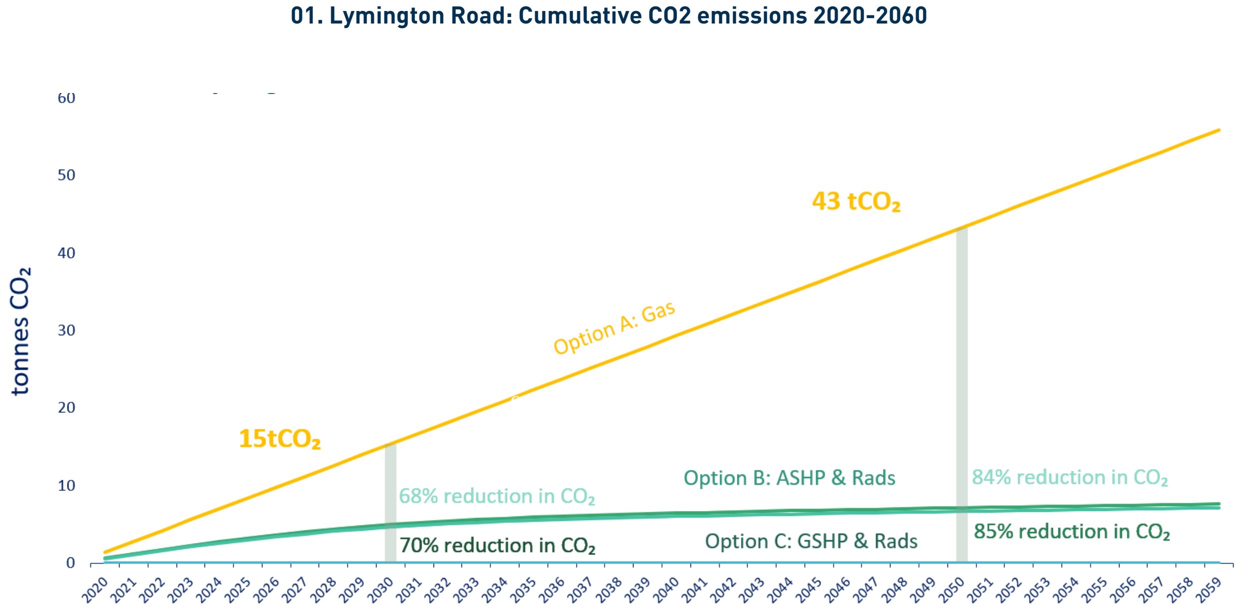
Air Source: The rear garden has ample space for an air source heat pump monobloc external unit. However, the flat is bordered on three sides by other flats and so a particularly low noise ASHP unit would be required.

Shared Ground Source Ambient Loop: The block of flats has enough surrounding communal areas, within the building curtilage to accommodate a shared ambient loop. The majority of the flats in the block are local authority owned. If the local authority were willing to invest in a shared ambient loop for the building it may be possible for the private leaseholders to join the scheme and pay a proportion of the overall cost.

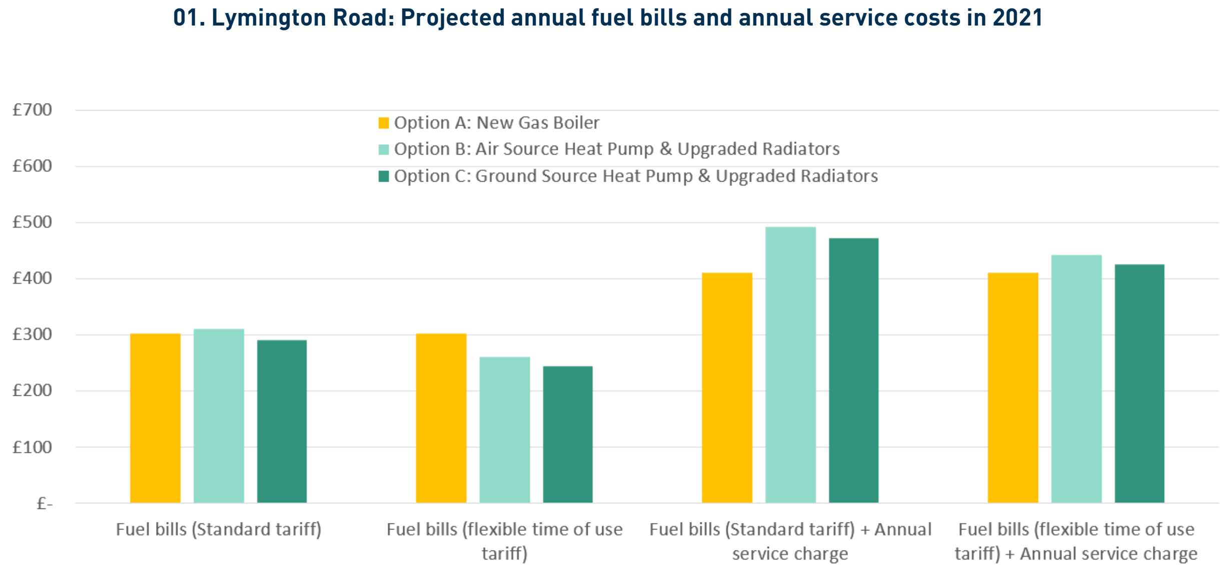
Options appraisal summary of results: 01. Lymington Road

		Retrofit scenario		
Packages of retrofit measures		1a (BAU)	1b	1c
	Heating technology installed	**Replacement Gas combi-boiler** Worcester Greenstar 28kW	**Air to water monobloc heat pump** Mitsubishi 4.8kW + 170l Cylinder	**Ground source heat pump** Vaillant Geo-therm mini 3kW on shared ambient loop
	Heat emitter upgrades	None	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	
	Air tightness (Average Air Changes per hour at ambient air pressure)	0.59 Ach (ambient)	0.59 Ach (ambient)	0.59 Ach (ambient)
Energy performance	EPC	C (70)	C (70)	C (70)
	kWh per m^2 pa	69	69	69
System design	Peak heat load (kW)	2.6	2.6	2.6
	Heat emitter output (kW at ▲T 50°C)	3.9	7.0	7.0
	Required flow temp for -1.8°C day	50	40	40
	Assumed efficiency / SPF H4	0.89	2.89	3.09
CO_2 emissions	Cumulative kg by 2030	15,347	4,939	4,619
	Cumulative kg by 2050	43,251	7,111	6,650
Upfront CAPEX costs	Heating system	£ 2,017	£ 8,151	£ 18,426
	Heat emitters	£ -	£ 1,758	£ 1,758
	Energy efficiency	£ -	£ -	£ -
Grant	RHI	£ -	£ 2,899	£ 9,946
Annual costs	Fuel bill	£ 302	£ 311	£ 291
	Service	£ 109	£ 182	£ 210
Life time costs (Including current RHI)	10 year	£ 6,028	£ 11,488	£ 20,254
	20 year	£ 12,597	£ 20,592	£ 20,355
	30 year	£ 19,165	£ 25,592	£ 29,538
	40 year	£ 25,734	£ 34,696	£ 34,611

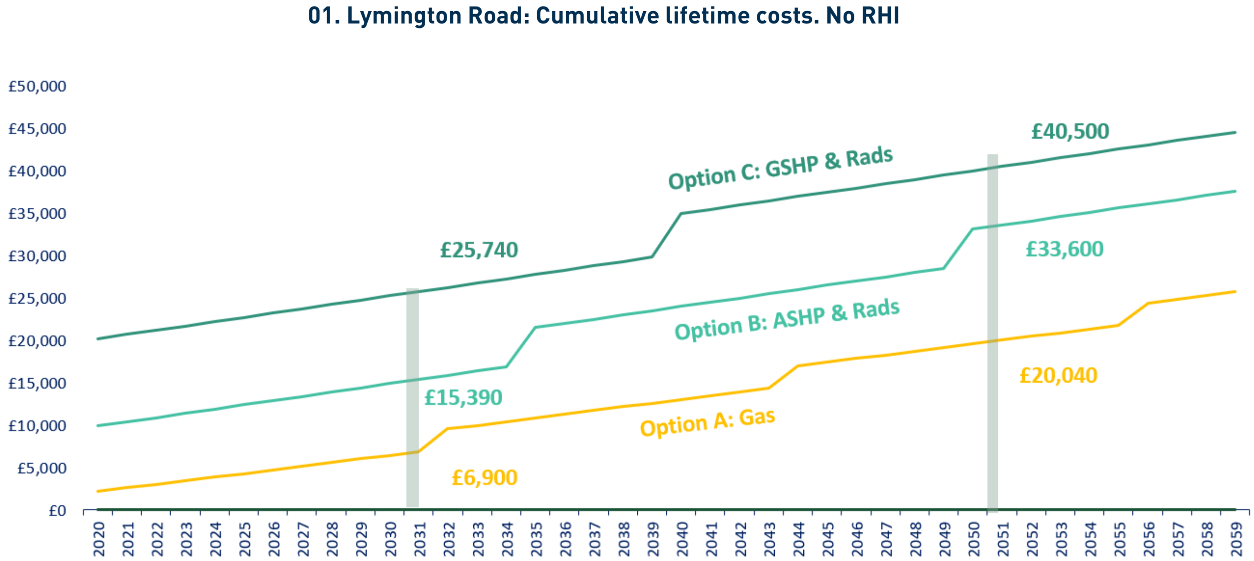
CO_2 emissions

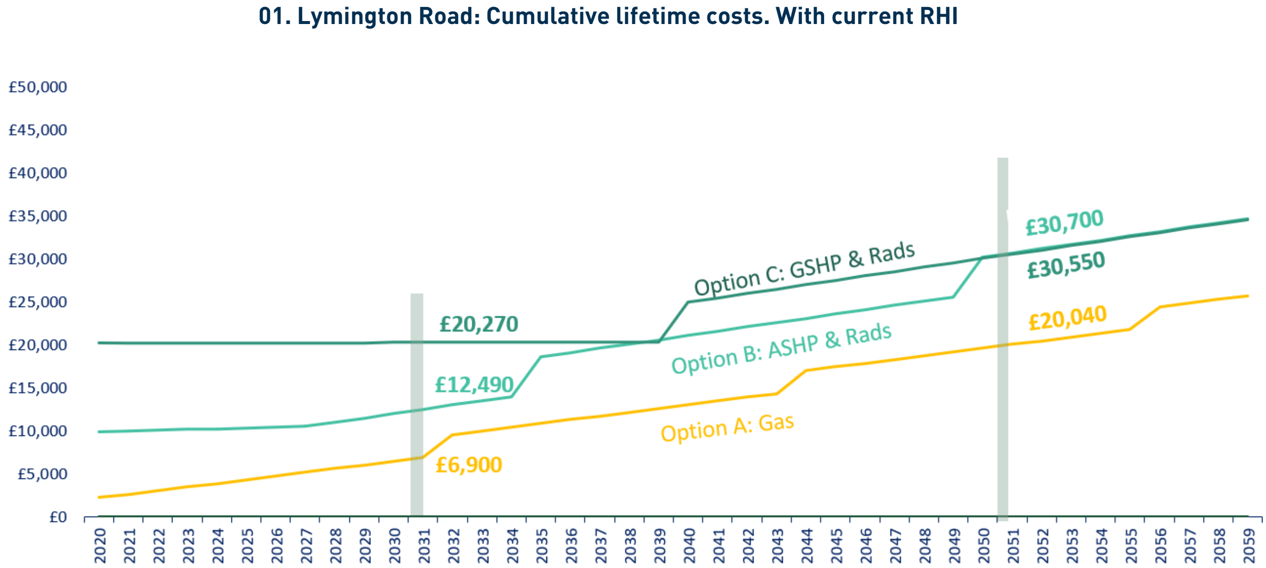


Fuel bills and service charges

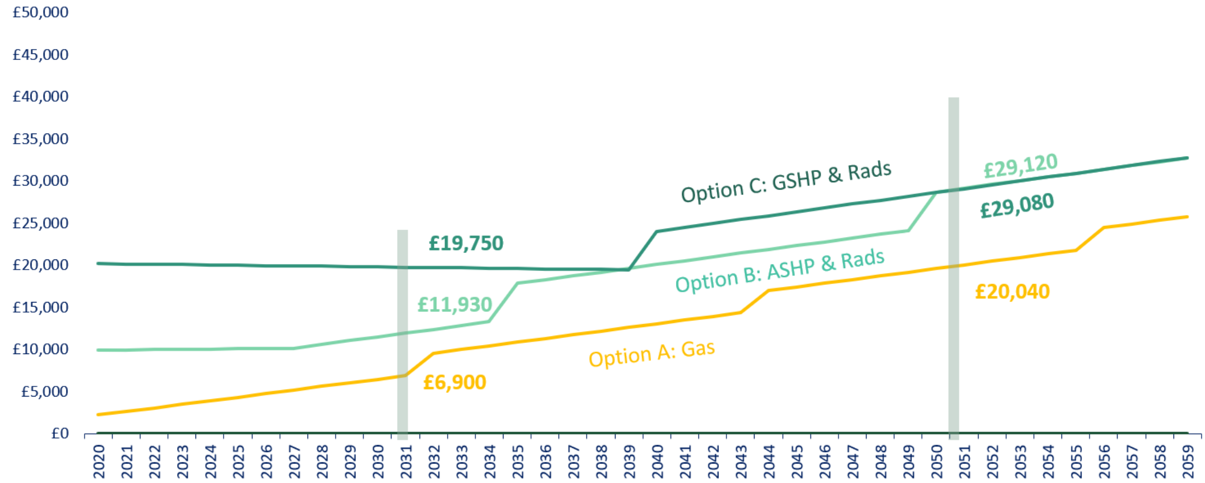


Lifetime costs and sensitivity analysis

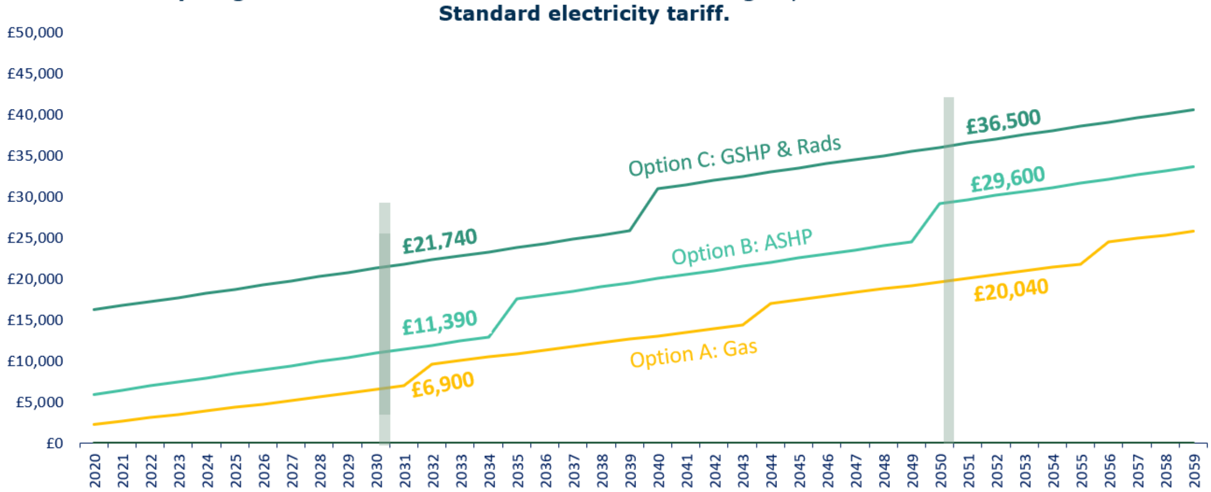




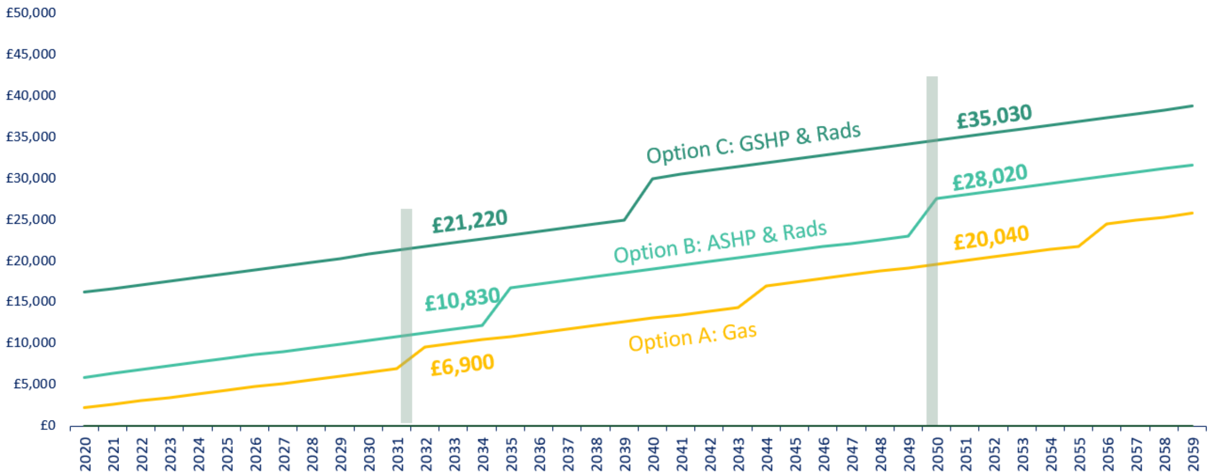
01. Lymington Road: Cumulative lifetime costs with current RHI & Time of use tariff

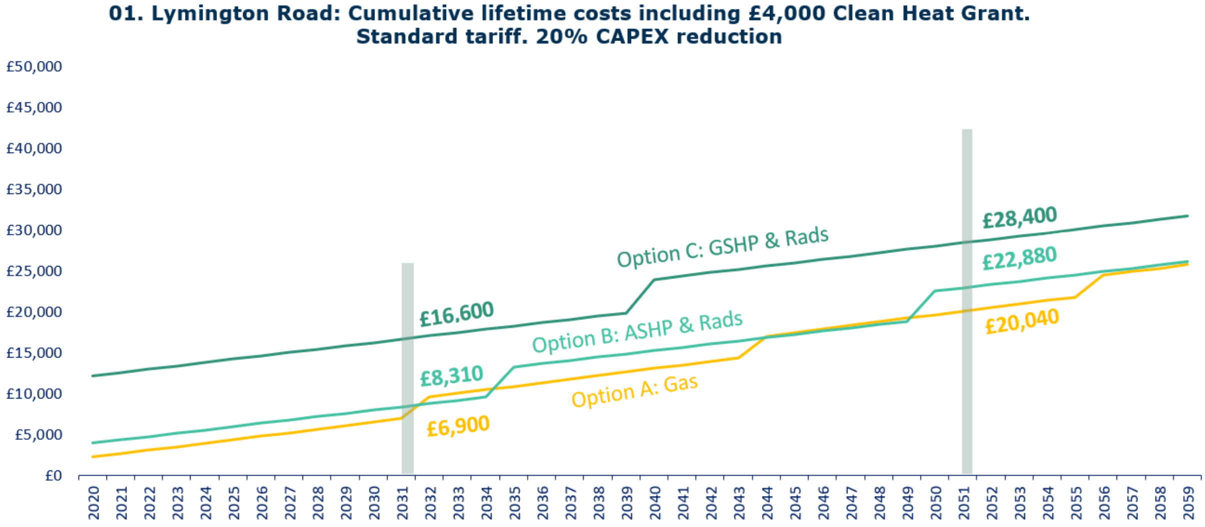


01. Lymington Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.

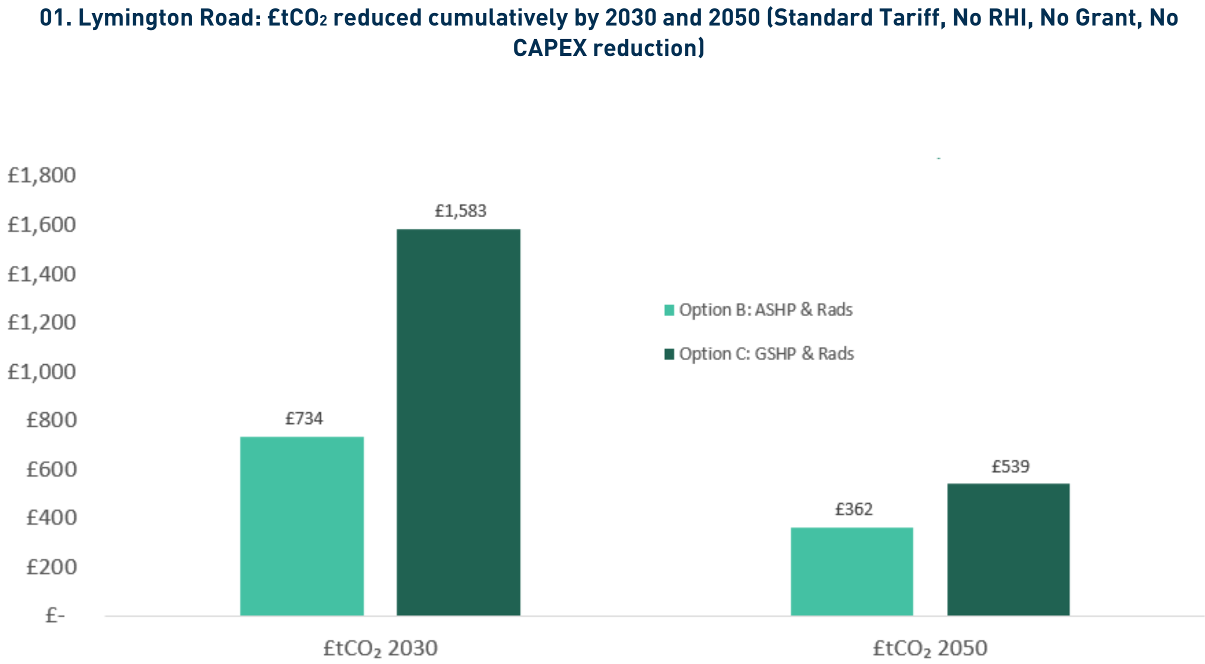


01. Lymington Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.





Cost of carbon reduction: £ per tonne of CO_2 reduced



01 Lymington Road: Summary of options appraisal

- **CO_2 savings:** Under the BAU scenario, this property is predicted to emit 43tCO_2 cumulatively by 2050. Both scenarios B and C could deliver significant CO_2 savings relative to BAU of 68% and 70% respectively by 2030 and 84% and 85% by 2050 respectively.

- **Fuel bills:** Under standard tariffs, fuel bills are predicted to increase marginally under Option B (ASHP and radiators), but decrease marginally under Option C (Ground source heat pump and radiators). In both cases, the fuel bills benefit from the removal of the gas standing charge from the property which forms a relatively high proportion of the overall bill (the electricity standing charge is not included in the heat pump fuel bill as it is not an additional cost). Under a time of use tariff, energy bills for both Options B and C are predicted to reduce relative to gas (the reasonable energy efficiency in this flat enables heat load to be shifted outside of peak hours).

- **Operating costs**: When annual services are factored in, Options B and C increase overall operating costs relative to gas. However, the service costs for heat pumps could be expected to fall over time as the market develops.

- **Lifetime costs:** Under all scenarios, heat pump lifetime costs are higher than the BAU gas lifetime costs. Current levels of RHI for ground source heat pumps make Option C equally attractive to Option A over 30 years. However, under the proposed £4,000 Clean Heat Grant, Option B (air source heat pump) would have the lower lifetime costs. When the £4,000 Clean Heat Grant and a 20% reduction in CAPEX costs is factored in, Option B (air source heat pump) comes close to achieving cost parity with the BAU gas scenario with 30 years costs of £22,880 vs £20,040. A 20% up-front cost reduction could be consistent with:

    - Bulk procurement by a local authority or social landlord or other collective purchasing scheme.
    - Long term cost reductions due to the mass market adoption of heat pumps
    - Changes to current VAT rates on heat pumps (i.e. removal of the 20% VAT rate paid on heat pumps in a retrofit context)
    - An additional up-front capital grant (e.g. a boiler scrappage scheme).

- **Cost of carbon reduction:** The cost of carbon reduction is lower for Option B (air source heat pump) than Option C (ground source heat pump) over both 10 and 30 years. The marginal additional efficiency of the ground source heat pump does not compensate for the higher up-front costs.

- **Conclusion:** Under these assumptions, the ASHP option is deemed to have lower overall costs than the communal GSHP option for this dwelling. However, the combined ambient loop GSHP may bring a range of other advantages, notably a much lower noise level in a relatively dense urban environment.

02. Two bed mid-floor flat, EPC B: Cavendish House, Barnet

Age	Type	Floor area (m²)	EPC rating
1930s (refurbished)	2-bed mid floor flat	76	B (82)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
1,978	2,349	4,327	NA
Space heating demand (kWh per m² pa)	Current space and water heating system	Secondary heating	Current flow temperature
26	'A' rated gas combi-boiler & radiators (single panel) (no hot water cylinder)	None	65°C
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
2.09	2.90	1.39	59°C
Monthly indicative gas usage (kWh) 2019			
Jan	551	Jul	164
Feb	561	Aug	176
Mar	469	Sep	236
Apr	364	Oct	346
May	230	Nov	508
Jun	164	Dec	557

Assessment of retrofit potential: 02. Cavendish House

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	No	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	Maybe*
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	Yes
	Wall mounted	No	Available service ducts for internal pipework?	Yes
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Limited	Available water source	No
Suitable space for hot water cylinder?		Limited	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

The block of flats has recently been refurbished with modern double glazing and wall insulation. According to the EPC assessment, the flat already has a very low level of space heating demand <30kW/m^2/pa/ making it well suited to heat pump retrofit. We therefore assumed that no further thermal fabric upgrades were necessary at this property. We would recommend that a heat transfer co-efficient test is undertaken to ensure that levels of thermal efficiency are as good as is suggested by the EPC.

Heat emitter upgrades considered

Essential: Existing radiators are single panel. Upgrading to triple panel convector of the same dimensions would enable a flow temperature of 35°C.

Heat pump options considered

Air Source: Options for locating an Air Source Heat Pump are very limited. However, the internal cupboard space has the potential to fit a fully internal air source heat pump unit and hot water cylinder.

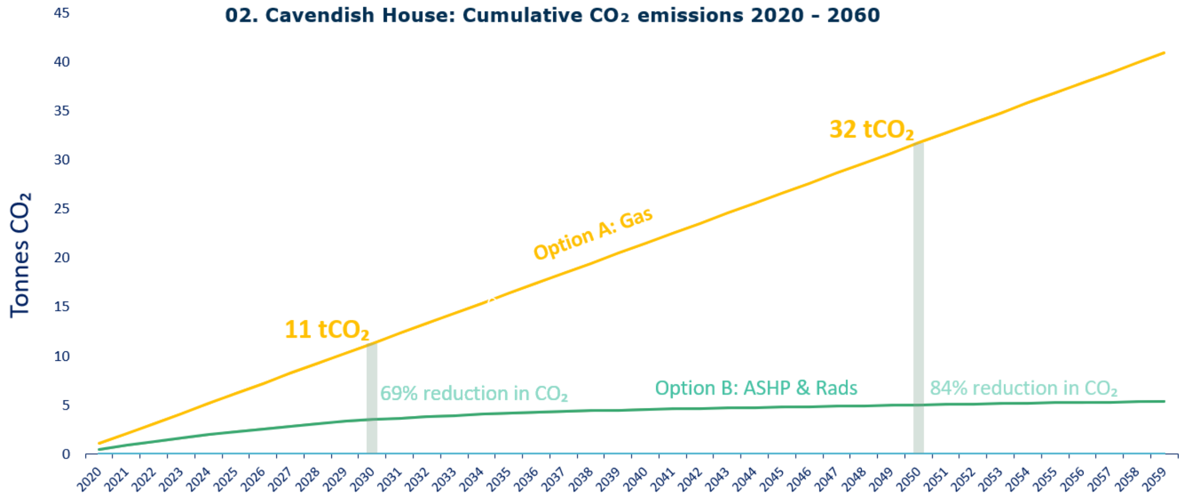
Ground Source: The large surrounding gardens provide an opportunity for a shared communal ground loop or individual ground source heat pump. However, the block is privately owned with individual private leaseholders owning each flat. Obtaining the necessary communal buy-in and freeholder permission would be challenging in this context. Therefore, communal ground source has not been considered. The flat is on the mid floor and obtaining permission from the freeholder for an individual ground source heat pump is likely to be problematic.

*Individual ground source loop would require freeholder permission

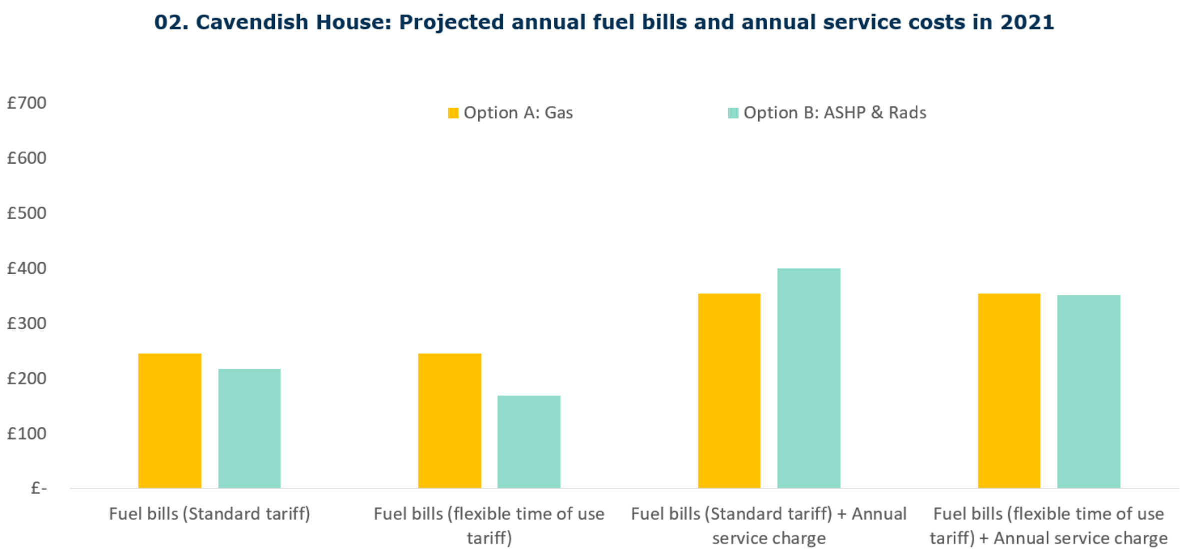
Options appraisal summary of results: 02. Cavendish House

		Retrofit scenario	
		2a (BAU)	2b
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler** Ideal 24kW Combi	**Air to water heat pump** Ground Sun GA 200 with integrated cylinder
	Heat emitter upgrades	None	Triple panel convector
	Energy efficiency upgrades	None	None
	Air tightness (Average Air Changes per hour at ambient air pressure)	0.62	0.62
Energy performance	EPC	B (82)	B (82)
	kWh per m^2 pa	26	26
System design	Peak heat load (kW)	2.1	2.1
	Heat emitter output (kW at ▲T 50°C)	2.9	10.2
	Required flow temp for -1.8°C day	59	36
	Assumed efficiency / SPF H4	0.89	3.02
CO_2 emissions	Cumulative kg by 2030	11,231	3,459
	Cumulative kg by 2050	31,650	4,979
Upfront CAPEX costs	Heating system	£ 2,017	£ 8,817
	Heat emitters	£ -	£ 2,226
	Energy efficiency	£ -	£ -
Grant	RHI	£ -	£ 2,170
Annual costs	Fuel bill	£ 245	£ 218
	Service	£ 109	£ 182
Life time costs (Including current RHI)	10 year	£ 5,481	£ 12,500
	20 year	£ 11,410	£ 21,038
	30 year	£ 17,340	£ 25,084
	40 year	£ 23,269	£ 33,622

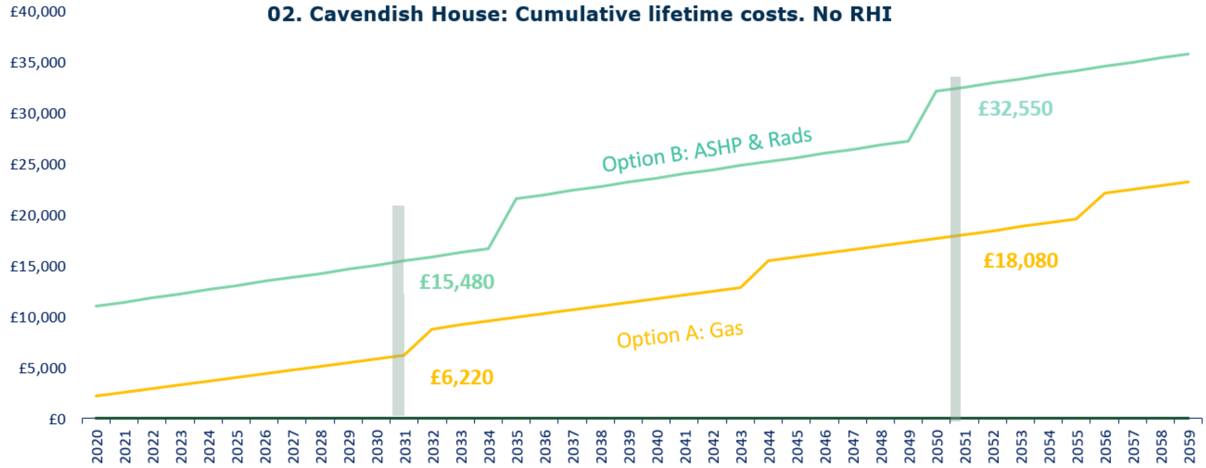
CO_2 emissions

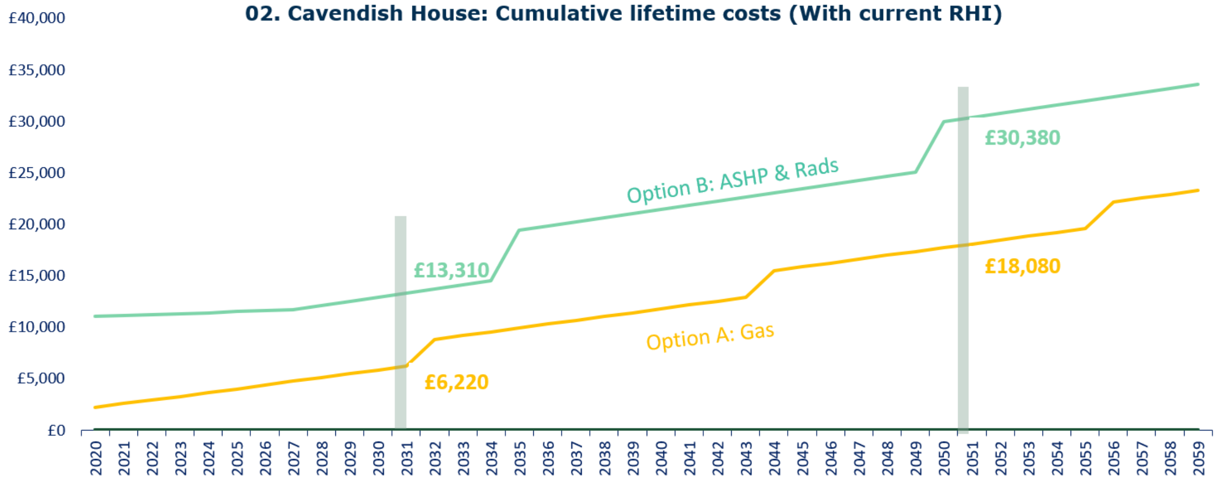


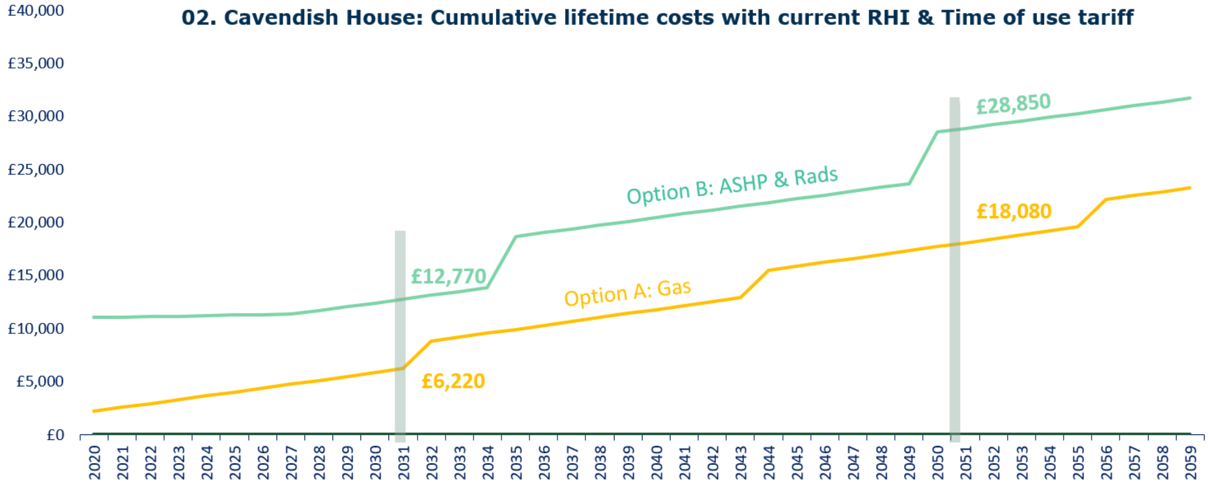
Fuel bills

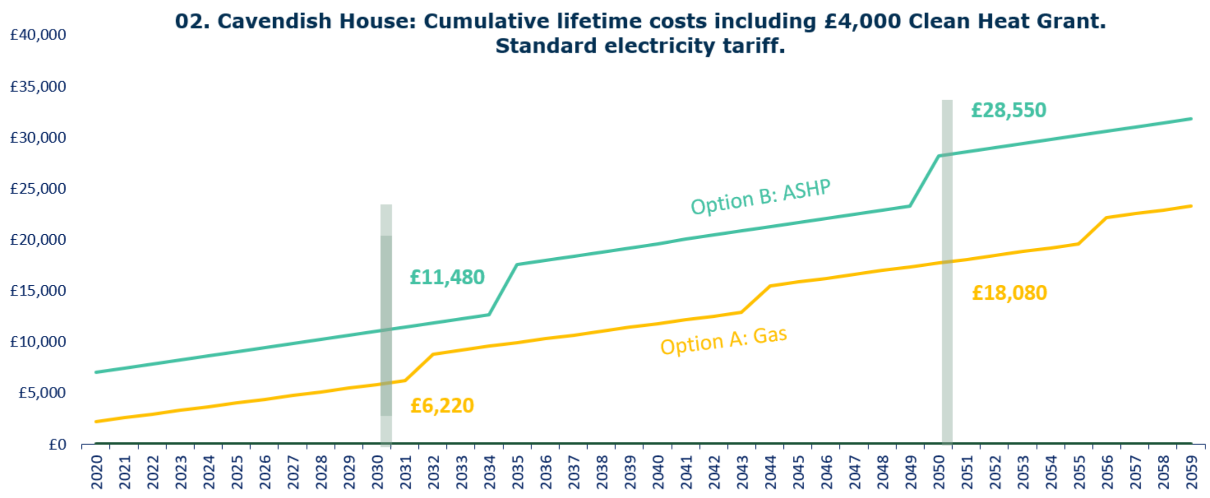


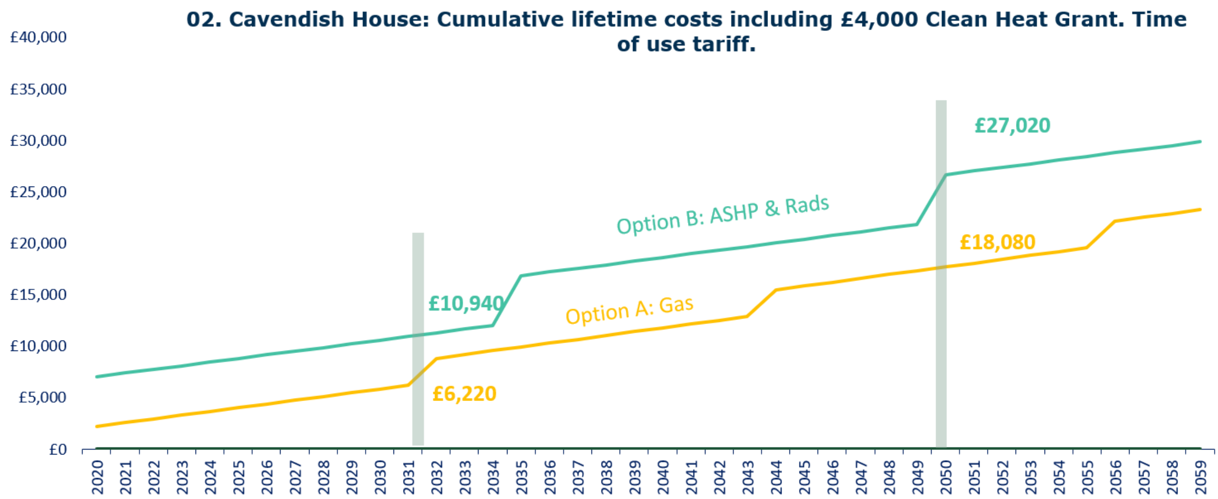
Lifetime costs and sensitiviy analysis

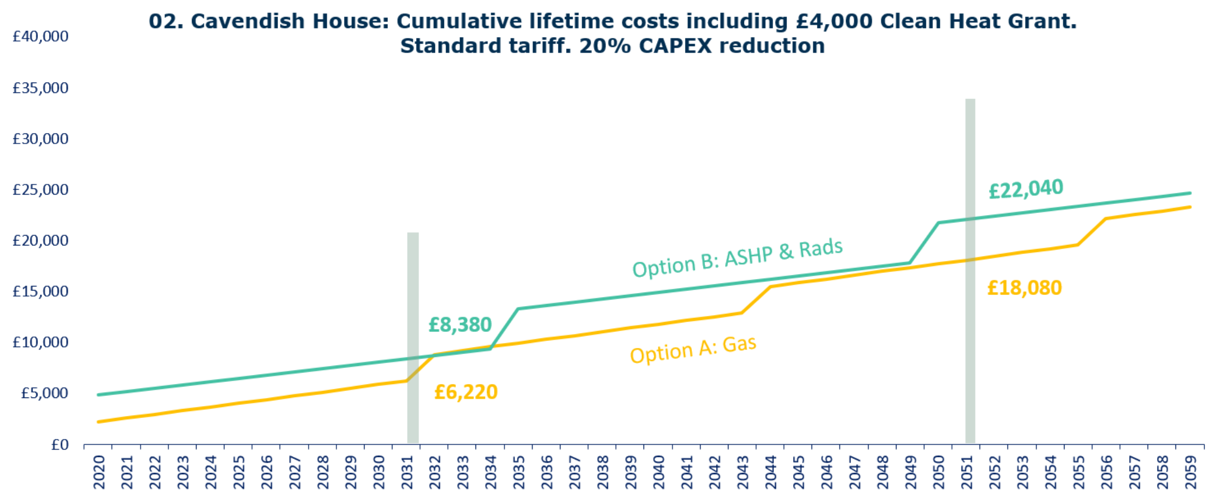






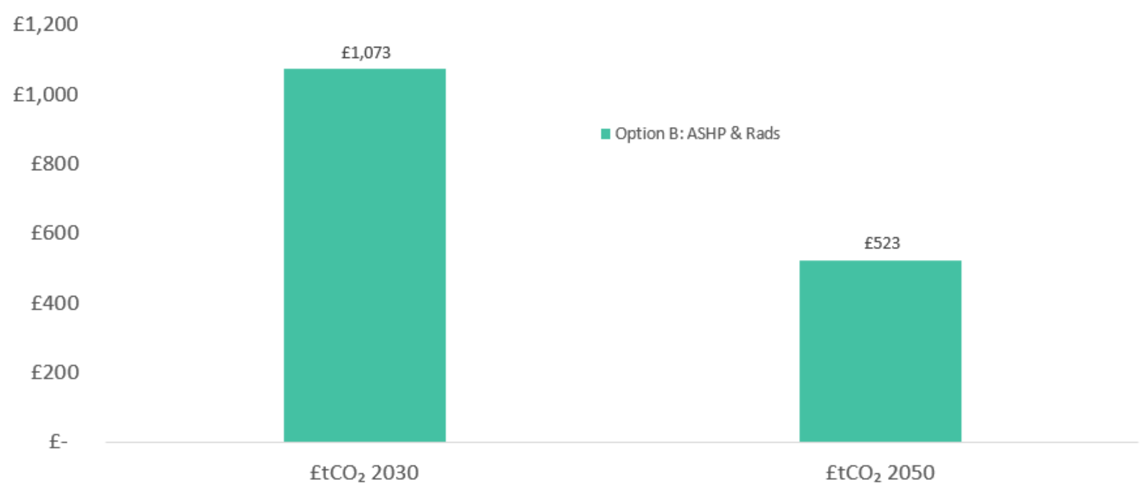

02. Cavendish House: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.
£11,480
£6,220
£28,550
£18,080
Option B: ASHP
Option A: Gas


02. Cavendish House: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.
£10,940
£6,220
£27,020
£18,080
Option B: ASHP & Rads
Option A: Gas


02. Cavendish House: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard tariff. 20% CAPEX reduction
£8,380
£6,220
£22,040
£18,080
Option B: ASHP & Rads
Option A: Gas

Cost of carbon reduction: £ per tonne of CO_2 reduced

02. Cavendish House: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



02 Cavendish House: Summary of options appraisal

- **CO_2 savings:** Under the BAU scenario, this property is predicted to emit 32tCO_2 cumulatively by 2050. The heat pump option results in a significant CO_2 emissions savings of 69% by 2030 and 84% by 2050.

- **Fuel bills:** Under a standard tariff, fuel bills decrease marginally relative to gas. This is helped by the removal of the gas standing charge from the property. Under a time of use tariff, the decrease in fuel bills is greater. The good levels of energy efficiency in this property enable a significant level of load shifting of heat demand outside of peak hours.

- **Operating costs**: When annual services are factored in, the heat pump option marginally increases overall operating costs relative to gas. However, the service costs for heat pumps could be expected to fall over time as the market develops.

- **Lifetime costs:** Under all scenarios, heat pump lifetime costs are higher than the BAU gas lifetime costs. However, when the £4,000 Clean Heat Grant and a 20% reduction in CAPEX costs is factored in, Option B (air source heat pump) comes close to achieving cost parity with the BAU gas scenario with 30 years costs of £20,040 (ASHP) vs £18,080 (gas). A 20% up-front cost reduction could be consistent with:

    - Bulk procurement by a local authority or social landlord or other collective purchasing scheme.

    - Long term cost reductions due to the mass market adoption of heat pumps

  - Changes to current VAT rates on heat pumps
  - An additional up-front capital grant (e.g. a boiler scrappage scheme).

- **Cost of carbon reduction:** The cost of carbon reduction for Option B is relatively high. This is due to the relatively small carbon saving achieved in a small, individual, energy efficient flat with low heat demand.

03. Two bed ground floor flat, EPC C; Sherwin House, Lambeth

Age	Type	Floor area (m^2)	EPC rating
1930s	2-bed ground floor flat	52	C (74)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
3,870	1,808	5,678	NA
Space heating demand (kWh per m^2 pa)	Current space and water heating system	Secondary heating	Current flow temperature
74	Gas combi-condensing boiler with radiators (mix of single and double panel) No hot water cylinder	Gas room heater	Unknown
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
3.72	5.4	1.45	58°C
Monthly indicative gas usage (kWh) 2019			
Jan	800	Jul	127
Feb	819	Aug	136
Mar	666	Sep	252
Apr	489	Oct	454
May	254	Nov	743
Jun	127	Dec	812

Assessment of retrofit potential: 03. Sherwin House

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	No	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	No
	External walkway	Yes	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	Limited
	Wall mounted	No	Available service ducts for internal pipework?	Yes
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		No	Available water source	No
Suitable space for hot water cylinder?		No	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

The flat has double glazing but no wall insulation. The flat is freeholder owned in a predominantly local authority owned block. To our knowledge there are no plans to insulate the block as a whole and so we assumed that no further energy efficiency upgrades were undertaken in our scenarios. However, in reality this block would be likely to benefit from External Wall Insulation and measures to improve air tightness.

Heat emitter upgrades considered

Essential: Existing radiators are single panel. Upgrading to triple panel convector radiators could enable a flow temperature of 35°C. Checks would need to be made to ensure these protrude problematically in to the internal living space.

Heat pump options considered

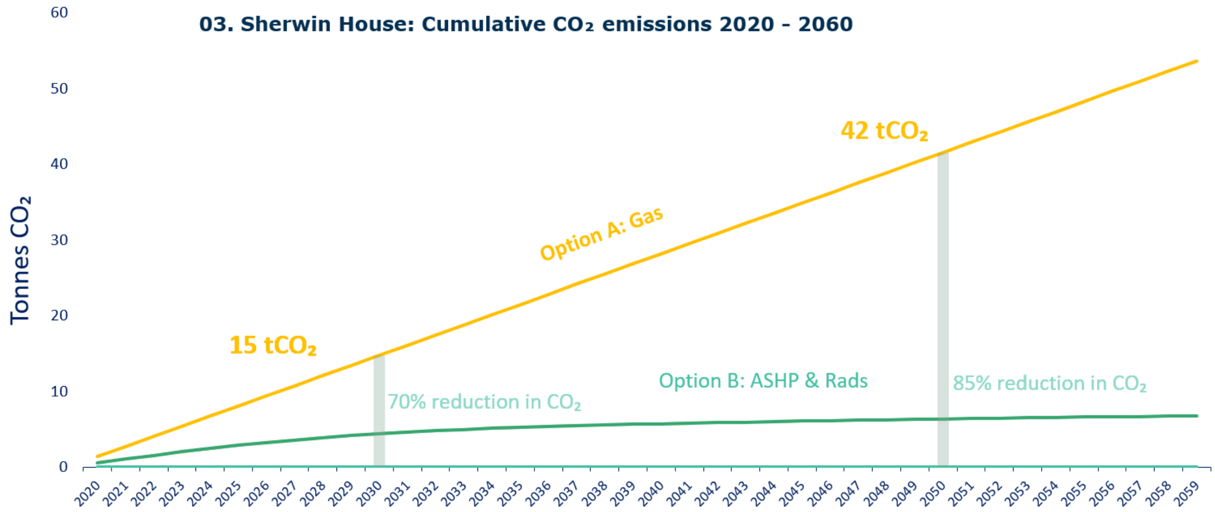
Air Source: Options for locating an Air Source Heat Pump are very limited. However, the external walkway could accommodate an external ASHP unit subject to a noise assessment and external access not being restricted due to the siting of heat pump. Due to the close proximity to neighbouring dwellings, planning permission may be required. Recommendation for options assessment: only consider heat pumps with noise levels below 45dB. There is very limited internal space for a hot water cylinder. Therefore, a hybrid heat pump or a heat pump capable of delivering instant hot water heating via an inline water heater should be considered.

Ground Source: It is possible that the wider estate could accommodate a shared ground source loop with individual heat pumps in each flat, or alternatively a communal heating system with a centralised heat pump providing heating and hot water. However, Sherwin House itself only has approximately 100m^2 of car parking space that could be used for borehole drilling. The flat is privately owned. Therefore, a shared ambient loop was not been considered in this instance. Although in reality, this would likely be the most technically suitable option with the fewest potential issues regarding noise.

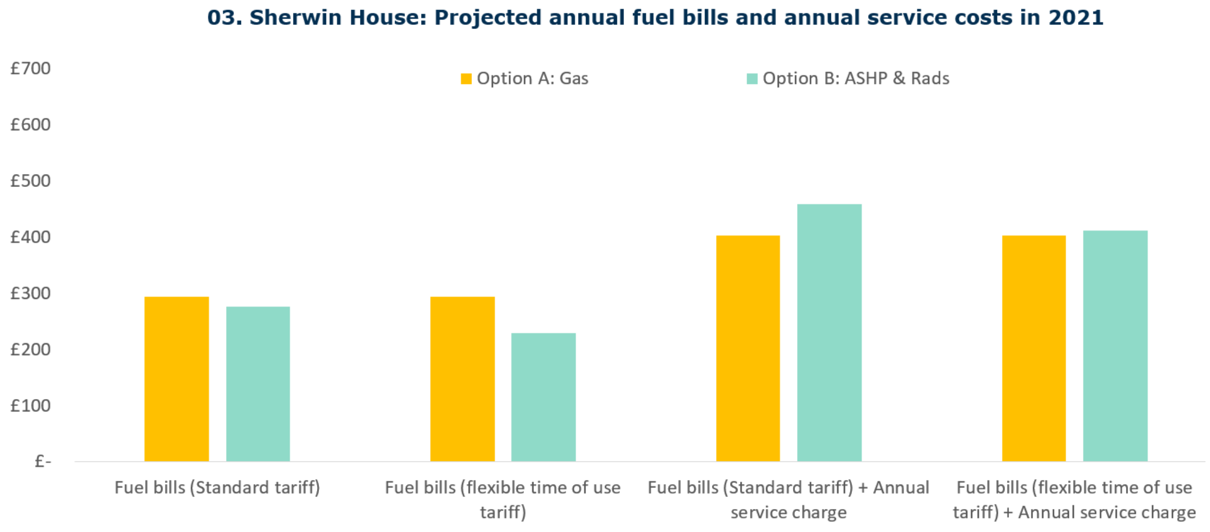
Options appraisal summary of results: 03. Sherwin House

		Retrofit scenario	
		3a	3b
Packages of retrofit measures	Heating technology installed	Replacement Gas combi-boiler	Air to water heat pump Veissman Vitocal 200 4.3k with instant hot water heater
	Heat emitter upgrades	None	Triple panel convector
	Energy efficiency upgrades	None	None
	Air tightness (Average Air Changes per hour at ambient air pressure)	0.99	0.99
Energy performance	EPC	C (74)	C (74)
	kWh per m^2 pa	74	74
System design	Peak heat load (kW)	3.7	3.7
	Heat emitter output (kW at ▲T 50°C)	5.4	9.8
	Required flow temp for -1.8°C day	58	44
	Assumed efficiency / SPF H4	0.89	3.12
CO_2 emissions	Cumulative kg by 2030	14,737	4,393
	Cumulative kg by 2050	41,532	6,325
Upfront CAPEX costs	Heating system	£ 2,017	£ 8,965
	Heat emitters	£ -	£ 2,226
	Energy efficiency	£ -	£ -
Grant	RHI	£ -	£ 2,892
Annual costs	Fuel bill	£ 294	£ 276
	Service	£ 109	£ 182
Life time costs (Including current RHI)	10 year	£ 5,947	£ 12,463
	20 year	£ 12,421	£ 21,239
	30 year	£ 18,895	£ 25,887
	40 year	£ 25,369	£ 34,664

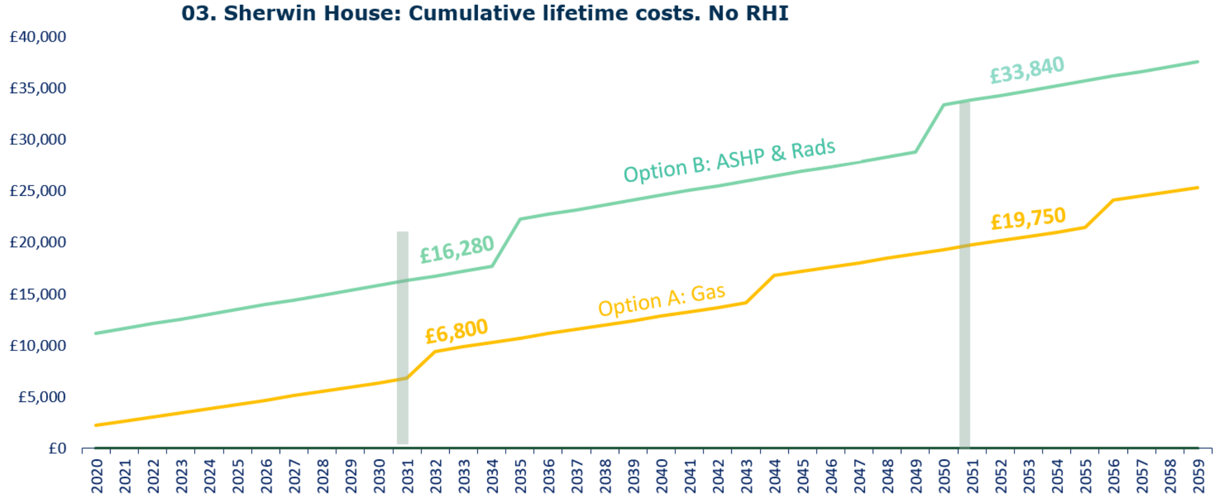
CO_2 emissions

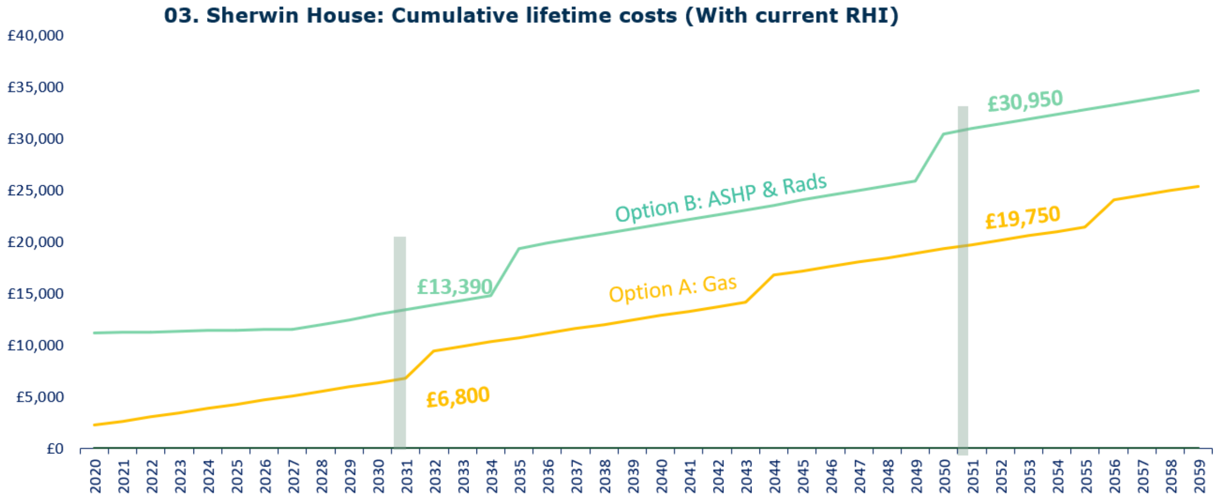


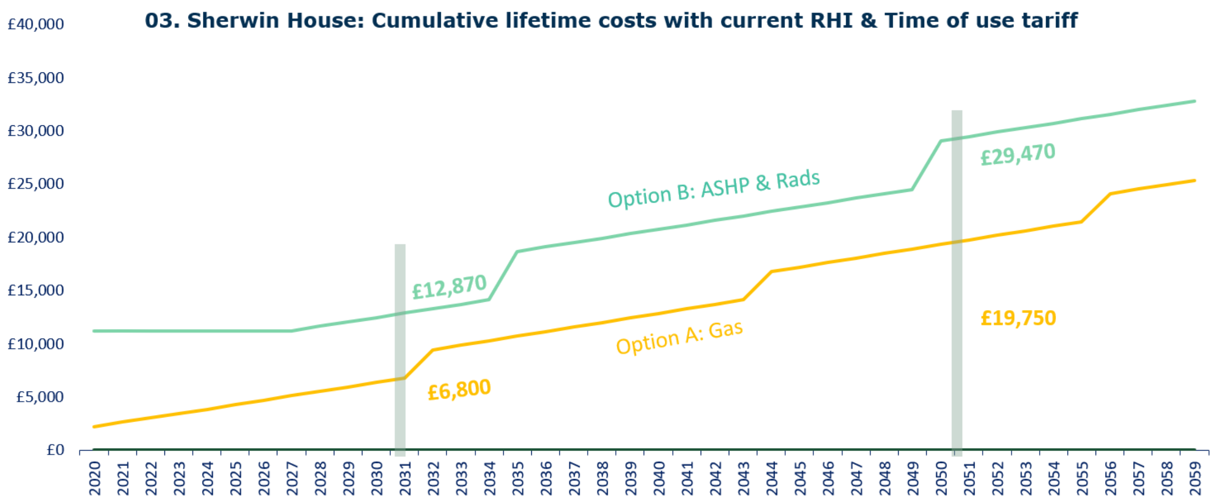
Fuel bills



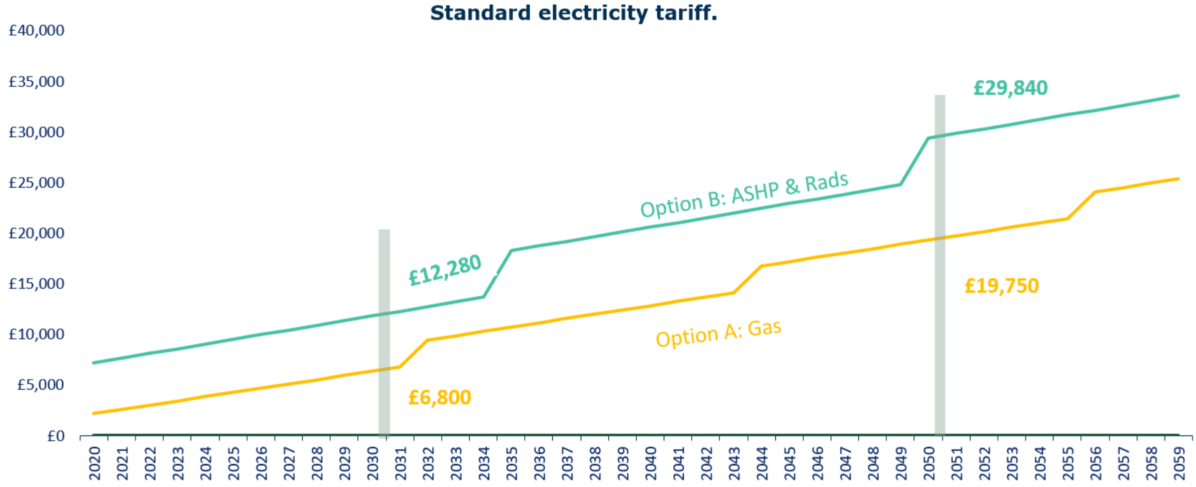
Lifetime costs and sensitiviy analysis



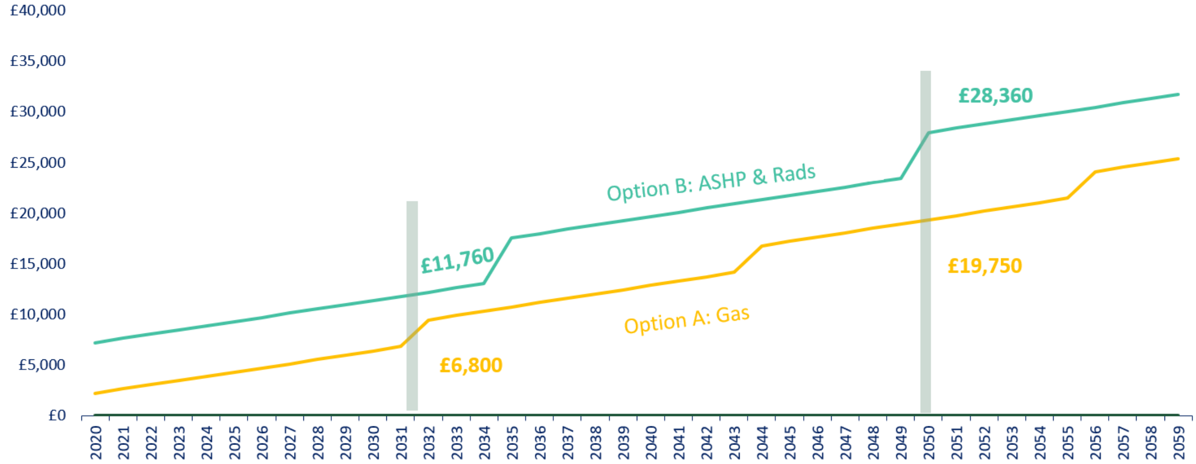




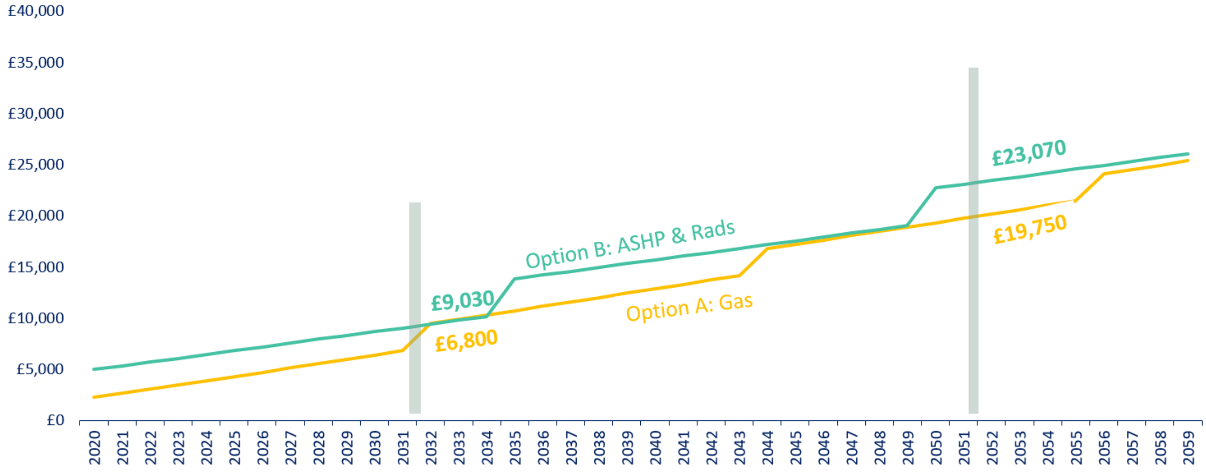
03. Sherwin House: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.



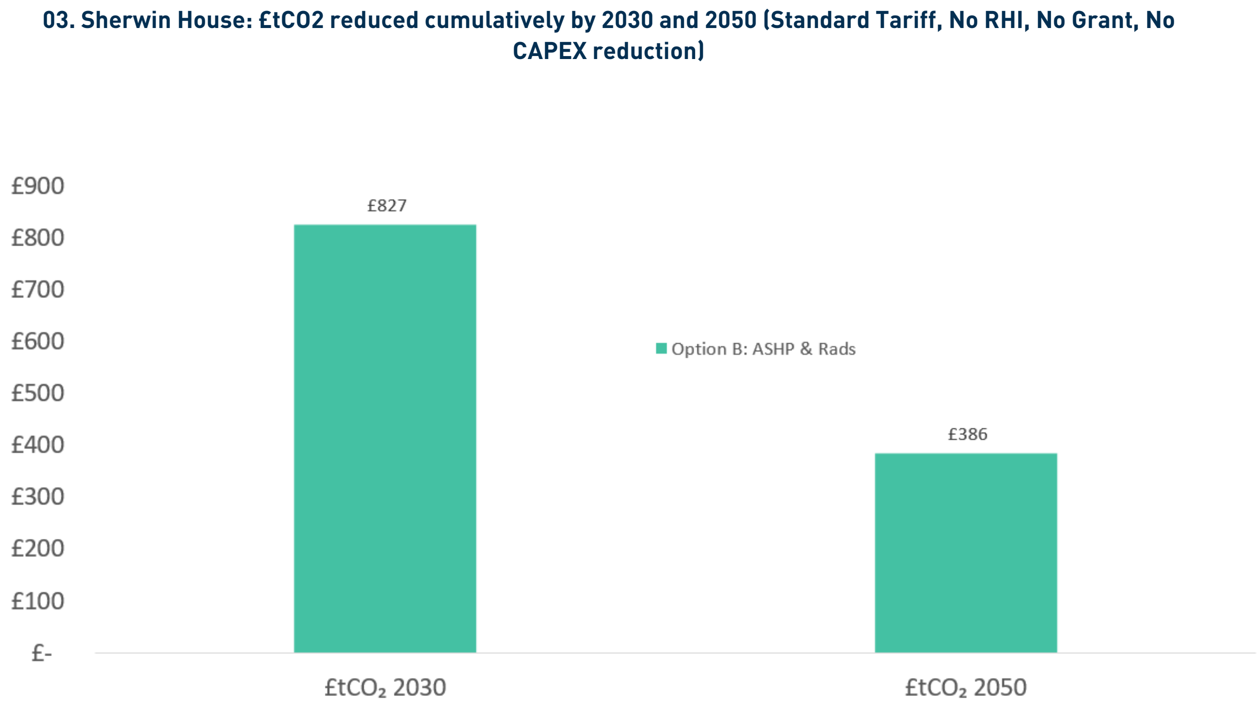
03. Sherwin House: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.



03. Sherwin House: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard tariff. 20% CAPEX reduction



Cost of carbon reduction: £ per tonne of CO_2 reduced



03 Sherwin House: Summary of options appraisal

- **CO_2 savings:** Under the BAU scenario, this property is predicted to emit 42tCO_2 cumulatively by 2050. The heat pump option results in a significant CO_2 emissions savings of 70% by 2030 and 85% by 2050.

- **CAPEX:** With no grant included, the up-front costs of the ASHP are significantly higher than the gas boiler. This is compounded by the fact that a relatively expensive ASHP was used in this instance due to the low noise levels required in built up flats.

- **Fuel bills:** Under a standard tariff, fuel bills decrease marginally relative to gas. This is helped by the removal of the gas standing charge from the property. Under a time of use tariff, the decrease in fuel bills is greater. The reasonable levels of energy efficiency in this property enable a level of load shifting of heat demand outside of peak hours.

- **Operating costs**: When annual services are factored in, the heat pump option marginally increases overall operating costs relative to gas. However, the service costs for heat pumps could be expected to fall over time as the market develops.

- **Lifetime costs:** Under all scenarios, heat pump lifetime costs are higher than the BAU gas lifetime costs. However, when the £4,000 Clean Heat Grant and a 20% reduction in CAPEX costs is factored in, Option B (air source heat pump) comes close to achieving cost parity with the BAU gas scenario with 30 years costs of £23,070 (ASHP) vs £19,750 (gas). The lifetime costs of the ASHP would be broadly equivalent to those of the gas boiler at year 12 (due to the assumed earlier replacement of the gas boiler) and only marginally more expensive at other time periods.

- A 20% up-front cost reduction could be consistent with:

    - Bulk procurement by a local authority or social landlord or other collective purchasing scheme.

    - Long term cost reductions due to the mass market adoption of heat pumps

    - Changes to current VAT rates on heat pumps

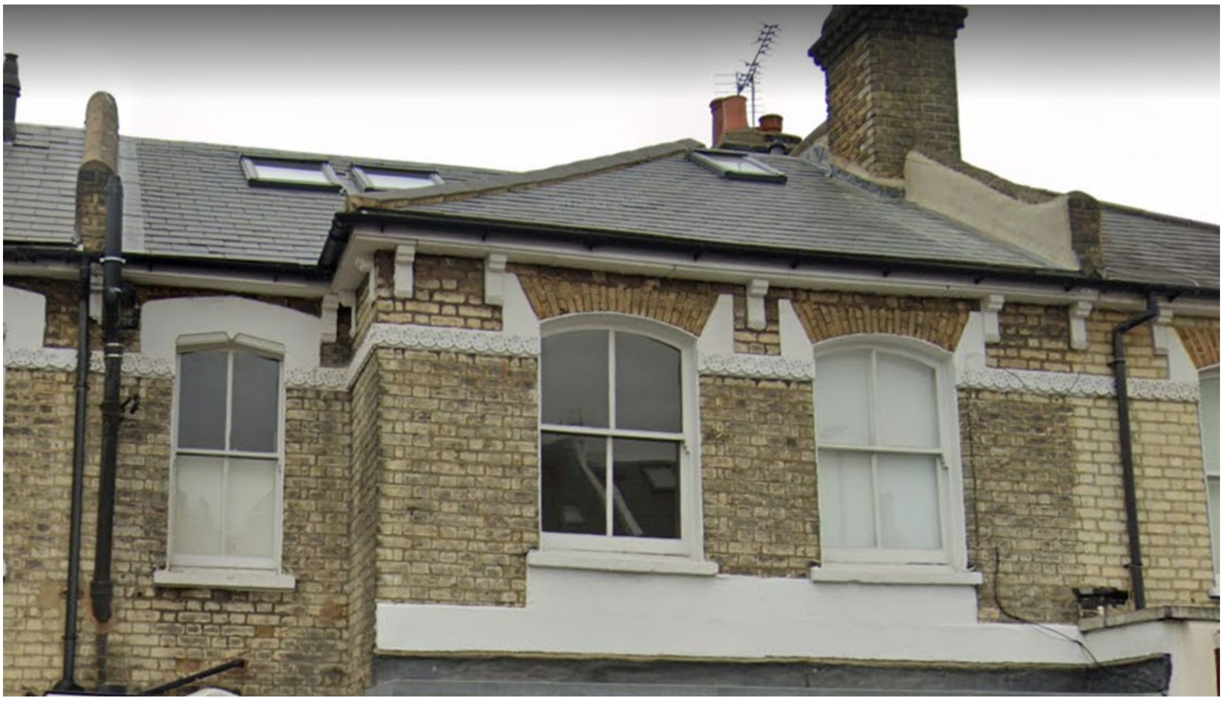
    - An additional up-front capital grant (e.g. a boiler scrappage scheme).

- **Cost of carbon reduction:** The cost of carbon reduction for Option B is relatively high. This is due to the relatively small carbon saving achieved in a small, individual, energy efficient flat with low heat demand.

- For this example, due to the low level of heating demand in this energy efficient flat, a £4,000 grant would be larger than the current RHI payments of £2,892.

- Although an ASHP was specified for this example, it is uncertain whether an ASHP would be able to achieve the low noise levels required in such a dense block of flats. Alternative systems may need to be explored such as a communal ambient loop arrangement, communal heating with a central heat pump or individual fully internal heat pumps.

04. Three bed, 2 storey maisonette, EPC D; Northcote Road, Wandsworth



Age	Type	Floor area (m²)	EPC rating
Victorian	3-bed, 2 storey mid terrace maisonette	114	D (62)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
11,967	2,278	14,245	15,052
Space heating demand (kWh per m² pa)	Current space and water heating system	Secondary heating	Current flow temperature
105	Gas combi-condensing boiler with radiators (mainly single panel). No hot water cylinder. Vaillant Eco-tec 25kW	Gas room heater	75°C
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
8.74	7.6	0.87	78°C
Monthly indicative gas usage (kWh) 2019			
Jan	2,878	Jul	201
Feb	1,917	Aug	166
Mar	1,862	Sep	282
Apr	1,287	Oct	1,250
May	532	Nov	2,245
Jun	170	Dec	2,262

Assessment of retrofit potential: 04. Northcote Road

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	No	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	No
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	Yes	Space for boreholes within building curtilage?	No
	Wall mounted	No	Available service ducts for internal pipework?	NA
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Yes	Available water source	No
Suitable space for hot water cylinder?		Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

This property currently has very poor levels of air tightness and thermal fabric efficiency. Thermal fabric and air tightness upgrades would be required in order for the building to be capable of retaining low temperature heat from a heat pump for a reasonable period of time.

Thermal performance could be improved with double glazing and improvements to air tightness. In addition, the property sits above a shop which is unheated at weekends - floor insulation could significantly improve thermal performance.

The property is currently planning an extension and mansard roof to the rear involving replacing a significant proportion of the roof. This could be an excellent opportunity to undertake deeper renovations to the whole of the thermal fabric to very high thermal performance levels <50kWh m^2 per year.

Heat emitter upgrades considered

Current radiators are single panel convector radiators covering a large overall surface area (nearly 5 m^2). The homeowner is keen to maintain a heritage aesthetic with the renovation of the property and therefore would prefer to install four column radiators - despite the significant cost premium of these over triple panel or double panel convector radiators (£0.37 per Watt vs £0.09 or £0.06 per Watt)

Heat pump options considered

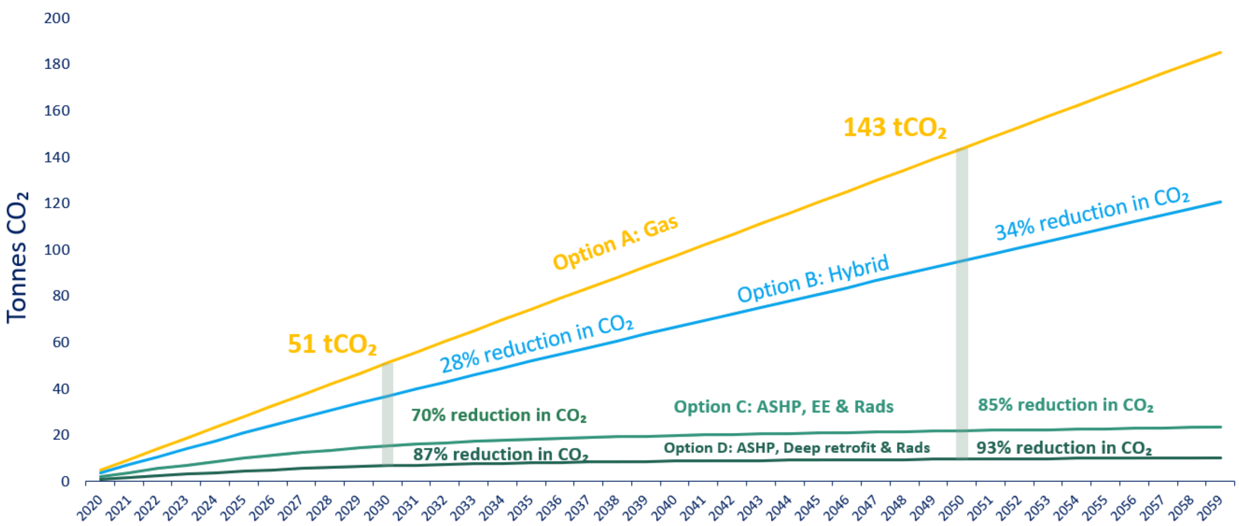
Air source located on the rear roof terrace to be created as part of the extension. Planning Permission may be necessary and careful siting away from bedroom windows. The flat is on the upper floors with no access to ground for ground source trench or borehole

Options appraisal summary of results: 04. Northcote Road

		Retrofit scenario			
		4a (BAU)	4b	4c	4d
Packages of retrofit measures	Heating technology installed	Replacement Gas combi-boiler	Hybrid heat pump Vaillant 8kW Hybrid	Air to water heat pump Mitsubishi 8kW with 210l cylinder	**Air to water heat pump** Vaillant Arotherm 5kW with Unistor 200l cylinder
	Heat emitter upgrades	None	None	Four Column radiators	Four Column radiators
	Energy efficiency upgrades	None	None	Double Glazed Sash Windows. Improved air tightness and loft insulation top up.	Deep retrofit
	Air tightness (Average Air Changes per hour at ambient air pressure)	1.3 Ach (ambient)	1.3 Ach (ambient)	0.85 Ach (ambient)	0.5 Ach (ambient)
Energy performance	EPC	D (62)	D (62)	C	A/B
	kWh per m^2 pa	105	105	86	40
System design	Peak heat load (kW)	8.7	8.7	7.2	3.4
	Heat emitter output (kW at ▲T 50°C)	7.6	7.6	15.3	15.3
	Required flow temp for -1.8°C day	79	79	48	36
	Assumed efficiency / SPF H4	0.89	2.22	2.65	3.31
CO_2 emissions	Cumulative kg by 2030	50,887	36,639	15,055	6,566
	Cumulative kg by 2050	143,410	94,838	21,675	9,454
Upfront CAPEX costs	Heating system	£ 2,395	£ 6,272	£ 9,098	£ 8,352
	Heat emitters	£ -	£ -	£ 5,924	£ 5,924
	Energy efficiency	£ -	£ -	£ 11,450	£ 45,486
Grant	RHI	£ -	£ -	£ 7,715	£ 4,711
Annual costs	Fuel bill	£ 800	£ 949	£ 947	£ 413
	Service	£ 109	£ 280	£ 182	£ 182
Life time costs (Including current RHI)	10 year	£ 11,206	£ 17,553	£ 29,052	£ 60,465
	20 year	£ 23,748	£ 35,314	£ 45,324	£ 70,757
	30 year	£ 36,291	£ 48,049	£ 56,836	£ 76,804
	40 year	£ 48,834	£ 65,810	£ 73,108	£ 87,095

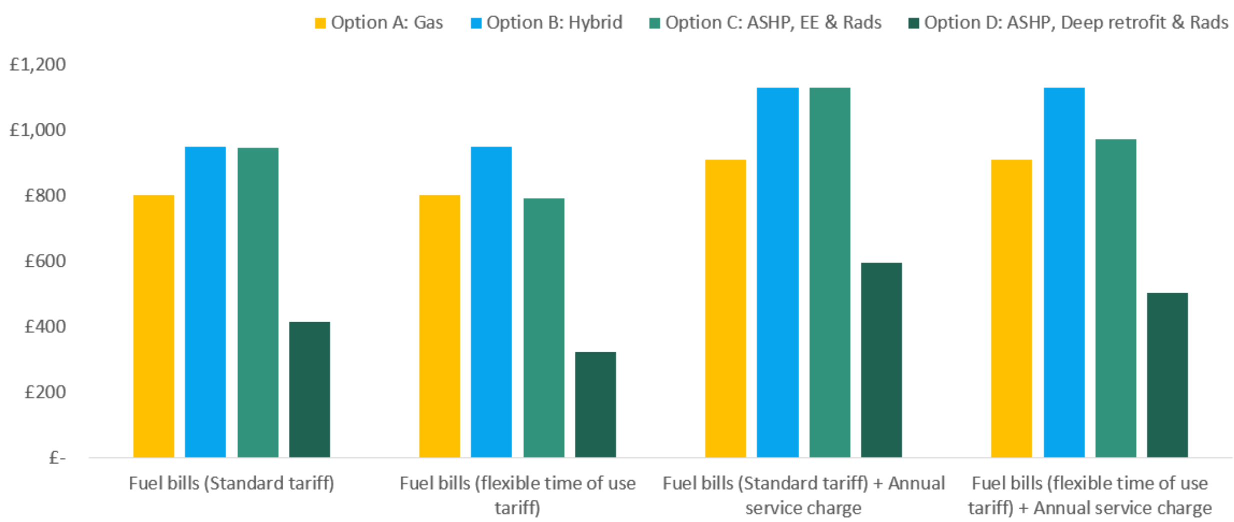
CO_2 emissions

04. Northcote Road: Cumulative CO_2 emissions 2020-2060

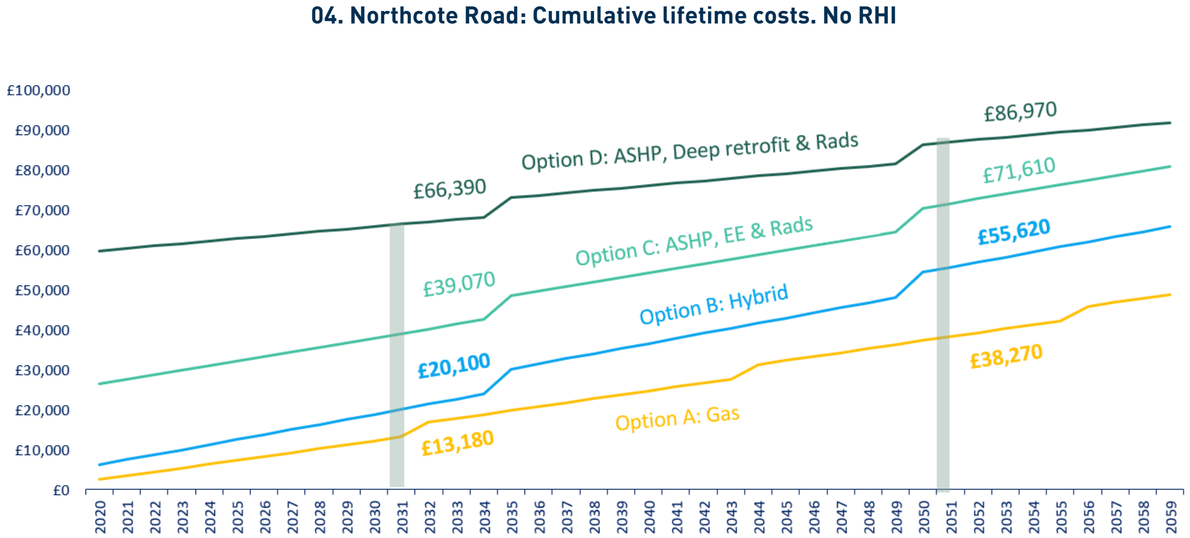


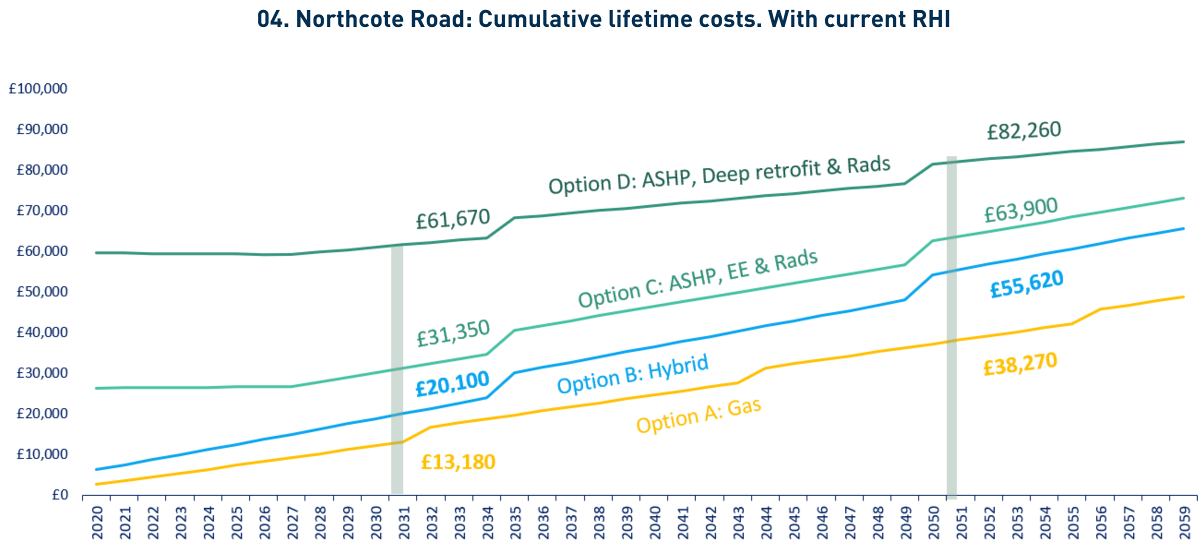
Fuel bills

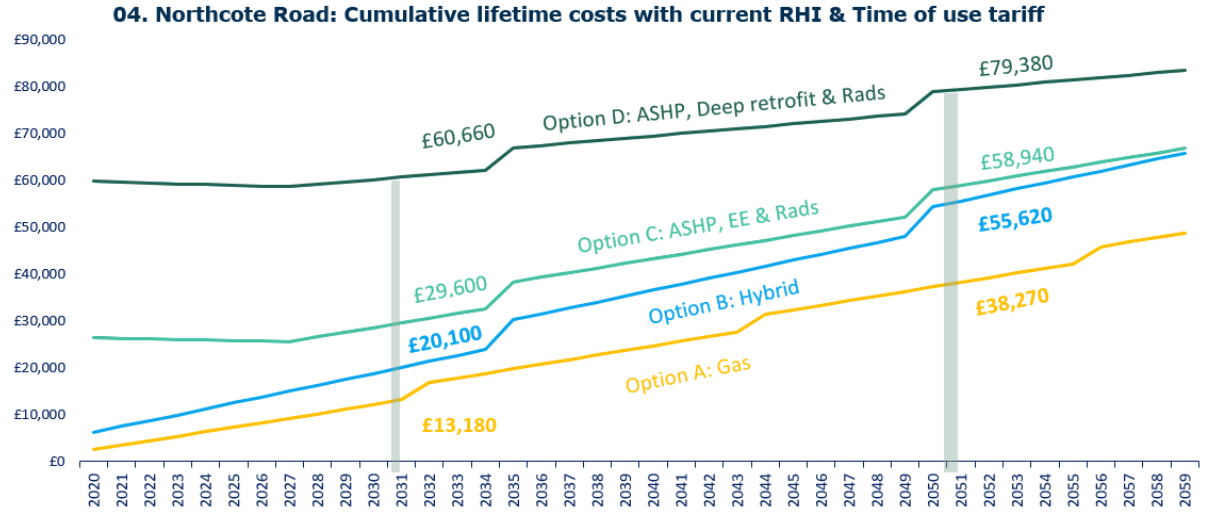
04. Northcote Road: Projected annual fuel bills and annual service costs in 2011

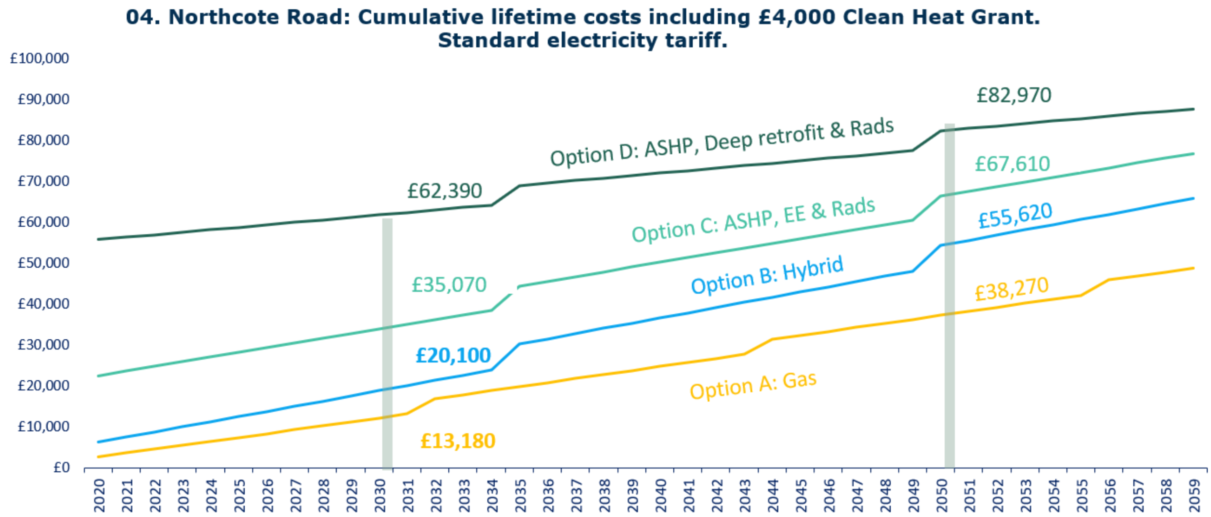


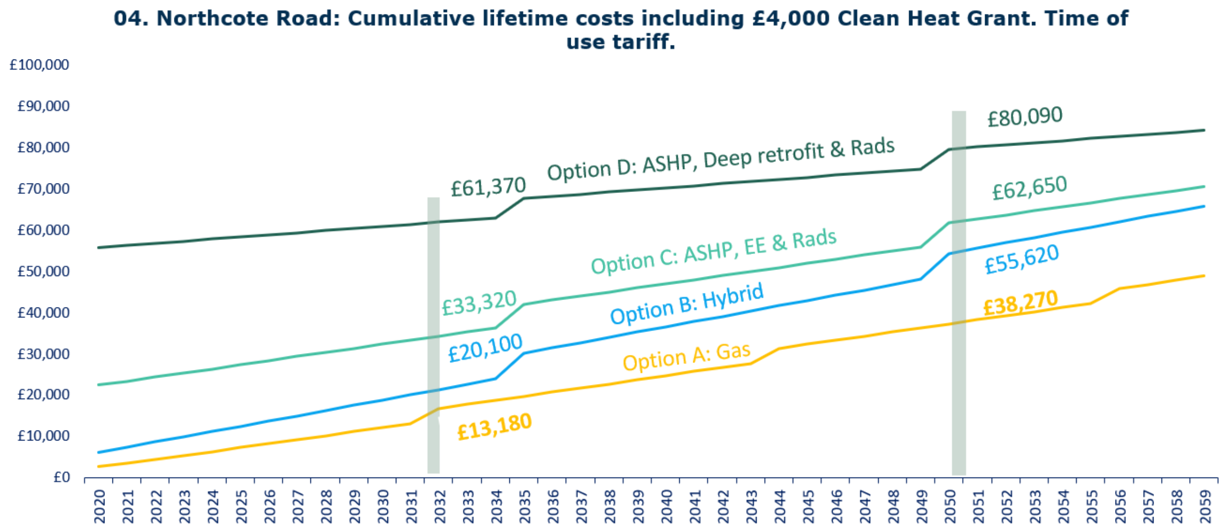
Lifetime costs and sensitivity analysis

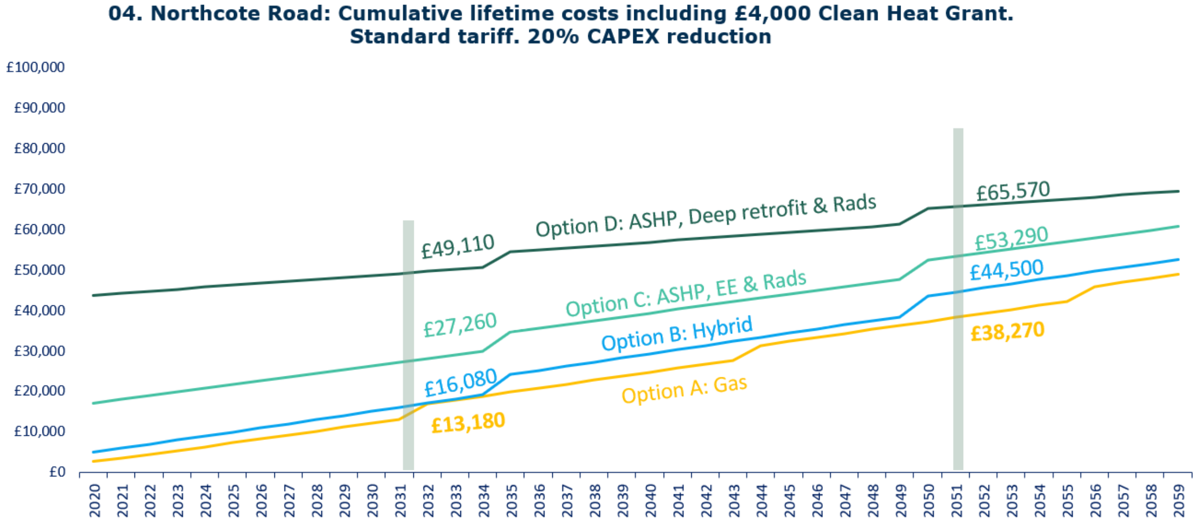





04. Northcote Road: Cumulative lifetime costs with current RHI & Time of use tariff
Option D: ASHP, Deep retrofit & Rads
£60,660
£79,380
Option C: ASHP, EE & Rads
£29,600
£58,940
Option B: Hybrid
£20,100
£55,620
Option A: Gas
£13,180
£38,270

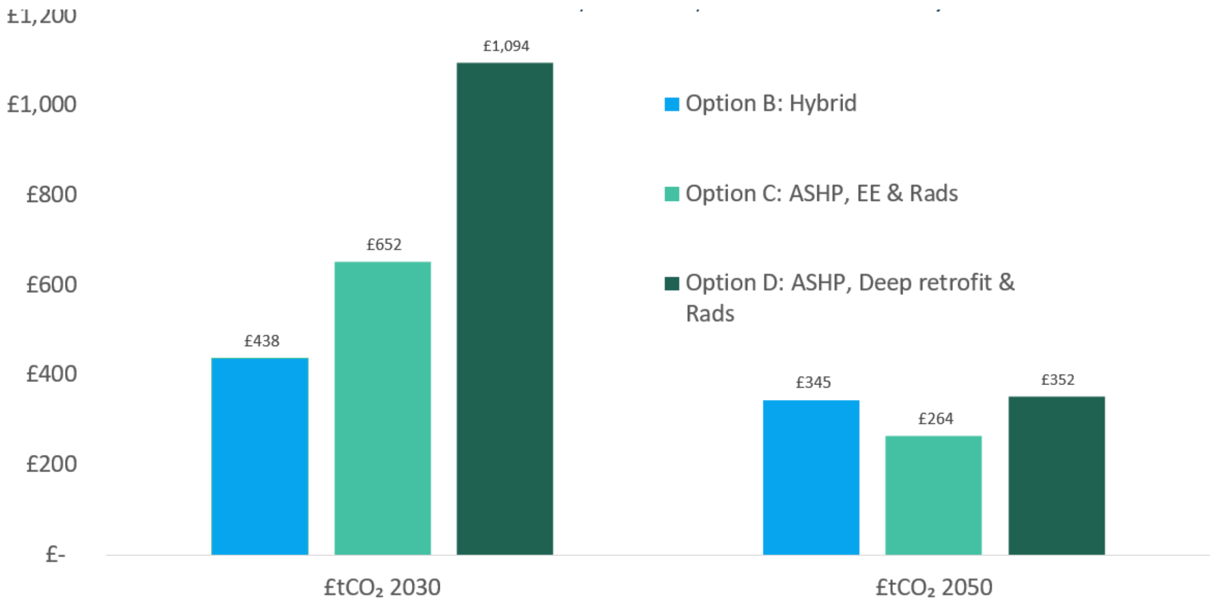

04. Northcote Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.
Option D: ASHP, Deep retrofit & Rads
£62,390
£82,970
Option C: ASHP, EE & Rads
£35,070
£67,610
Option B: Hybrid
£20,100
£55,620
Option A: Gas
£13,180
£38,270


04. Northcote Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.
Option D: ASHP, Deep retrofit & Rads
£61,370
£80,090
Option C: ASHP, EE & Rads
£33,320
£62,650
Option B: Hybrid
£20,100
£55,620
Option A: Gas
£13,180
£38,270



Cost of carbon reduction: £ per tonne of CO_2 reduced

04. Northcote Road: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



04 Northcote Road: Summary of options appraisal

- **CO_2 savings:** Option D: Deep retrofit, ASHP and upgraded heat emitters delivers the largest CO_2 savings of 87% by 2030 and 93% by 2050. In contrast, the Hybrid heat pump option delivers a 28% CO_2 emissions reduction by 2030 and 34% by 2050. In this case it was assumed that the heat pump element of the hybrid would provide 60% of the total space and water heating demand.

- **Fuel bills:** Option D is the only option to result in lower fuel bills under both a standard tariff and flexible tariff. Option B (hybrid heat pump) increases fuel bills. It is assumed that the hybrid heat pump is unable to benefit from the time of use tariff as it already programmed to provide the baseload heating only, with the gas boiler topping up heating to the required level.

- **Expensive energy efficiency in period property:** Both Options C and D involve energy efficiency retrofits that are very expensive. This is because there are extra costs assumed in the energy efficiency improvement of a period property. Notably the additional cost of double-glazed sash windows. In options C and D it was also assumed that current radiators were replaced with expensive, heritage style four column radiators, at a significant cost premium compared to standard triple panel convector radiators.

- **Overall lifetime costs:** The expensive nature of the energy efficiency retrofit means that neither options C nor D are able to achieve cost parity with the gas boiler or hybrid heat pump scenarios, under all RHI or grant assumptions and even with a 20% Capex reduction applied.

- **Improving the financial case for energy efficiency:** Planned maintenance on the property was not taken in to account in the financial case analysis. For example, it is likely that the windows may need some form of replacement in any case over the 30-year lifetime. Bringing forward this capital spend in to the energy efficiency retrofit would significantly improve the business case.

- **Cost of carbon reduction:** Whilst the Hybrid heat pump has the lowest cost of carbon reduction over a 10-year timeframe at £438 per tCO_2, Option B has the lowest cost of carbon reduction over 30 years at £264 per tCO_2. Option D has a cost of carbon of £352 per tCO_2 over 30 years.

- **RHI more generous than Clean Heat Grant:** In this example, due to the high heat demand of the property, the current RHI would result in a more generous subsidy than the proposed Clean Heat £4,000 grant.

- **Victorian terraces highly prevalent in London:** This example is typical of many period homes in London, many of which will require retrofit before heat pumps can be efficiently installed. This emphasises the fact that making the case for energy efficiency in these properties will require significant additional grant or other legislative mechanisms to incentivise installation of these measures.

05. Two bed mid-terrace house, EPC C, Electric heating; Aldenham Drive, Hillingdon

Age	Type	Floor area (m^2)	EPC rating
1980s	2-bed mid terrace house	60	C (70)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
3,969	1,926	5,895	NA
Space heating demand (kWh per m^2 pa)	Current space and water heating system	Secondary heating	Current flow temperature
66	Electric boiler with double panel radiators and hot water cylinder.	None	Unknown
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
3.55	11.2	3.15	41°C
Monthly indicative gas usage (kWh) 2019			
Jan	870	Jul	164
Feb	890	Aug	176
Mar	727	Sep	295
Apr	541	Oct	505
May	295	Nov	807
Jun	164	Dec	882

Assessment of retrofit potential: 05. Aldenham Drive

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	Yes	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	Yes
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	Yes
	Wall mounted	No	Available service ducts for internal pipework?	NA
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Yes	Available water source	No
Suitable space for hot water cylinder?		Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

The property currently has reasonable energy efficiency levels and a relatively low space heating demand at 66kWh/m^2/pa although the quality of the cavity wall insulation and double glazing should be checked as poor performance of these would lead to the EPC over-estimating the thermal performance of the fabric.

The EPC recommends installing floor insulation but, with it having a solid floor, this would have a relatively high upfront cost and low payback for the homeowner. Therefore, for this building we focussed on packages not involving energy efficiency upgrades.

Heat emitter upgrades considered

The property already has relatively large radiators for the level of heat loss. Therefore, a standard heat pump could operate efficiently at the required flow temperatures (41°C) and there are likely to be limited financial or performance benefits to upgrading heat emitters.

Heat pump options considered

Air Source: The property already has a hot water cylinder although the size of the coil may not be suitable for use with a heat pump. However, siting a heat pump internal unit and cylinder would be straightforward.

Ground Source: The surrounding estate would be well suited to a shared ground source ambient loop, with plenty of accessible spaces for boreholes and relatively dense arrangement of houses. However, the estate is predominantly privately owned and so getting multiple homeowners to buy in to the upfront costs would be challenging.

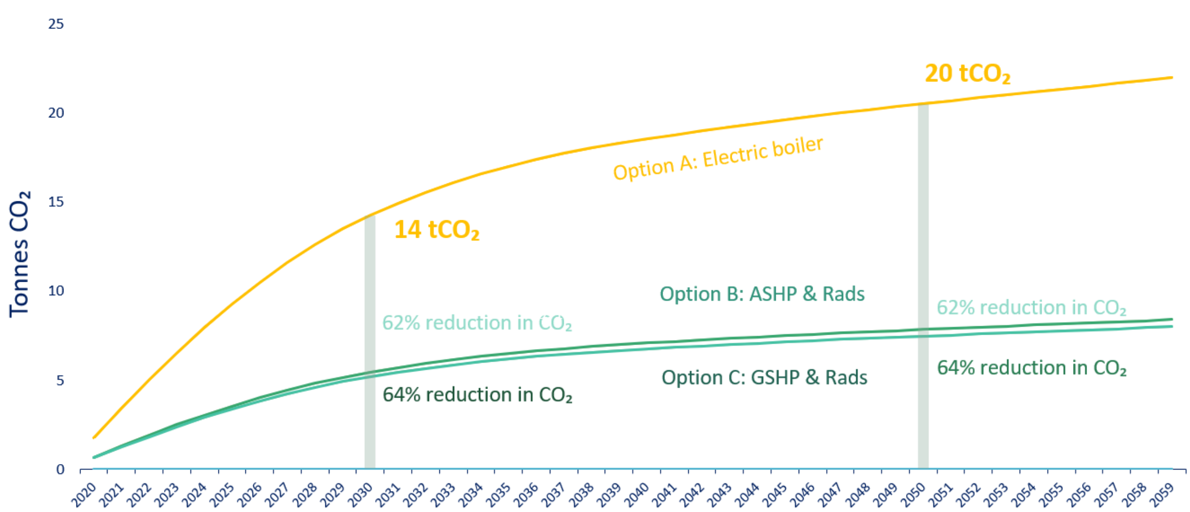
Options appraisal summary of results: 05. Aldenham Drive

		Retrofit scenario		
		5a	5b	5c
Packages of retrofit measures	Heating technology installed	**Replacement electric boiler**	Air to water heat pump HitAch (ambient)i Yutaki S 4.3 Split with 210 litere cylinder	**Ground source heat pump** Vaillant Geo-therm mini with shared ambient loop
	Heat emitter upgrades	None	None	
	Energy efficiency upgrades	None	None	
	Air tightness (Average Air Changes per hour at ambient air pressure)	1.1 Ach (ambient)	1.1 Ach (ambient)	1.1 Ach (ambient)
Energy performance	EPC	C (70)	C (70)	C (70)
	kWh per m^2 pa	66	66	66
System design	Peak heat load (kW)	3.6	3.6	3.6
	Heat emitter output (kW at ▲T 50°C)	11.2	11.2	11.2
	Required flow temp for -1.8°C day	41	41	41
	Assumed efficiency / SPF H4	1	2.62	2.75
CO_2 emissions	Cumulative kg by 2030	14,230	5,431	5,174
	Cumulative kg by 2050	20,487	7,819	7,450
Upfront CAPEX costs	Heating system	£ 2,288	£ 7,258	£ 18,426
	Heat emitters	£ -	£ -	£ -
	Energy efficiency	£ -	£ -	£ -
Grant	RHI	£ -	£ 2,733	£ 5,486
Annual costs	Fuel bill	£ 895	£ 342	£ 325
	Service	£ 109	£ 182	£ 182
Life time costs (Including current RHI)	10 year	£ 11,707	£ 9,287	£ 17,553
	20 year	£ 24,246	£ 18,091	£ 27,311
	30 year	£ 35,505	£ 23,408	£ 32,462
	40 year	£ 46,763	£ 32,213	£ 37,613

CO_2 emissions

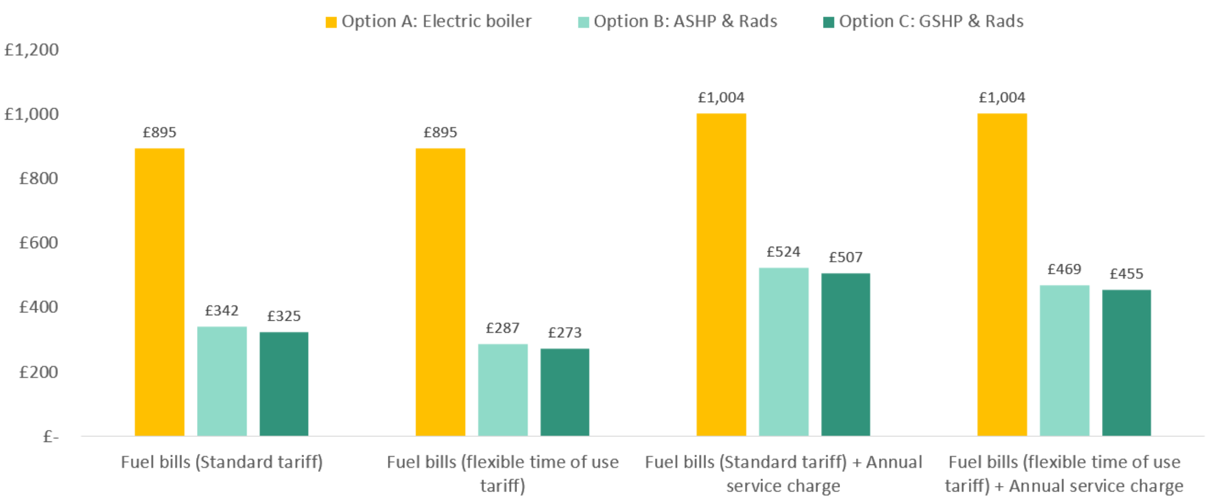
Both heat pump options results in significant CO_2 savings relative to direct electric heating. As all three scenarios involve electric heating, the level of savings remains the same over time, at 61 – 64%. The CO_2 savings are lower than for scenarios where the heat pump replaces gas due to the continuing decarbonisation of grid electricity.

05. Aldenham Drive: Cumulative CO2 emissions 2020-2060

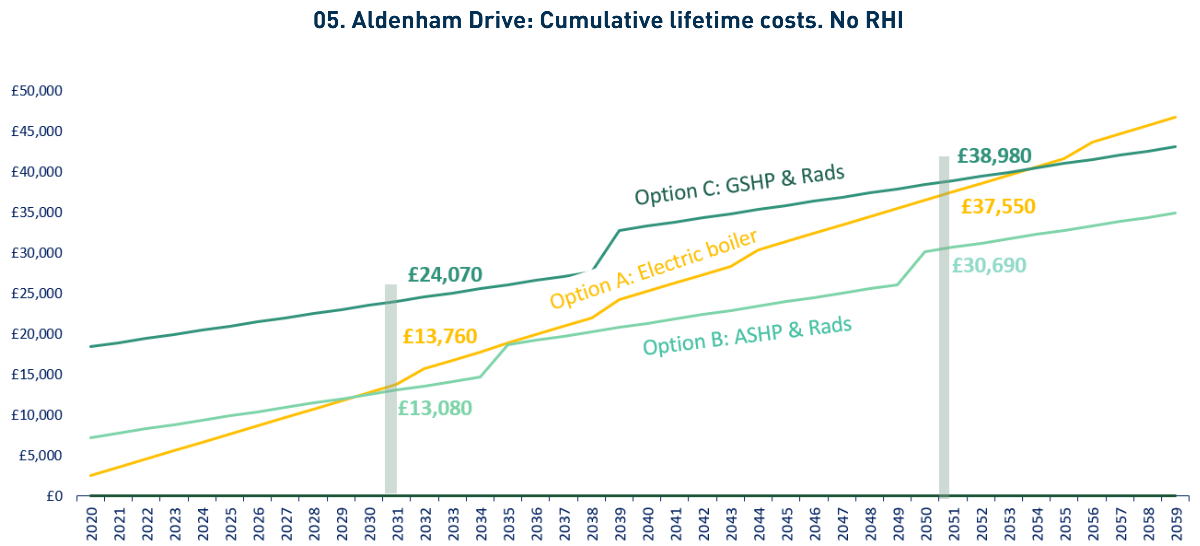


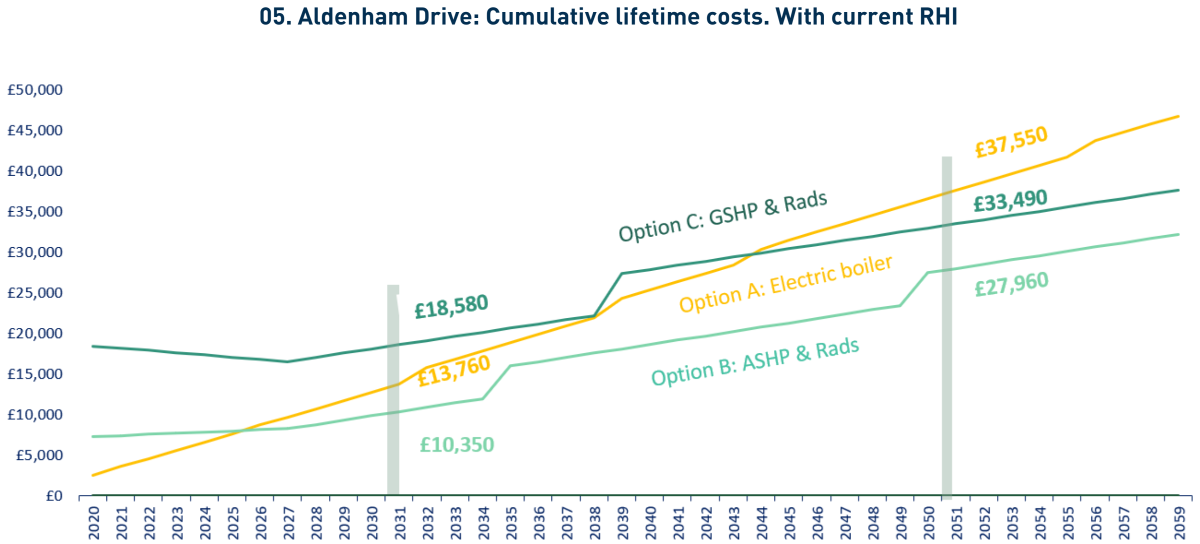
Fuel bills

05. Aldenham Drive: Projected annual fuel bills and annual service costs in 2011

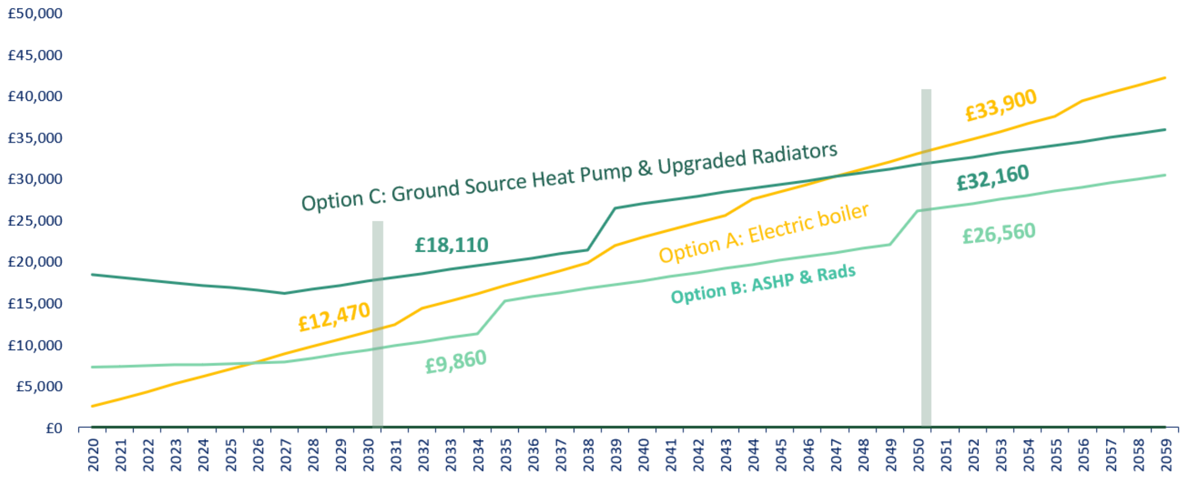


Lifetime costs and sensitivity analysis

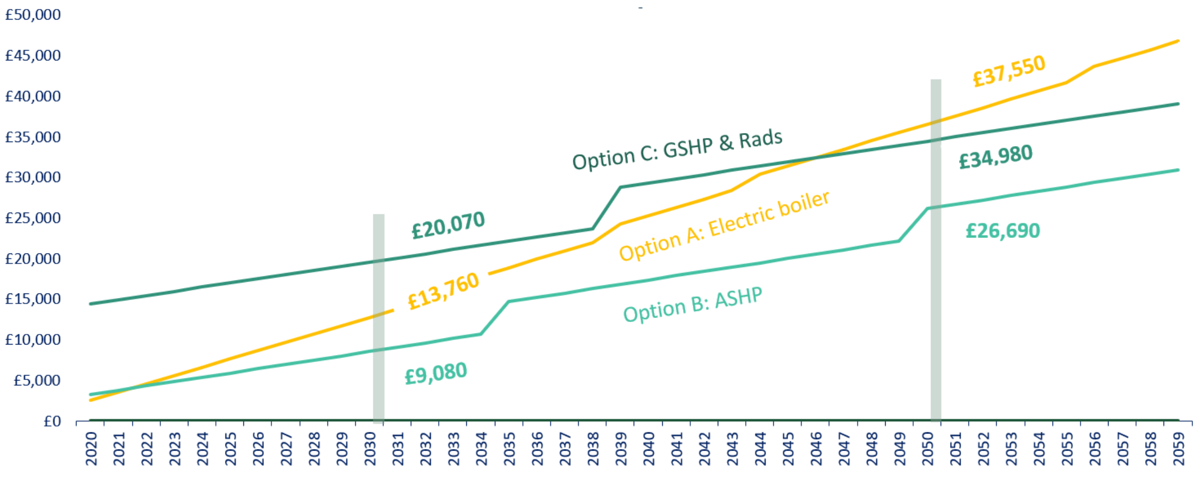




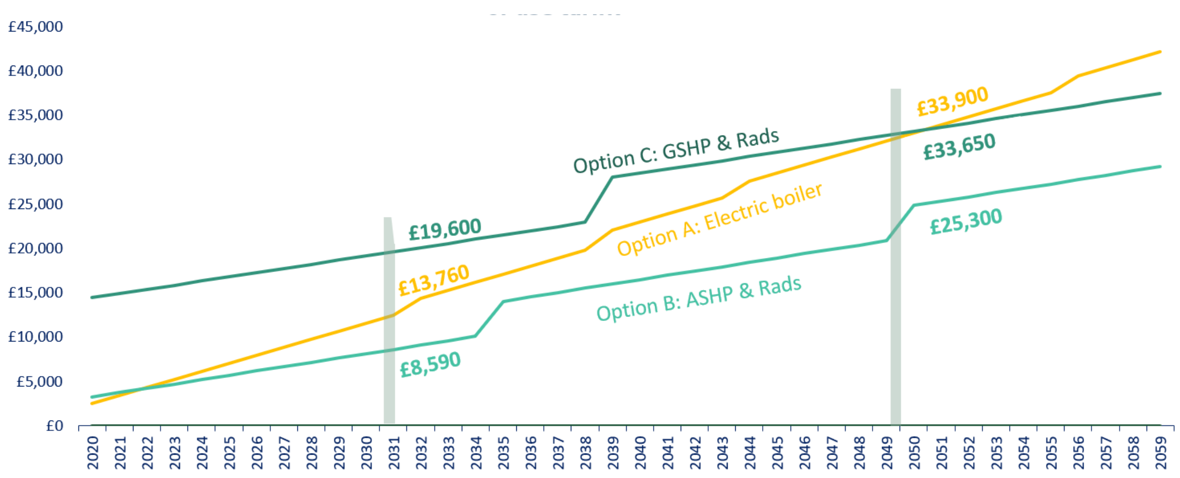
05. Aldenham Drive: Cumulative lifetime costs with current RHI & time of use tariff



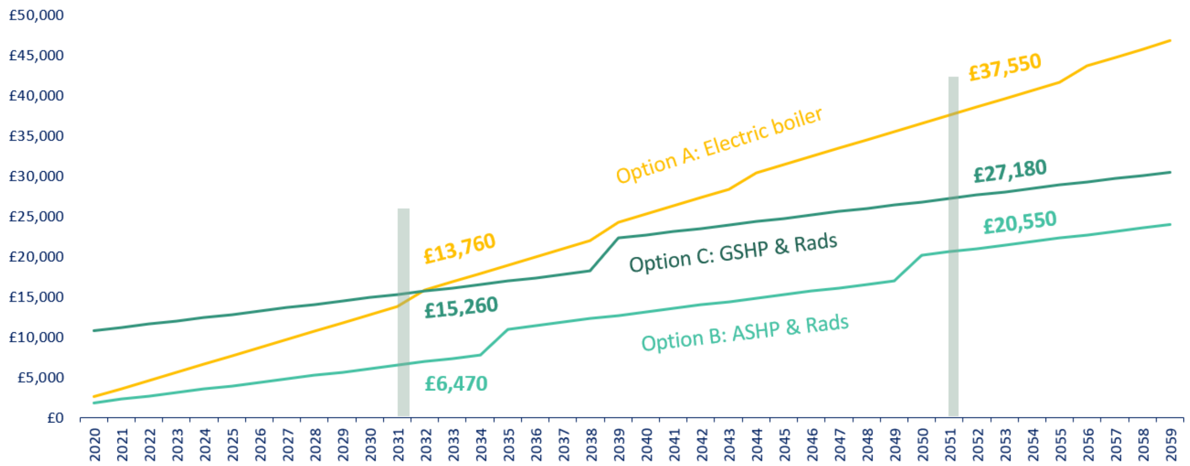
05. Aldenham Drive: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff



05. Aldenham Drive: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff

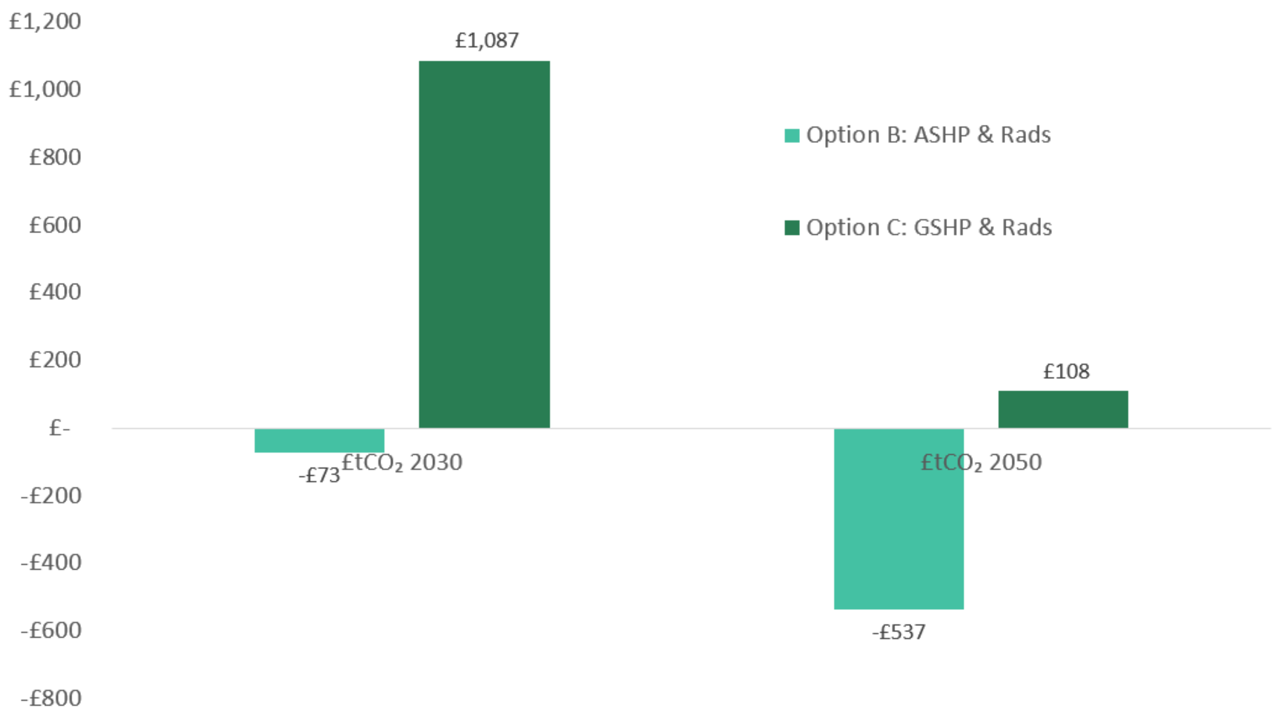


05. Aldenham Drive: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard tariff. 20% CAPEX reduction.



Cost of carbon reduction: £ per tonne of CO_2 reduced

05. Aldenham Road: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



05. Aldenham Drive: Summary of options appraisal

- **CO_2 savings:** Both heat pump options result in CO_2 savings of 62 – 64%. CO_2 savings are lower in this example as the BAU scenario is for a replacement electric boiler. This form of heating would also benefit from the continued decarbonisation of the grid to 2050.

- **Fuel bills:** This example highlights the large fuel bill savings (a 64% reduction) achievable by moving from direct electric heating to a heat pump.

- **Overall lifetime costs:** Option B (Air Source Heat Pump) has the lowest lifetime costs over both 10 and 30 years, with the fuel bills savings outweighing the additional up-front capital investment. This case is made even clearer with the RHI or Clean Heat £4,000 grant applied.

- **Communal Ground Source Heat Pump:** Option C remains more expensive than a direct electric boiler where no grant is applied. However, with the addition of a £4,000 grant and a 20% CAPEX reduction, Option C could become a lower cost option within 12 years.

- **Flexible time of use tariffs**: would reduce fuel bills under all cases, including the BAU scenario. In fact, a flexible tariff would have the greatest impact on the BAU replacement electric boiler.

- **EPC C rated:** The financial case for this property also demonstrates the relative strength of heat pump financial cases where energy efficiency is not required prior to the installation of the heat pump.

- **Cost of carbon reduction:** The cost of carbon reduction is negative in this example, as the heat pump options have a lower 10 year and 30 year lifetime cost than the Option A BAU scenario. This is despite the CO_2 emissions savings being relatively smaller than when replacing gas boilers.

- **Clean Heat Grant more generous than RHI:** In this example, a £4,000 Clean Heat Grant would be more generous than the RHI rates for the ASHP but less generous than the RHI grant for the GSHP.

06. Four bed mid terrace house, EPC C; Surrey Road, Southwark

Age	Type	Floor area (m²)	EPC rating
1980s	4-bed mid terrace house	93	C (74)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
6,701	1,963	8,654	NA
Space heating demand (kWh per m² pa)	Current space and water heating system	Secondary heating	Current flow temperature
72	'A' rated gas combi-boiler with radiators (mainly double convector). No hot water cylinder.	NA	65°C
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
4.8	10.30	2.15	48°C
Monthly indicative gas usage (kWh) 2019			
Jan	1,267	Jul	137
Feb	1,301	Aug	146
Mar	1,047	Sep	348
Apr	753	Oct	692
May	358	Nov	1,181
Jun	137	Dec	1,288

Assessment of retrofit potential: 06. Surrey Road

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	Yes	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	No
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	No
	Wall mounted	No	Available service ducts for internal pipework?	NA
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Yes	Available water source	No
Suitable space for hot water cylinder?		Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

The property has reasonable levels of energy efficiency and relatively low space heating requirement (72 kWh per m^2 pa). Air tightness improvements should be considered to further reduce space heating demand. However, energy efficiency upgrades were not considered essential for effective performance of the heat pump.

Heat emitter upgrades considered

The property already has relatively large radiators for the level of heat loss. Therefore, a low temperature heat pump could operate efficiently at the required flow temperatures (48°C) and there may be limited benefits to upgrading heat emitters. Two scenarios (1 including radiator upgrades and 1 excluding radiator upgrades) were used to test this.

Heat pump options considered

Air Source: located to the rear of the property. Due to the close proximity of neighbours on either side, a heat pump with very low noise levels (below 45dB) may be necessary to conform to Permitted Development guidelines under MCS 020.

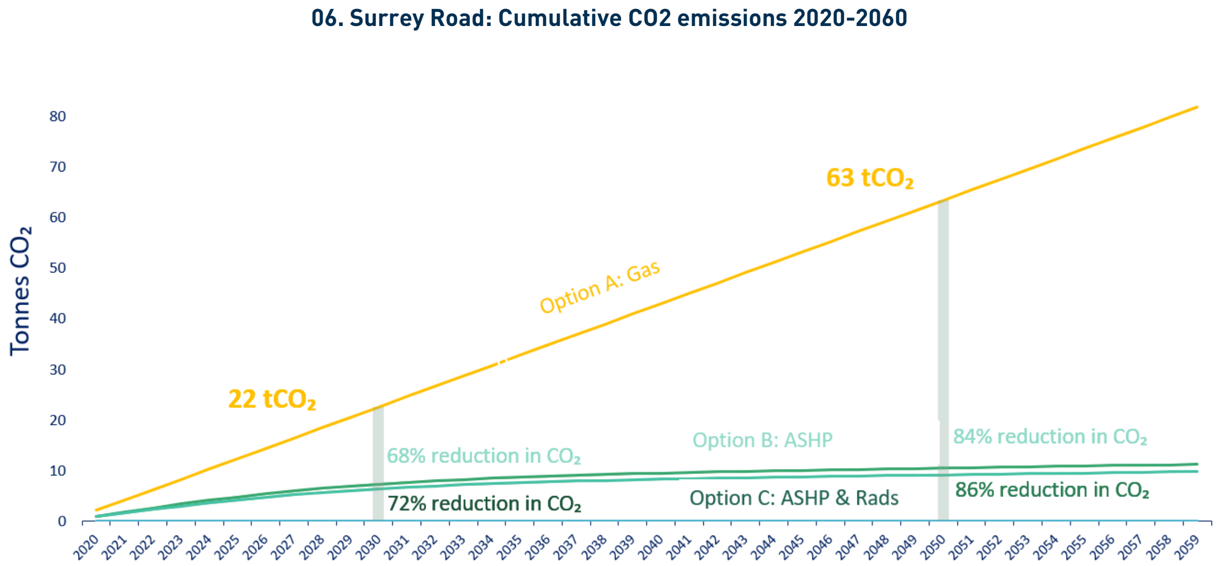
Ground Source: The property has no easily accessible space for borehole drilling. The surrounding neighbourhood is densely urban with no communal shared space. Therefore, the area does not lend itself easily to a shared ambient loop.

Options appraisal summary of results: 06. Surrey Road

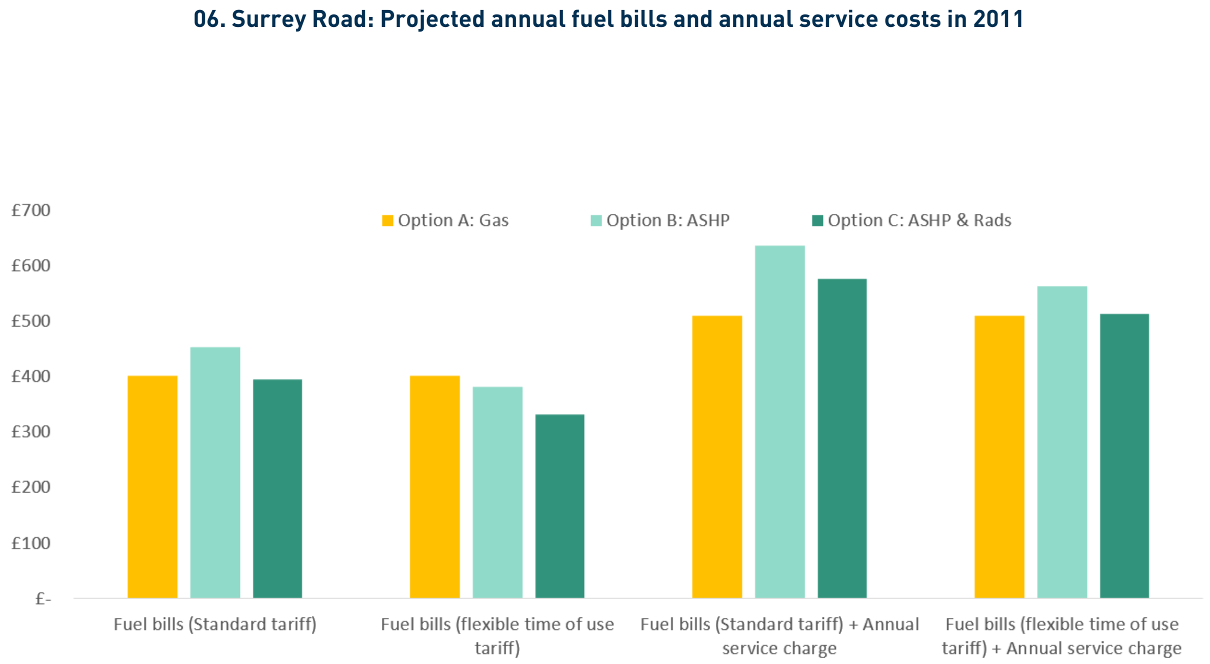
		Retrofit scenario		
		6a	6b	6c
Packages of retrofit measures	Heating technology installed	**Replacement gas boiler**	**Air to water heat pump** IVT AirX 50 / 190L AirModule	**Air to water heat pump** IVT AirX 50 / 190L AirModule
	Heat emitter upgrades	None	None	Triple panel convector
	Energy efficiency upgrades	None	None	
	Air tightness (Average Air Changes per hour at ambient air pressure)	1.08 Ach (ambient)	1.08 Ach (ambient)	1.08 Ach (ambient)
Energy performance	EPC	C (74)	C (74)	C (74)
	kWh per m^2 pa	72	72	72
System design	Peak heat load (kW)	4.8	4.8	4.8
	Heat emitter output (kW at ▲T 50°C)	10.3	10.3	19.6
	Required flow temp for -1.8°C day	48	48	37
	Assumed efficiency / SPF H4	0.89	2.89	3.32
CO_2 emissions	Cumulative kg by 2030	22,462	7,228	6,292
	Cumulative kg by 2050	63,301	10,407	9,059
Upfront CAPEX costs	Heating system	£ 2,395	£ 10,065	£ 10,065
	Heat emitters	£ -	£ -	£ 3,346
	Energy efficiency	£ -	£ -	£ -
Grant	RHI	£ -	£ 4,243	£ 4,534
Annual costs	Fuel bill	£ 402	£ 455	£ 396
	Service	£ 109	£ 182	£ 182
Life time costs (Including current RHI)	10 year	£ 7,427	£ 11,616	£ 14,133
	20 year	£ 15,555	£ 24,348	£ 26,262
	30 year	£ 23,682	£ 30,821	£ 32,132
	40 year	£ 31,809	£ 43,552	£ 44,261

CO_2 emissions

Both heat pump options results in significant CO_2 savings relative to direct electric heating. The additional impact of upgrading the radiators (to reduce flow temperatures from 48°C to 37°C) is small in terms of CO_2 reduction but is likely to lead to additional comfort for the homeowner and lower peak demands on the electricity network.

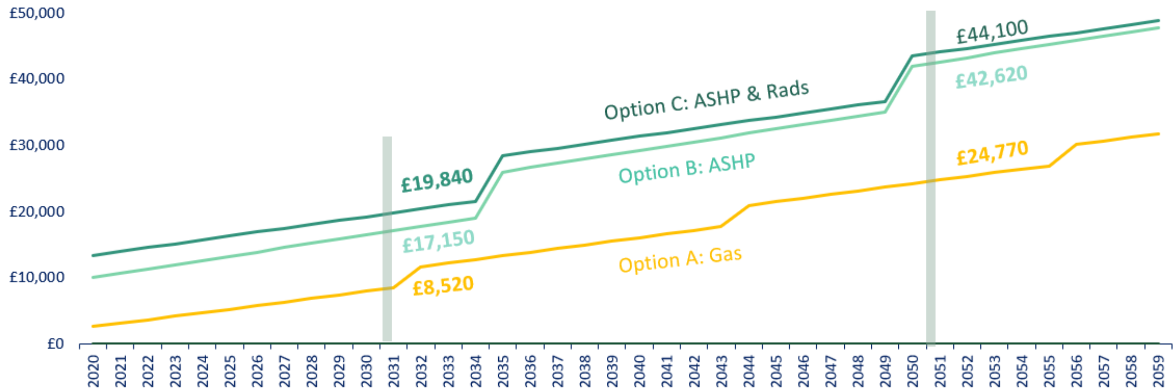


Fuel bills

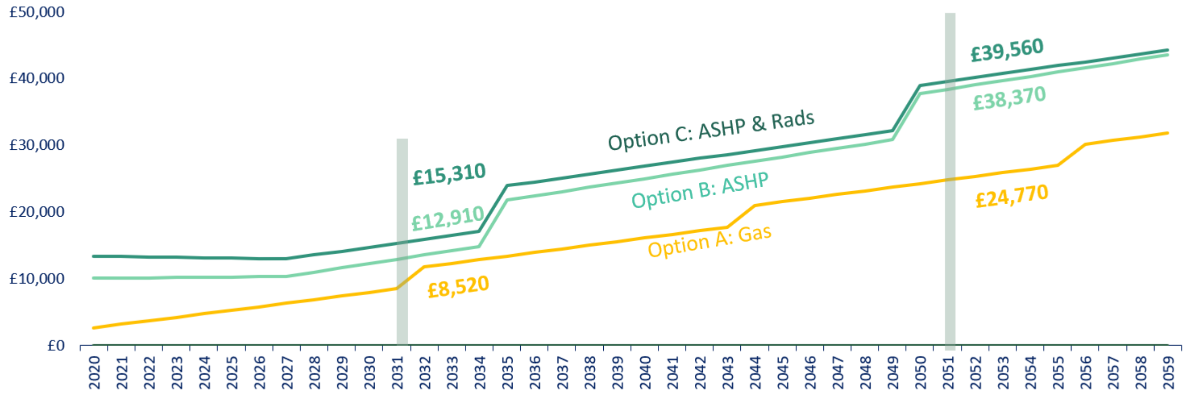


Lifetime costs and sensitivity analysis

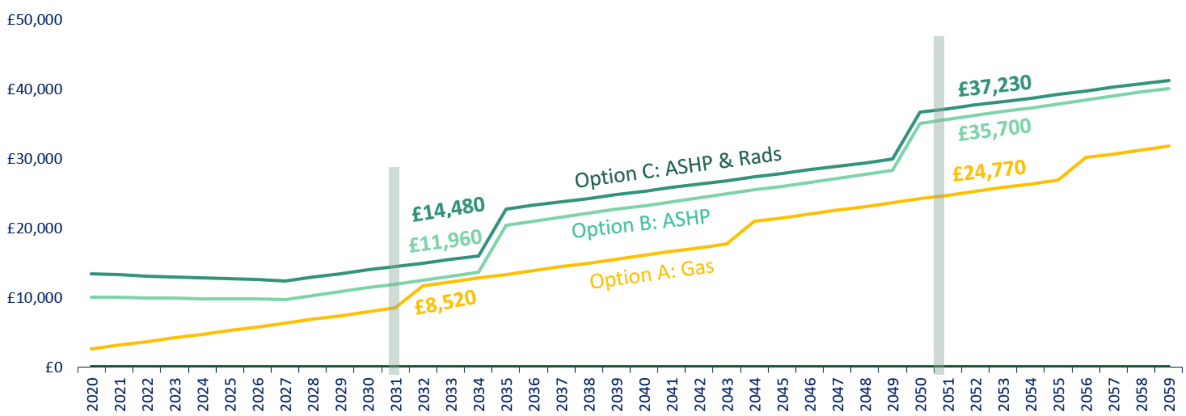
06. Surrey Road: Cumulative lifetime costs. No RHI



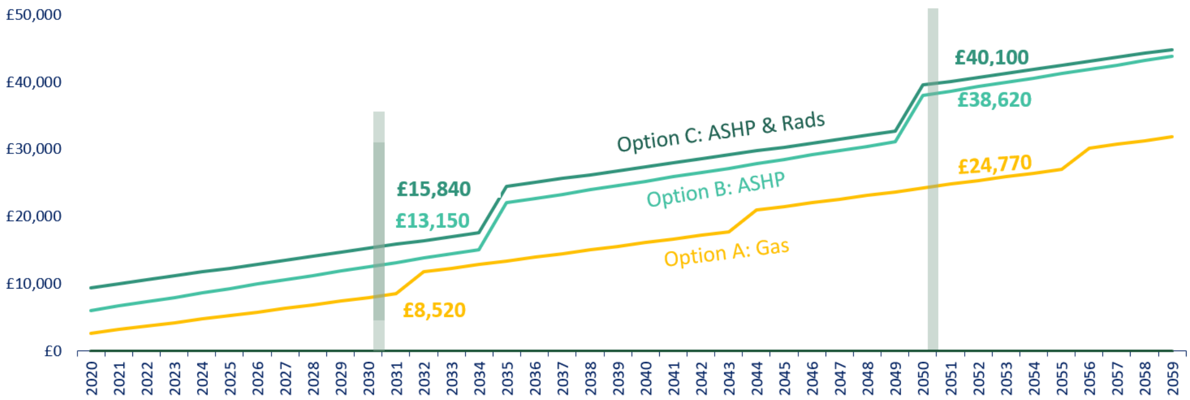
06. Surrey Road: Cumulative lifetime costs. With current RHI



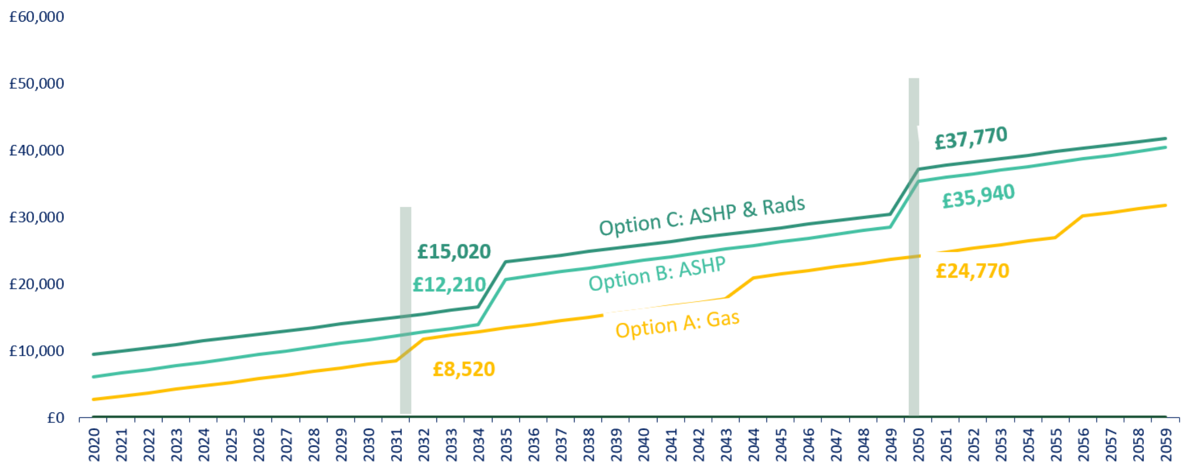
06. Surrey Road: Cumulative lifetime costs with current RHI & time of use tariff



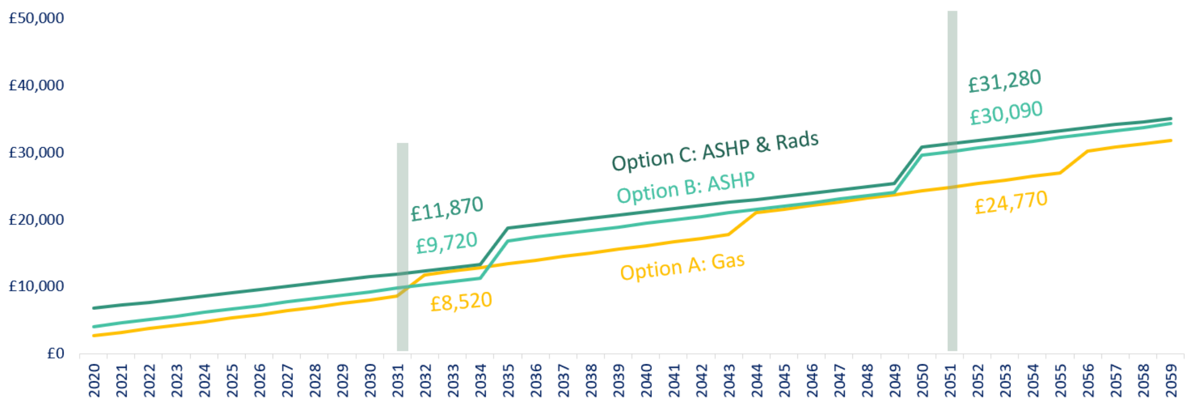
06. Surrey Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.



06. Surrey Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.

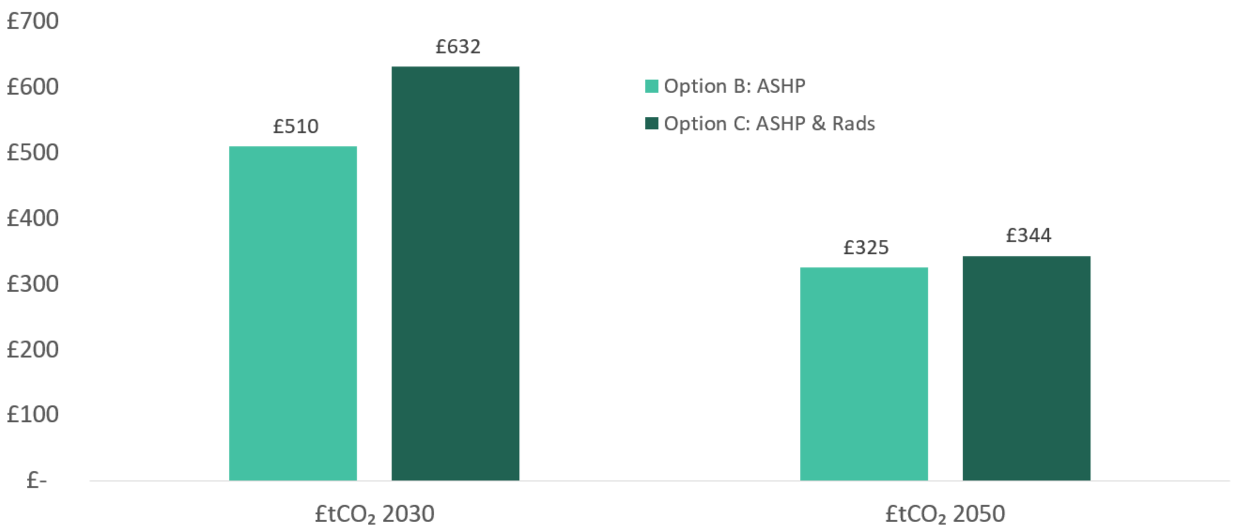


06. Surrey Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard tariff. 20% CAPEX reduction.



Cost of carbon reduction: £ per tonne of CO_2 reduced

06. Surrey Road: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



06. Surrey Road: Summary of options appraisal

- **CO_2 savings:** Both heat pump options result in CO_2 savings of 84 - 86%.

- **Fuel bills:** In Option C, the high efficiency of the heat pump model used, combined with the installation of triple panel convector radiators to achieve a low flow temperature of 37°C means that a very high efficiency of 3.32 may be possible and fuel bills would be lower than for gas, even on a standard tariff. This is also helped by the removal of the gas standing charge to the property. However, when annual service charges are applied, both heat pump options have higher OPEX than the gas boiler option.

- **Overall lifetime costs:** If a £4,000 grant is combined with a 20% up front capital cost reduction, then Option B comes close to cost parity with the gas boiler option at year 10.

- **Additional investment in triple panel convector radiators does not payback its investment**: Generally speaking, additional investment in heat emitters to deliver lower flow temperatures can result in a positive payback, as this enables the heat pump to operate more efficiently. However, in this case, because the flow temperatures are already within a comfortable operating range for the ASHP in Option B (47°C), the additional impact of the radiators to bring flow temperatures down to 37°C is relatively small and the additional investment does not payback.

- **EPC C rated:** The financial cases for this property also demonstrate the relative strength of heat pump financial cases where energy efficiency is not required prior to the installation of the heat pump.

- **Cost of carbon reduction:** A relatively low cost of carbon reduction is achieved in Option B (£325 per tCO_2 by 2050). This is due to the fact that energy efficiency measures and upgraded heat emitters are not required prior to installation of the heat pump.

- **Relatively high upfront costs:** A more expensive ASHP unit with very low noise levels was chosen for this example due to the close proximity of neighbouring properties.

- **RHI more generous than £4,000 Clean Heat Grant.** In this example, the RHI would be marginally more generous than a £4,000 Clean Heat Grant for the ASHP.

07. 4 bed detached house; EPC D; Mowbray Road, Croydon

Age	Type	Floor area (m²)	EPC rating
1960s	4-bed detached house	133	D (66)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
16,416	3,821	20,237	15,275
Space heating demand (kWh per m² pa)	Current space and water heating system	Secondary heating	Current flow temperature
123	'A' rated has combi-boiler with radiators (mix of double convector and single convector). No cylinder	Wood burner in main living area.	65°C
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
7.81	13.8	1.77	52°C
Monthly indicative gas usage (kWh) 2019			
Jan	2,756	Jul	301
Feb	1,941	Aug	230
Mar	1,862	Sep	294
Apr	1,312	Oct	1,309
May	543	Nov	2,215
Jun	167	Dec	2,345

Assessment of retrofit potential: 07. Mowbray Road

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	Yes	Available & accessible space for ground trench	Yes
	Balcony	No	Available & accessible space for bore hole	Yes
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	Yes
	Wall mounted	No	Available service ducts for internal pipework?	NA
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Yes	Available water source	No
Suitable space for hot water cylinder?		Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

EPC recommendations include some relatively cost effective energy efficiency measures including loft insulation top up (100mm - 300mm) plus solid floor insulation (suspended timber floor). Also, the homeowner is currently considering an extension and alterations to the rear aspect of the property and is interested in expanding this project to include a deep retrofit of the entire building to low carbon standards.

Heat emitter upgrades considered

The property already has relatively large radiators for the level of heat loss although radiator upgrades would reduce flow temperatures further and improve efficiency. Current radiators are a mixture of double panel (downstairs) and single panel (upstairs).

Heat pump options considered

Accessible space to both the front and rear of the property provide options for heat pump ground loop or borehole installation. However, the homeowner does not want the disruption to the garden areas that would be necessary in this case and these are unlikely to be cost effective for a single dwelling. Therefore, only Air Source Heat Pump options were explored.

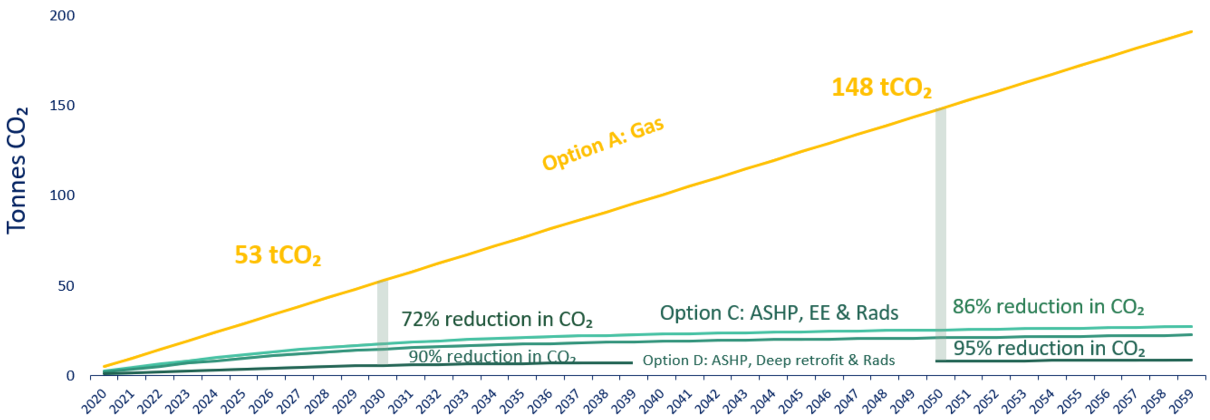
Options appraisal summary of results: 07. Mowbray Road

		Retrofit scenario			
		7a	7b	7c	7d
Packages of retrofit measures	Heating technology installed	Replacement Gas combi-boiler	**Air to water heat pump** Panasonic Aquarea 9kW monobloc plus 210l cylinder	**Air to water heat pump** Daikin Altherma 7kW Monobloc	**Air to water heat pump** Vaillent Arotherm 3.5kW with 200l Cylinder
	Heat emitter upgrades	None	None	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	Improved air tightness and insulation	Deep fabric retrofit
	Air tightness (Average Air Changes per hour at ambient air pressure)	1.12 Ach (ambient)	1.12 Ach (ambient)	0.67 Ach (ambient)	0.10 Ach (ambient)
Energy performance	EPC	D (66)	D (66)	C	A/B
	kWh per m^2 pa	123	123	98	30
System design	Peak heat load (kW)	8.7	8.7	6.9	2.1
	Heat emitter output (kW at ▲T 50°C)	13.8	13.8	27.8	25.0
	Required flow temp for -1.8°C day	53	53	38	25
	Assumed efficiency / SPF H4	0.89	2.79	2.81	3.14
CO_2 emissions	Cumulative kg by 2030	52,525	17,509	14,479	5,493
	Cumulative kg by 2050	148,026	25,208	20,846	7,909
Upfront CAPEX costs	Heating system	£ 2,395	£ 9,588	£ 8,470	£ 7,402
	Heat emitters	£ -	£ -	£ 4,340	£ 4,160
	Energy efficiency	£ -	£ -	£ 3,700	£ 42,427
Grant	RHI	£ -	£ 9,734	£ 8,139	£ 3,651
Annual costs	Fuel bill	£ 823	£ 1,101	£ 911	£ 345
	Service	£ 109	£ 182	£ 182	£ 182
Life time costs (Including current RHI)	10 year	£ 11,423	£ 11,560	£ 18,334	£ 55,134
	20 year	£ 24,221	£ 29,749	£ 33,801	£ 64,078
	30 year	£ 37,018	£ 42,841	£ 49,268	£ 73,021
	40 year	£ 49,815	£ 61,030	£ 60,409	£ 78,378

CO_2 emissions

All heat pump options results in significant CO_2 savings relative to the gas boiler. The deep retrofit option achieves approximately 95% cumulative CO_2 reduction by 2050.

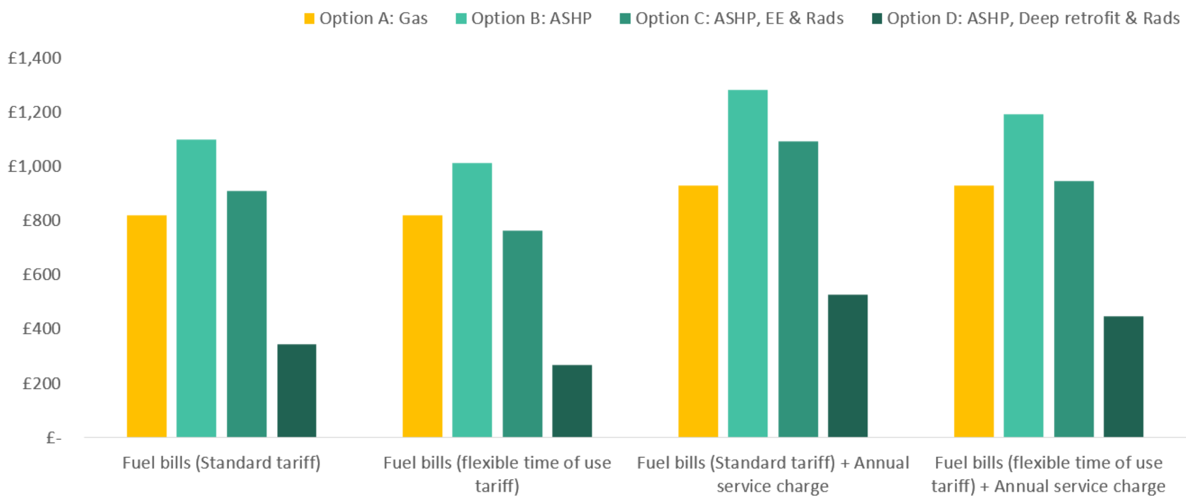
07. Mowbray Road: Cumulative CO2 emissions 2020-2060



Fuel bills

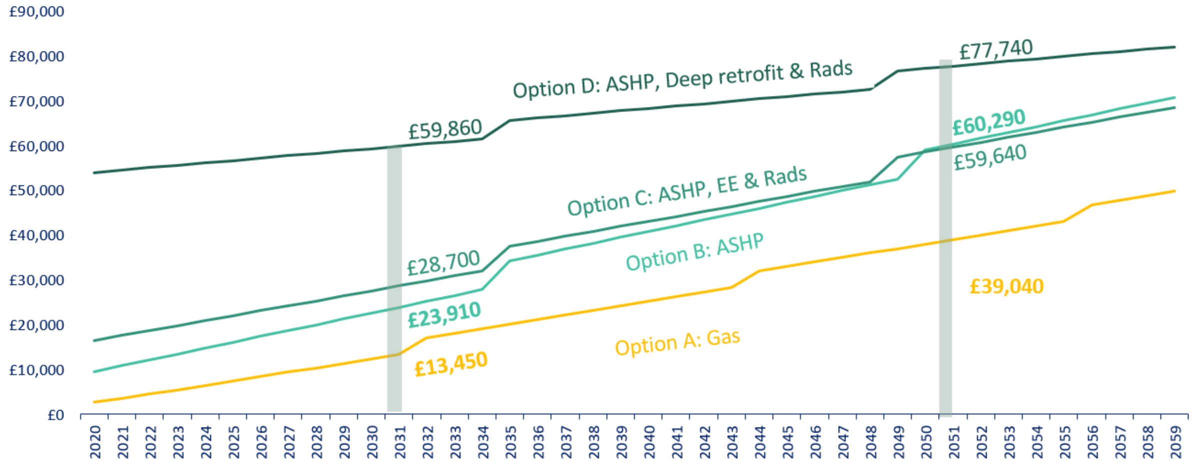
This example demonstrates the potential for fuel bills to increase significantly in a larger property that requires flow temperatures towards the top of the heat pump operating ranges (Option B = 53°C). Option B could see fuel bills increase by approx. £350 over Option A. Fuel bills for option B remain broadly equivalent to gas if cheaper tariffs are assumed although the building's ability to shift space heating load is limited in Option B. Even under Option C, with improved insulation, air tightness and heat emitters (flow temp: 38°C) fuel bills have the potential to increase by approx. £130. Option D sees a reduction of £550 – £720 relative to Option A.

07. Mowbray Road: Projected annual fuel bills and annual service costs in 2011

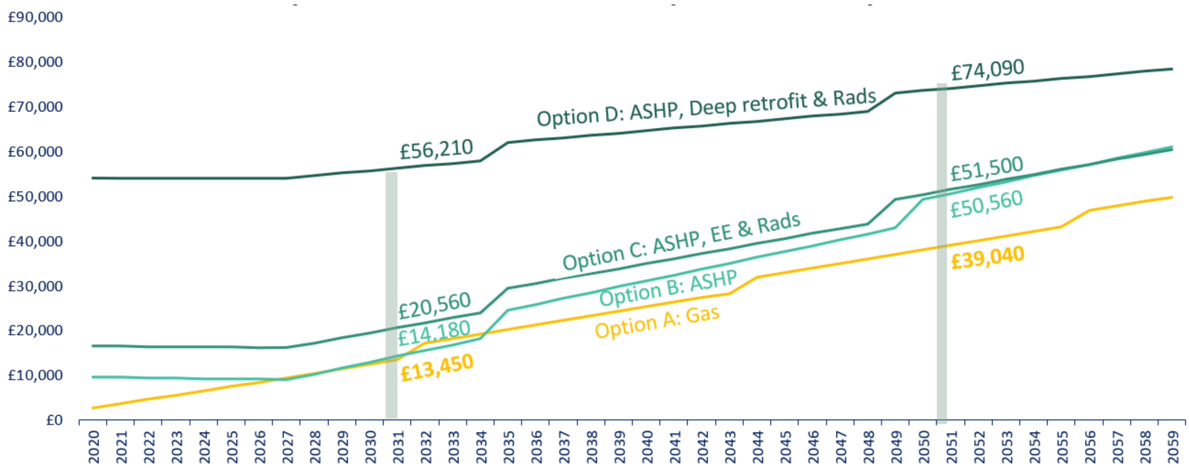


Lifetime costs and sensitivity analysis

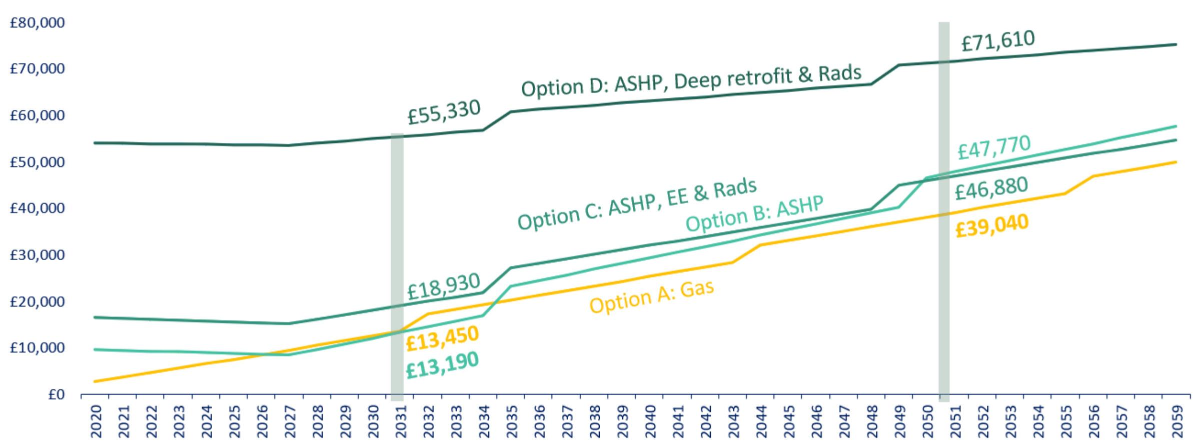
07. Mowbray Road: Cumulative lifetime costs. No RHI

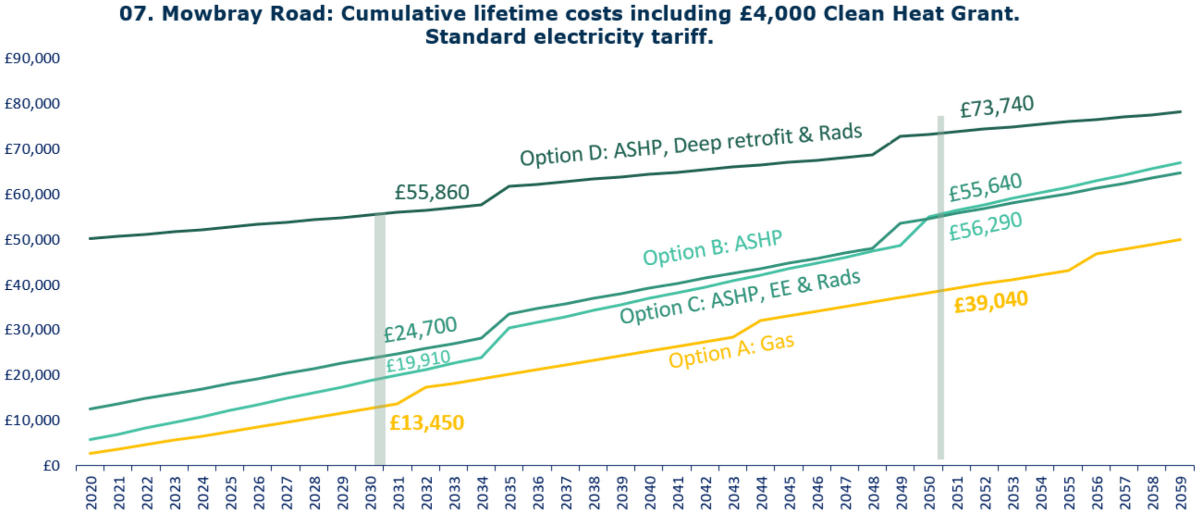


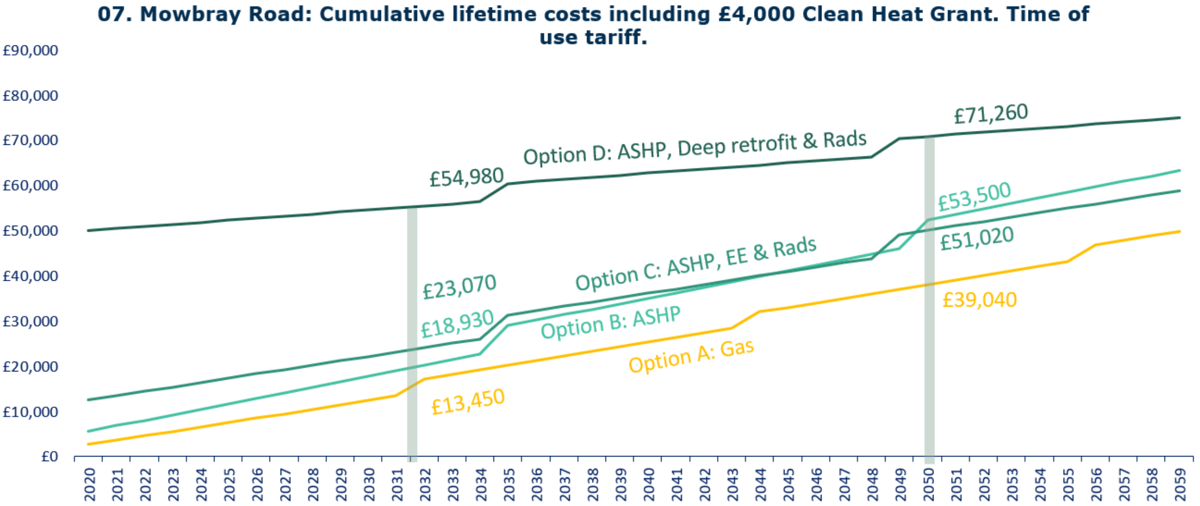
07. Mowbray Road: Cumulative lifetime costs. With current RHI



07. Mowbray Road: Cumulative lifetime costs with current RHI & time of use tariff




07. Mowbray Road: Cumulative lifetime costs including £4,000 Clean Heat Grant.
Standard electricity tariff.
Option D: ASHP, Deep retrofit & Rads
Option B: ASHP
Option C: ASHP, EE & Rads
Option A: Gas
£55,860
£73,740
£55,640
£56,290
£39,040
£24,700
£19,910
£13,450
£90,000
£80,000
£70,000
£60,000
£50,000
£40,000
£30,000
£20,000
£10,000
£0
2020
2059


07. Mowbray Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.
Option D: ASHP, Deep retrofit & Rads
Option C: ASHP, EE & Rads
Option B: ASHP
Option A: Gas
£54,980
£71,260
£53,500
£51,020
£39,040
£23,070
£18,930
£13,450
£90,000
£80,000
£70,000
£60,000
£50,000
£40,000
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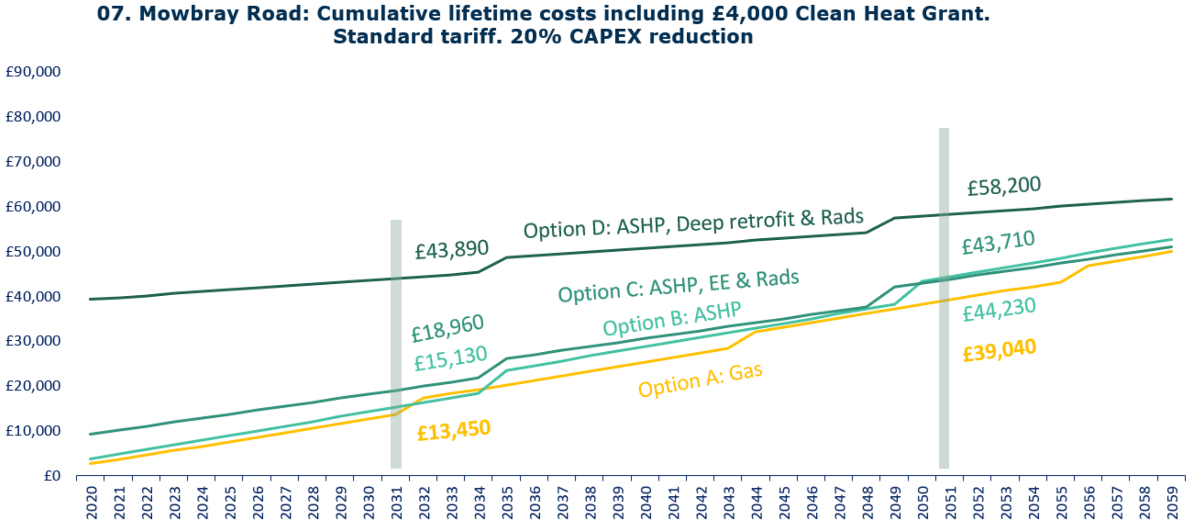
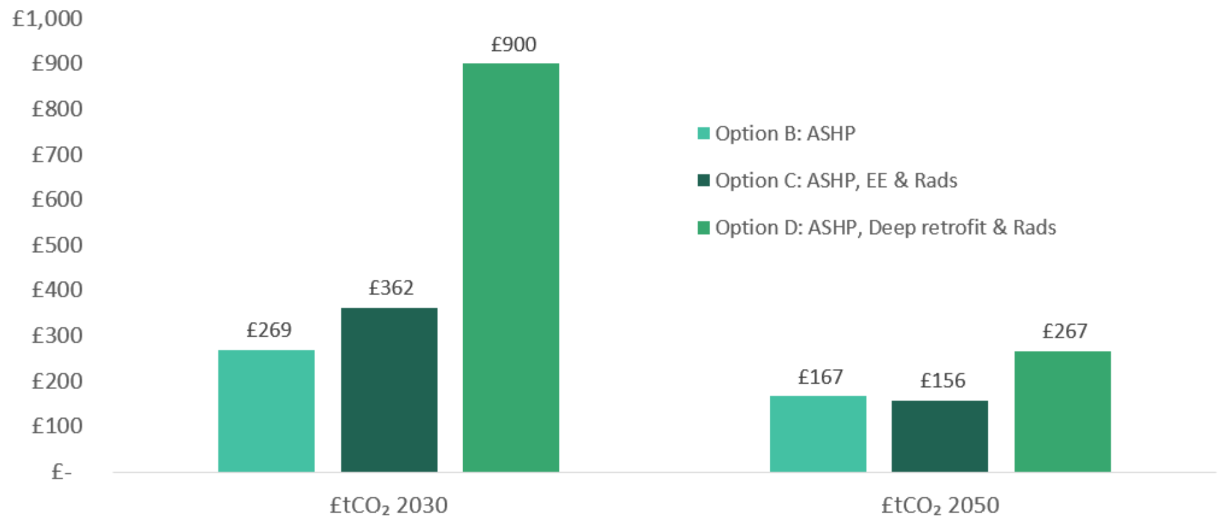
£20,000
£10,000
£0
2020
2059


07. Mowbray Road: Cumulative lifetime costs including £4,000 Clean Heat Grant.
Standard tariff. 20% CAPEX reduction
Option D: ASHP, Deep retrofit & Rads
Option C: ASHP, EE & Rads
Option B: ASHP
Option A: Gas
£43,890
£58,200
£43,710
£44,230
£39,040
£18,960
£15,130
£13,450
£90,000
£80,000
£70,000
£60,000
£50,000
£40,000
£30,000
£20,000
£10,000
£0
2020
2059

Cost of carbon reduction: £ per tonne of CO_2 reduced

07. Mowbray Road: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



07. Mowbray Road: Summary of Options Appraisal

- **CO_2 savings:** Option D delivers a CO_2 saving of 95% by 2050. In contrast, Options B and C deliver CO_2 savings of 86 – 87%.
- **Fuel bills:** Option D is the only option to deliver fuel bill reductions, with fuel bills reduced by up to 75%.
- **Overall lifetime costs:** If a £4,000 grant is combined with a 20% up front capital cost reduction, then Option B comes close to cost parity with the gas boiler option at year 10. Option D, the Deep retrofit of the building to Enerphit Standards, remains more expensive in terms of lifetime costs at all timeframes and regardless of grant payments or CAPEX reductions.
- **Cost effective energy efficiency measures:** Option C includes a number of cost-effective energy efficiency measures such as increased loft insulation. This investment just pays for itself within the 30-year timeframe and results in Option C having the lowest cost of carbon reduction by year 30.

- **Additional investment in triple panel convector radiators:** The benefits of the partial retrofit + upgraded heat emitters (enabling a reduced flow temperature from 53°C – 38°C) achieve payback within the 30 year timeframe, with the initial capital investment in heat emitters and energy efficiency counter balanced by a lower capital cost for the heat pump plus a lower overall demand for heat. In this case, the heat pump efficiency only improved marginally under our modelling scenario, despite the reduction in flow temperature. This is due to different predicted efficiencies of the specific heat pump products used in each scenario.

- **Cost of carbon:** Option B delivers a low cost of carbon of £269 over 10 years. This is due to the relatively good efficiency of the heat pump achieved in a building that is relatively energy efficient and has flow temperatures below 55°C without requiring the upgrade of heat emitters. However, over a 30-year timeframe, the reduction in energy demand that results from the cost-effective energy efficiency measures means that Option C has the lowest cost of carbon at £156 per tCO_2.

- **RHI more generous than £4,000 Clean Heat Grant** In this example, due to the high heat demand of the property under Options B and C, the RHI (at £9,734 and £8,139 respectively) is significantly more generous than the proposed £4,000 Clean Heat Grant.

08. 3 bed mid-terraced house, EPC E; Albany Road, Newham

Age	Type	Floor area (m^2)	EPC rating
1900s	3-bed mid terrace house	94	E (53)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
12,788	1,954	14,472	10,218
Space heating demand (kWh per m^2 pa)	Current space and water heating system	Secondary heating	Current flow temperature
136	'A' rated gas combi-boiler with radiators (mostly single panel) No cylinder.	1 wood burner. 2 fan heaters.	75°C
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
4.87	5.1	1.05	70°C
Monthly indicative gas usage (kWh) 2019			
Jan	1,885	Jul	173
Feb	1,437	Aug	102
Mar	920	Sep	176
Apr	1,142	Oct	979
May	501	Nov	1,524
Jun	233	Dec	1,146

Assessment of retrofit potential: 08. Albany Road

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	Yes	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	Yes
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	Yes
	Wall mounted	No	Available service ducts for internal pipework?	NA
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Yes	Available water source	No
Suitable space for hot water cylinder?		Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

EPC recommendations include relatively cost-effective measures including loft insulation top up (100mm - 300mm) plus suspended timber floor insulation. This home was reported as being particularly draughty. We therefore specified a bespoke package of air tightness measures including draught proofing around doors and windows and sealing any gaps in floor boards, around plug sockets and any pipes in to the house such as gas, water and sewage. We assumed that this package of measures (improved loft insulation, floor insulation and air tightness) could improve the natural air change rate from 1.24 to 0.72 ACH. Mechanical extract ventilation is likely to be needed to compensate for this, particularly in kitchens and bathrooms.

Heat emitter upgrades considered

Radiator upgrades would be essential to enable the heat pump to operate efficiently. Current radiators are generally single panel or single convector radiators.

Heat pump options considered

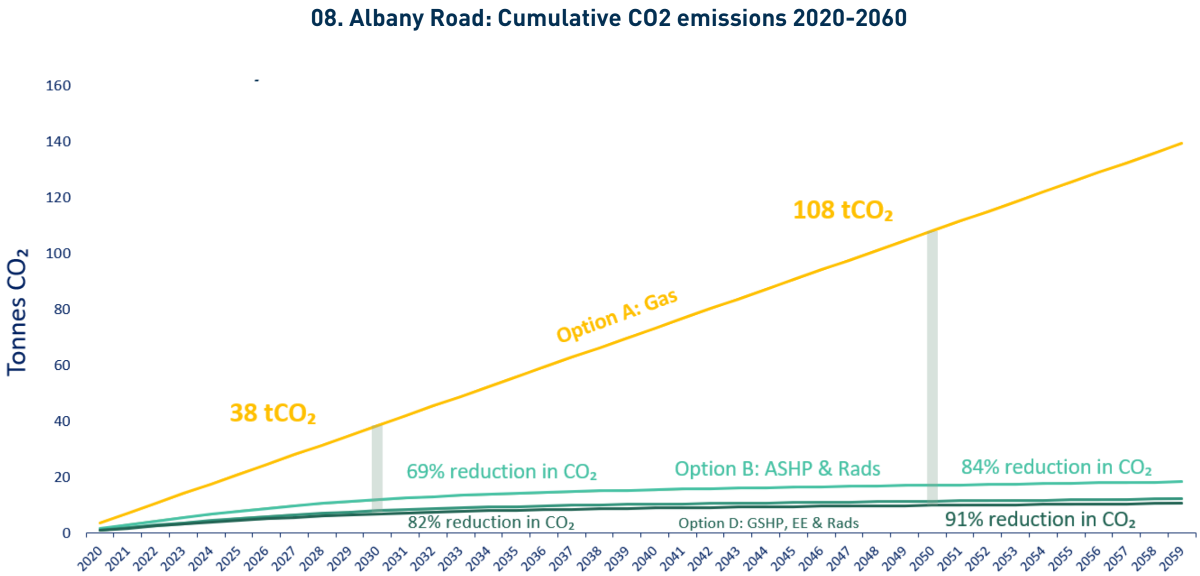
Front gardens could enable installation of a borehole for Ground Source Heat Pump. A shared ambient loop could be installed if neighbouring dwellings were willing to invest in the cost. Suitable space foe air source heat pump to rear of property that is sufficient distance from neighbouring property.

Options appraisal summary of results: 08. Albany Road

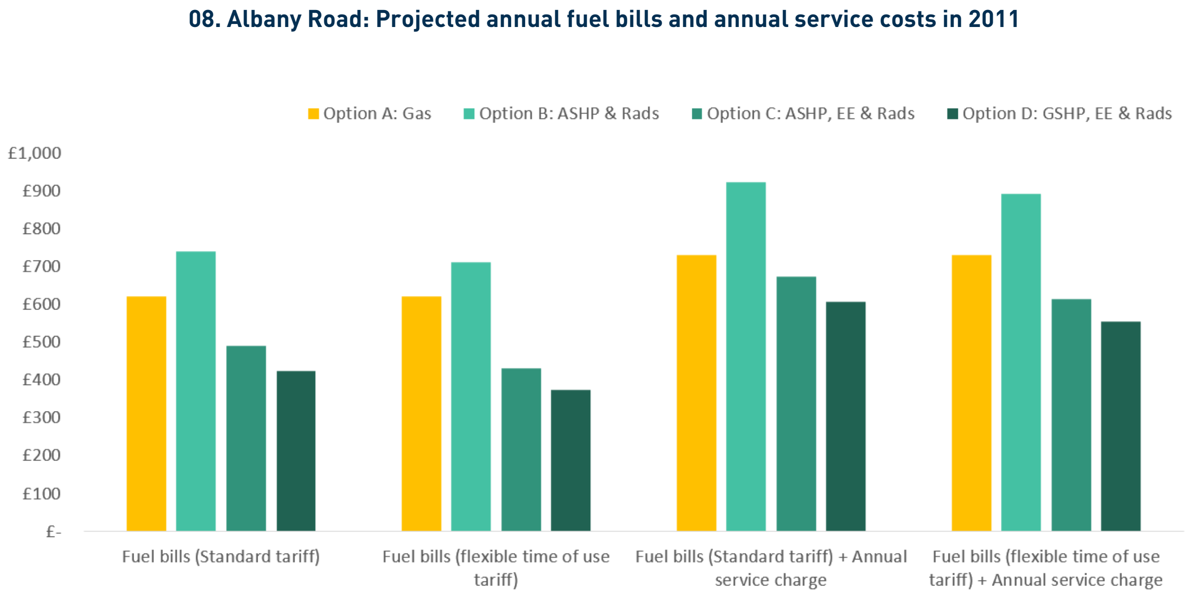
		Retrofit scenario			
		8a	8b	8c	8d
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler**	**Air to water heat pump**	**Air to water heat pump**	**Ground Source Heat Pump**
	Heat emitter upgrades	None	Triple panel convector	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	Improved air tightness, loft insulation and floor inslation.	Improved air tightness, loft insulation and floor inslation.
	Air tightness (Average Air Changes per hour at ambient air pressure)	1.24 Ach (ambient)	1.24 Ach (ambient)	0.72 Ach (ambient)	0.72 Ach (ambient)
Energy performance	EPC	E (53)	E (53)	D	D
	kWh per m^2 pa	103	103	86	86
System design	Peak heat load (kW)	5.7	5.7	4.8	4.8
	Heat emitter output (kW at ▲T 50°C)	5.1	15.6	15.6	15.6
	Required flow temp for -1.8°C day	77	43	40	40
	Assumed efficiency / SPF H4	0.89	3.02	3.1	3.21
CO_2 emissions	Cumulative kg by 2030	38,263	11,783	7,816	6,771
	Cumulative kg by 2050	107,832	16,965	11,253	9,748
Upfront CAPEX costs	Heating system	£ 2,395	£ 8,826	£ 8,151	£ 20,715
	Heat emitters	£ -	£ 2,959	£ 2,959	£ 2,959
	Energy efficiency	£ -	£ -	£ 3,400	£ 3,400
Grant	RHI	£ -	£ 7,392	£ 5,098	£ 9,065
Annual costs	Fuel bill	£ 623	£ 741	£ 492	£ 426
	Service	£ 109	£ 182	£ 182	£ 210
Life time costs (Including current RHI)	10 year	£ 9,528	£ 12,806	£ 15,545	£ 23,793
	20 year	£ 20,109	£ 26,783	£ 26,501	£ 34,642
	30 year	£ 30,691	£ 40,760	£ 37,458	£ 41,101
	40 year	£ 41,273	£ 50,165	£ 44,310	£ 47,560

CO_2 emissions

All heat pump options results in significant CO_2 savings relative to the gas boiler. The deep retrofit option achieves approximately 95% cumulative CO_2 reduction by 2050.

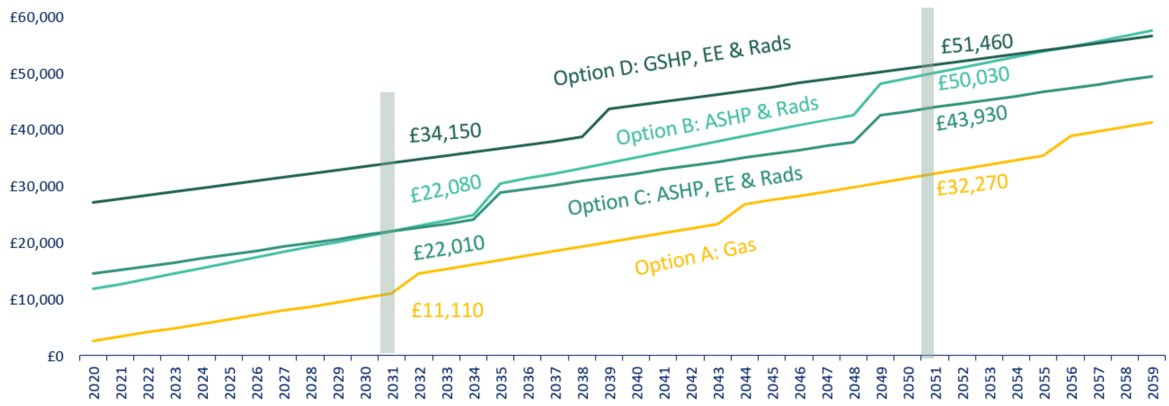


Fuel bills

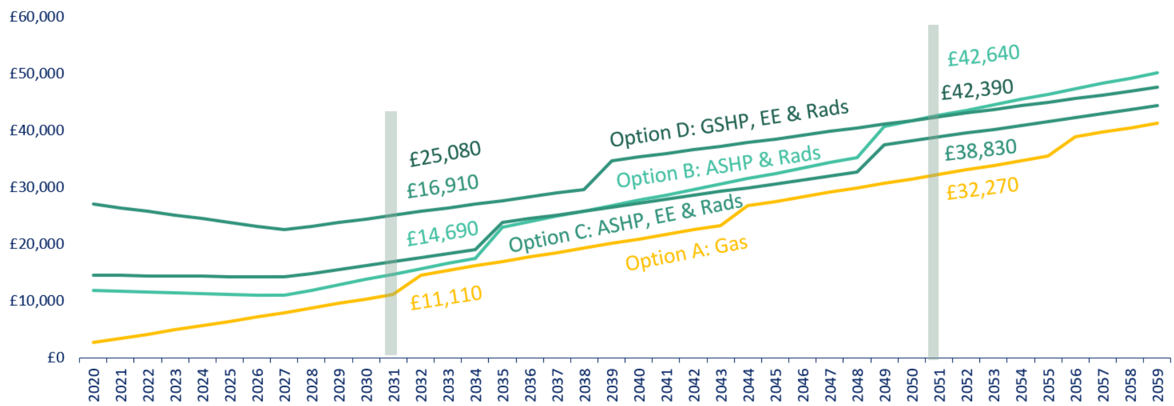


Lifetime costs and sensitivity analysis

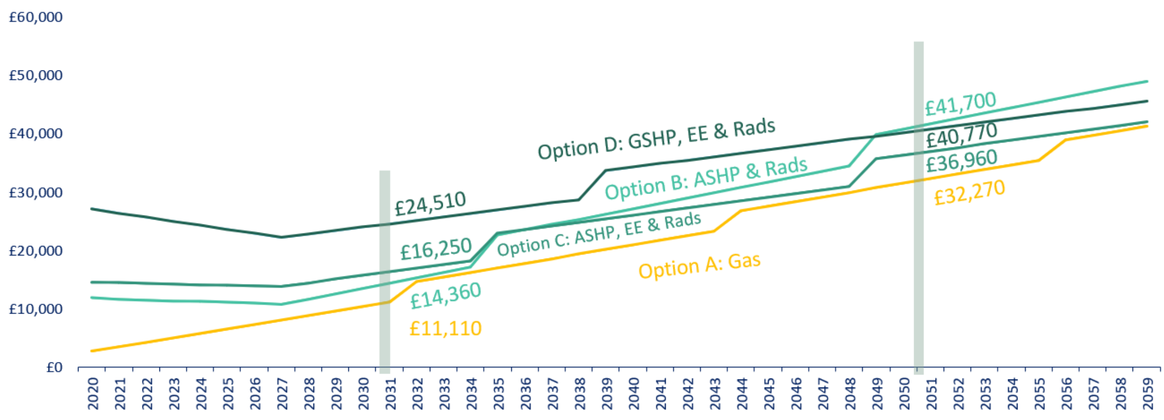
08. Albany Road: Cumulative lifetime costs. No RHI

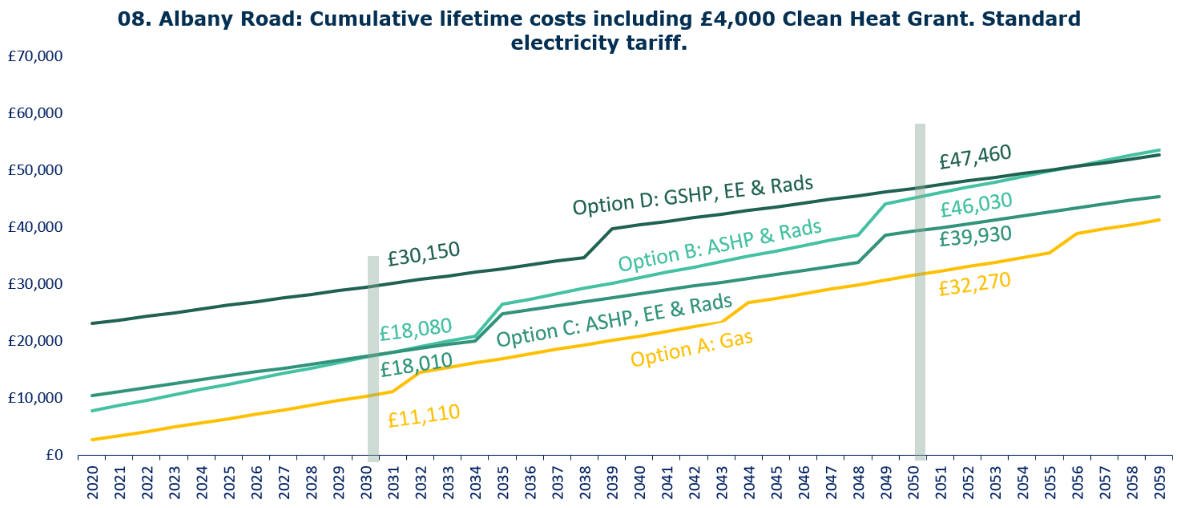


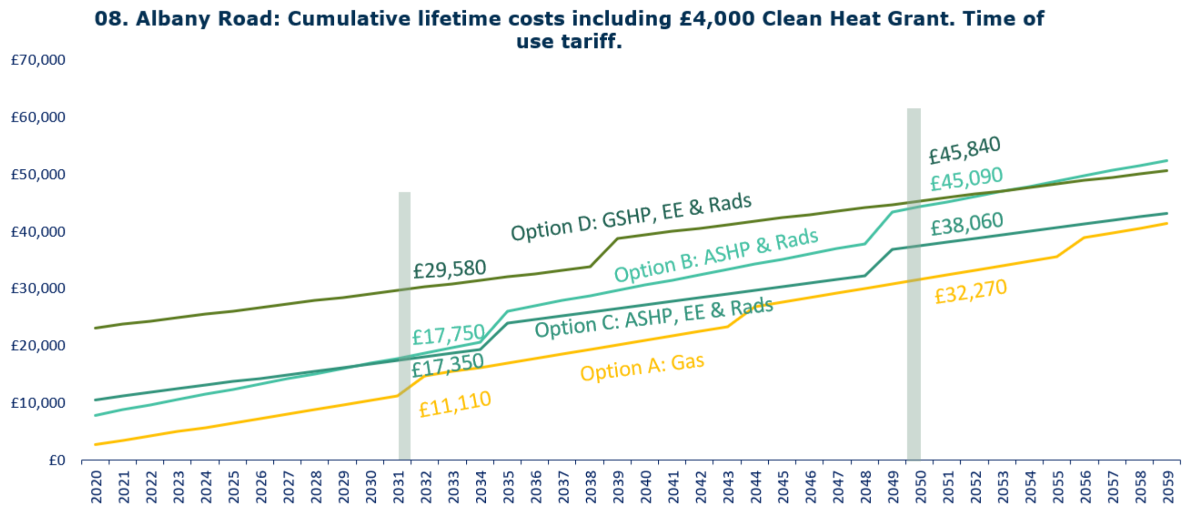
08. Albany Road: Cumulative lifetime costs. With current RHI

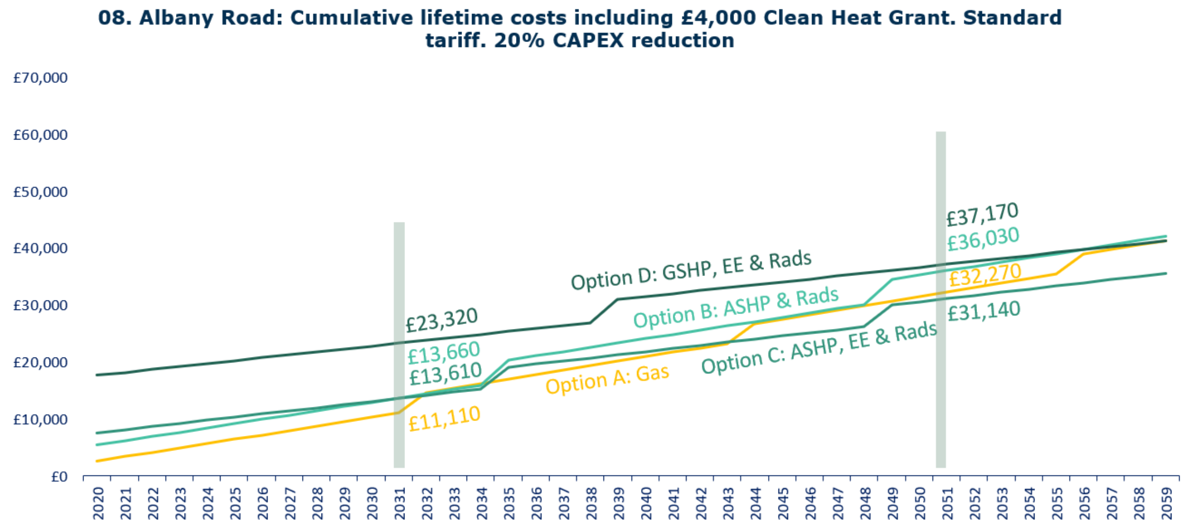


08. Albany Road: Cumulative lifetime costs with current RHI & Time of use tariff



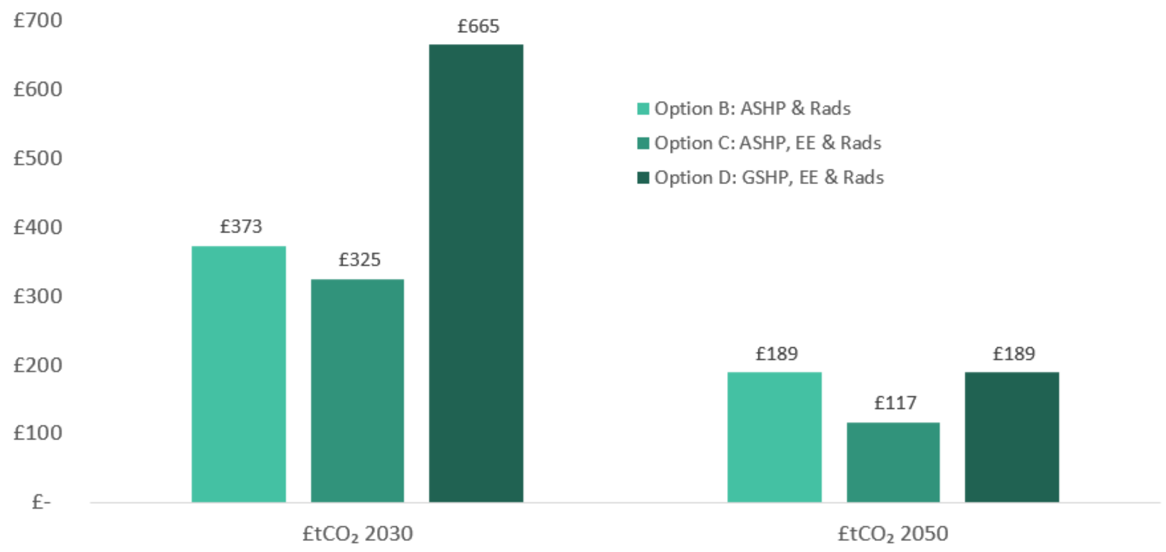

08. Albany Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.
£70,000
£60,000
£50,000
£40,000
£30,000
£20,000
£10,000
£0
Option D: GSHP, EE & Rads
Option B: ASHP & Rads
Option C: ASHP, EE & Rads
Option A: Gas
£30,150
£18,080
£18,010
£11,110
£47,460
£46,030
£39,930
£32,270
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059


08. Albany Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.
£70,000
£60,000
£50,000
£40,000
£30,000
£20,000
£10,000
£0
Option D: GSHP, EE & Rads
Option B: ASHP & Rads
Option C: ASHP, EE & Rads
Option A: Gas
£29,580
£17,750
£17,350
£11,110
£45,840
£45,090
£38,060
£32,270
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059


08. Albany Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard tariff. 20% CAPEX reduction
£70,000
£60,000
£50,000
£40,000
£30,000
£20,000
£10,000
£0
Option D: GSHP, EE & Rads
Option B: ASHP & Rads
Option A: Gas
Option C: ASHP, EE & Rads
£23,320
£13,660
£13,610
£11,110
£37,170
£36,030
£32,270
£31,140
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059

Cost of carbon reduction: £ per tonne of CO_2 reduced

08. Albany Road: £tCO_2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



08. Albany Road: Summary of Options Appraisal

- **CO_2 savings:** All heat pump options deliver significant CO_2 savings of 84% - 91% over 30 years.
- **Fuel bills:** Options C and D both deliver significant reductions in fuel bills, due to the reduction in heat demand delivered through energy efficiency measures. The additional efficiency of the GSHP means that it delivers the lowest fuel bills.
- **Overall lifetime costs:** If a £4,000 grant is combined with a 20% up front capital cost reduction, then Option C becomes a cheaper option than the gas boiler over a 30-year timeframe. This is due to the cost-effective energy efficiency measures undertaken in the property that reduce heat demand and enable a lower flow temperature and higher heat pump efficiency. Option C also comes close to cost parity with the gas boiler under current RHI rates. Option D, the individual Ground Source Heat Pump remains more expensive than the other options at all timeframes and under all levels of grant. This is due to the very high upfront costs of the individual ground source heat pump.
- **Cost of carbon:** Option C delivers a very low cost of carbon reduction. This is due to the cost effective nature of the energy efficiency measures delivering a significant reduction in space heating demand. Furthermore, the capital costs of the heat pump unit are relatively low in this case: There are no special requirements (for example for a particularly low noise heat pump) and the 5 – 6kW output is a competitive area of the heat pump market.
- **RHI more generous than £4,000 Clean Heat Grant.** In this example, the current RHI (between £5,000 and £9,000 for Options B – D) is significantly more generous than the proposed £4,000 Clean Heat Grant
- Above all, this example demonstrates the positive impact of cost-effective energy efficiency measures on the overall business case for heat pump retrofit, with the investment in energy efficiency potentially generating a positive payback within a 10 year timeframe.

09. Five bed mid terraced house, EPC E; Tradescant Road, Lambeth

Age	Type	Floor area (m²)	EPC rating
Victorian	5-bed mid terrace house	142	E (51)
Space heating demand (EPC) kWh pa	Water heating demand (EPC) kWh	Space and water heating demand (EPC) kWh pa	Monitored gas use (2019)
22,086	1,716	23,802	NA
Space heating demand (kWh per m² pa)	Current space and water heating system	Secondary heating	Current flow temperature
156	Gas combi-boiler with radiators (single panel)	NA	Unknown
Space heating load (kW @-1.8°C)	Current heat emitters (kW at Delta T50°C)	Radiator over size factor @ Delta T50°C	Required minimum flow temperature with existing radiators (°C)
14.5	13.8	0.95	74°C
Monthly indicative gas usage (kWh) 2019			
Jan	3,705	Jul	120
Feb	3,816	Aug	129
Mar	3,026	Sep	791
Apr	2,103	Oct	1,904
May	849	Nov	3,467
Jun	120	Dec	3,772

Assessment of retrofit potential: 09. Tradescant Road

Potential for air source heat pump (external unit)			**Potential for individual GSHP**	
Is there a suitable space for external fan unit that would comply with MCS 020 requirements for Permitted Development?	Rear garden	Yes	Available & accessible space for ground trench	No
	Balcony	No	Available & accessible space for bore hole	No
	External walkway	No	**Potential for shared ambient loop**	
	Roof terrace	No	Space for boreholes within building curtilage?	No
	Wall mounted	No	Available service ducts for internal pipework?	NA
Potential for heat pump (internal unit)			**Other source potential**	
Suitable space for internal ASHP?		Yes	Available water source	No
Suitable space for hot water cylinder?		Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

The property has a very high level of heat loss with single glazing, 100mm of loft insulation and poor air tightness. Reducing heat demand through a combination of improved glazing and insulation and improvements to air tightness would be essential to accommodate flow temperatures below 55°C.

Heat emitter upgrades considered

All radiators are currently single panel and would need upgrading before low temperature heat pumps options could be considered.

Heat pump options considered

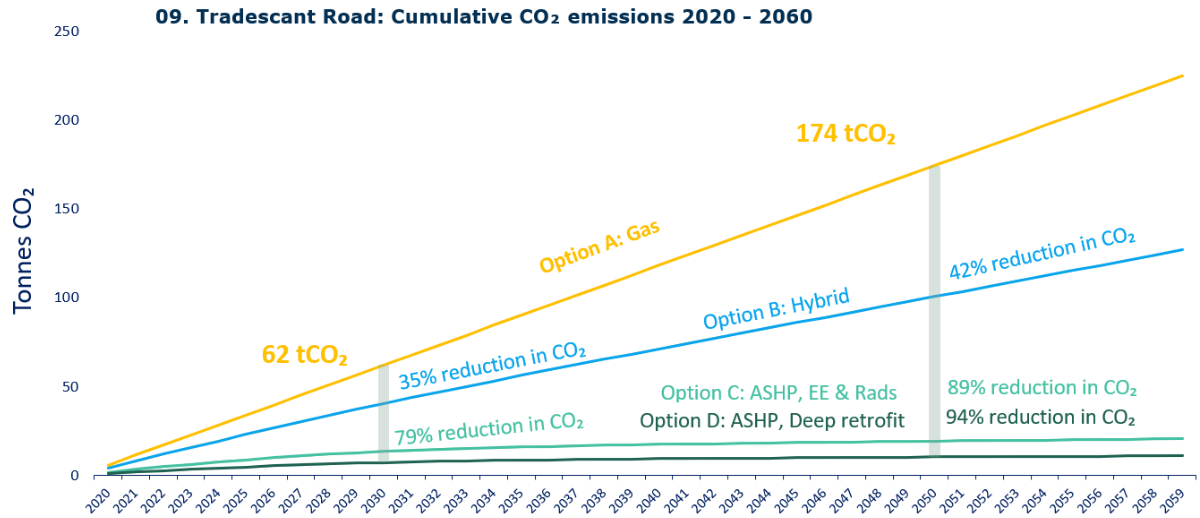
The property could potentially utilise a hybrid heat pump in its current condition to deliver the necessary flow temperature of up to 74°C. There are no easy options for installing a ground source heat pump at the property as the rear garden is inaccessible for borehole drilling and not large enough to accommodate a ground trench. However, there is a suitable location to the rear of the property for an Air Source Heat Pump.

Options appraisal summary of resutls: 09. Tradescant Road

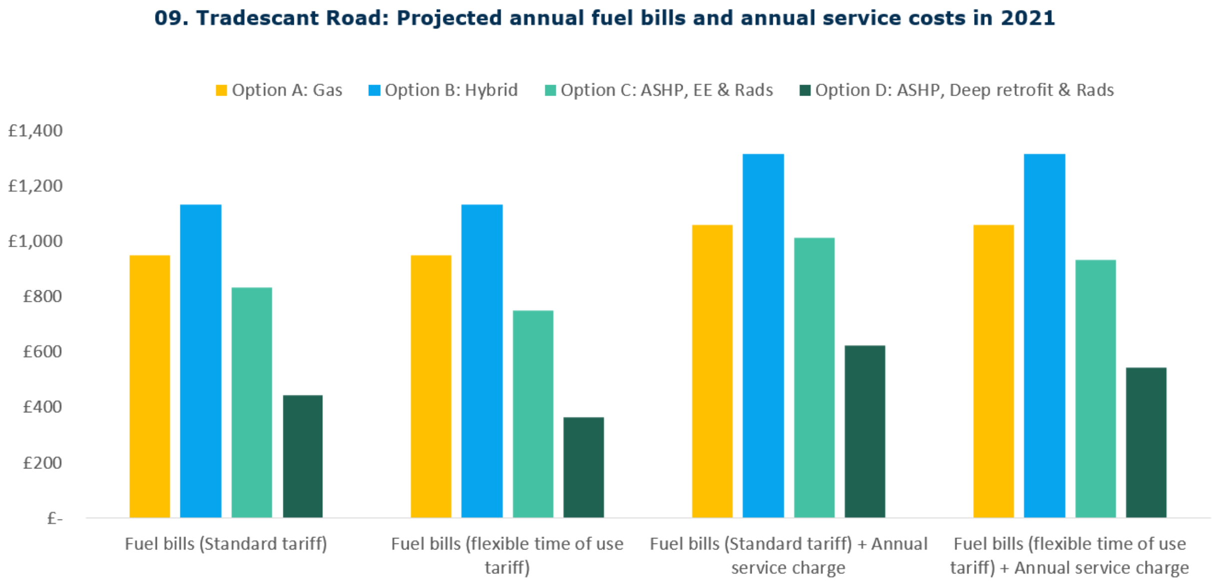
		Retrofit scenario			
		9a	9b	9c	9d
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler**	**Hybrid heat pump** Daikin Altherma 5 / 33kW Hybrid	**Air to water heat pump** HitAch (ambient)i Yutaki 11kW split with 210l cylinder	**Air to water heat pump** Vaillant Arotherm 5kw
	Heat emitter upgrades	None	None	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	Improved air tightness, double glazing and loft insulation.	Deep retrofit
	Air tightness (Average Air Changes per hour at ambient air pressure)	1.5 Ach (ambient) (ambient)	1.5 Ach (ambient) (ambient)	1.1 Ach (ambient) (ambient)	0.8 Ach (ambient) (ambient)
Energy performance	EPC	E (51)	E (51)	D	B
	kWh per m^2 pa	156	156	96	46
System design	Peak heat load (kW)	14.5	14.5	9.0	4.3
	Heat emitter output (kW at ▲T 50°C)	13.8	13.8	27.0	23.0
	Required flow temp for -1.8°C day	74	74	41	35
	Assumed efficiency / SPF H4	0.89	2.22	3.09	3.31
CO_2 emissions	Cumulative kg by 2030	61,778	40,156	13,256	7,050
	Cumulative kg by 2050	174,102	100,393	19,085	10,151
Upfront CAPEX costs	Heating system	£ 2,436	£ 6,196	£ 10,354	£ 8,113
	Heat emitters	£ -	£ -	£ 4,722	£ 3,980
	Energy efficiency	£ -	£ -	£ 17,200	£ 56,658
Grant	RHI	£ -	£ -	£ 7,734	£ 4,161
Annual costs	Fuel bill	£ 952	£ 1,133	£ 834	£ 443
	Service	£ 109	£ 280	£ 182	£ 182
Life time costs (Including current RHI)	10 year	£ 12,703	£ 16,944	£ 32,346	£ 68,827
	20 year	£ 26,986	£ 33,806	£ 46,568	£ 77,486
	30 year	£ 41,270	£ 45,679	£ 55,102	£ 82,024
	40 year	£ 55,553	£ 62,541	£ 69,324	£ 90,683

CO_2 emissions

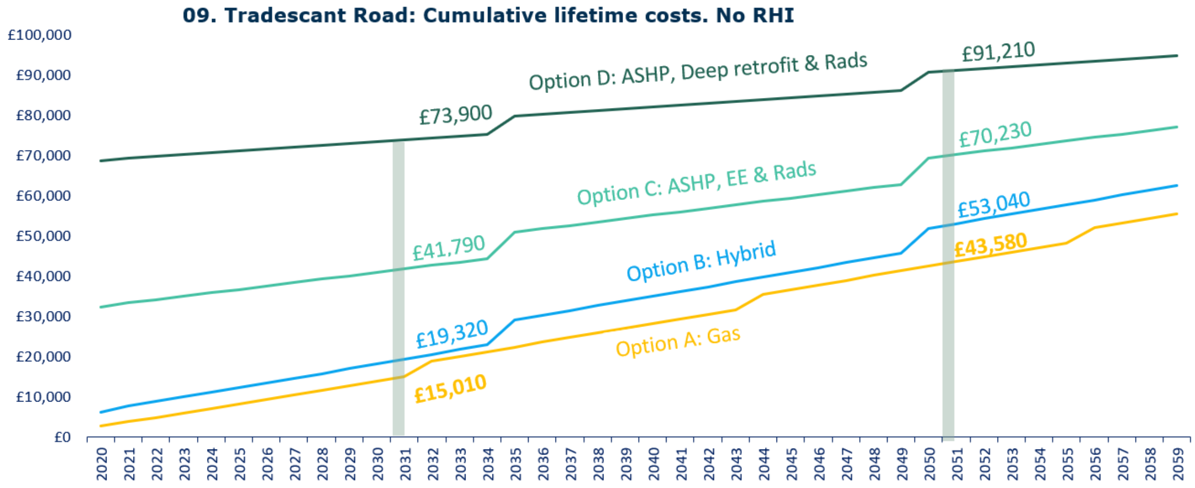
All heat pump options results in significant CO_2 savings relative to the gas boiler. The deep retrofit option achieves approximately 95% cumulative CO_2 reduction by 2050. The hybrid heat pump option achieves a 42% reduction in CO_2 emissions by 2050.

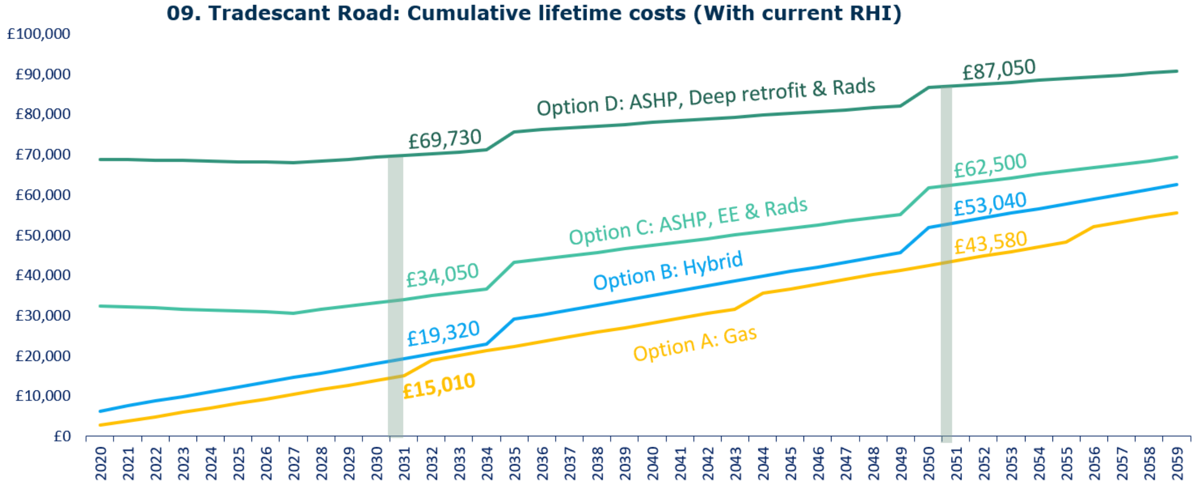


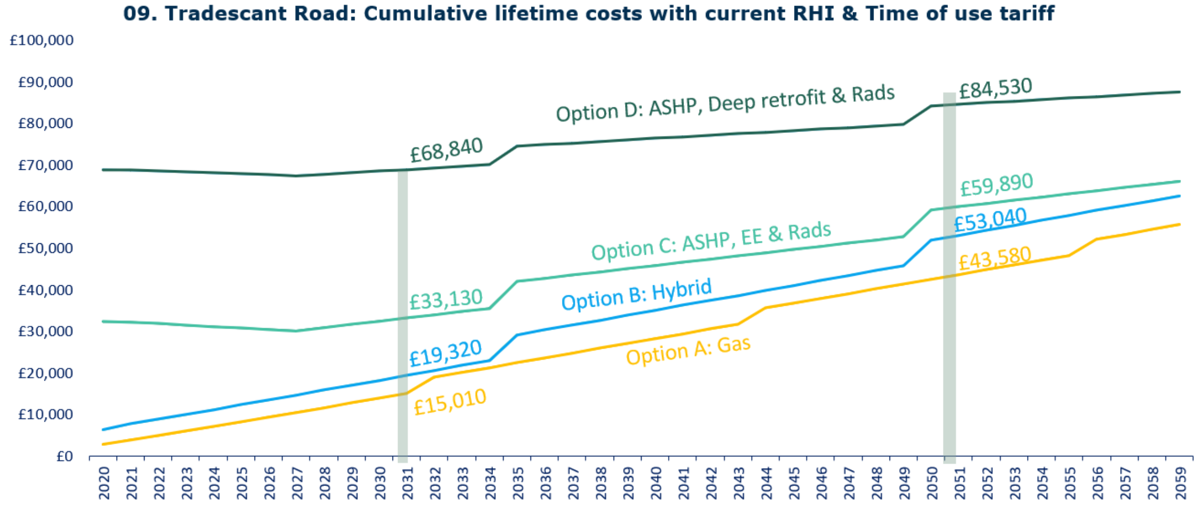
Fuel bills



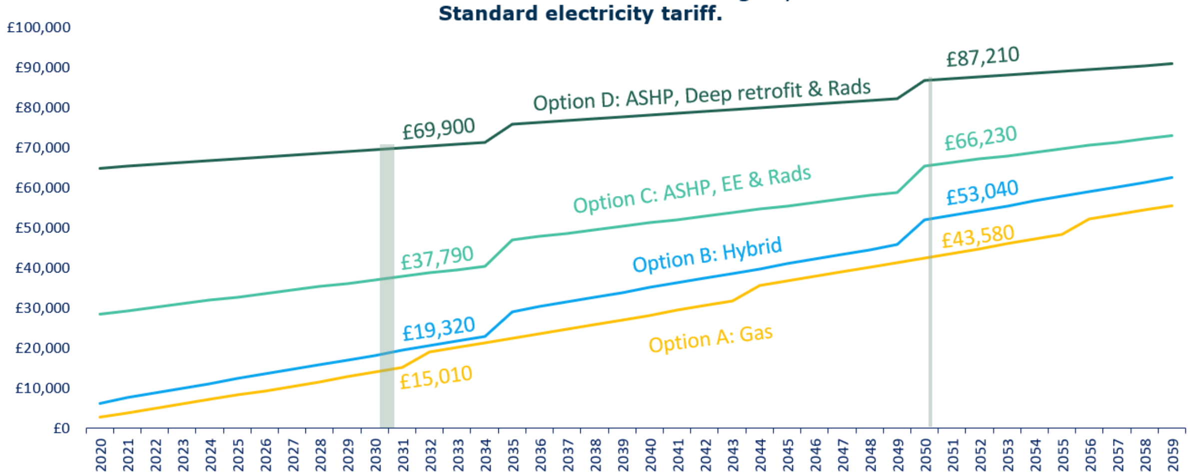
Lifetime costs and sensitivity analysis



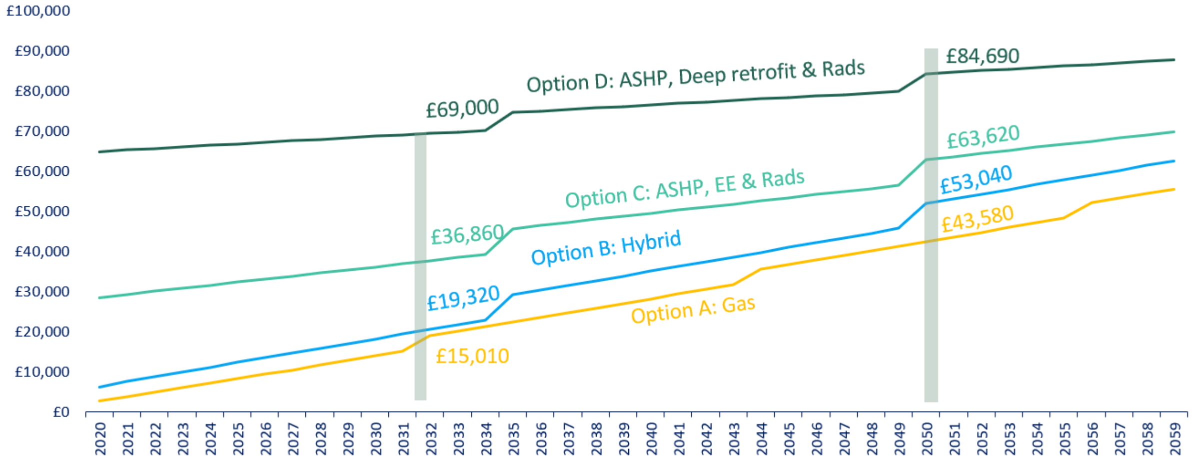




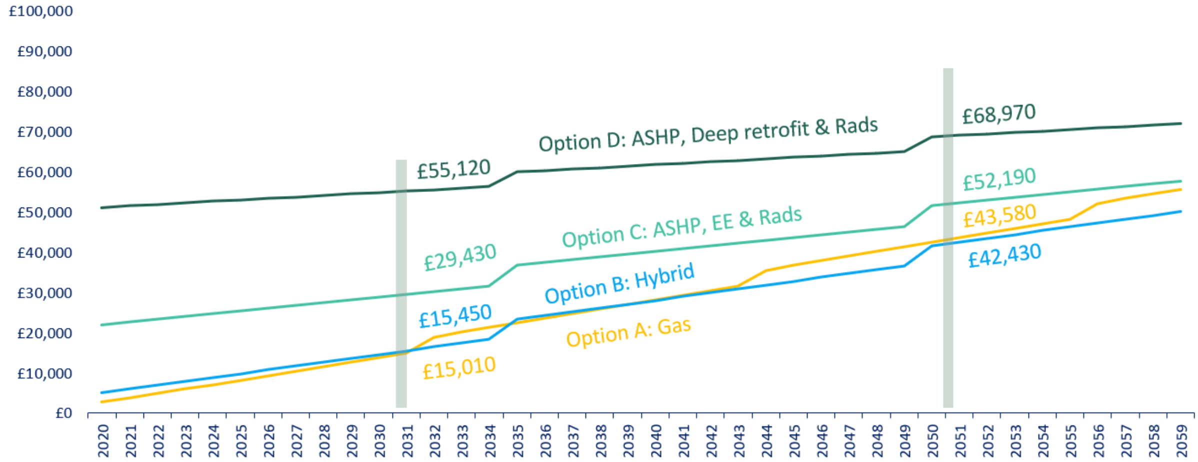
09. Tradescant Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard electricity tariff.



09. Tradescant Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Time of use tariff.

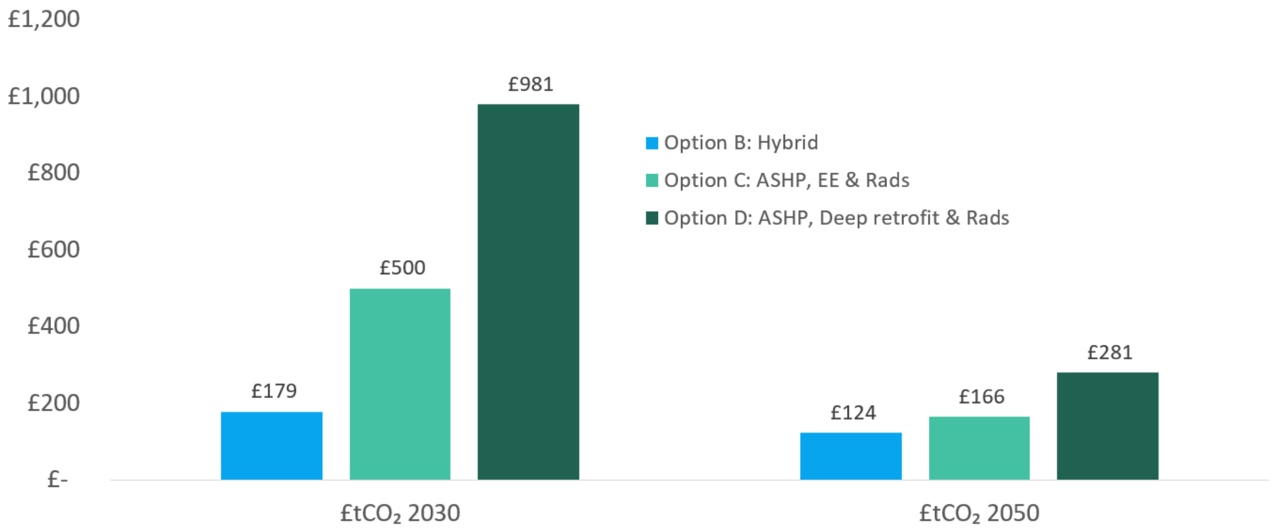


09. Tradescant Road: Cumulative lifetime costs including £4,000 Clean Heat Grant. Standard tariff. 20% CAPEX reduction



Cost of carbon reduction: £ per tonne of CO_2 reduced

09. Tradescant Road: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



09. Tradescant Road: Summary of Options Appraisal

- The hybrid heat pump increases fuel bills but delivers the lowest level of CO_2 emissions reductions. However, because the hybrid has the lowest up-front costs (due to the fact that it can deliver the high flow temperatures required in the current building without improvements to the energy efficiency or radiators), the hybrid heat pump has the lowest cost of carbon reduction of both the 10 and 30 year timeframes.

- Expensive energy efficiency improvements and heat emitter upgrades are essential to all standard heat pump options in this building. These energy efficiency measures are expensive due to the heritage nature of the property (for example, a cost premium has been calculated for installing double glazed sash windows). These measures do not pay for themselves within the 40 year timeframe assessed in this study. Energy efficiency improvement would be essential to the efficient operation of a standard temperature heat pump. This highlights a particularly challenging yet common archetype for heat pump retrofit in London.

- **CO_2 savings:** All heat pump options deliver significant CO_2 savings of 84% - 91% over 30 years.

- **Fuel bills:** Options C and D both deliver significant reductions in fuel bills, due to the reduction in heat demand delivered through energy efficiency measures.

- **Cost of carbon:** despite the high up-front cost of energy efficiency measures under Option B and C, the cost per tCO_2 reduced through these options is relatively low at £166 and £281 per tCO_2 respectively. This is due to the very large CO_2 savings achieved.

- **RHI more generous than £4,000 Clean Heat Grant.** In this example, the current RHI (between ££4,100 and £7,000 for Options C and D) is more generous than the proposed £4,000 Clean Heat Grant.

10. Communally heated flats, Ernest Dence Estate, Greenwich

The Ernest Dence estate in Greenwich is a solid brick tenement block containing 95 one, two and three bedroom flats. It is highly typical of inter-war tenement blocks found across London. Heating is currently provided by 3 communal gas boilers that are in need of replacement.

Project background

The London Borough of Greenwich commissioned an assessment of the feasibility of replacing the gas boilers with a low carbon heating system.

This project is part of a wider EU funded programme called Sharing Cities[3], which aims to deliver innovative and low emission technologies in the areas of housing, energy, and transport; and explore how digital approaches and data can be used to better services. As part of Sharing Cities, the Council committed to exploring the introduction of an innovative low emission communal heating system at Ernest Dence estate. The estate was already earmarked as in need of works, and the EU funded project offered the opportunity of funding and expertise to explore innovative and lower carbon solutions.

An initial study on heat supply options for Ernest Dence was undertaken in 2017 by Sustainable Energy Ltd. Further work was commissioned in early 2019 through the Mayor of London's Decentralised Energy Enabling Project (DEEP)[4], to refine the specification for this specialist system, conduct borehole testing, and produce a procurement pack, with which the Borough can go out to procure for the build, operation and maintenance of the new system. This work is being undertaken by Sustainable Energy.

Heat pump and energy efficiency options considered: Ernest Dence Estate

Shallow aquifer (river gravel) water source Heat Pump

Initial studies suggest there is good potential for using the shallow river gravels underneath the estate as the heat source. This would require only a 10m depth borehole, meaning there would be both lower drilling costs and lower pumping costs for abstraction. The river gravel source would have lower filtration requirements than the river itself and higher mean temperatures than the river. Further hydrogeological survey would be required to confirm borehole layout and availability of heat resource over time.

Aquifer source heat pump

A second option considered was an aquifer source heat pump, which would require a 90m borehole depth. The aquifer has higher source temperatures than the river and gravel source. However, this would require greater abstraction energy associated with a deeper pump. Water must be injected back in to the aquifer.

[3] http://www.sharingcities.eu/

[4] https://www.london.gov.uk/what-we-do/environment/energy/energy-supply

Air source heat pump

There is a suitable location on-site for an Air Source Heat Pump unit to serve the central energy centre.

Upgrades to the Communal heating system and heat distribution system

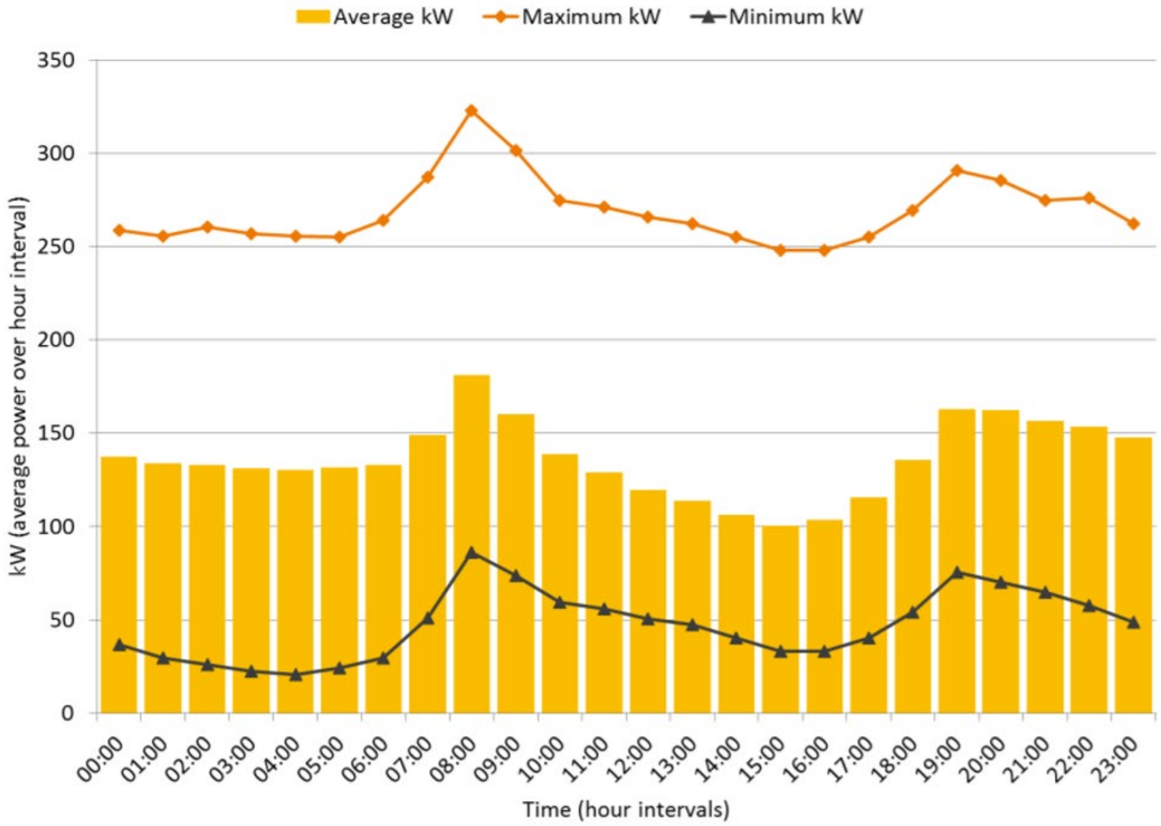
A number of necessary upgrades have been identified to the heat distribution system that would apply under all scenarios. These include:

1. Heat Interface Units to enable better tenant control of heating and hot water and billing for individual use.
2. Upgrades to heat distribution pipework (to enable system losses <10%)

Energy efficiency retrofit options

The estate has double glazing but otherwise has a poor thermal fabric. Walls are solid brick. Floors are un-insulated and the level of loft insulation is unknown but assumed to be minimal. Surveys undertaken as part of the Sharing Cities funded feasibility assessment suggest that heat loss is high at approx. 110 – 130kWh per m^2 pa. Therefore, a deep retrofit of the full thermal fabric of the building could deliver a substantial reduction in space heating demand.

Figure: modelled hourly heat demand average, maximum and minimum. Source: Sustainable Energy Ltd feasibility study for London Borough of Greenwich

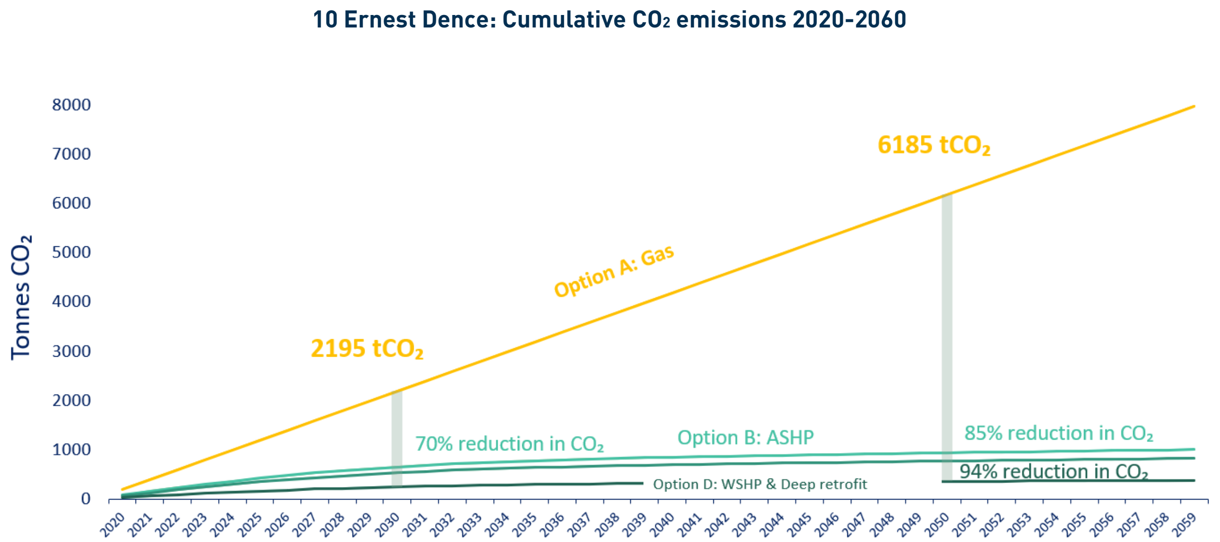


Options appraisal summary of results: 10. Ernest Dence Estate

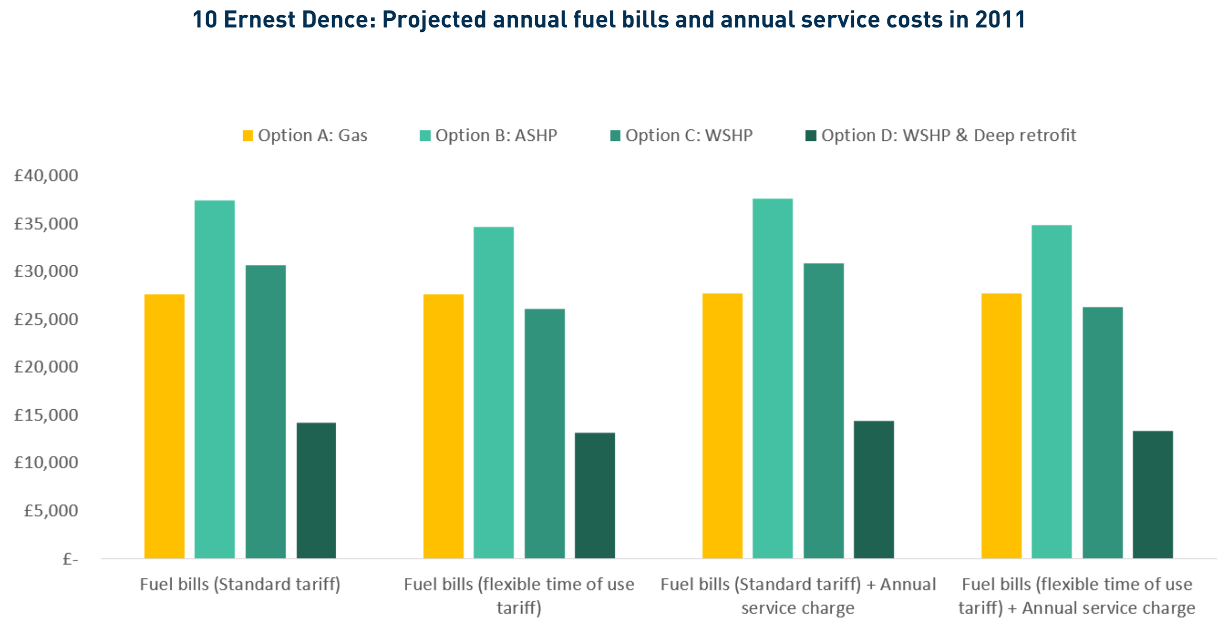
		Retrofit scenario			
		10a	10b	10c	10d
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler**	**Air Source Heat Pump 400kW**	**Shallow aquifer source heat pump 400kW**	**Shallow aquifer source heat pump 100kW**
	Heat emitter upgrades	Replace existing pipework to ensure <10% heat losses.			
	Energy efficiency upgrades	None	None	None	Deep retrofit of wall and windows
	Air tightness (Average Air Changes per hour at ambient air pressure)	Unknown	Unknown	Unknown	0.1Ach (ambient)
Energy performance	EPC	C-E	C-E	C-E	A-B
	kWh per m^2 pa	118	118	118	30
System design	Peak heat load (kW)	333kW	333kW	333kW	100kW
	Heat emitter output (kW at ▲T 50°C)	427.5	427.5	427.5	427.5
	Required flow temp for -1.8°C day	60°C - 63°C	60°C - 63°C	60°C - 63°C	45°C
	Assumed efficiency / SPF H4	0.91	3.20	3.9	3.6
CO_2 emissions	Cumulative kg by 2030	2,194,500	652,113	535,067	248,424
	Cumulative kg by 2050	6,184,500	938,876	770,360	357,667
Upfront CAPEX costs	Heating system	£ 50,500	£ 471,560	£ 672,152	£ 317,449
	Heat emitters	£ 800,000	£ 800,000	£ 800,000	£ 700,000
	Energy efficiency	£ -	£ -	£ -	£ 1,818,300
Grant	RHI	£ -	£ 458,271	£ 1,038,231	£ 353,494
Annual costs	Fuel bill	£ 27,618	£ 37,459	£ 30,735	£ 14,270
	Service	£ 4,200	£ 4,200	£ 6,300	£ 5,250
Life time costs (Including current RHI)	10 year	£ 1,180,518	£ 1,440,190	£ 1,322,521	£ 2,856,462
	20 year	£ 1,636,625	£ 1,896,674	£ 1,159,871	£ 2,881,153
	30 year	£ 2,362,233	£ 2,649,634	£ 2,199,735	£ 3,503,640
	40 year	£ 2,818,340	£ 3,347,313	£ 2,583,523	£ 3,705,077

CO_2 emissions

All heat pump options deliver large reduction in CO_2 emissions. However, only option 10d (deep retrofit plus heat pump) delivers a reduction in space heating demand commensurate with an overall energy system net zero target.

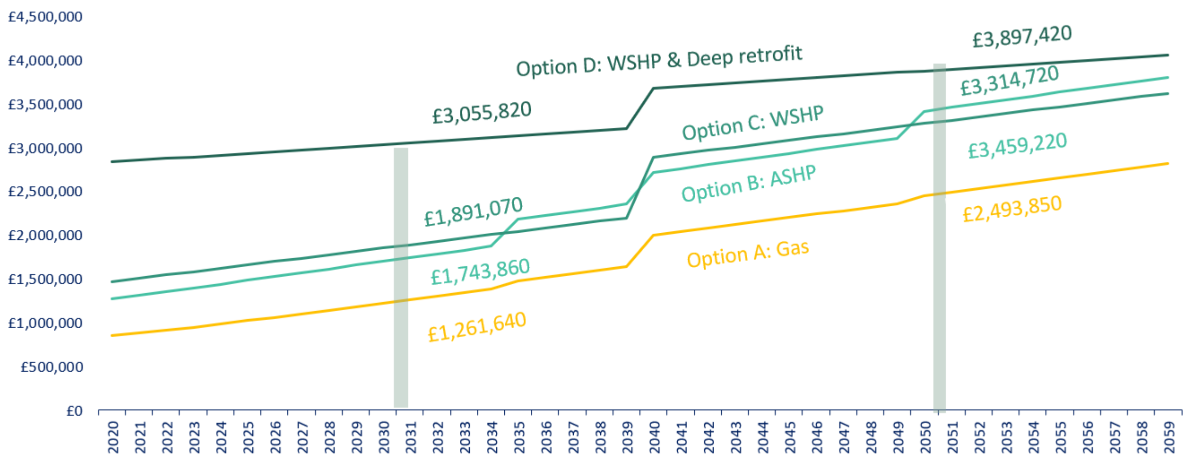


Fuel bills

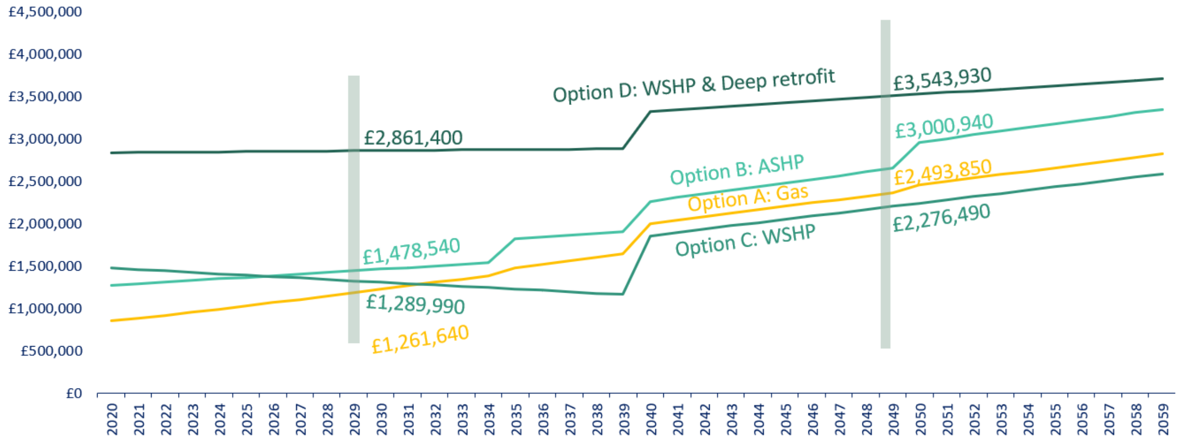


Lifetime costs and sensitivity analysis

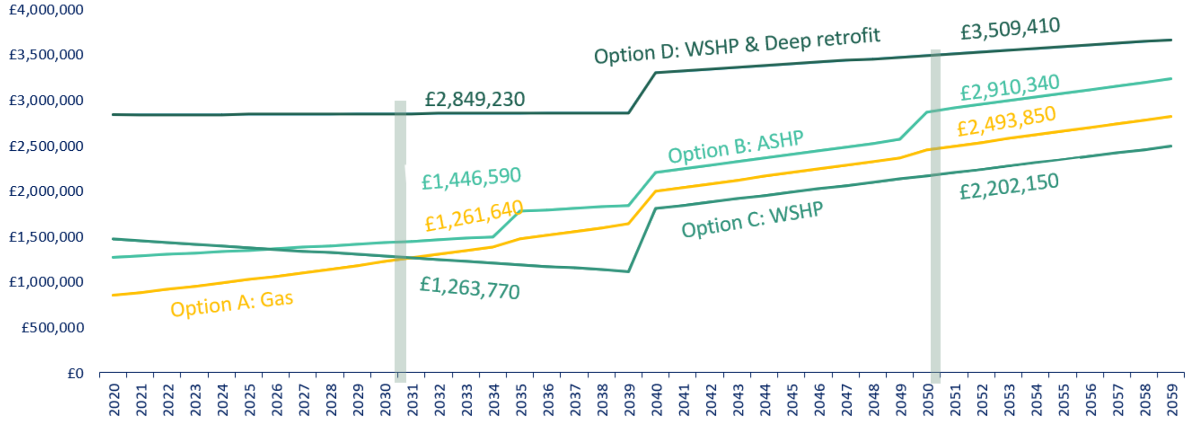
10 Ernest Dence: Cumulative lifetime costs. No RHI



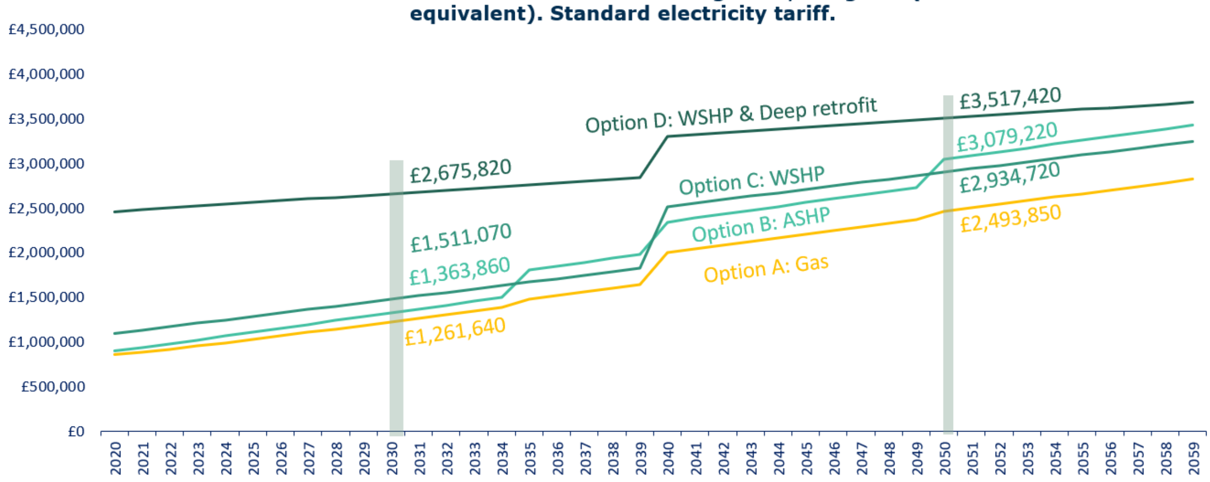
10 Ernest Dence: Cumulative lifetime costs. With current RHI



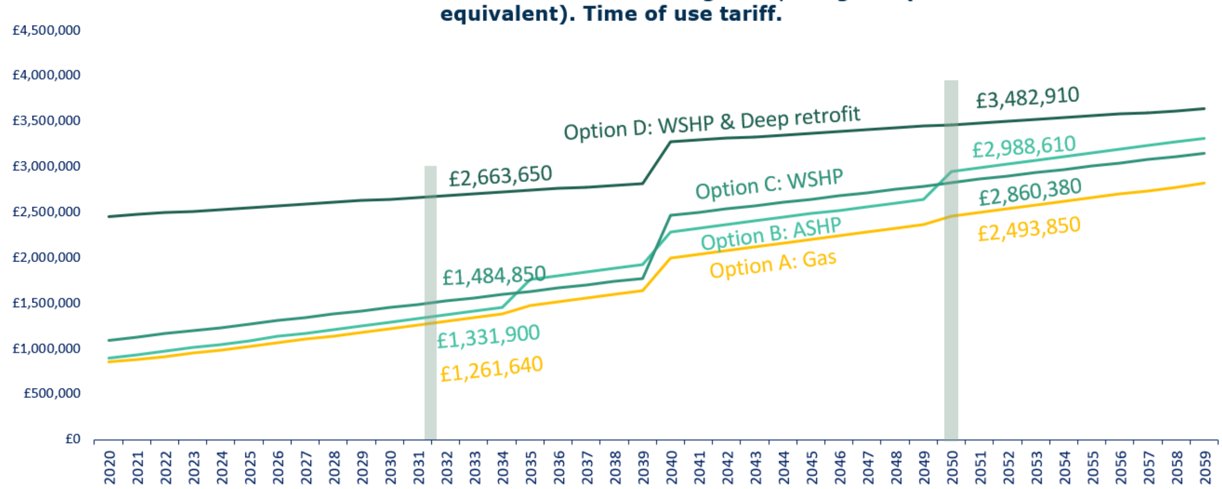
10 Ernest Dence: Cumulative lifetime costs with current RHI & Time of use tariff



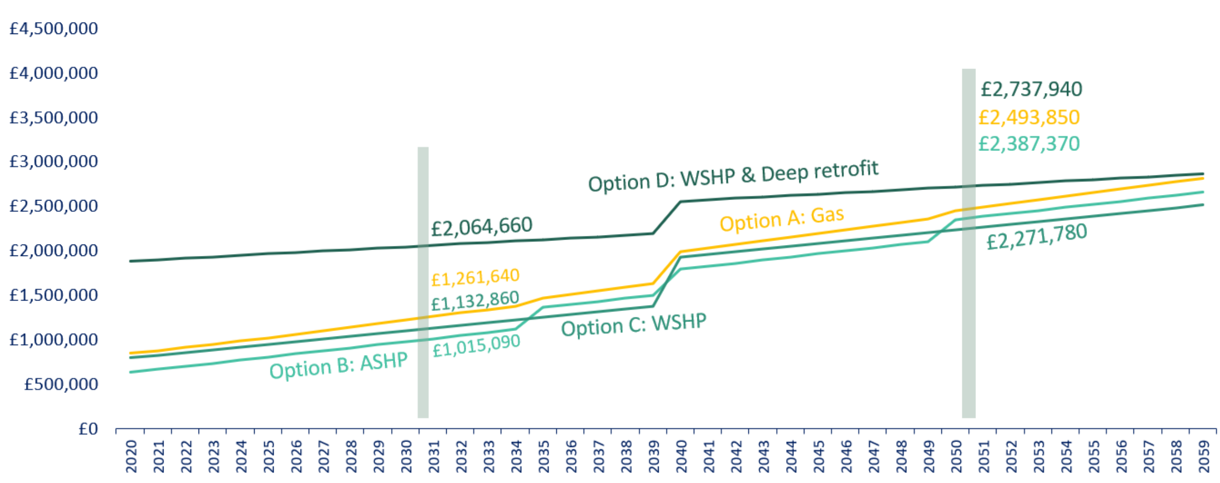
10. Ernest Dence: Cumulative lifetime costs including £380,000 grant (Clean Heat Grant equivalent). Standard electricity tariff.



10. Ernest Dence: Cumulative lifetime costs including £380,000 grant (Clean Heat Grant equivalent). Time of use tariff.

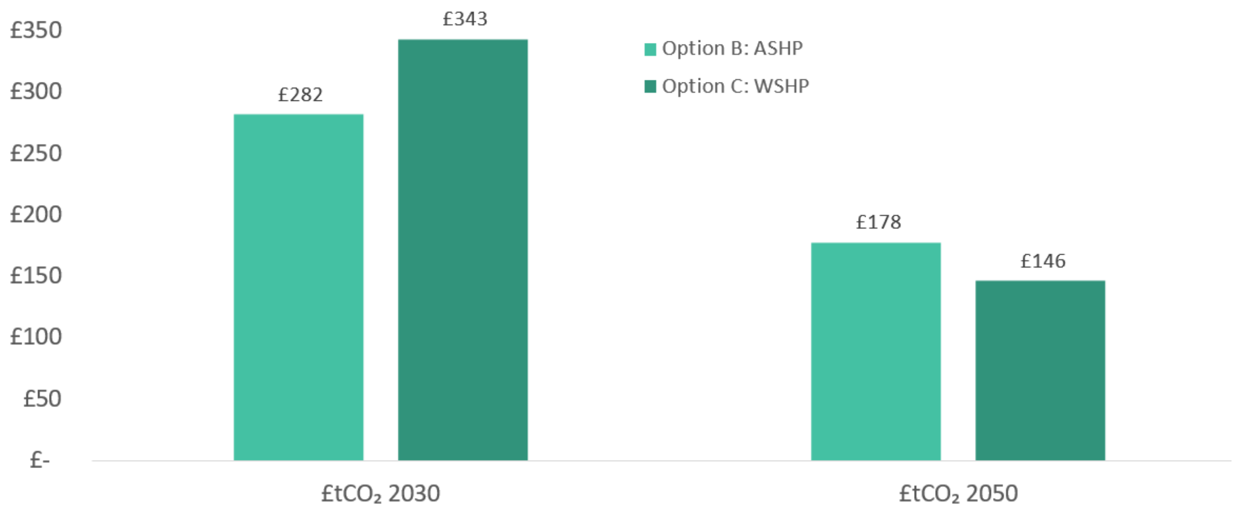


10. Ernest Dence: Cumulative lifetime costs including £380,000 grant (Clean Heat Grant equivalent). Standard tariff. 20% CAPEX reduction



Cost of carbon reduction: £ per tonne of CO_2 reduced

10. Ernest Dence: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



Summary of Options Appraisal Analysis:

- **CO_2 savings:** Cumulatively, over 30 years, the BAU scenario is predicted to emit 6,185 tonnes of CO_2. All three heat pump options are predicted to deliver significant CO_2 savings of 85%, 87% and 94% respectively relative to the BAU.

- **Fuel bills:** Under standard tariffs, fuel bills are predicted to increase under both Option B (ASHP) and Option C (WSHP). Under a time of use tariff, fuel bills are predicted to decrease marginally under Option C. We used a conservative estimate that a time of use tariff could reduce fuel bills by 7.5% in this building whereas in practice a higher saving could be achievable. For Option A (Deep retrofit and WSHP) fuel bills are predicted to decrease under all tariffs.

- **Overall lifetime costs:** Current levels of RHI are relatively generous for ground and water source heat pumps, meaning that Option C (WSHP) is able to achieve lower lifetime costs than the BAU over 30 years according to our analysis. The lifetime costs of the BAU in this example are relatively high as it is assumed that the communal heating pipework and HIUs need replacing under all scenarios.

- **Deep retrofit:** Although the deep retrofit option delivers significant reductions in fuel bills, these are not sufficient to repay the additional capital investment over 30 years. However, it was assumed that no energy efficiency costs are included in the BAU scenario. In practice, upgrades to the building fabric may be required in any case over 30 years. In this case the energy efficiency measures could be undertaken by bringing forward planned capital spend.

- **Clean Heat Grant:** We included a scenario which assumes a £4,000 grant per flat. At the time of writing it is not thought likely that the Clean Heat Grant will be made available to Registered Social Landlords. However, this scenario was included to demonstrate the potential impact that an equivalent grant could have. Under this scenario, the costs of the heat pump options remain more expensive than BAU over 30 years but only marginally so. Where a 30% CAPEX reduction is factored in on top of the grant, Option B (ASHP) becomes lower cost than BAU over 10 and 30 years.

- **Cost of carbon:** Option D (deep retrofit and WSHP) has a very high cost of CO_2 reduction over 20 years although this reduces significantly when looked at over a 30 year period. However, the lowest costs of carbon are achieved by Option C (WSHP). Because the BAU scenario is relatively expensive in this building, the costs of CO_2 reduction are relatively low compared to other buildings as the cost of CO_2 is measured relative to the BAU costs.

11. Enfield Tower Block of 50 flats; (individual electric heating)

Property characteristics:	
Property age	1960s
Property size	50 flats (mixture of 1,2 and 3
Treated Floor Area	~2,900m^2
EPC Ratings	D – E

Whole building energy demand	
Space heating demand (EPC) kWh pa	~130,000 kWh pa
Water heating demand (EPC) kWh pa	~105,000 kWh pa
Space heating demand per m2	~40-50
Space heating peak load	1.9 – 2.8kW
Heat pump flow temperature	45 - 55°C
Heat pump hot water flow temperature	60-65°C

Per flat energy demand	
Per flat space heating demand kWh pa (average)	~2,600kWh pa
Per flat water heating demand kWh pa (average)	~2,100kWh pa

Assessment of retrofit potential: 11. Enfield Tower Block

Potential for large communal air source heat pump (Monobloc or split / VRF) external units		**Potential for individual GSHP**	
Roof	Yes*Subject to noise assessment	Available & accessible space for ground trench	Yes
Other exterior	Yes * Subject to noise assessment	Available & accessible space for bore holes	Yes
Potential for individual air source heat pump units		Available service ducts suitable for internal pipework (ambient)?	Yes
External walkway	No	Existing pipework or suitable service ducts for communal heating pipes (high temperature heat distribution)	**No**
Balcony	No	**Space for large communal internal unit**	
Wall mounted	No	Large existing space for centralised plant	No
Space for internal heat pump unit		**Potential external space for separate energy centre**	**Yes**
Suitable cupboard space for internal air source heat pump?	Yes	Available water source	No
Suitable space for hot water cylinder?	Yes	Waste heat, tube, sewer, other	No

Energy efficiency upgrades considered

The block of flats has already been retrofitted to a high level of thermal performance with external wall insulation, double glazing and flat roof insulation. EPC certificates suggest that space heating demand is already below 50kWh per m^2 per year.

Heat emitter upgrades considered

Existing heat emitters consist of electric underfloor heating. Upgraded to double panel convector radiators considered. Increasing to triple panel convector radiators may cause access issues in narrow corridors.

Heat pump options considered

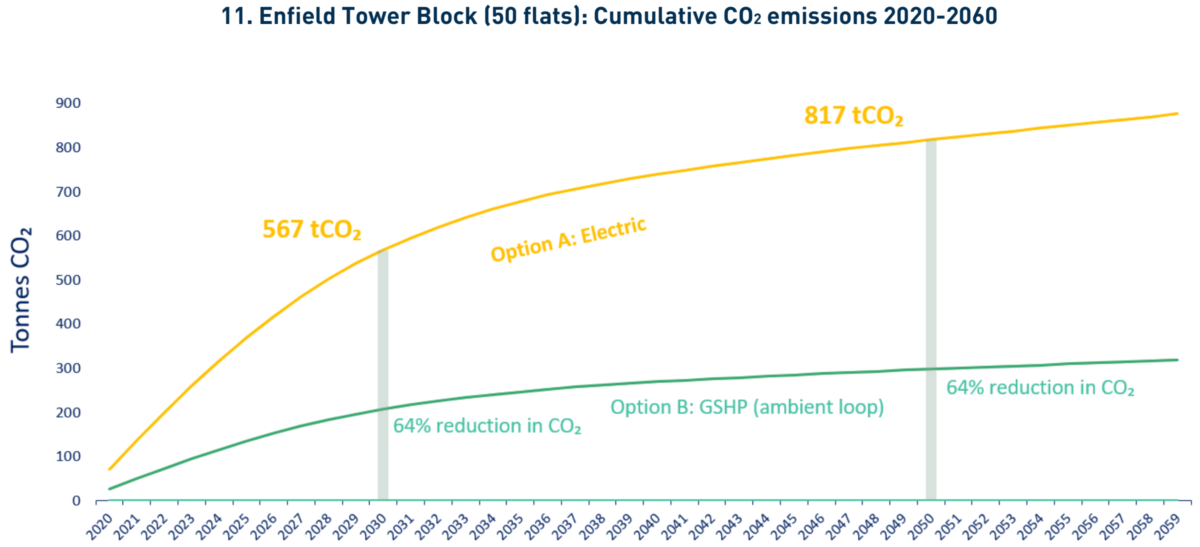
Air Source: The building could potentially accommodate roof mounted air source heat pumps subject to noise levels being acceptable in the top floor flats, however, the roof space is relatively limited for the size of external evaporator units required

Ground Source: The building is surrounded by extensive green space within the curtilage of the property, with excellent easy access for borehole drilling. There is a lack of existing space for a large centralised heat pump in the building and retrofitting insulated hot water pipes to the building was considered too expensive. However, ambient temperature pipes can be accommodated relatively easily in to the existing building service ducts.

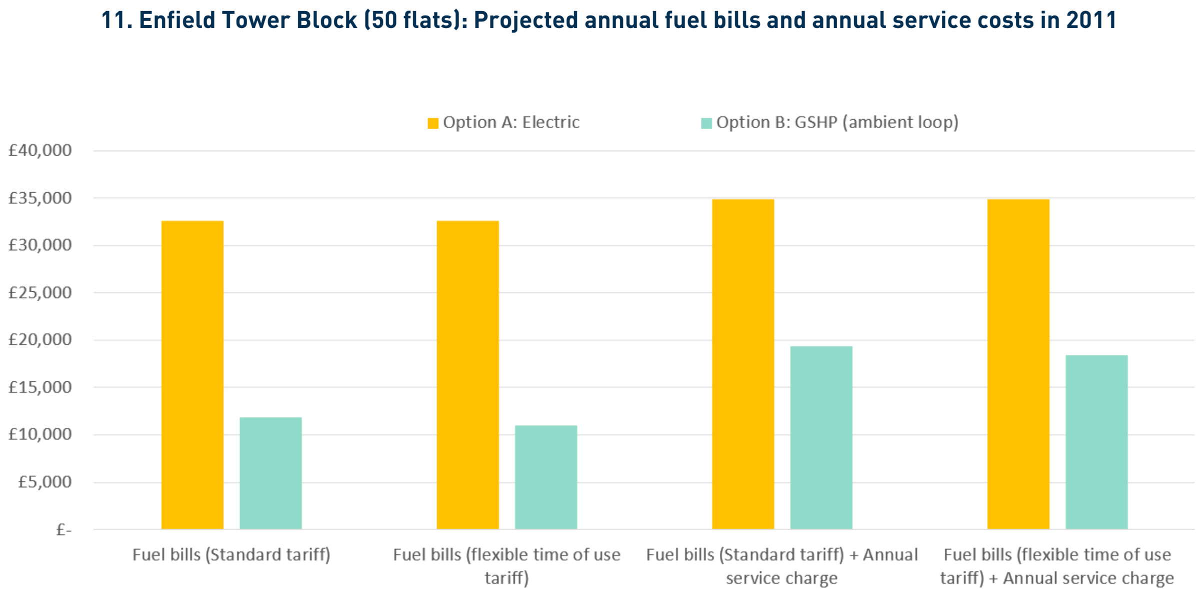
Options appraisal summary of results: 11. Enfield Tower Block

		Retrofit scenario	
		11a	11b
Packages of retrofit measures	Heating technology installed	**Replacement electric heating**	**Shared ground loop (ambient temperature) with individual heat pumps for each flat: 3kW to 6kW x 50 (200kW total)**
	Heat emitter upgrades	None	None
	Energy efficiency upgrades	None	None
	Air tightness (Average Air Changes per hour at ambient air pressure)	Unknown	Unknown
Energy performance	EPC	B - D	B - D
	kWh per m^2 pa	45 - 50	45 - 50
System design	Peak heat load (kW)	~1.5-3kW per flat	~1.5-3kW per flat
	Heat emitter output (kW at ▲T 50°C)	~1.5-3kW per flat	~3 - 7 kW per flat
	Required flow temp for -1.8°C day	65°C	45°C
	Assumed efficiency / SPF H4	1	2.75
CO_2 emissions	Cumulative kg by 2030	567,252	206,273
	Cumulative kg by 2050	816,697	296,981
Upfront CAPEX costs	Heating system	£ 212,500	£ 734,745
	Heat emitters	£ -	£ 60,375
	Energy efficiency	£ -	£ -
Grant	RHI	£ -	£ 916,646
Annual costs	Fuel bill	£ 32,584	£ 11,849
	Service	£ 2,250	£ 7,500
Life time costs (Including current RHI)	10 year	£ 535,382	£ 560,178
	20 year	£ 897,966	£ 741,494
	30 year	£ 1,418,049	£ 894,328
	40 year	£ 1,780,632	£ 1,092,995

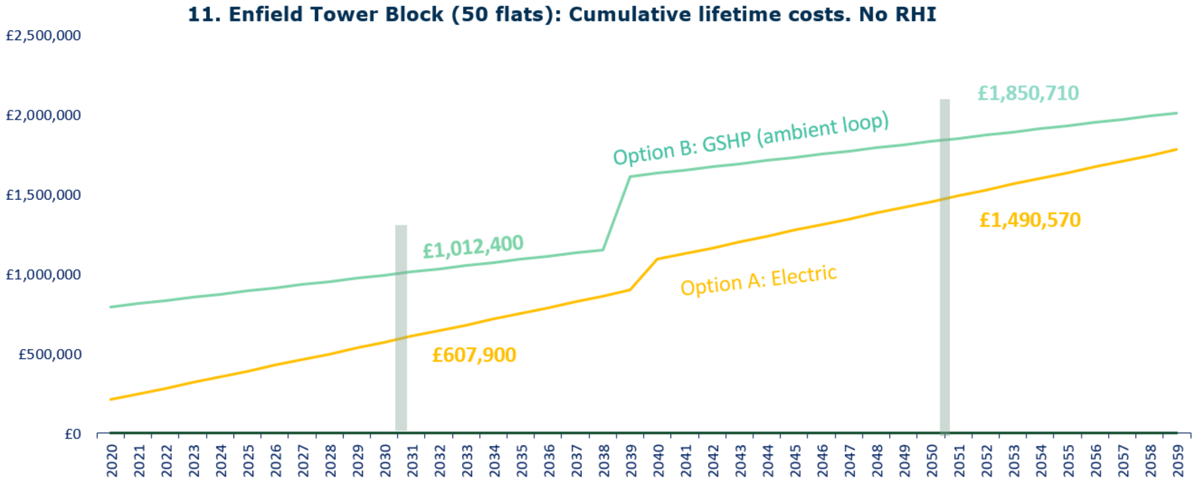
CO_2 emissions

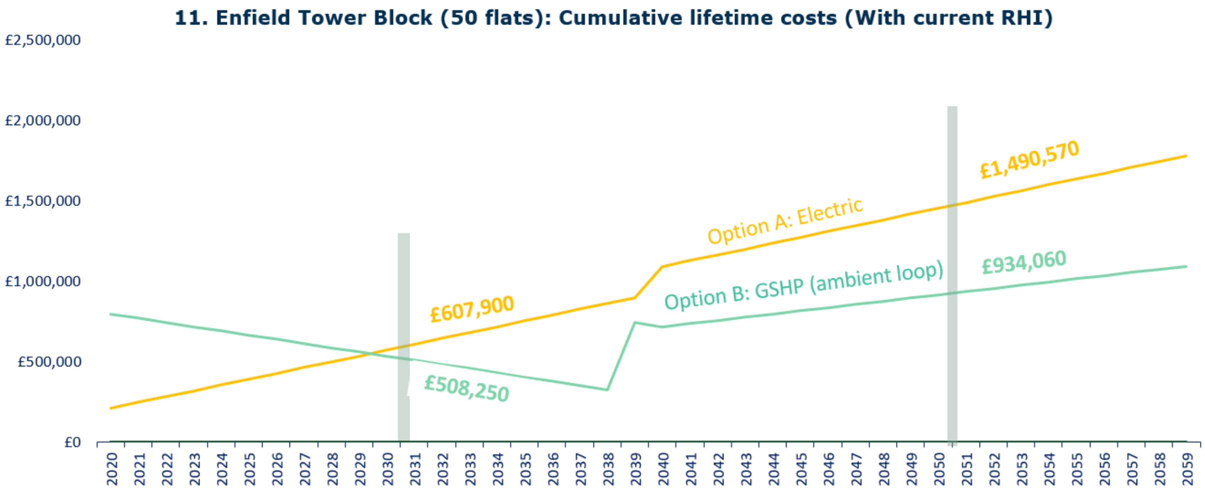


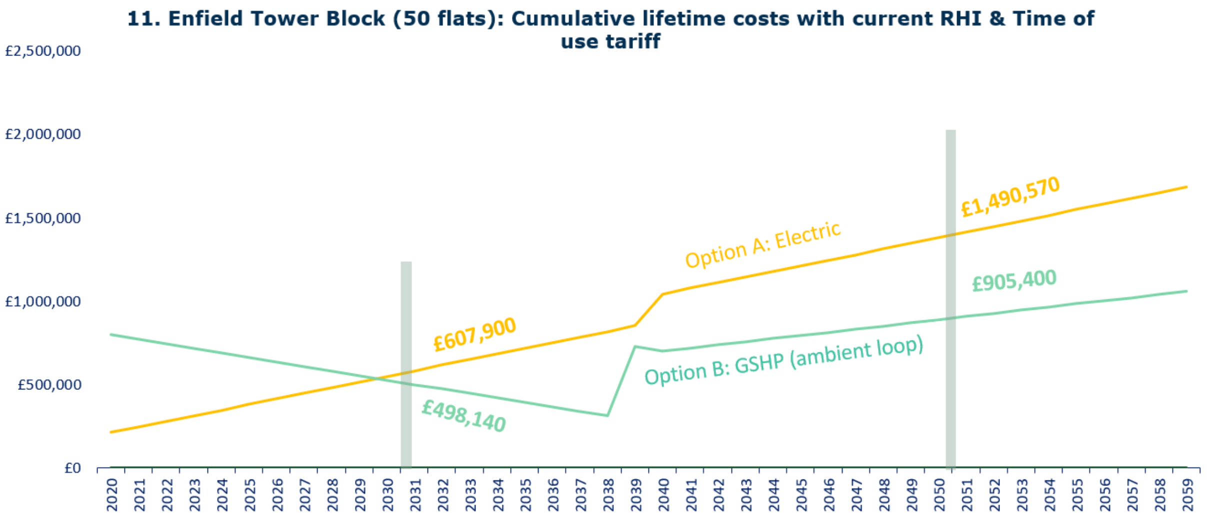
Fuel bills

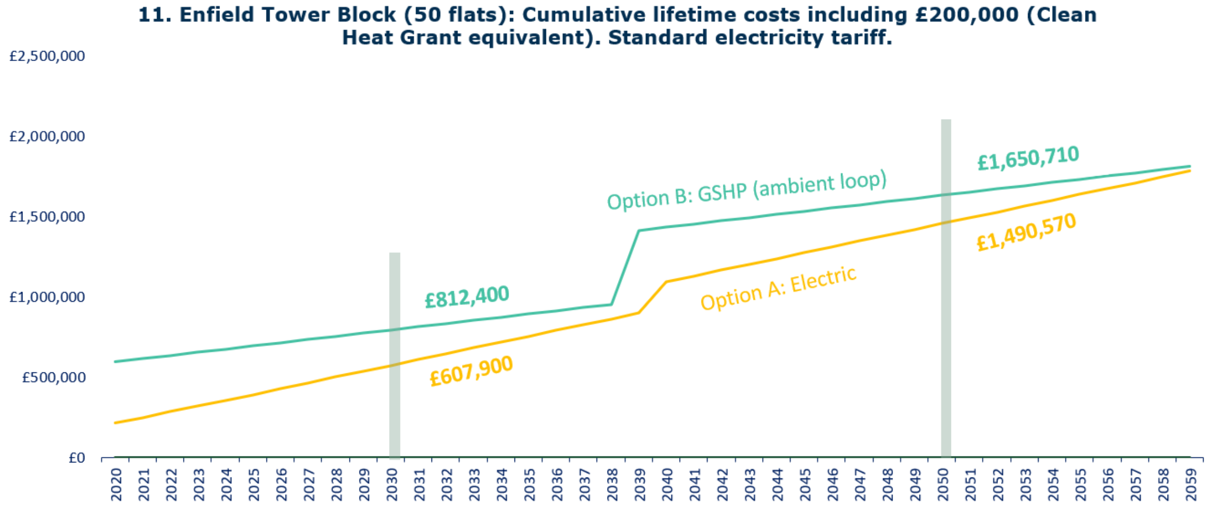


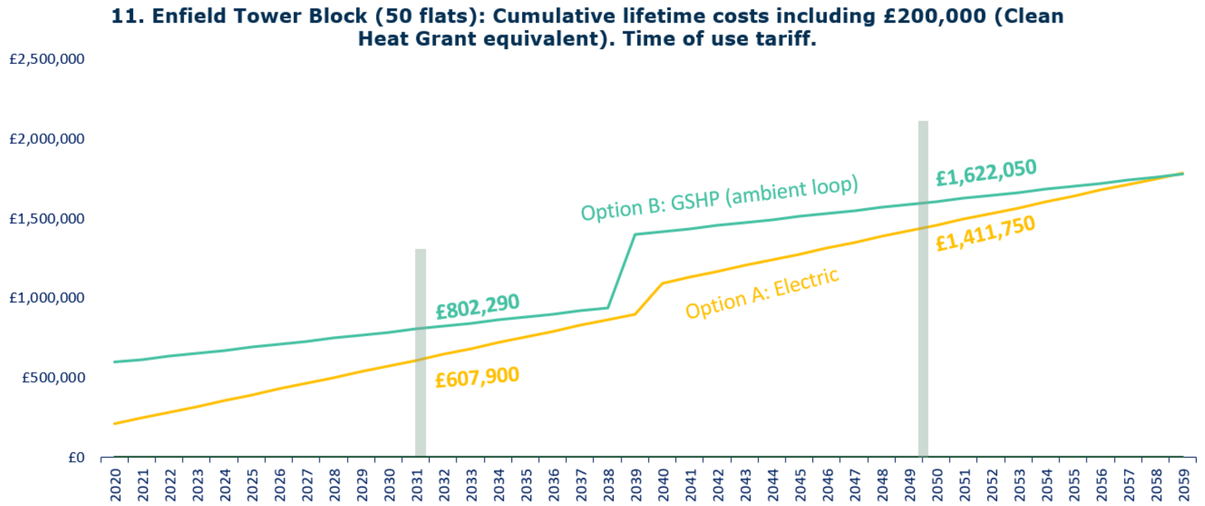
Lifetime costs and sensitivity analysis

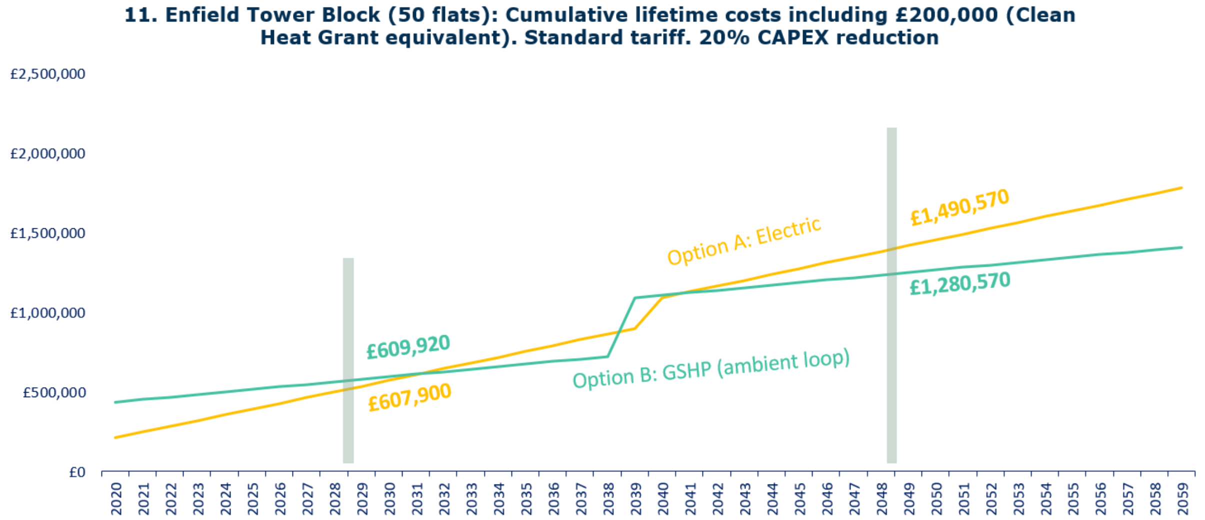






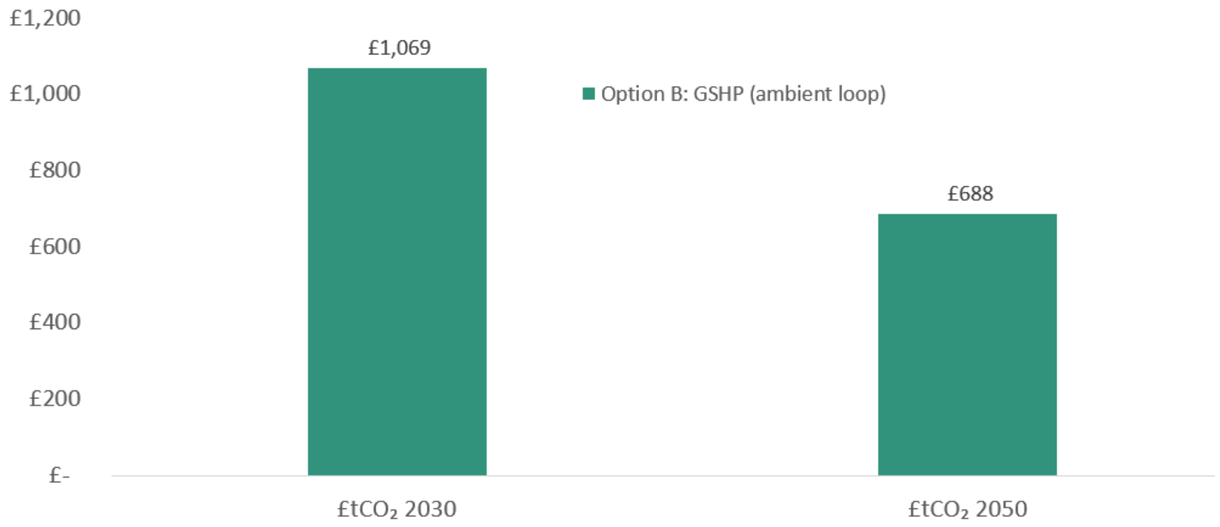

11. Enfield Tower Block (50 flats): Cumulative lifetime costs including £200,000 (Clean Heat Grant equivalent). Standard electricity tariff.
£2,500,000
£2,000,000
£1,500,000
£1,000,000
£500,000
£0
Option B: GSHP (ambient loop)
Option A: Electric
£1,650,710
£1,490,570
£812,400
£607,900
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059


11. Enfield Tower Block (50 flats): Cumulative lifetime costs including £200,000 (Clean Heat Grant equivalent). Time of use tariff.
£2,500,000
£2,000,000
£1,500,000
£1,000,000
£500,000
£0
Option B: GSHP (ambient loop)
Option A: Electric
£1,622,050
£1,411,750
£802,290
£607,900
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059


11. Enfield Tower Block (50 flats): Cumulative lifetime costs including £200,000 (Clean Heat Grant equivalent). Standard tariff. 20% CAPEX reduction
£2,500,000
£2,000,000
£1,500,000
£1,000,000
£500,000
£0
Option A: Electric
Option B: GSHP (ambient loop)
£1,490,570
£1,280,570
£609,920
£607,900
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059

Cost of carbon reduction: £ per tonne of CO_2 reduced

11. Enfield Tower Block: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



Summary of Options Appraisal Analysis:

- **CO_2 savings:** Cumulatively, over 30 years, the BAU scenario is predicted to emit 817 tonnes of CO_2. This figure is relatively low compared to equivalent blocks of flats heated by gas boilers. This is due to the declining carbon intensity of grid electricity between now and 2050. However, in reality, it will be necessary to reduce overall demand for electricity at the system level. The heat pump option reduces energy use and CO_2 emission by 64% relative to the BAU. This is the same over 10 years and 30 years as the declining carbon intensity of electricity impacts both the BAU and heat pump scenario equally.

- **Fuel bills:** Under standard tariffs, fuel bills are predicted to decrease significantly under the heat pump option, by 64%. We did not model the time of use tariff for the BAU scenario, although the BAU scenario could stand to benefit significantly from shifting peak load, given the retrofit improvements already undertaken to improve the thermal efficiency of the building.

- **Overall lifetime costs:** Current levels of RHI are relatively generous for shared ground source loops in block of flats (which qualify for 20 years Non-domestic RHI payments). This means that with the current RHI, the heat pump Option is significantly lower cost than BAU over 30 years.

- **Clean Heat Grant**: We modelled a scenario including £4,000 Clean Heat Grant for each flat (a total of £200,000). This grant would be significantly less generous than the current non-domestic RHI, making the heat pump option marginally more expensive over 30 years than BAU. However, when a 20% CAPEX reduction is factored in, the heat pump option would again be lower cost over 30 years than BAU.

- **Cost of carbon:** As the 30 year carbon savings are relatively lower in an electrically heated building than a gas heated building, the cost of carbon reduction is over 30 years is relatively higher. However, the cost of CO_2 reduction figures quoted in our chart are calculated before any grant levels are taken in to account. Under current RHI levels, the heat pump scenario is cheaper than BAU meaning the cost of CO_2 reduction would be negative.

12. Small office building; Gifford House, Merton

Address	Borough	Building type	Age	Floor area (m²)
Gifford House	Merton	Small 2-storey office building	1983	Approx 1,000m²
Current space heating	Current heat emitters	Current hot water system	Cooling and air-conditioning	Existing renewable energy
Gas condensing boiler (2 x 100kW) Trend DP control panel. Flow temp 70°C (80°/60°)	Panel Radiators. Good level of insulation on pipework including insulation on valves and flanges.	Rinnai wall hung gas fired water heater.	Single air con unit in printer room.	None.
Annual gas used (kWh) Monitored 2018/19	Annual electricity used kWh (monitored two-year average)	Approx annual gas bill	Approx annual electricity bill	Current EPC rating
69,388	45,434	£2,082	£6,815	Unknown
Hot Water Schedule	Peak load demand for space heating (from half hourly monitored data)	Heating schedule	Potential for renewable energy	
08:00 - 18:00 Monday to Friday	108kW	07:30 - 19:00 Monday to Friday	Roof space for Solar PV or Solar thermal	

Monthly gas usage kWh (Syslink) 2018/19			
Apr	6,766	Oct	5,242
May	3,488	Nov	9,030
Jun	597	Dec	10,024
Jul	598	Jan	13,847
Aug	1,051	Feb	9,885
Sep	628	Mar	8,232
Total		69,388	

Assessment of retrofit potential: 12. Gifford House

Potential for large air source heat pump (Monobloc or split / VRF) external units.		**Potential for individual ground source heat pump**	
Roof	No	Available & accessible space for ground trench	Limited
Other exterior	Yes * Subject to noise assessment	Available & accessible space for bore holes	Yes
Space for internal heat pump unit		Available open water source	No
Suitable space for internal air source heat pump	Yes	Waste heat, tube, sewer, other	No
Suitable space for hot water cylinder / thermal store	Yes	**Space for large communal internal unit**	
Potential external space for separate energy centre	**No**	Existing space for centralised plant	Yes

Energy efficiency upgrades considered

The office building features double glazing and cavity wall insulation. Further upgrades to the energy efficiency of the building would be beneficial and would be necessary to be compatible with net zero carbon objectives. However, for this example we tested the business case for different heat pumps without the costs of energy efficiency measures to establish the relative merits of a scheme to replace only the heating system at end of life. We did not include solar PV in the scenarios for the same reason.

Heat emitter upgrades considered

Existing radiators are a mixture of double panel and single panel and assumed to be designed for flow temperatures >60°C. Upgrading to triple panel convector radiators or similar could enable flow temperatures below 55°C.

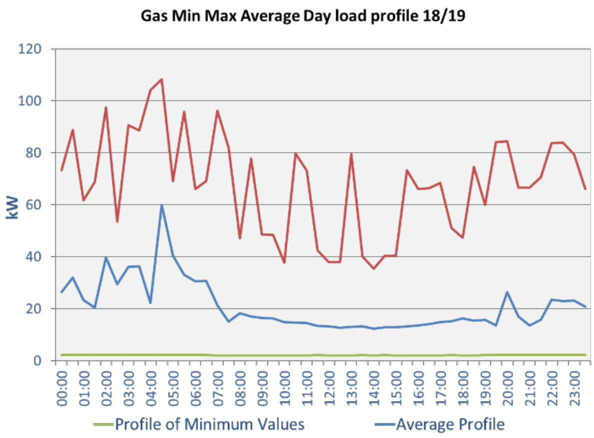
Heat pump options considered

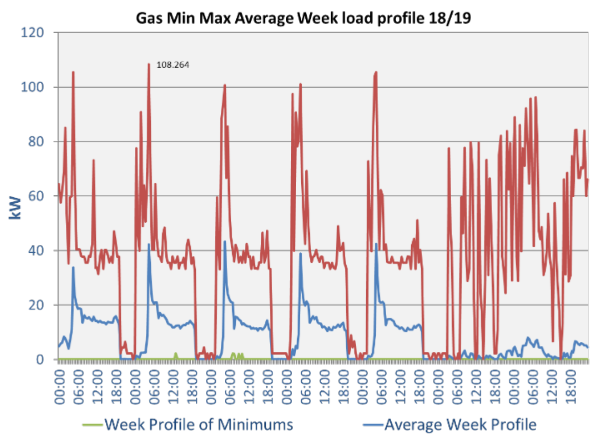
Air Source: The building offers several locations for installing internal and external units. For this building, we modelled the relative costs and performance of a high temperature (70°C) heat pump using existing radiators.

Ground Source: The building is surrounded by grass areas and a large car park offering sufficient space for vertical ground source boreholes.

Current gas use profile

It was not feasible within this study to undertake detailed heat loss calculations on the non-domestic buildings. However, we were able to assess half hourly smart meter data to gain an understanding of peak loads and required capacity. The following graphs show current energy demand in kW: minimum demand (green line), maximum demand (red line) and average demand (blue line). The current energy use of the buildings suggests that demand peaks at around 120kW during winter mornings. However, levelling out the profile of heat demand (primarily by turning the heat pump on earlier in the morning) could reduce the peak demand. Feedback from heat pump installers suggests that a heat pump capacity of approx. 90kW would be appropriate.



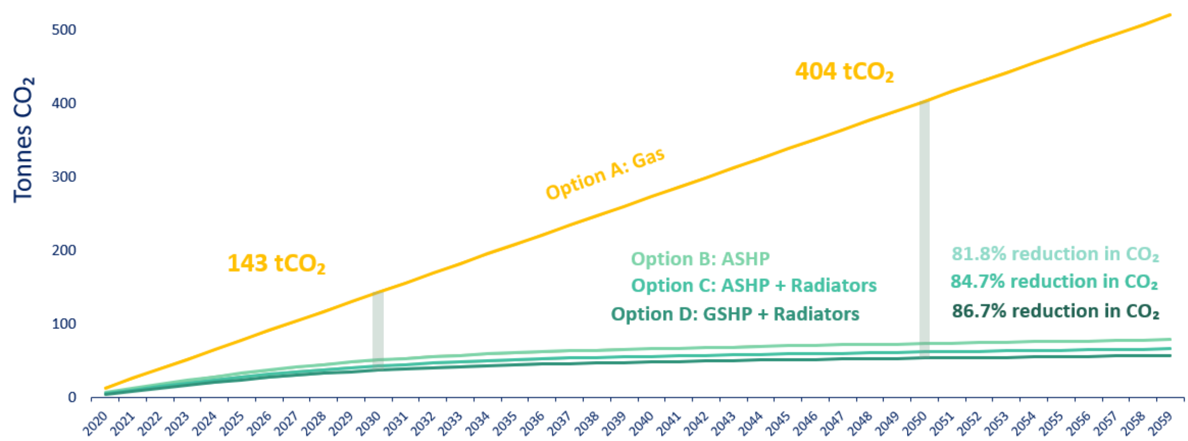


Options appraisal summary of results: 12. Gifford House

		Retrofit scenario			
		12a	12b	12c	12d
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler**	**Air Source Heat Pump 90kW 400kW**	**Air Source Heat Pump 90kW 400kW**	**Ground source heat pump 90kW**
	Heat emitter upgrades	None	None	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	None	None
	Air tightness (Average Air Changes per hour at ambient air pressure)	Unknown	Unknown	Unknown	Unknown
Energy performance	EPC	No Epc	No Epc	No Epc	No Epc
	kWh per m^2 pa	70	70	70	70
System design	Peak heat load (kW)	90kW	90kW	90kW	90kW
	Heat emitter output (kW at ▲T 50°C)	~100kW	~100kW	~240kW	~240kW
	Required flow temp for -1.8°C day	70°C	70°C	~50°C	~50°C
	Assumed efficiency / SPF H4	0.92	2.70	3.2	3.7
CO_2 emissions	Cumulative kg by 2030	143,220	50,995	43,027	37,212
	Cumulative kg by 2050	403,621	73,419	61,947	53,576
Upfront CAPEX costs	Heating system	£ 10,601	£ 97,369	£ 97,369	£ 168,958
	Heat emitters	£ -	£ -	£ 21,225	£ 21,225
	Energy efficiency	£ -	£ -	£ -	£ -
Grant	RHI	£ -	£ 31,828	£ 30,237	£ 94,504
Annual costs	Fuel bill	£ 1,802	£ 2,929	£ 2,472	£ 2,138
	Service	£ 525	£ 788	£ 788	£ 788
Life time costs (Including current RHI)	10 year	£ 39,800	£ 117,340	£ 134,314	£ 172,358
	20 year	£ 84,785	£ 203,635	£ 215,832	£ 152,804
	30 year	£ 113,765	£ 240,492	£ 249,503	£ 252,725
	40 year	£ 158,749	£ 342,701	£ 346,936	£ 282,910

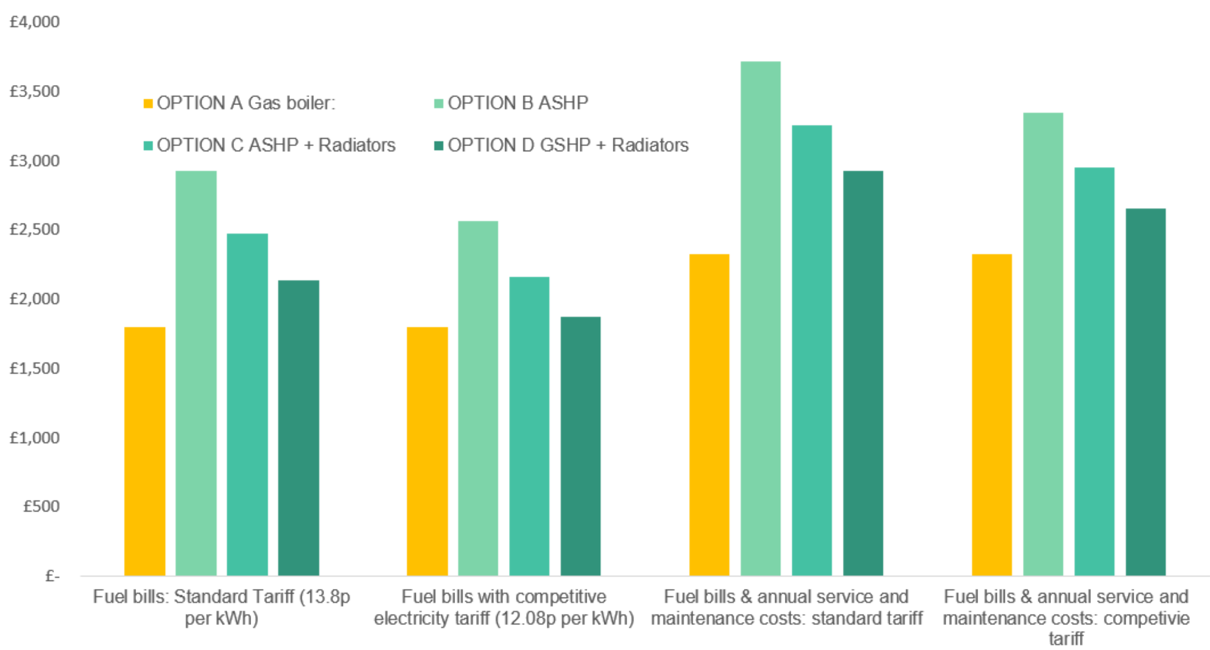
CO_2 emissions

12. Gifford House: Cumulative CO_2 emissions 2020-2060



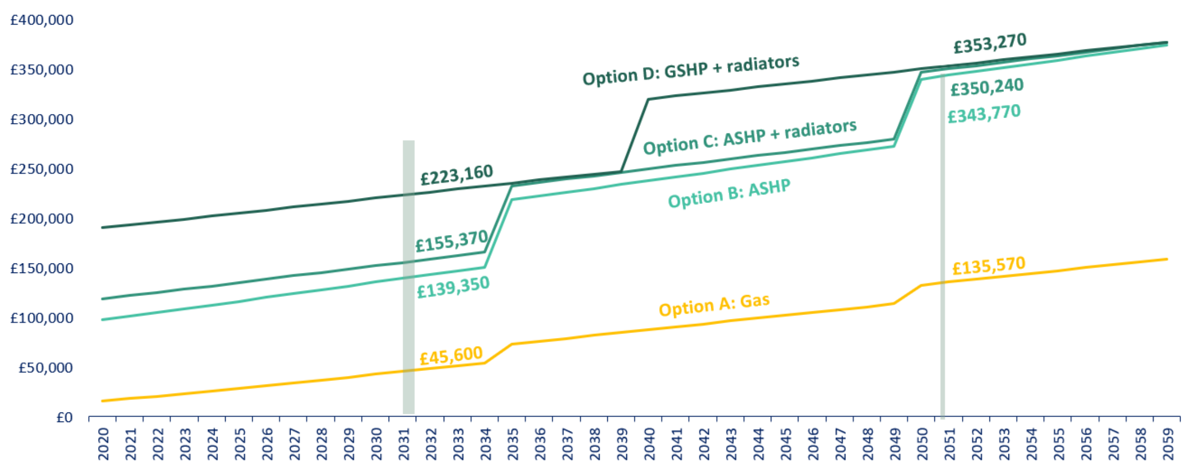
Fuel bills

12. Gifford House: Projected annual fuel bills and service costs in 2021 with different electricity tariffs

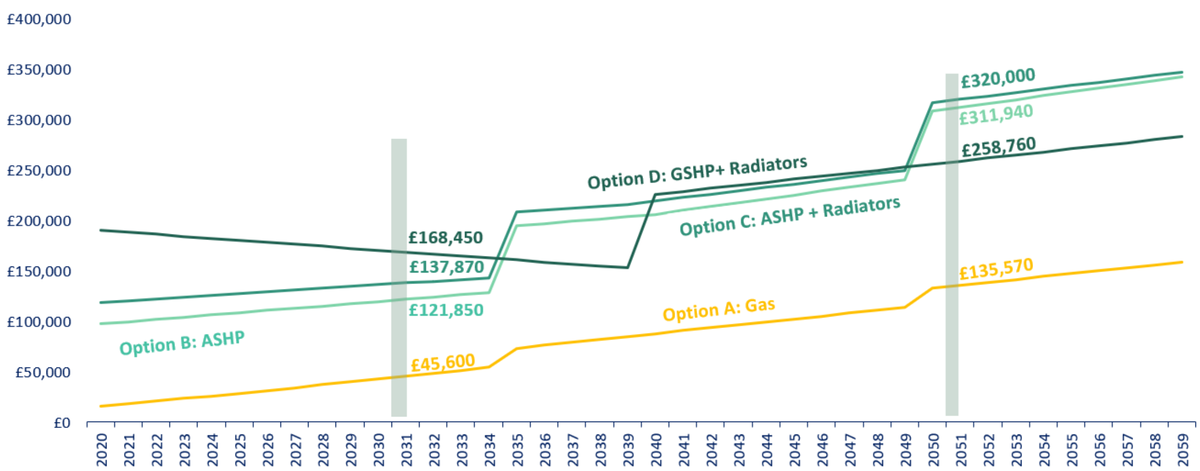


Lifetime costs and sensitivity analysis

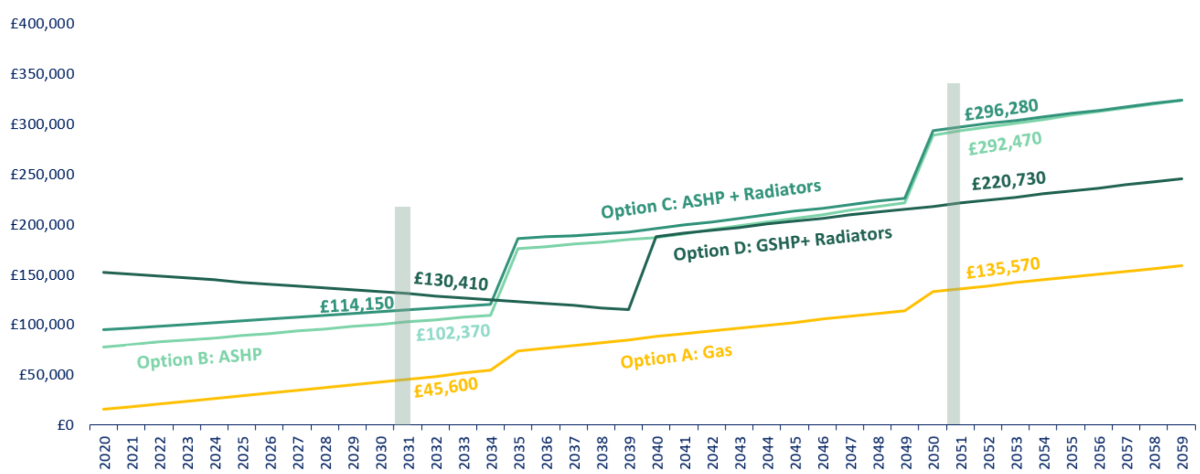
12. Gifford House: Cumulative lifetime costs. No RHI



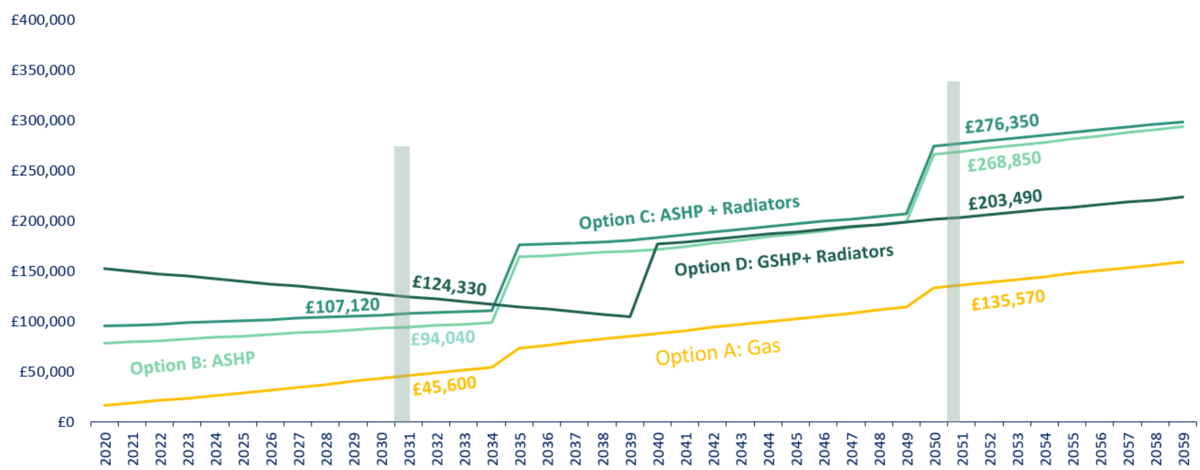
12. Gifford House: Cumulative lifetime costs. With current RHI



12. Gifford House: Cumulative lifetime costs woth current RHI and 20% CAPEX reduction.

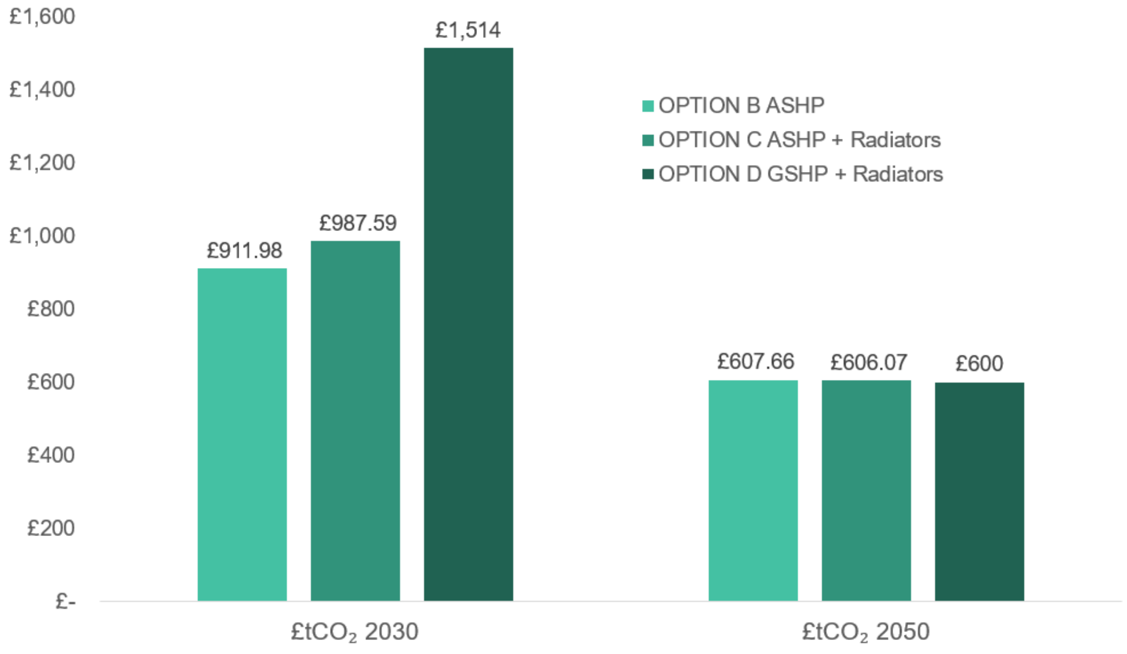


12. Gifford House: Cumulative lifetime costs with current tariff. 20% CAPEX reduction and competitive tariff



Cost of carbon reduction: £ per tonne of CO_2 reduced

12. Gifford House: £tCO2 reduced cumulatively by 2030 and 2050 (Standard Tariff, No RHI, No Grant, No CAPEX reduction)



Summary of Options Appraisal Analysis:

- **CO_2 savings:** Cumulatively, over 30 years, the BAU scenario is predicted to emit 404 tonnes of CO_2. All three heat pump options deliver significant CO_2 savings between 82% and 87% over 30 years. Option D (ground source heat pump and radiators) delivers the highest CO_2 savings due to having the highest efficiency of the heat pump operation.

- **Fuel bills and operating costs:** Under standard tariffs, fuel bills are predicted to increase under all heat pump options. This continues to be the case when a more competitive electricity tariff is assumed. Servicing costs are also predicted to be marginally higher for the heat pump scenarios than the BAU gas scenario. However, in this analysis we did not factor in the building specific potential for benefiting from time of use tariffs or other payments for flexibility services. Non-domestic buildings have significant potential to benefit from these and this could reduce overall operating costs.

- **Lifetime costs:** The 30 years costs of all the heat pump options are higher than the gas BAU costs, despite the relatively generous payments for ground source heat pumps under the non-domestic RHI. However, factoring in additional payments for flexibility services could improve the financial case further.

- In this building, the air source heat pump options had lower lifetime costs than the ground source heat pump option, despite the better assumed efficiency of the ground source heat pump. However, when the current non-domestic RHI rates are taken into account, the ground source heat pump option has lower lifetime costs.

13. Medium office building; Billet Road, Waltham Forest

Address	Borough	Building type		Age	Floor area (m²)
Billet Road	Waltham Forest	Medium 3 storey office building		1970s	2,581
Current space heating	Current heat emitters	Current hot water system		Cooling and air-conditioning	Existing renewable energy
Unknown	Unknown	Unknown		Unknown	19.2 kWp roof mounted Solar PV
Annual gas used (kWh) (18/19)	Annual electricity used kWh (18/19)	Approx annual gas bill		Approx annual electricity bill	Current EPC rating
238,172	Unknown	£7,145		Unknown	C
Monthly gas usage					
Monitored gas usage kWh					
Month	2018/19 Heating	2018/19 DHW	Month	2018/19 Heating	2018/19 DHW
Apr	33,416	636	Oct	29,594	915
May	21,047	685	Nov	37,812	1,057
Jun	13,602	640	Dec	45,673	689
Jul	10,575	693	Jan	38,987	931
Aug	13,069	651	Feb	40,789	766
Sep	18,320	716	Mar	40,157	801
Total				233,012	5,160

Assessment of retrofit potential: 13. Billet Road

Potential for large air source heat pump (Monobloc or split / VRF) external units.		**Potential for individual ground source heat pump**	
Roof	Yes* Subject to noise assessment	Available & accessible space for ground trench	Yes
Other exterior	Yes * Subject to noise assessment	Available & accessible space for bore holes	Yes
Space for internal heat pump unit		Available water source (shallow aquifer / ground water)	Yes* Subject to survey
Suitable space for internal air source heat pump	Yes	Waste heat, tube, sewer, other	No
Suitable space for hot water cylinder / thermal store	Yes	**Space for large communal internal unit**	
Potential external space for separate energy centre	**Yes**	Existing space for centralised plant	Yes

Energy efficiency upgrades considered

The office building features UPVC double glazing and cavity wall insulation (assumed). However, gas use in the building is relatively high compared to benchmark buildings of this type. A deep retrofit including facade and roof insulation as well as new windows was therefore considered. The building already has solar PV installed. Further upgrades were not considered. Existing 19.2kWp solar PV system.

Heat emitter upgrades considered

Existing radiators are assumed to be a mixture of double panel and single panel and assumed to be designed for flow temperatures >60°C. It is considered to upgrade to triple panel radiators.

Heat pump options considered

Air Source: The building offers several locations for installing internal and external kit.

Ground Source: The building's surroundings and spacious car park offer sufficient space for vertical ground source boreholes.

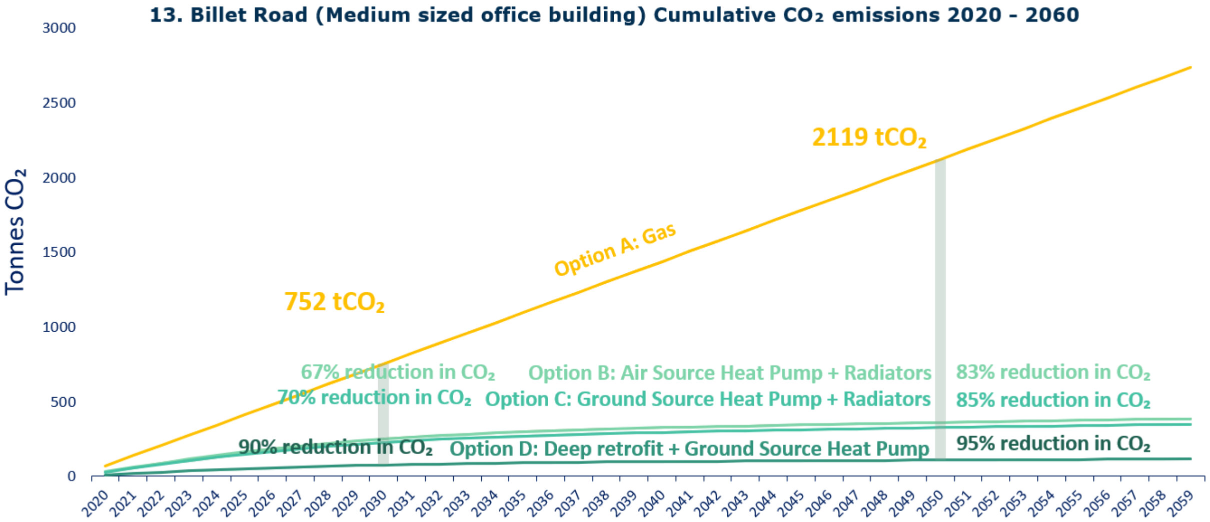
Water source: The geology of the area (adjacent to the River Lea) is highly likely to be either Alluvium or River Terrace Deposits offering excellent potential for shallow boreholes accessing ground water through an open or closed loop arrangement. Without a further study, it was not possible to quantify the potential water source. Therefore, a closed loop ground source option was modelled. However, capital cost savings and a performance uplift could be achieved if an open loop, ground water source heat pump were found to be feasible.

It was not feasible to undertake detailed heat loss calculations for non-domestic buildings in this study. However, based on the monthly gas consumption of the building, feedback from heat pump installers was that a heat pump with a capacity of approximately 180kW would be sufficient to meet the heat demand.

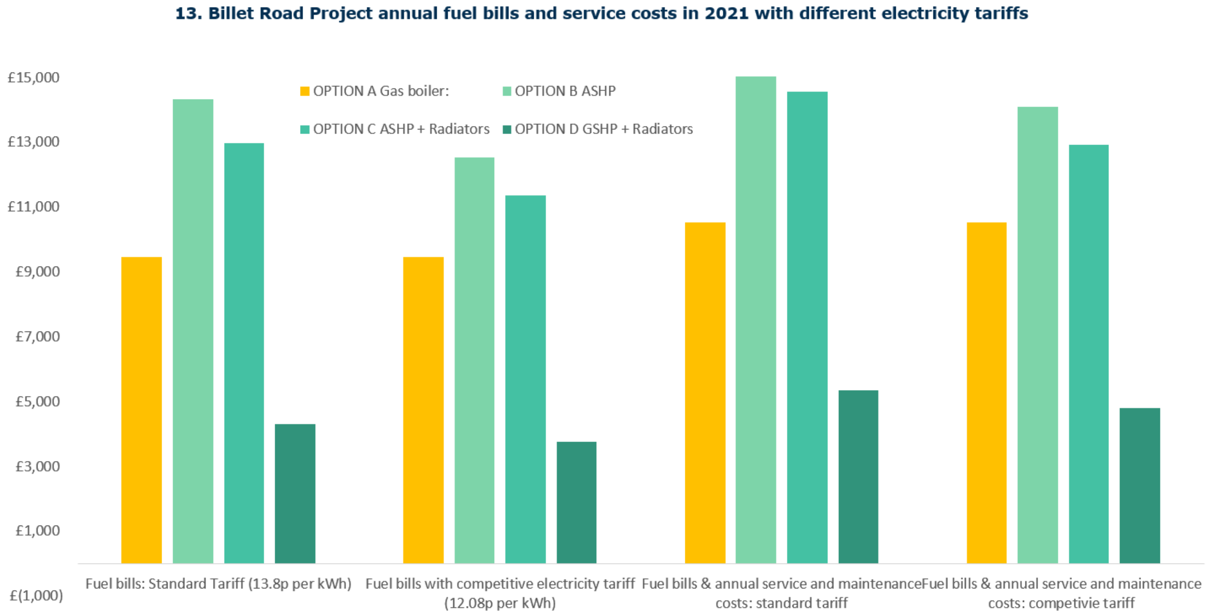
Options appraisal summary of results: 13. Billet Road

		Retrofit scenario			
		13a	13b	13c	13d
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler**	**Air Source Heat Pump 180kW**	**Ground Source Heat Pump 180kW**	**Ground source heat pump 64kW**
	Heat emitter upgrades		Triple panel convector	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	None	Deep retrofit
	Air tightness (Average Air Changes per hour at ambient air pressure)	Unknown	Unknown	Unknown	Unknown
Energy performance	EPC	C	C	C	A/B
	kWh per m^2 pa	80	80	80	30
System design	Peak heat load (kW)	180kW	180kW	180kW	64kW
	Heat emitter output (kW at ▲T 50°C)	~200kW	450kW	450kW	450kW
	Required flow temp for -1.8°C day	70°C	~55°C	~55°C	~35°C
	Assumed efficiency / SPF H4	0.92	2.90	3.2	3.6
CO_2 emissions	Cumulative kg by 2030	751,728	249,199	225,837	74,748
	Cumulative kg by 2050	2,118,506	358,783	325,147	107,617
Upfront CAPEX costs	Heating system	£ 21,910	£ 175,096	£ 306,675	£ 139,198
	Heat emitters	£ -	£ 33,280	£ 33,280	£ 33,280
	Energy efficiency	£ -	£ -	£ -	£ 104,000
Grant	RHI	£ -	£ 158,706	£ 422,924	£ 160,902
Annual costs	Fuel bill	£ 9,461	£ 14,315	£ 12,973	£ 4,294
	Service	£ 1,050	£ 1,575	£ 1,575	£ 1,050
Life time costs (Including current RHI)	10 year	£ 131,459	£ 280,323	£ 274,283	£ 824,977
	20 year	£ 288,424	£ 489,658	£ 202,837	£ 799,839
	30 year	£ 423,478	£ 654,810	£ 643,187	£ 974,029
	40 year	£ 580,442	£ 947,675	£ 794,333	£ 1,029,342

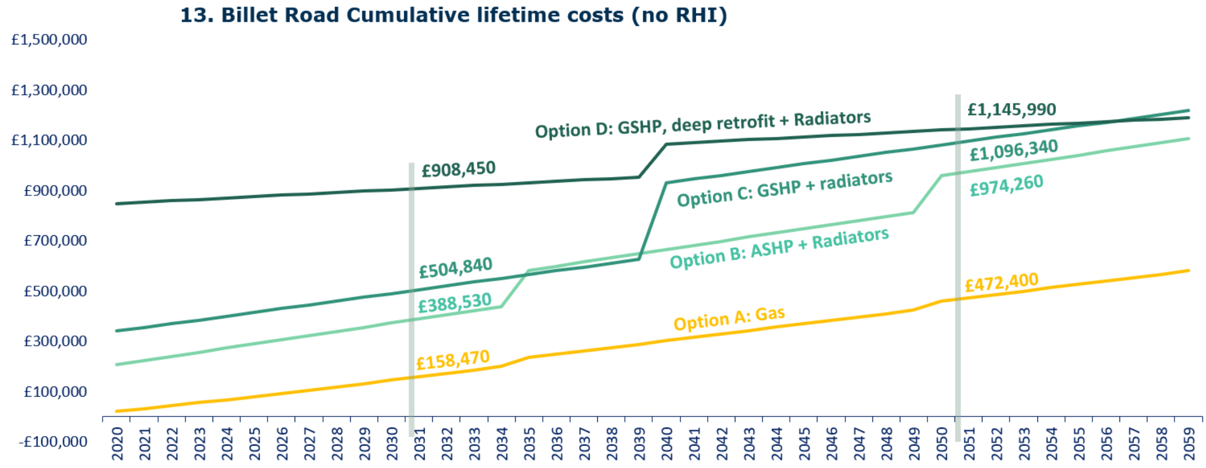
CO_2 emissions

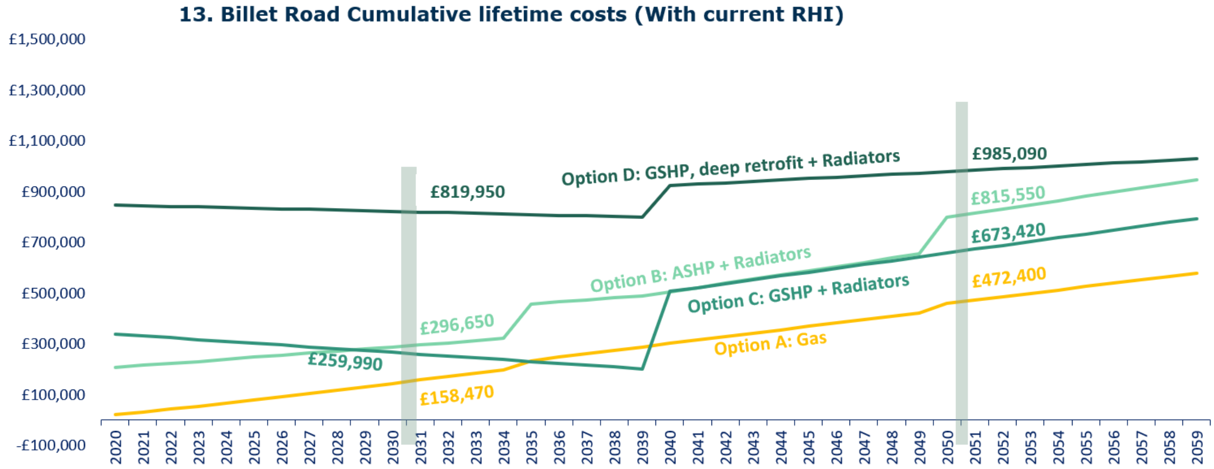


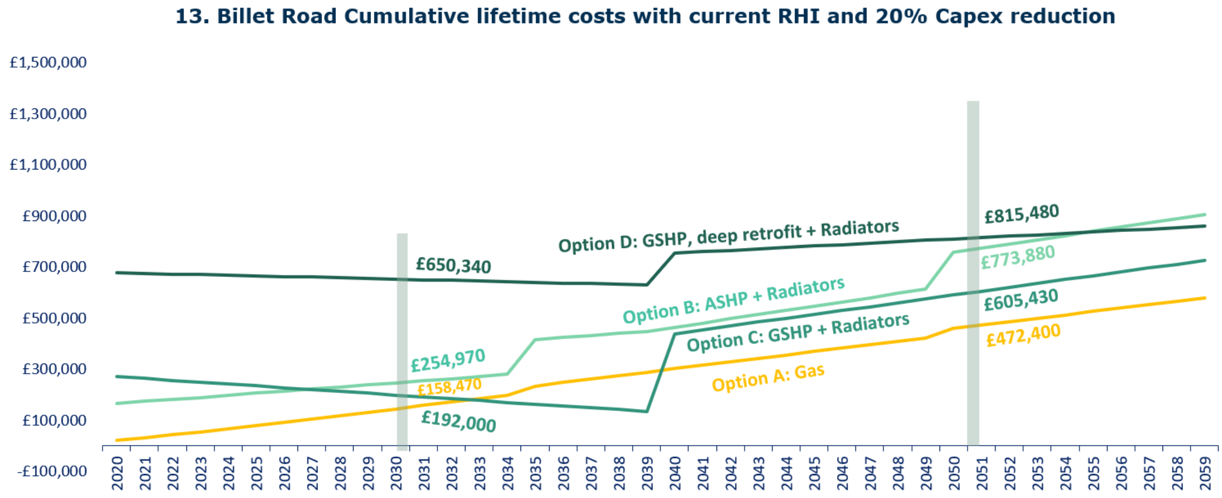
Fuel bills

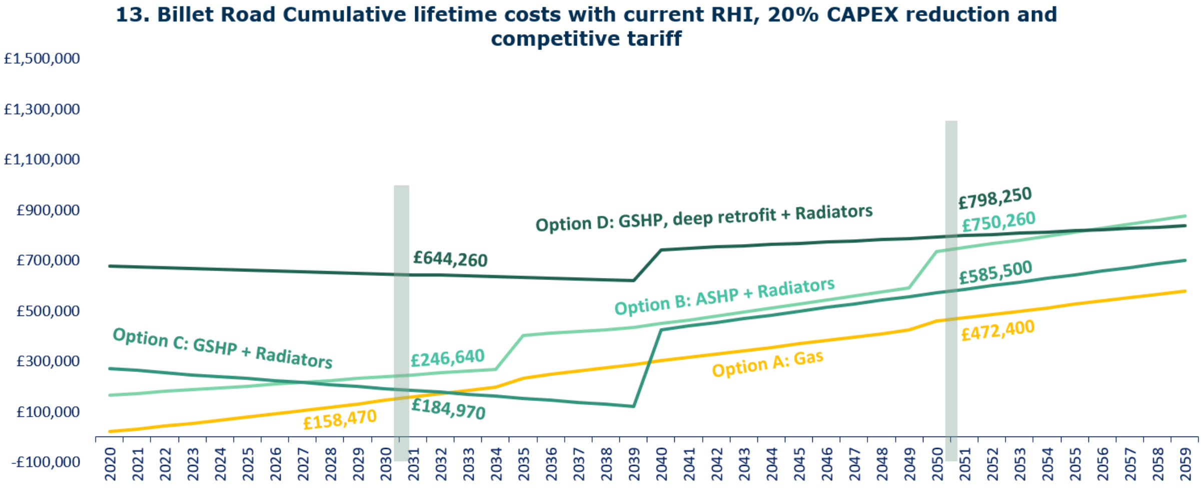


Lifetime costs and sensitivity analysis

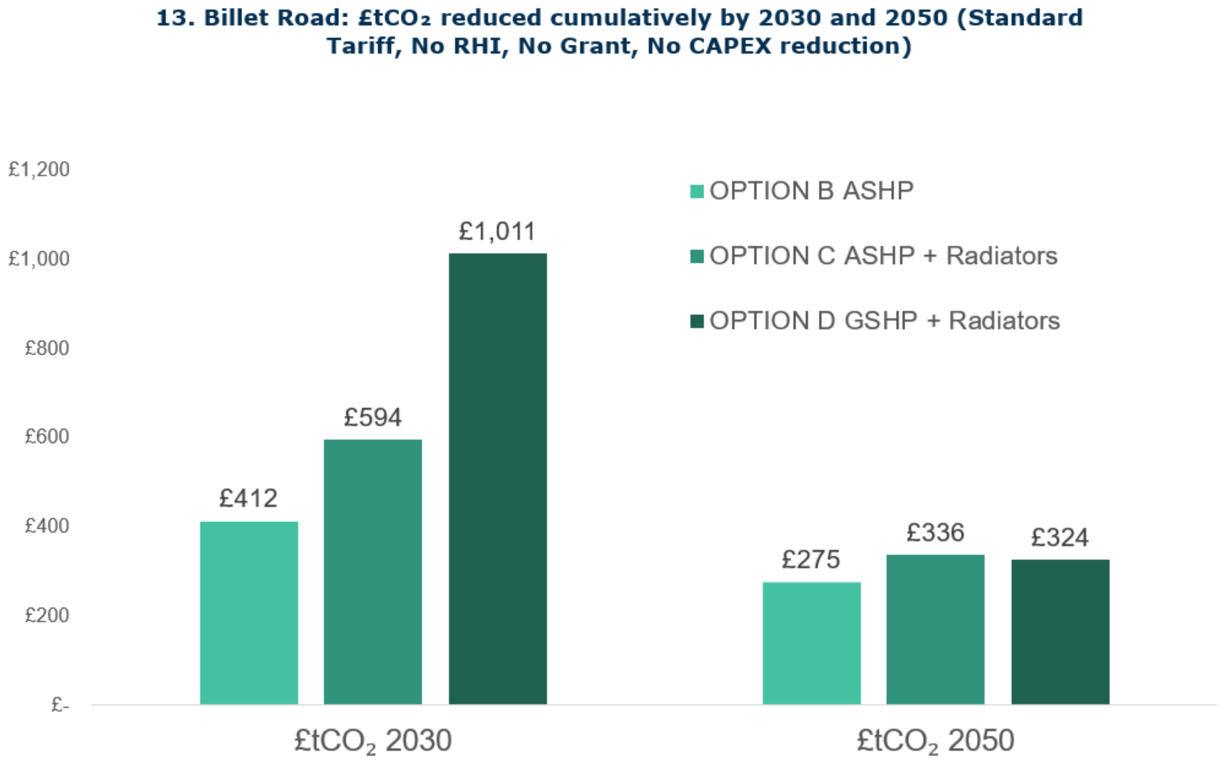








Cost of carbon reduction: £ per tonne of CO_2 reduced



Summary of Options Appraisal Analysis:

- **CO_2 savings:** Cumulatively, over 30 years, the BAU scenario is predicted to emit 2,119 tonnes of CO_2. The two heat pump options deliver significant CO_2 savings of 83% and 85%. Option D (retrofit of the building fabric plus ground source heat pump) delivers the highest CO_2 savings of 95% over 30 years.

- **Fuel bills and operating costs:** Under standard tariffs, fuel bills are predicted to increase under options B and C but decrease significantly under Option D. This is also the case when a more competitive electricity tariff is assumed. However, in this analysis we did not factor in the building specific potential for benefiting from time of use tariffs or other payments for flexibility services. Non-domestic buildings have significant potential to benefit from these and this could reduce overall operating costs.

- **Lifetime costs:** The 30 year lifetime costs for all heat pump options are higher than the gas BAU option when no grants are taken in to account. However, when current non-domestic RHI rates are incorporated, Option C becomes lower cost than BAU over the 16 - 20 year timeframe, although the anticipated CAPEX expenditure on replacement equipment at year 20 would make it more expensive over 20 - 30 years.

- The additional cost of the energy efficiency investment under Option D (deep retrofit and ground source heat pump) does not pay for itself over 30 years despite the reduced fuel bills.

14. Large office building, Docklands Road; Newham

Address	Borough	Building type	Age	Floor area (m^2)
1000 Docklands Road	Newham	Large office block	Post 2000	37,544
Current space heating	Current heat emitters	Current hot water system	Cooling and air-conditioning	Existing renewables
Two boiler rooms each containing 2 x Gas boiler: Remeha P300-13 with BMS, insulated pipes and intelligent boiler load control. Output 210 - 543 kW per boiler Flow temp 70° (80°/60°)	Fan coil system with controls	Heatrae Sadia mega flo with unvented hot water cylinder with insulated pipes. Lochinvar water heater 379 litres.	Mechancial air conditioning. Ventilation: extractor fans and supply fans, chillers x 2.	None
Annual space heating gas used (kWh) (monitored two year average)	Annual electricity used kWh (monitored two year average)	Approx annual gas bill	Approx annual electricity bill	Current EPC rating
1,571,111	4,360,536	£ 43,991	£ 479,659	D

	kWh gas usage by month		Peak gas usage		Electricity usage
	West Wing [kWh]	East Wing [kWh]	Max HH demand (West Wing) kW	Max HH demand (East Wing) kW	kWh
Month	2018	2018	2018	2018	2018
Jan					354,727
Feb	92,728		802		332,546
Mar	129,166		806		340,798
Apr	63,754		943		323,342
May	30,318		537		341,146
Jun	9,854		68		338,464
Jul	9,001		67		382,579
Aug	9,377		68		365,799
Sep	9,216		89		328,034
Oct	24,714	15,079	689	820	360,398
Nov	133,560	111,246	674	873	355,141
Dec	150,910	109,934	782	933	323,979
Total	1,671,624	1,470,598			4,146,953

Assessment of retrofit potential: 14. Dockalnds Road

Potential for large air source heat pump (Monobloc or split / VRF) external units.		**Potential for individual ground source heat pump**	
Roof	Yes	Available & accessible space for ground trench	Yes
Other exterior	Yes	Available & accessible space for bore holes	Yes
Space for internal heat pump unit		Available water source (open water)	Yes* Subject to permissions
Suitable space for internal air source heat pump unit	Yes	Waste heat, tube, sewer, other	No
Suitable space for hot water cylinder / thermal store	Yes	**Space for large communal internal unit**	
Potential external space for separate energy centre	**Yes**	Existing space for centralised plant	Yes

Energy efficiency upgrades considered

The building is less than twenty years old with modern double glazing. The recommendation report accompanying the Display Energy Certificate (DEC) includes a series of recommendations around updating and servicing the HVAC systems. The only recommendation relevant to the building fabric is to regularly check the condition of the building fabric and insulation and to ensure that air gaps are sealed. A very large proportion of energy usage is due to cooling. Passive shading measures could provide significant benefit but were outside the scope of this study.

Heat emitter upgrades considered

The fan coil units are likely to already be providing flow temperatures below 55°C and so replacements were not likely to be necessary for heating or cooling purposes.

The DEC report includes a recommendation with HIGH priority to engage experts to review the overall ventilation strategy and propose an investment programme for upgrading and / or switching to alternative solutions to improve efficiency. We assumed that this improvement programme would take place under all scenarios, including BAU.

Heat pump options considered

Air Source: The building's flat roof offers sufficient space for external fan units that could replace the existing electric chiller units. A reversible Variable Refrigerant Flow (VRF) system could be considered to provide both heating and cooling.

Ground Source: There is sufficient nearby ground for borehole drilling and a closed ground loop providing a source for heating and ambient temperature cooling would be a good potential option. However, given the excellent potential for water source at the site, that was considered likely to have a better financial case due to the lower capital costs of not installing a ground loop.

Water Source: The building is located adjacent to Royal Albert Docks and therefore suitable for water source. As a significant amount of energy is required for cooling, a reversible water source heat pump could offer significant savings by providing ambient temperature passive cooling, replacing the existing electric chillers.

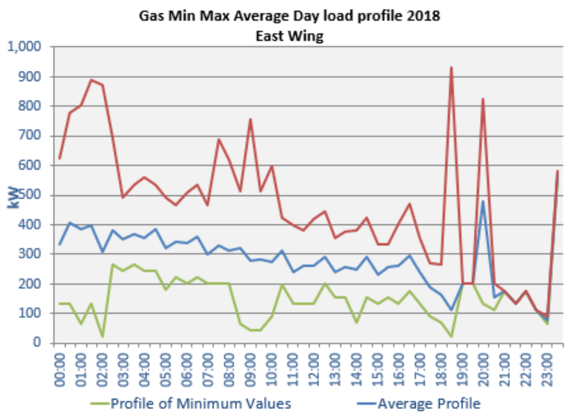
Renewable energy options considered:

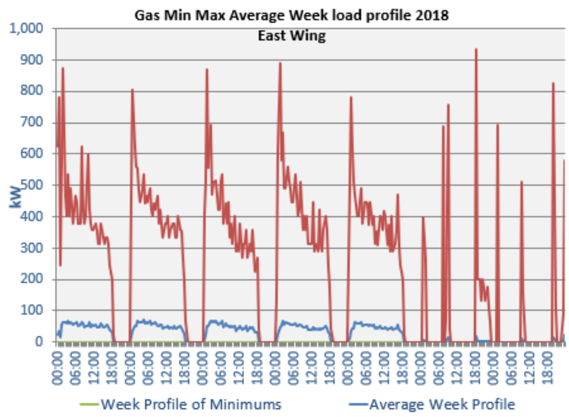
The roof has available space for 670kWp of Solar PV subject to necessary permissions (notably from the London City Airport which is adjacent to the site).

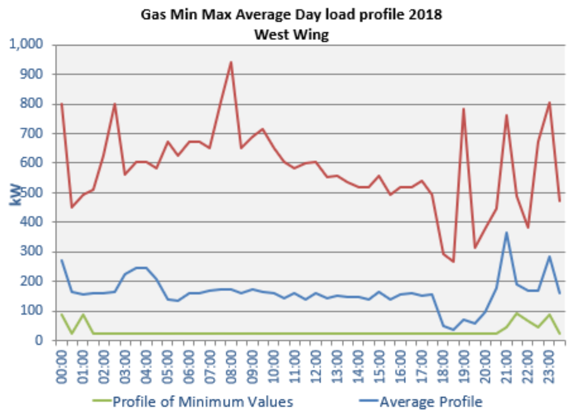
Current gas use profile

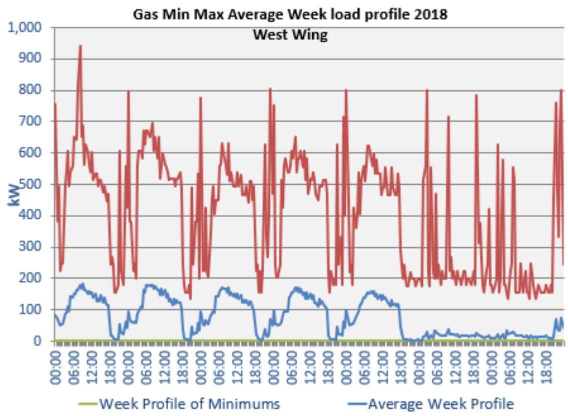
It was not feasible within this study to undertake detailed heat loss calculations on the non-domestic buildings. However, we were able to assess half hourly smart meter data to gain an understanding of peak loads and required capacity. The following graphs show current energy demand in kW: minimum demand (green line), maximum demand (red line) and average demand (blue line). The current energy use of the buildings suggests that demand peaks at over 900kW during winter mornings for both the East Wing and the West Wing.

However, levelling out the profile of heat demand could reduce the peak demand. Feedback from heat pump installers suggests that a heat pump capacity of approx. 1,000kW could be sufficient for both wings of the building alongside a stronger focus on energy management and improvement and of the heating and ventilation systems within the building.









Cooling and ventilation demand

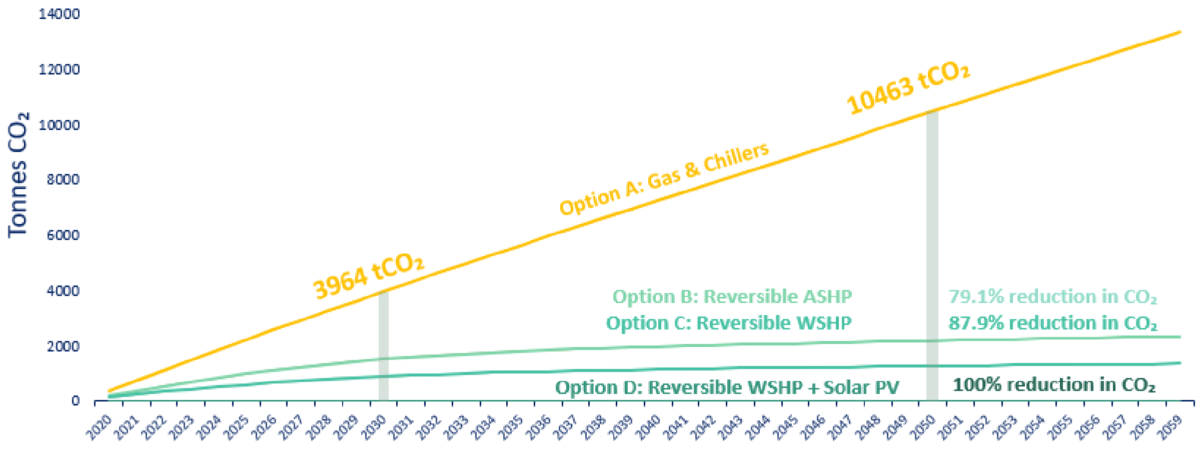
Detailed data on cooling and ventilation demand were not available for this study, however, this is expected to account for a large proportion of the overall 4,000MWh demand for electricity. In reality, a much more detailed study of the cooling and ventilation requirements would be required to determine the appropriate heat pump size and optimal configuration for either passive or active cooling.

Options appraisal summary of results: 14. Dockands Road

		Retrofit scenario			
		14a	14b	14c	14d
Packages of retrofit measures	Heating technology installed	**2000kW Replacement Gas combi-boiler & replacement chillers**	**Air Source Heat Pump (reversible VRF) 1000kW**	**Water Source Heat Pump (reversible) 1000kW**	**Water source heat pump (reversible) 1000kW & 670kWP Solar PV**
	Heat emitter upgrades	None	None	None	None
	Energy efficiency upgrades	None	None	None	None
	Air tightness (Average Air Changes per hour at ambient air pressure)	Unknown	Unknown	Unknown	Unknown
Energy performance	EPC	D	D	D	D
	kWh per m^2 pa	70	70	70	70
System design	Peak heat load (kW)	1800.0	1800.0	1800.0	1800.0
	Heat emitter output (kW at ▲T 50°C)	Unknown	Unknown	Unknown	Unknown
	Required flow temp for -1.8°C day	70°C	70°C	~50°C	~50°C
	Assumed efficiency / SPF H4	0.92	3.10	3.9	3.9
CO_2 emissions	Cumulative kg by 2030	3,963,735	1,517,182	894,026	- 94,726
	Cumulative kg by 2050	10,462,773	2,184,358	1,268,028	- 98,435
Upfront CAPEX costs	Heating system	£ 110,223	£ 945,988	£ 1,416,704	£ 1,416,704
	Heat emitters	£ -	£ -	£ -	£ -
	Energy efficiency	£ -	£ -	£ -	£ 607,500
Grant	RHI	£ -	£ 766,771	£ 2,322,890	£ 2,322,890
Annual costs	Fuel bill	£ 135,568	£ 165,497	£ 131,549	£ 52,329
	Service	£ 4,200	£ 4,200	£ 7,350	£ 7,350
Life time costs (Including current RHI)	10 year	£ 1,899,144	£ 2,175,837	£ 1,659,348	£ 885,947
	20 year	£ 3,868,328	£ 4,223,955	£ 2,936,087	£ 698,671
	30 year	£ 5,443,740	£ 5,954,929	£ 4,266,435	£ 637,403
	40 year	£ 7,412,924	£ 8,386,433	£ 6,704,619	£ 1,752,833

CO_2 emissions

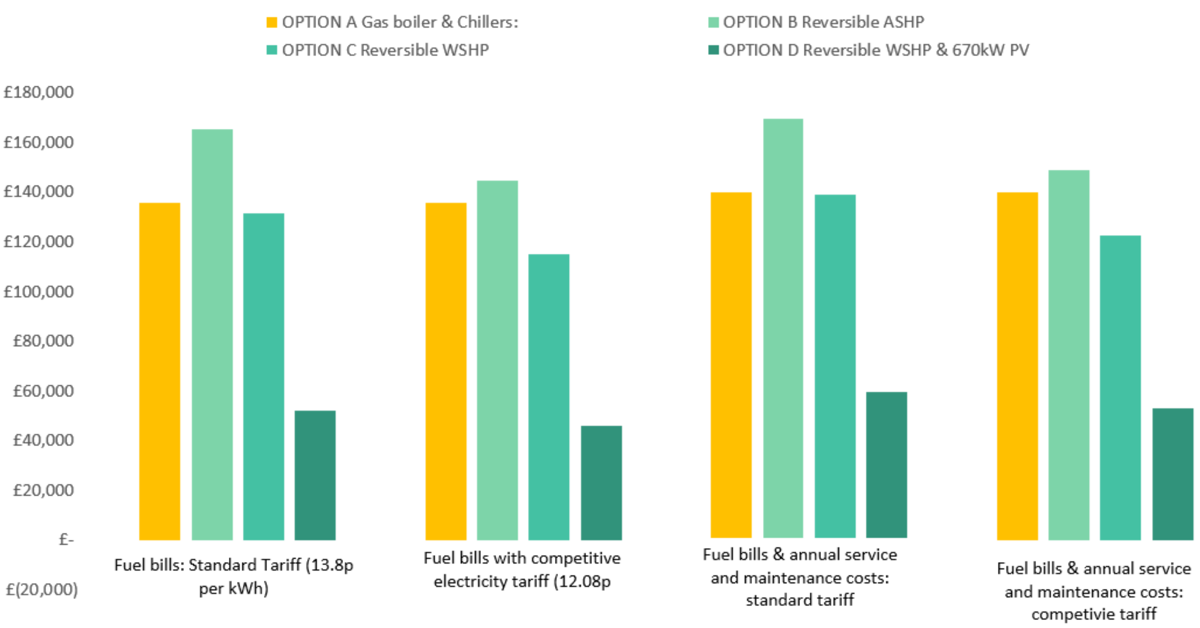
14. Docklands Road Cumulative CO_2 emissions 2020-2060



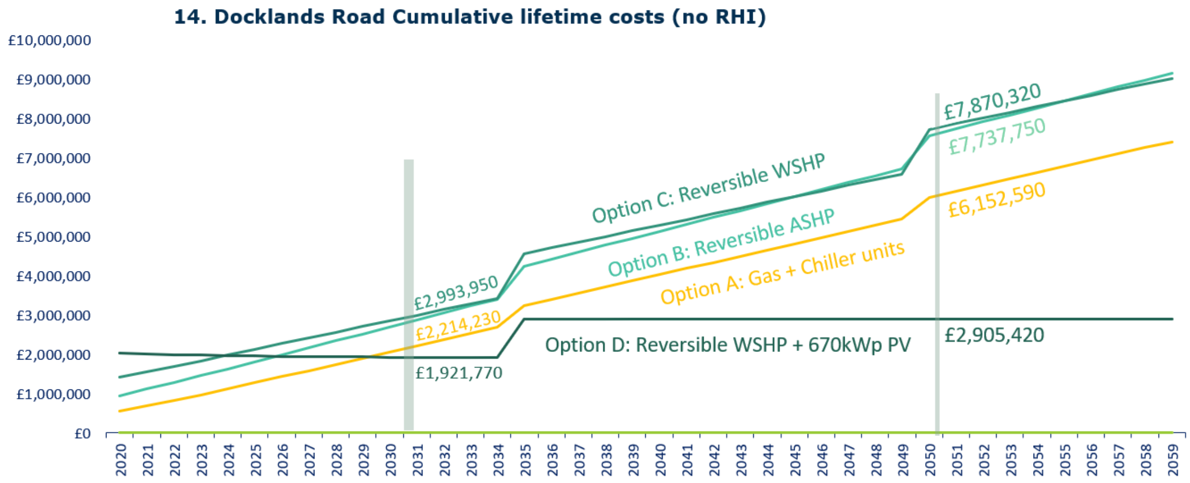
Fuel bills

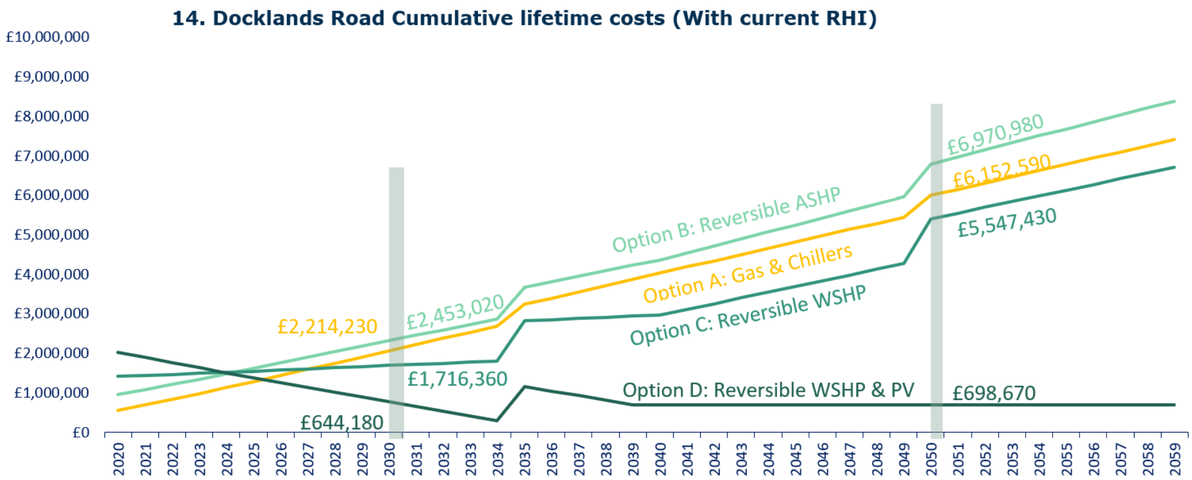
Option D generates net revenue for the building thanks to the very large solar array (670kWp). When this solar array is combined with a highly efficient WSHP (450%) that delivers both heating and cooling to the building and due to the high co-incidence of solar generation with demand for cooling, the building is still able to export excess solar electricity to the grid. All other heat pump options deliver savings relative to gas due to the high efficiencies achieved by the heat pump.

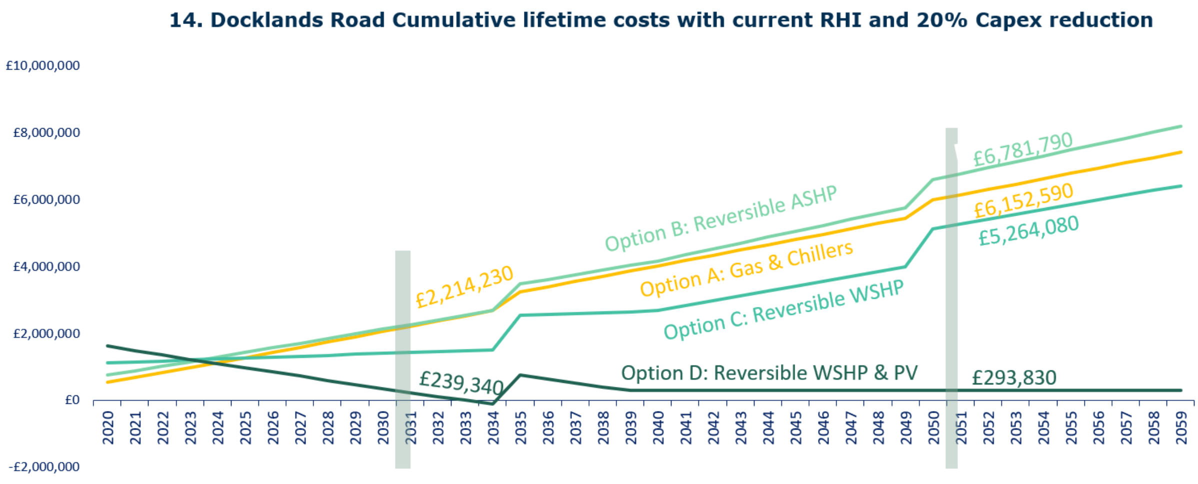
14. Docklands Road Project annual fuel bills and service costs in 2021 with different electricity tariffs

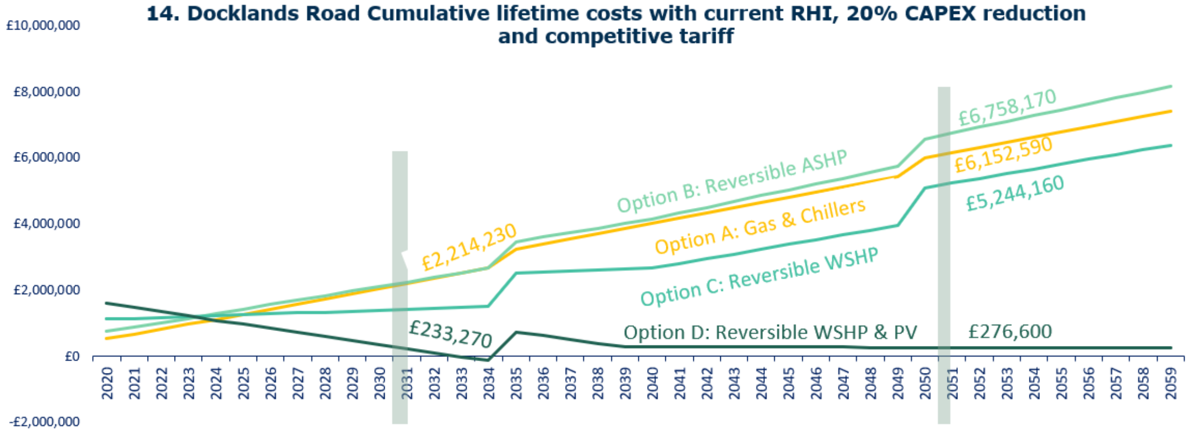


Lifetime costs and sensitivity analysis

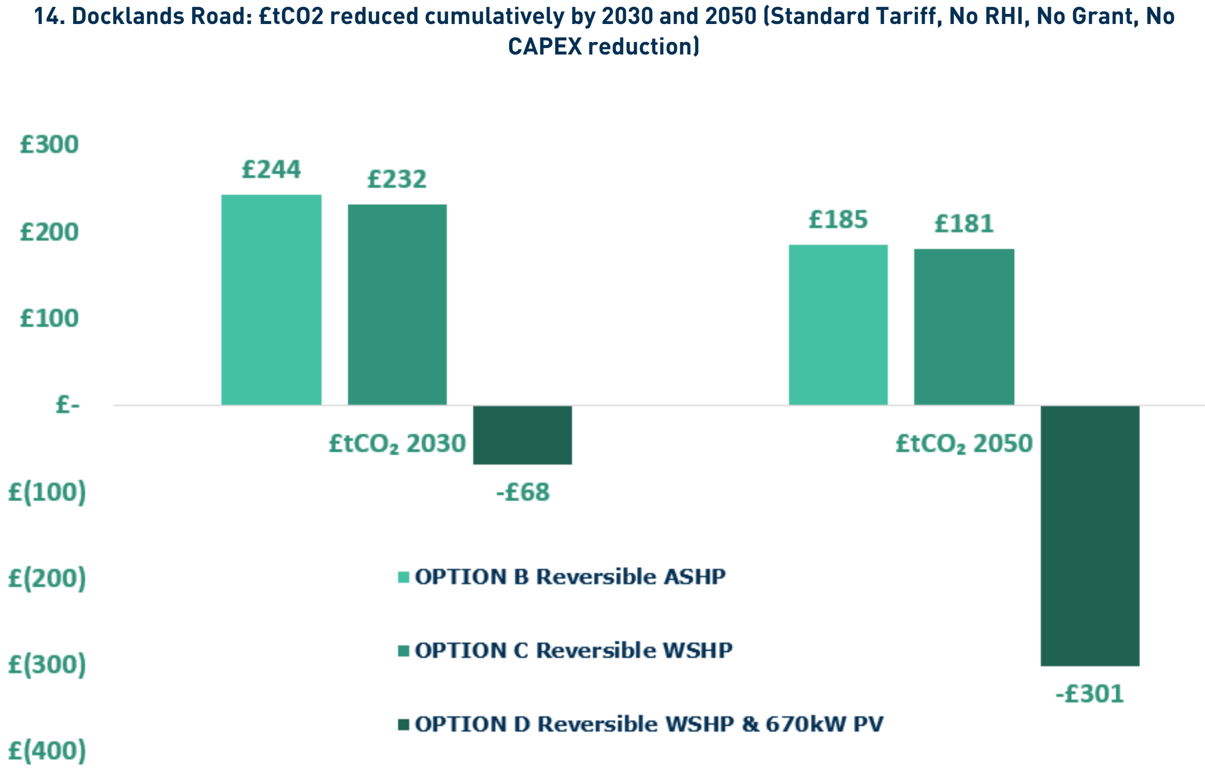








Cost of carbon reduction: £ per tonne of CO_2 reduced



Summary of Options Appraisal Analysis:

- **CO_2 savings:** Cumulatively, over 30 years, the BAU scenario is predicted to emit 10,463 tonnes of CO_2. Option A (air source heat pump) delivers CO_2 savings of 79%. Option B (water source heat pump) delivers CO_2 savings of 88%. This greater saving is due to increased efficiency in heating mode but also the ability to deliver passive cooling in this building with substantial cooling demand. Option D (water source heat pump plus Solar PV) is capable of delivering CO_2 savings of greater than 100%.

- **Fuel bills and operating costs:** Under standard tariffs, fuel bills are predicted to increase marginally under option A (air source heat pump) but decrease marginally under Option B (water source heat pump with passive cooling). Fuel bills are predicted to reduce significantly under Option D due to the avoided expenditure on electricity due to the solar panels. However, we did not model the possible financial benefits of payments for flexibility services and time of use which could be substantial in a building of this size and improve the business case even further.

- **Lifetime costs:** Even without the RHI, the potential benefits of a reversible heat pump combined with Solar PV in this building mean that lifetime costs over 30 years would be lower for Option D than for BAU. This is primarily due to the strong financial return of the solar PV offsetting the large demand for electricity in the building. Option C is more expensive than BAU over 30 years but less expensive when RHI is factored in. Although Option C has higher up-front costs than BAU, this gap is smaller because it is assumed that the electric chillers and gas boilers would both need replacing under BAU. Additional payments for flexibility (not modelled in the scope of this study) would improve the lifetime financial case for the heat pump options further.

15. Wimbledon Library, Merton

Address	Borough	Building type	Age	Floor area (m2)
Wimbledon Library	Merton	Medium 3 storey library	~1890	1700m²
Current space heating	**Current heat emitters**	**Current hot water system**	**Cooling and air-conditioning**	**Existing renewable energy**
Two gas-fired 160kW Concord CXI boilers, controlled by a Trend BEMS, well insulated including insulating jackets on valves and flanges.	Radiators, some with TRV	Unknown	None .	None.
Annual gas used (kWh) (18/19)	**Annual electricity used kWh (18/19)**	**Approx annual gas bill Opening hours**		
141,705	132,686	Mon-Fri: 09:30-19:00, Sat: 09:30-17:00, Sun: Closed		

Monthly gas usage kWh (sysLink) 2018/19			
Apr	16,983	Oct	12,099
May	727	Nov	22,804
Jun	156	Dec	27,537
Jul	0	Jan	36,714
Aug	598	Feb	20,965
Sep	2,379	Mar	21,586
Total			**141,705**

Assessment of retrofit potential: 15. Winbledon Library

Potential for large air source heat pump (Monobloc or split / VRF) external units.		**Potential for individual ground source heat pump**	
Roof	Limited	Available & accessible space for ground trench	No
Other exterior	Yes	Available & accessible space for bore holes	No
Space for internal heat pump unit		Available water source (open water)	No
Suitable space for internal air source heat pump unit	Yes	Waste heat, tube, sewer, other	No
Suitable space for hot water cylinder / thermal store	Limited	**Space for large communal internal unit**	
Potential external space for separate energy centre	**No**	Existing space for centralised plant	Limited

Energy efficiency upgrades considered

Listed building with limited opportunities for thermal fabric improvements. An energy efficiency survey from 2014 lists only draught proofing amongst the recommended measures. However, in this study we have examined the potential for heritage sensitive upgraded glazing to improve thermal performance and air tightness.

Heat emitter upgrades considered

Existing radiators are a mixture of double panel and single panel and assumed to be designed for flow temperatures >60°C. Upgrading heat emitters would be essential to enable lower flow temperatures. However, due to the heritage value and constant use of the building, avoiding disruption may be a high priority. Therefore, consider the option of a high temperature heat pump for this location.

Heat pump options considered

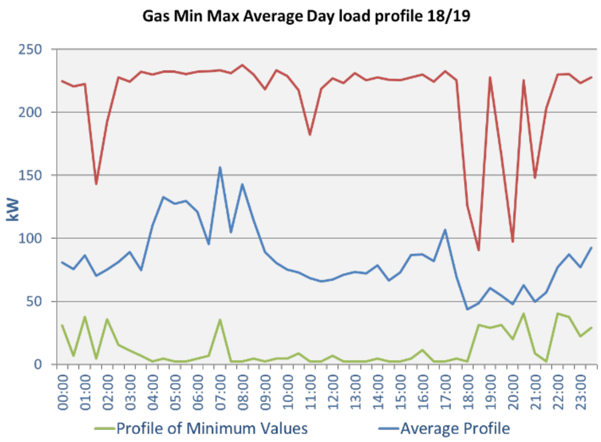
Air Source: The building offers limited locations for installing internal and external air source heat pump equipment but a suitable location could be established on the roof or to the side of the building. Planning permission would almost certainly be required due to the potential visual impact of the heat pump units from the road and due to the heritage status of the building.

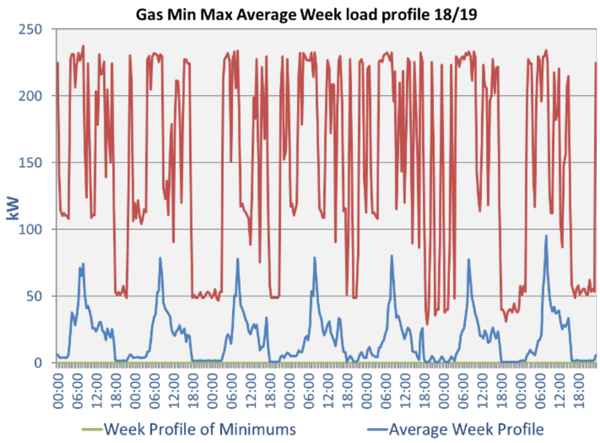
Ground Source: Insufficient space for boreholes or trenches. The building is surrounded on all sides by pavements or adjoining other buildings.

Current gas use profile

It was not feasible within this study to undertake detailed heat loss calculations on the non-domestic buildings. However, we were able to assess half hourly smart meter data to gain an understanding of peak loads and required capacity. The following graphs show current energy demand in kW: minimum demand (green line), maximum demand (red line) and average demand (blue line). The current energy use of the buildings suggests that demand peaks at around 240kW during winter mornings.

However, levelling out the profile of heat demand could reduce the peak demand. Feedback from heat pump installers suggests that a heat pump capacity of approx. 150kW could be sufficient.

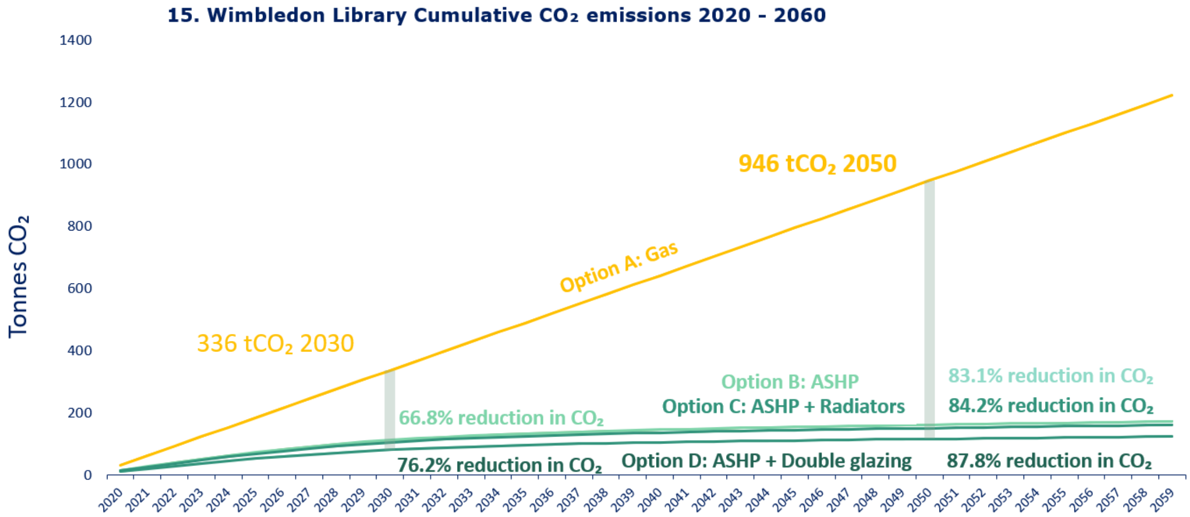




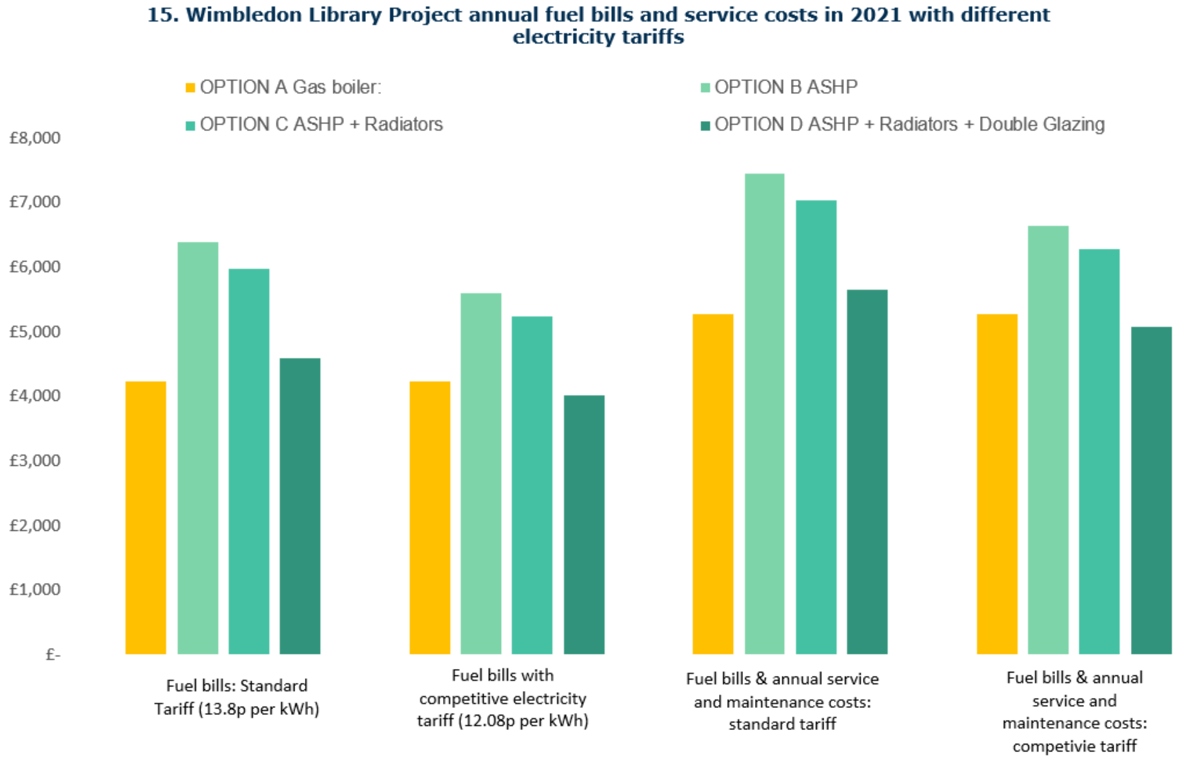
Options appraisal summary of results: 15. Wimbledon Library

		Retrofit scenario			
		15a	15b	15c	15d
Packages of retrofit measures	Heating technology installed	**Replacement Gas combi-boiler**	**High temperature Air Source Heat Pump 150kW**	**Air Source Heat Pump 150kW**	**Air Source Heat Pump 120kW**
	Heat emitter upgrades	None	None	Triple panel convector	Triple panel convector
	Energy efficiency upgrades	None	None	None	Double Glazing
	Air tightness (Average Air Changes per hour at ambient air pressure)	Unknown	Unknown	Unknown	Unknown
Energy performance	EPC	Unknown	Unknown	Unknown	
	kWh per m^2 pa	95	95	95	80
System design	Peak heat load (kW)	150kW	150kW	150kW	120kW
	Heat emitter output (kW at ▲T 50°C)	~150kW	~150kW	~320kW	~320kW
	Required flow temp for -1.8°C day	70°C	70°C	55°C	45°C
	Assumed efficiency / SPF H4	0.92	2.90	3.1	3.3
CO_2 emissions	Cumulative kg by 2030	335,505	111,220	104,045	79,920
	Cumulative kg by 2050	945,513	160,129	149,798	115,064
Upfront CAPEX costs	Heating system	£ 14,859	£ 226,334	£ 143,423	£ 129,419
	Heat emitters	£ -	£ -	£ 44,080	£ 44,080
	Energy efficiency	£ -	£ -	£ -	£ 104,000
Grant	RHI	£ -	£ 74,560	£ 74,560	£ 60,967
Annual costs	Fuel bill	£ 4,222	£ 6,389	£ 5,977	£ 4,591
	Service	£ 1,050	£ 1,050	£ 1,050	£ 1,050
Life time costs (Including current RHI)	10 year	£ 76,508	£ 261,569	£ 218,910	£ 302,151
	20 year	£ 164,981	£ 447,967	£ 342,968	£ 409,054
	30 year	£ 231,071	£ 521,419	£ 412,118	£ 464,420
	40 year	£ 319,543	£ 745,097	£ 573,457	£ 601,807

CO_2 emissions

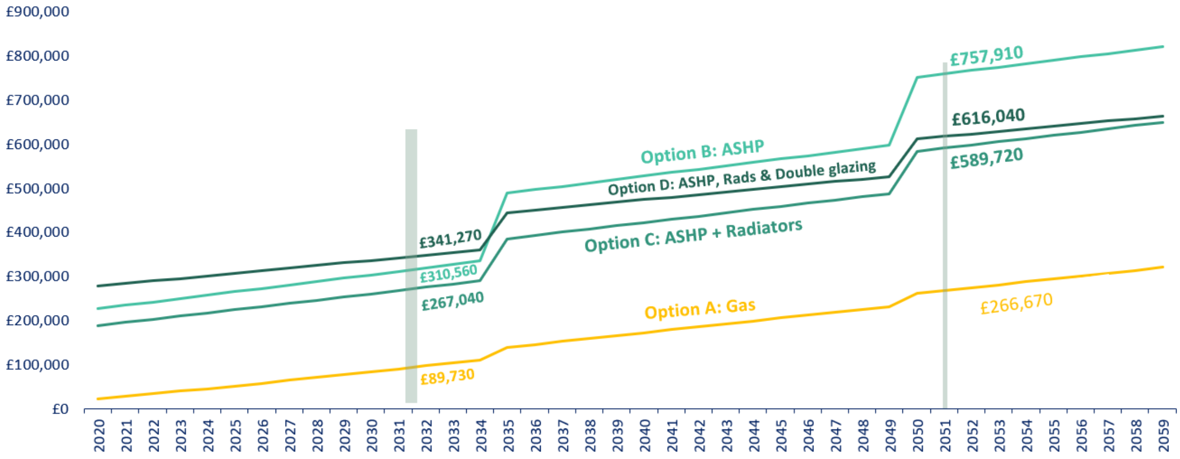


Fuel bills

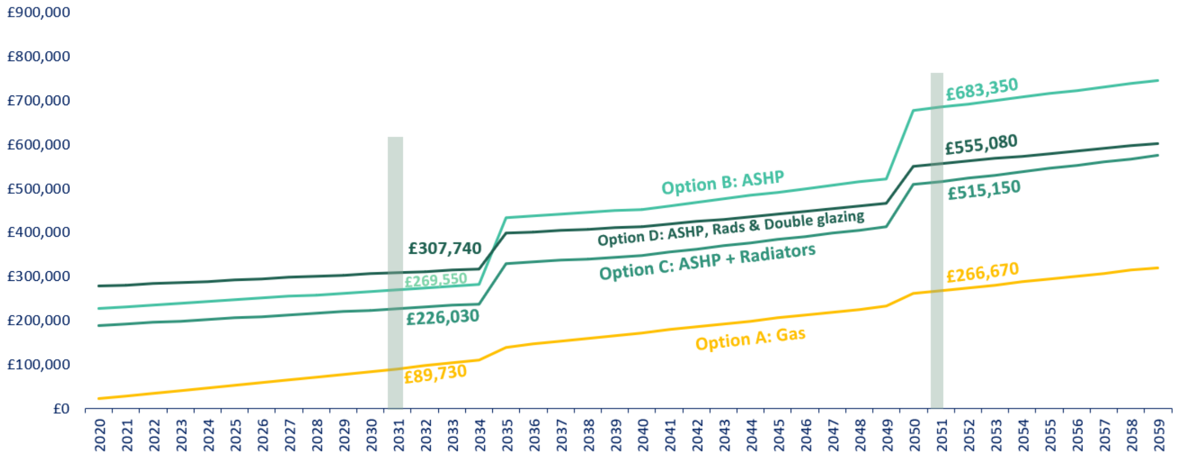


Lifetime costs and sensitivity analysis

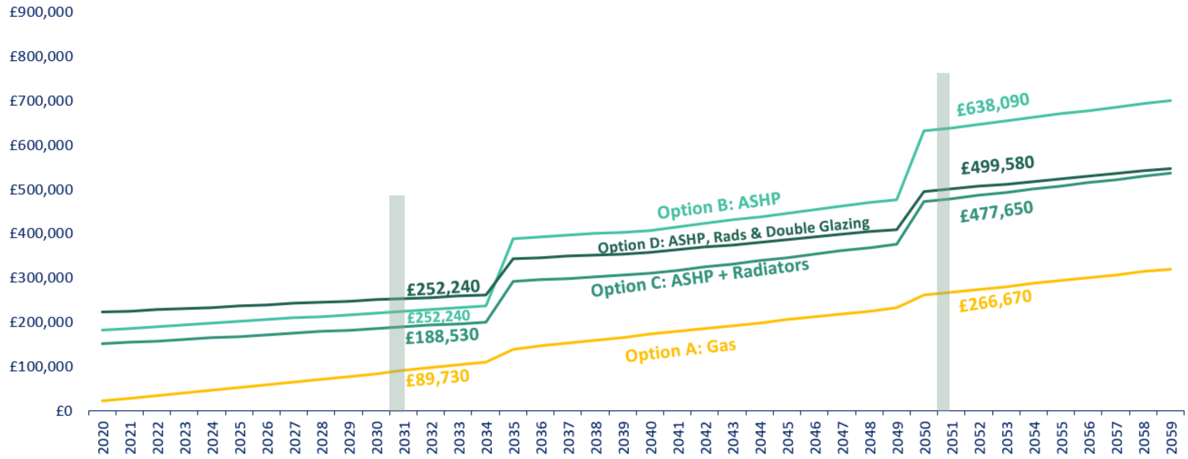
15. Wimbledon Library Cumulative lifetime costs (no RHI)

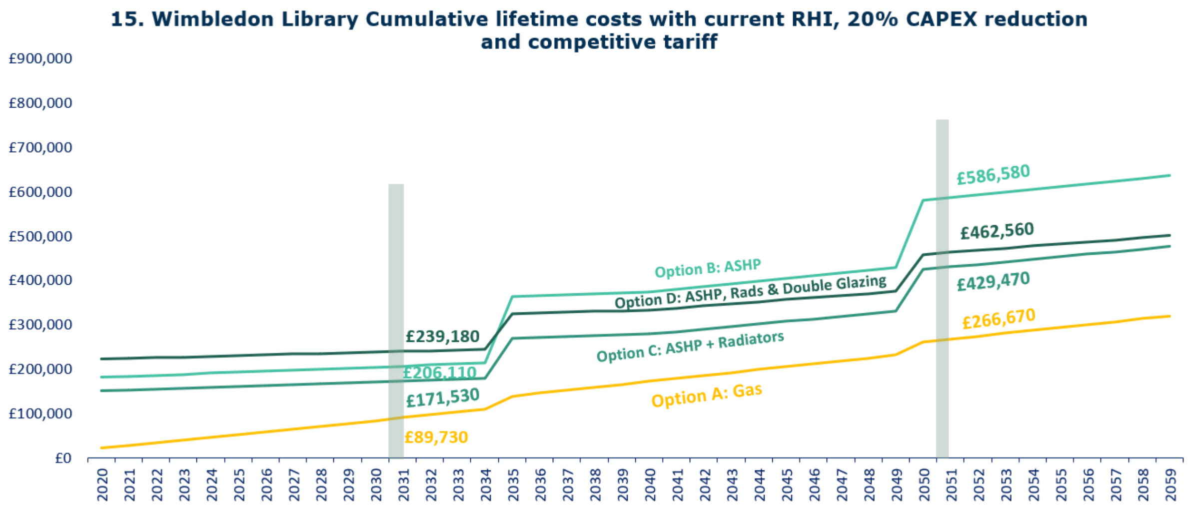


15. Wimbledon Library Cumulative lifetime costs (With current RHI)

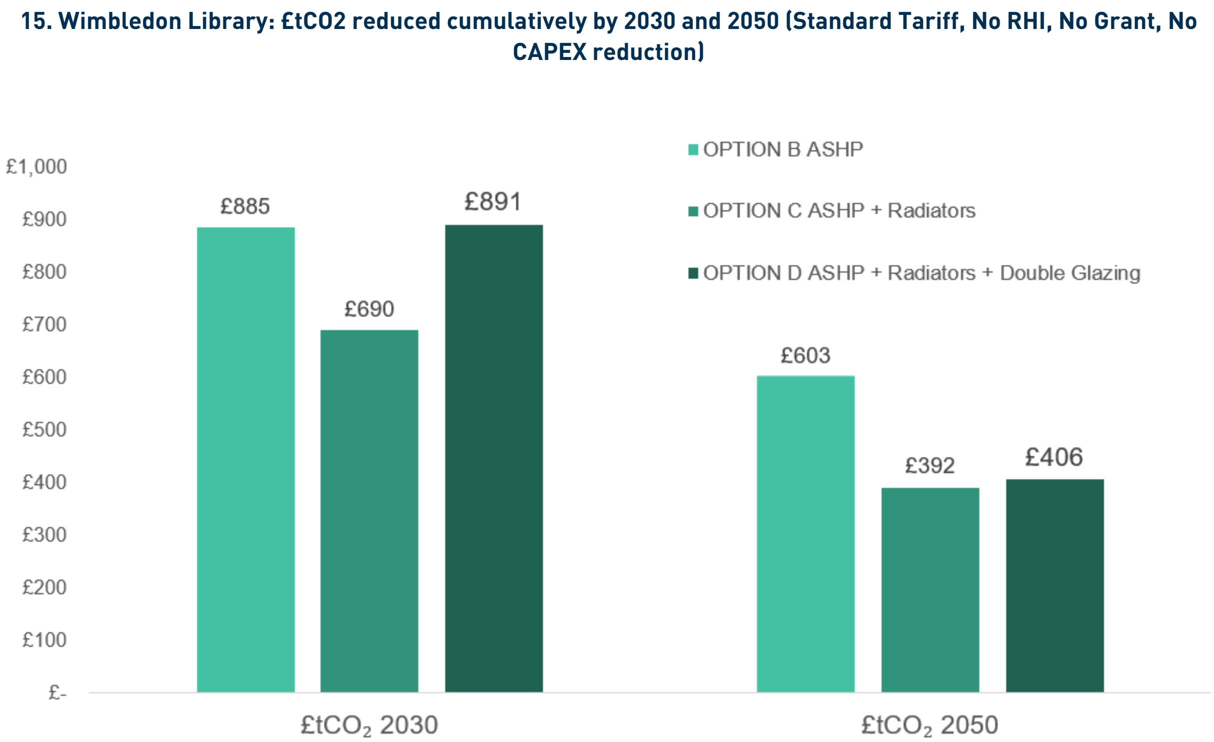


15. Wimbledon Library Cumulative lifetime costs with current RHI and 20% Capex reduction





Cost of carbon reduction: £ per tonne of CO_2 reduced



Summary of Options Appraisal Analysis:

- **CO_2 savings:** Cumulatively, over 30 years, the BAU scenario is predicted to emit 946 tonnes of CO_2. The high temperature air source heat pump (option B) is predicted to save 83%. The inclusion of radiators and moving to a standard temperature heat pump (Option C) is predicted to save 84%. The inclusion of double-glazing increases savings to 87%.

- **Fuel bills and operating costs:** Under standard tariffs, fuel bills are predicted to increase under all heat pump options. However, when a more competitive electricity tariff is assumed, fuel bills are predicted to decrease marginally under Option D (heat pump and double glazing).

- **Lifetime costs:** All heat pump options are predicted to be more expensive than the gas BAU over 30 years, even when RHI and a 20% CAPEX reduction are taken in to account. Over 30 years, the lowest lifetime costs for the heat pump options is option C (ASHP plus radiators). Under Option D, the high cost of the double glazing does not get repaid through the lower fuel bills over 30 years. Under Option B (high temperature air source heat pump) the higher up-front cost of the heat pumps plus the higher fuel bills mean that this has the highest 30 year costs.

Methodology and assumptions

For further information on each of the steps below, please refer to the Heat pump retrofit in London: Technical guidance.

For each of the 9 individual domestic buildings, we undertook the following research and analysis:

Heat loss calculations

For each domestic building we undertook a room by room heat loss calculation according to BS EN 12831-1 Method for the calculation of the design heat load. Heat loss assessments were based on a combination of detailed property floor plans, site visits, internal photographs and Energy Performance Certificate information. We used a version of the MCS heat pump installer tool available on the MCS website. However, we updated a number of the assumptions around air changes per hour to be compatible with the latest 2017 revisions to BS EN 12831. Heat loss calculations were used to determine the optimal size of heat pump necessary to meet the peak heat load.

Energy use calculations

We used EPCs to gather data on the baseline space and water heating demand in the property. We used RDSAP 10.1 methodology for calculating annual space and water heating demand following improvements to the properties. Wherever possible we used smart meter readings provided by homeowners and tenants to understand actual energy use in relation to modelled energy use. However, reliable smart meter or other meter reading data was only available for properties 04, 07 and 08.

Heat emitter calculations

We used visual surveys of the properties to ascertain information on the size and type of radiators used. This was used to determine the current kW output of the radiators at a Delta T of 50°C.

Assessment of retrofit potential

We undertook remote and in-person visual inspections of the properties to determine their suitability for different types of heat pump system, energy efficiency measures and other renewable energy measures. The high level assessment was a subjective assessment of retrofit options likely to be more or less suitable for each property, rather than a definitive assessment of the feasibility for different measures. The key questions in determining which measures may be suitable for different properties were:

1. What are the available heat sources that could be utilised?

2. Is there sufficient internal and external space for the technology?

3. Would installation of the technology be likely to comply with Permitted Development planning rules and MCS 020 Standards on noise and visual impact?

4. Would installation of the technology involve potentially significant legal costs in terms of freeholder permission for leaseholder access to building communal spaces or external walls?

5. Is there any additional site-specific considerations that would influence the choice of heat pump, energy efficiency and heat emitters? For example the heritage status of the property or the wishes of the householder for, for example, 'traditional' style radiators or double glazing retrofit.

Choosing specific technologies for each building

Having developed the building profiles, we consulted extensively with heat pump manufacturers and installers on the types of heat pump and heating system that they would specify in each case. In a number of cases, heat pump installers provided anonymous indicative costings for specific makes and models. We attempted to choose specific technologies that would be suitable for overcoming the unique challenges of each installation. For example, in buildings 03 and 06, heat pumps with a particularly low sound power level were chosen to overcome potential planning concerns. In building 02, due to the lack of external space for siting the heat pump, a fully internal unit was chosen with ducts to the outside wall. Technologies were chosen based on our ability to access cost and performance information consistently.

It is important to note that the inclusion of particular technologies in this study in no way represents a recommendation or endorsement for that technology. This was a hypothetical study and neither the Carbon Trust nor the GLA have first-hand experience of these technologies in operation.

Predicting heat pump performance

To understand the likely performance of the heat pump in-situ we used the BRE's Domestic Annual Heat Pump Efficiency Estimator. This tool estimates the likely SP4 whole heating system efficiency for given flow and source temperatures. The tool utilises the manufacturer published Seasonal Co-efficient of Performance (SCoP) for specific heat pump technologies and determines the likely variation from published values with different heat sources, levels of dwelling heat loss, emitter design flow temperature and presence of weather compensation. Further information on the BRE tool can be found here[5]. Please refer to the Heat pump retrofit in London: Technical guidance for further information on predicting heat pump performance in-situ.

Calculating CO_2 emissions

CO_2 emissions were calculated year by year up to 2060 using the Treasury Green Book marginal CO_2 emission rates for gas and electricity[6]. When calculating CO_2 emissions, we took in to account the predicted annual efficiency of the heat pump and residual energy use of the building following upgrades to energy efficiency.

[5] https://www.bregroup.com/heatpumpefficiency/index.jsp

[66] Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal: Data tables 1 – 19.

BEIS Long Run Marginal CO_2 emissions factors for electricity					
	Domestic kgCO_2 per kWh	Commercial / Public kgCO_2 per kWh		Domestic kgCO_2 per kWh	Commercial / Public kgCO_2 per kWh
2020	0.296	0.290	**2036**	0.065	0.064
2021	0.283	0.278	**2037**	0.058	0.057
2022	0.269	0.264	**2038**	0.052	0.051
2023	0.255	0.250	**2039**	0.046	0.045
2024	0.240	0.236	**2040**	0.041	0.040
2025	0.224	0.220	**2041**	0.040	0.039
2026	0.207	0.203	**2042**	0.038	0.038
2027	0.189	0.186	**2043**	0.037	0.036
2028	0.171	0.167	**2044**	0.036	0.035
2029	0.151	0.148	**2045**	0.034	0.034
2030	0.130	0.127	**2046**	0.033	0.032
2031	0.116	0.113	**2047**	0.032	0.031
2032	0.103	0.101	**2048**	0.030	0.030
2033	0.092	0.090	**2049**	0.029	0.028
2034	0.082	0.080	**2050**	0.028	0.027
2035	0.073	0.071	**2051**	0.028	0.027

Up-front CAPEX costs

We estimated the costs of heat pump technologies by:

1. Developing a bottom up costing model for each building utilising wholesaler and manufacturer price lists.

2. Estimating days required for design, installation and commissioning of systems based on consultation with heat pump installers and using day rates for heating engineers quoted in Spon's Mechanical & Electrical Services Price Book 2020.

3. Asking heat pump manufacturers and installers to provide specific costs for installed heat pump systems in each of the buildings.

4. Asking heat pump manufacturers and installers to provide indicative cost guides for different types of system.

5. Cross referencing and sense checking the bottom up system prices (steps 1 and 2) with quoted prices and guide prices from manufacturers and installers (steps 3 and 4).

Fuel bills

To calculate fuel bills, we used rates for electricity and gas quoted in the Treasury Green Book Guidance. We used the Central scenario for both domestic and non-domestic fuel prices between 2020 and 2060.

The Treasury Green Book rates are typically used for evaluation purposes and provide a combined figure that encompasses both the standard tariff per kWh and the daily standing charge. For buildings with low heat use, the standing charge can make a significant proportion of the overall fuel bills and the potential to remove the gas standing charge can be a significant benefit of installing a heat pump. Therefore, for domestic properties, we divided the Treasury Green Book combined cost per kWh into a standing charge and unit cost as follows:

	Fuel	Unit cost per kWh	Standing charge per annum
Treasury Green Book Domestic Retail Gas and Electricity Prices: Domestic Central scenario: 2020	Gas	£0.046	£0
	Electricity	£0.185	£0
Fuel prices used in this analysis for domestic: 2020	Gas	£0.032	£87.60
	Electricity	£0.152	£73.00
Treasury Green Book Domestic Retail Gas and Electricity Prices: Commercial / Public Sector Central scenario: 2020	Gas	£0.029	£0
	Electricity	£0.137	£0
Fuel prices used in this analysis for non-domestic and blocks of flats: 2020	Gas	£0.029	£0
	Electricity	£0.137	£0

Annual service costs

Annual servicing is an essential aspect of maintaining good performance for both heat pumps and gas boilers. Therefore, our cost assumption is that all technologies are serviced annually. We invited heat pump manufactures and installers to provide data on annual service costs. We also undertook a web-based search of available gas boiler and heat pump service and maintenance plans available on the market. Based on this research, we used the following annual service rates for each domestic technology:

Technology	Assumed annual service cost
Gas boiler annual service	£109
Air Source Heat Pump Annual Service	£182
Ground source heat pump annual service	£210
Hybrid heat pump annual service	£280[7]

[7] We were unable to find costs for hybrid heat pump service plans. Due to the nature of the technology, service costs and likely to include elements of both a gas boiler service and an air source heat pump, but with some efficiencies resulting from the single service. Therefore, an assumed a combined rate of £280 was used but there is high uncertainty in this figure.

For non-domestic, commercial properties and blocks of flats we estimated a value for servicing and maintenance based on heating engineer day rates in Spon's Mechanical & Electrical Services Price Book 2020 combined with an estimated number of days based on CIBSE guidance. This was sense checked against published rates for heat pump and gas boiler servicing from companies.

We assumed that servicing rates would stay the same over the lifetime of the analysis. Ie we did not assume that heat pump servicing costs will fall over time. In practice, there is scope for heat pump costs to reduce over time as the market matures. In contrast, the market for servicing gas boilers is very mature and highly competitive, with little scope for further cost reductions. It is possible therefore, that our analysis over-represents the servicing costs for heat pumps over time.

Dynamic time of use tariffs

Dynamic time of use tariffs have the potential to significantly improve the business case for installing heat pumps. Time of use tariffs supply electricity at cheaper rates outside of peak hours, typically between 16:30 and 19:30. Therefore, by shifting heating load outside of these hours, building owners with heat pumps can benefit from lower fuel bills. Therefore, for each domestic building we also modelled fuel bills where a dynamic time of use tariff is used. We did not model this for non-domestic buildings; However, there is significant potential for non-domestic buildings to benefit from dynamic time of use tariffs. For non-domestic buildings we modelled a separate scenario using a more competitive electricity tariff.

The ability of each building to shift heating load outside of peak hours will depend on a wide variety of factors, including the timing of current demand for heating (e.g. homeowners that typically return home late in the evening will have lower demand during peak hours). Another key factor is the energy efficiency of the building and its ability to retain heat over a period of time. To understand this factor, we developed a simple model simulating the rate of heat loss for each building and the number of half hour periods over which heating could be suspended without internal temperatures dropping below 18°C, for a range of average monthly external temperatures. Based on this, we assumed that the potential reductions in heating demand, based on an active profile of load shifting could be as follows:

<table>
<tr><th colspan="4">Potential heating bill savings from agile tariff modelled for each building scenario</th></tr>
<tr><th>Property</th><th>Option B</th><th>Option C</th><th>Option D</th></tr>
<tr><td>01. Lymington Road</td><td>16.0%</td><td>16.0%</td><td>-</td></tr>
<tr><td>02. Cavendish House</td><td>22.3%</td><td>-</td><td>-</td></tr>
<tr><td>03. Sherwin House</td><td>16.9%</td><td>-</td><td>-</td></tr>
<tr><td>04. Northcote Road</td><td>0.0%</td><td>16.5%</td><td>22.0%</td></tr>
<tr><td>05. Aldenham Road</td><td>12.9%</td><td>12.9%</td><td>-</td></tr>
<tr><td>06. Surrey Road</td><td>18.6%</td><td>18.6%</td><td>-</td></tr>
<tr><td>07. Mowbray Road</td><td>8.0%</td><td>16.0%</td><td>22.7%</td></tr>
<tr><td>08. Albany Road</td><td>4.0%</td><td>12.0%</td><td>12.0%</td></tr>
<tr><td>09. Tradescant Road</td><td>0.0%</td><td>9.9%</td><td>18.0%</td></tr>
<tr><td>10. Ernest Dence</td><td>7.5%</td><td>7.5%</td><td>7.5%</td></tr>
<tr><td>11. Enfield Tower Block</td><td>7.5%</td><td>7.5%</td><td>7.5%</td></tr>
<tr><td>12. Gifford House</td><td colspan="3" rowspan="4">Agile tariffs were not modelled for non-domestic buildings.</td></tr>
<tr><td>13. Billet Road</td></tr>
<tr><td>14. Docklands ad</td></tr>
<tr><td>15. Wimbledon Library</td></tr>
</table>

The table illustrates that buildings with a better level of energy efficiency and lower heat loss are able to retain heat, and therefore shift heating load, to a greater degree than buildings with poor energy efficiency. In some cases, e.g. 09. Tradescant Road and 04. Northcote Road, our model suggests that these buildings would currently not be able to shift any heat load whilst retaining thermal comfort. The assumptions are based on a basic model, that is attempting to re-create a complex real-world scenario and there is a high level of uncertainty surrounding these estimates. Nevertheless, it provides a useful guide to the potential benefits of load shifting in different properties.

Lifetime costs

Lifetime costs were calculated cumulatively for 40 years and presented in the charts at 10 and 30 years. We did not apply a discount rate. We did not apply inflation, so all costs are quoted in real 2020 terms and include VAT. This method was deemed the most transparent for understanding real costs.

We have presented a range of scenarios for lifetime costs for each building:

Scenario	Description
Standard tariff: No Renewable Heat Incentive (RHI).	This scenario shows the lifetime costs of the options with no RHI or other grant applied. Treasury Green Book electricity and gas prices are used as described above.
Standard tariff, current RHI	This scenario shows a typical costs appraisal for an installation utilising current RHI payments. This would apply to installations commissioned before 31st March 2022.
Flexible time of use tariff, current RHI	This scenario has been modelled using the 2019 published half hourly London rates for the Octopus energy agile time of use tariff and utilising current RHI payments. The capacity of each building to store heat was modelled to predict the extent to which building may be able to shift heating load outside of the peak hours of 16:30 – 19:30 as detailed above.
Standard tariff, £4,000 Clean Heat Grant	This scenario applies a flat £4,000 capital cost grant as has been proposed in the government's 'Future Support for Low Carbon Heat' Consultation document.
Flexible time of use tariff, £4,000 Clean Heat Grant	This scenario combines the flat £4,000 capital grant proposed by the government alongside the use of a flexible time of use tariff.
Standard tariff, £4,000 Clean Heat Grant + 20% Capex reduction	In this scenario, we factored in a potential 20% reduction in the upfront cost of installing the heat pump and energy efficiency, as well as the Clean Heat Grant. This 20% cost reduction could represent savings from bulk purchase of systems[8] or result from maturation of the heat pump[9] market or a potential additional incentive from a public body. A 20% reduction could also be achieved by removing VAT on the sale of heat pump equipment in retrofit (typically 20% on equipment and 5% on labour).

[8] The prices for heat pumps used elsewhere in this study are the price paid for an individual heat pump only. Significant savings may be available to a social landlord, for example, when procuring multiple heat pumps for a large-scale boiler replacement programme.

[9] A 2016 study by Delta EE for DECC suggested that "In a UK mass market scenario for Air Source Heat Pumps (ASHP), we would expect an overall cost reduction of ~20% compared to current costs": *Potential cost reductions for air source heat pumps: DECC 2016*

RHI Rates

We used the latest RHI rates available at the time of writing. These were issues in April 2020 as follows:

Technology	Rate per kWh	Payment period
Domestic Air Source Heat Pump	£0.1071	7 years
Domestic Ground Source Heat Pump	£0.2089	7 years
Non-Domestic Air Source Heat Pump	£0.0279	20 years
Non-Domestic Ground / Water Source Heat Pump Tier 1	£0.0872	20 years
Non-Domestic Ground / Water Source Heat Pump Tier 2	£0.0260	20 years

Measure lifetimes

A key factor in the costs analysis is the rate at which capital equipment must be replaced within the overall 40-year time period. We used standard lifetimes for each technology based on consultation with installers and manufacturers and information provided in CIBSE guidance. The following assumed lifetimes and replacement timetables were used:

- Gas boiler: 12 years
- Air Source Heat Pump: 15 years
- Ground Source Heat Pump: 20 years
- Closed ground loops: 50 years

It was assumed that all or a proportion of capital equipment would require replacing at these time periods. Where capital equipment was replaced, installation costs were typically lower compared to initial installation. This is because the additional work of transforming the heating system would not be necessary the second time around (e.g. installing new pipework to the hot water cylinder).