



Carbon Reduction Options for Churches Using Oil for Heating

Diocese of Gloucester case studies





Summary

To limit global warming, one of the actions required is a rapid reduction in the carbon emissions from our buildings. Heating buildings contributes to 17 per cent of overall carbon emissions in the UK. ([Department for Business, Energy and Industrial Strategy, Clean Growth – Transforming Heating 2018.](#))

It is, therefore, vital that we look to decarbonise the heating systems that serve our buildings. In 2020, only 7.9 per cent of the energy used to heat our buildings came from renewable sources. ([Department for Business, Energy and Industrial Strategy, Digest of UK Energy Statistics 2020.](#))

In the UK, our buildings are predominantly heated using natural gas. However, the most significant challenge is how to decarbonise the heating systems in rural buildings that run on oil.

Historic England invited the Diocese of Gloucester to participate in a research project looking at viable methods of low carbon heating in churches and their associated buildings. The research focuses on oil-fired heating systems, because oil produces more carbon dioxide emissions than other fuels used to heat buildings.

The key finding from this research is that no single heating technology is recommended for all historic buildings, or even for each historic building type. Across the six buildings, air source heat pump, biomass and electric heating were recommended in equal proportions.

To determine the most viable heating technology for a particular building, a detailed technical feasibility study needs to be carried out at the concept stage. The recommended heating technology depends on many factors, including the building's site, location, size and form; the use and operation of the building; the condition of the existing heating system; and the nature of the existing utility infrastructure.

The drivers behind this research include the 2030 net zero carbon target set by the Church of England's General Synod and the 2050 net zero carbon target set by the UK government.

Front cover: Church of St
Michael and All Angels,
Poulton, Gloucestershire.

This document has been prepared by Dan McNaughton. First published by Historic England, February 2026.

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Historic England, 2026, Diocese of Gloucester. Carbon reduction options for churches using oil for heating. Swindon. Historic England.

HEAG331

[HistoricEngland.org.uk/advice/technical-advice/building-services-engineering](https://historicengland.org.uk/advice/technical-advice/building-services-engineering)



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1

Introduction

This project looks at developing low and zero carbon heating options for four churches and their associated buildings in Gloucestershire. Currently, these buildings rely on oil for their heating and they have been identified by the Church of England as buildings which do not have a local natural gas infrastructure. Our research, therefore, assesses the viability of different fuels and heating systems.

Carbon dioxide is produced when we burn fuel to generate energy, and it is the main greenhouse gas in the UK. Greenhouse gases absorb and reflect some of the solar radiation that is radiated by the Earth and the human-caused increases in greenhouse gases are responsible for the Earth becoming warmer over time. The 'carbon dioxide emission factor' is a measure of the amount of carbon dioxide produced by providing one kilowatt hour (kWh) of energy. Naturally, different fuels have different carbon dioxide emission factors, and oil produces more carbon dioxide emissions than all other fuels except coal.

Table 1:
Carbon dioxide emission factor of fuels.

Fuel	CO ₂ emission factor (kgCO ₂ /kWh)	Data source
Natural gas	0.216	SAP 2012
LPG	0.241	
Biogas	0.098	
Oil	0.298	
Coal	0.394	
Biomass (wood pellets)	0.039	
Grid electricity*	0.239	carbonintensity.org.uk Data correct 11:00, 20 January 2022

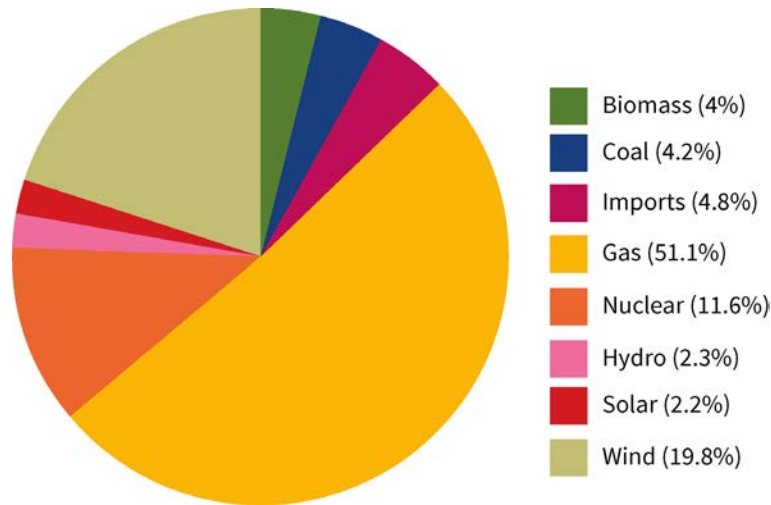
*Note: The grid electricity carbon dioxide emissions include green tariffs, which generate electricity from renewable energy sources. Green tariffs may provide electricity from 100 per cent renewable energy sources, or they may involve buying certificates from renewable energy generators. In 2019, renewable sources generated 37.1 per cent of total electricity produced in the UK, and the rest of the generation was produced by the combustion of fossil fuels.

Table 1 shows that the existing oil-fired heating systems will produce more carbon dioxide emissions than all other fuels except coal. To achieve the Church of England’s net zero carbon target by 2030, or make significant steps towards achieving that target, heating systems will need to be fuelled by biomass, grid electricity or renewable energy sources, such as solar or wind.

The mix of fuels that are used to generate grid electricity is constantly varying and in the past two years there have been days which have seen renewable energy generation providing 25 per cent of the grid electricity with no coal used.

Figure 1:
Current electricity
generation mix for
Great Britain.

Data correct at 11 am,
20 January 2022.
carbonintensity.org.uk



The carbon dioxide emissions produced by grid electricity have decreased in recent years, and the Department for Business, Energy and Industrial Strategy has projected that the grid carbon emissions factor will be as low as 0.041kgCO₂/kWh by 2035 as the grid continues to decarbonise. This is significantly lower than the 0.239kgCO₂/kWh observed at 11 am on 20 January 2022. From an environmental perspective, this positive projection makes grid electricity an attractive option for heating systems currently fuelled by oil.

Our research also assesses the viability of different fuels and heating systems from a cost perspective. Currently, the UK energy market is in flux, with significant price rises observed in 2022 and further price increases forecast in the near future. To illustrate the scale of these price changes, the cost of oil for one of the study participants rose from £0.45/l (per litre) in July 2020 to £0.98/l in May 2022 (an increase of around 118 per cent in 22 months).

A number of factors are causing volatility in the energy market, and prices are, therefore, unpredictable. This will, likely, have impacted the financial assessments in this research. As such, the financial feasibility of the options proposed here should be revisited before any detail design phases are carried out.

The calculations in this research for heating oil are based on a competitive quotation provided in May 2022. All of the calculations for electricity were carried out based on the energy price cap, set by Ofgem for the period 1 April to 30 September 2022. The energy price cap is for domestic consumers only. However, a business energy supplier confirmed that non-domestic energy costs are generally similar and are usually fixed for an agreed period.

Descriptions of renewable and alternative technologies and the different types of heating systems are appended to this document. For further reading, refer to Historic England's 'Low and Zero Carbon Technologies' webpage: historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/low-and-zero-carbon-technologies.

2

Scope

The research aims were:

- Offer low and zero carbon heating options to move away from using oil
- Find solutions that have minimal impact on the historic significance
- Provide heating options that suit the use of the building.

Non-intrusive surveys were carried out at the churches and their associated buildings. These included assessing the existing heating system and electricity supply. The other building services systems were not surveyed. The remit of the surveys did not cover opening up, dismantling, testing, disconnecting or reconnecting the plant and systems.

The Diocese of Gloucester chose four churches for this research, one in each of the categories below:

Category A

A single church building that is on oil and has a reliable three-phase electricity supply.

Category B

A church plus one or more related buildings (such as a separate church hall, nearby vicarage and/or church school), all of which are on oil and have reliable three-phase electricity supplies.

Category C

A single church building that is on oil and has no electricity supply or a single-phase electricity supply.

Category D

A church plus one or more related buildings (such as a separate church hall, nearby vicarage and/or church school), all of which are on oil and have no electricity supply or a single-phase electricity supply.

This research project is preliminary advice and should not be used as design or installation information.

Any proposed works will need to comply with current building regulations. Planning and faculty approval may be required.

3

Church of the Holy Rood, Daglingworth (Category C)

The Church of the Holy Rood is a Grade I-listed building dating back to the Anglo-Saxon period in the 11th century. It is located in the conservation area of Daglingworth and the Cotswolds Area of Outstanding Natural Beauty. There are a number of Grade II-listed monuments, one Grade II*-listed monument and one scheduled monument within the churchyard.

Church Heritage Record

facultyonline.churchofengland.org/church-heritage-record-daglingworth-holy-rood-616286

Historic England listing entry

historicengland.org.uk/listing/the-list/list-entry/1090207

A non-intrusive survey of the Church of the Holy Rood was carried out on 3 December 2020.

Note: This church was intended to be a Category A church that already has a three-phase electricity supply. It currently has a single-phase supply, with an intention to upgrade to a three-phase supply. This means it is one of three Category C churches that have been investigated for this report.

Figure 2:
Church of the Holy Rood,
Daglingworth.



3.1 Site appraisal

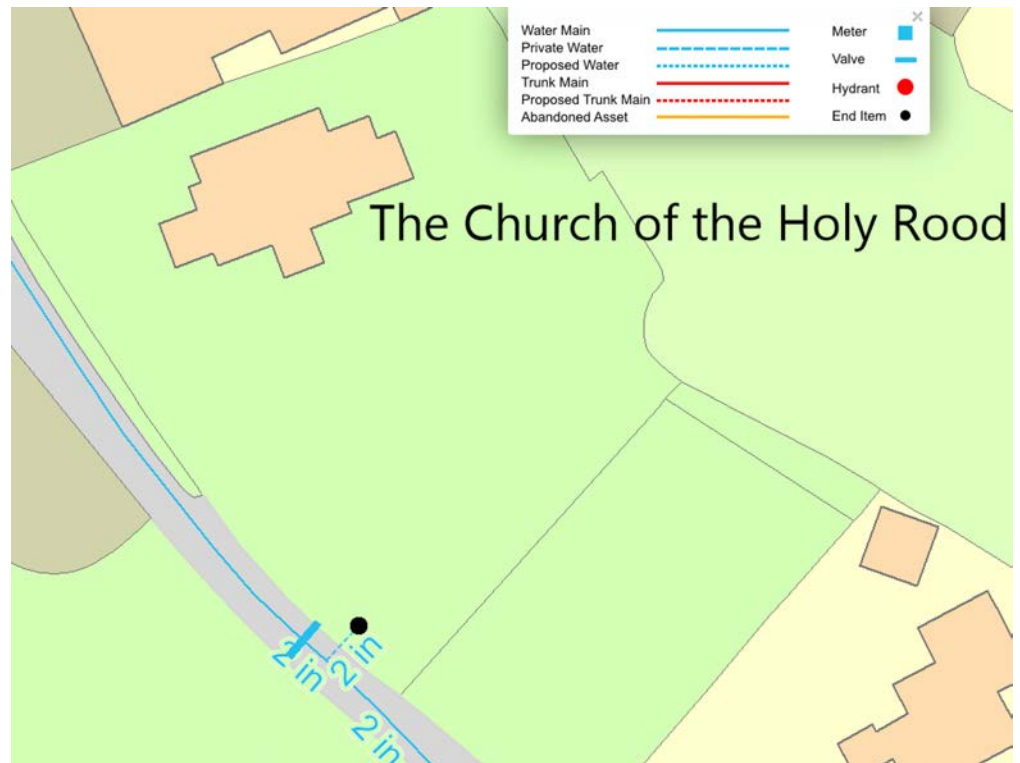
The church and graveyard (highlighted yellow on Figure 3) are situated at a high point on the outskirts of the rural village of Daglingworth. The graveyard is at or near capacity, with very little spare land that could be used for renewable or alternative technologies. The church has acquired the land highlighted in red on Figure 3, historically known as ‘glebe land’, for the purpose of extending the graveyard. This glebe land is located approximately 40m to the south of the church.

The church has no mains water supply. The current heating system incorporates a feed and expansion tank, which is topped up manually when required. There is a mains water supply tap to the south of the graveyard (Figure 3). Thames Water’s records show a 2 inch water main in Church Lane, with a 2 inch private water supply connection to the external tap in the graveyard (Figure 4).

Figure 3:
Church site.



Figure 4:
Thames Water records.



This plan is produced by Thames Water Utilities Ltd Crown copyright and database rights 2021 Ordnance Survey 100019345. This map is to be used for the purposes of viewing the location of Thames Water plant only. Any other uses of the map data or further copies are not permitted. The position of the apparatus shown on this plan is given without obligation and warranty, and the accuracy cannot be guaranteed. This information is valid for the date printed. Service pipes are not shown but their presence should be anticipated. No liability of any kind whatsoever is accepted by Thames Water for any error or omission. The actual position of mains and services must be verified on site before any works are undertaken.

The small area immediately to the north of the church contains the existing oil tank and plant room access steps (Figure 5). The purple area is the current access route for the oil to be supplied from Church Lane. There is a large neighbouring residential property, which shares a boundary with the church site.

The incoming electricity supply enters the vestry from below ground at the location shown in Figure 5. The precise route of this electricity supply is unknown. It most likely crosses the purple area and connects from Church Lane, or it could be routed across the land to the north-east of the church site.

Figure 5:
External plant and utilities.



3.2 Existing heating system

The existing heating system is a low temperature hot water system with radiators. The radiators are manufactured by Faral and are unusual in that the heated water flows through a column style construction, with plates to encourage convection on the front face and top.

The oil-fired boiler is installed in a basement plant room below the vestry. A fenced enclosure adjacent to the plant room surrounds the oil tank. There is a plug-in, radio-signalled sensor in the vestry, which indicates when the oil level is low.

Pipework is distributed within the floor making use of the grille-covered floor trenches that run along most of the length of the church. These trenches do not heat the church directly, because the distribution pipework is insulated and the grilles are covered in carpet. An existing chimney suggests that the church used to be heated by a solid fuel-fired furnace, which would have provided heat via the ventilated trenches (effectively acting as a trench heater).

The boiler is controlled by a programmable timer located inside the vestry. There is also a thermostat with a setpoint of 18°C and a frost thermostat located in the north aisle.

The heat loss for the church is estimated to be 43.3kW, which is similar to the 41kW capacity of the existing oil boiler. This heat loss estimate has been determined using a rule of thumb calculation. Detailed heat loss calculations should be carried out at the project design stage. The main purpose of the heat loss estimates in this research is to allow low and zero carbon heating technologies to be accurately sized and costed.

Figure 6:
Faral column radiator.



Figure 7:
Oil-fired boiler (left).

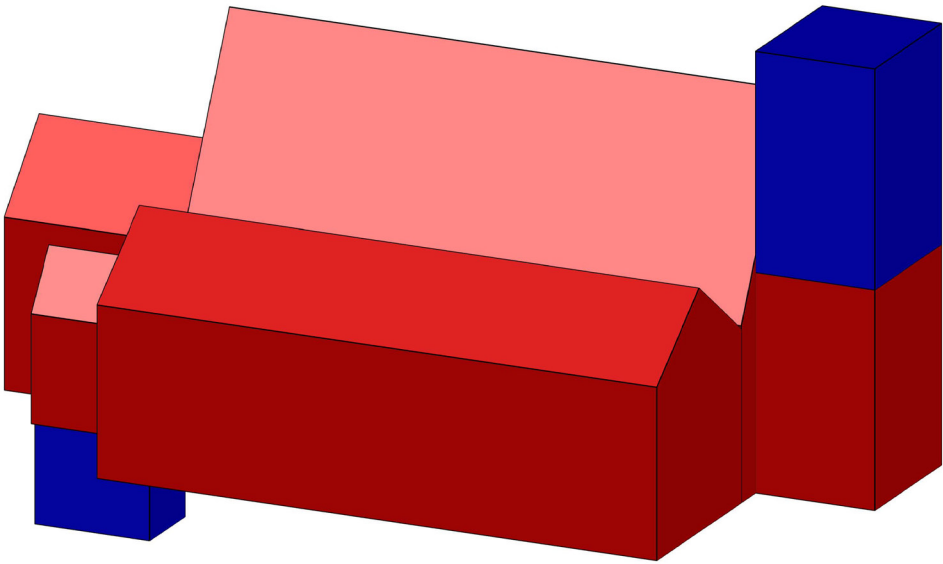
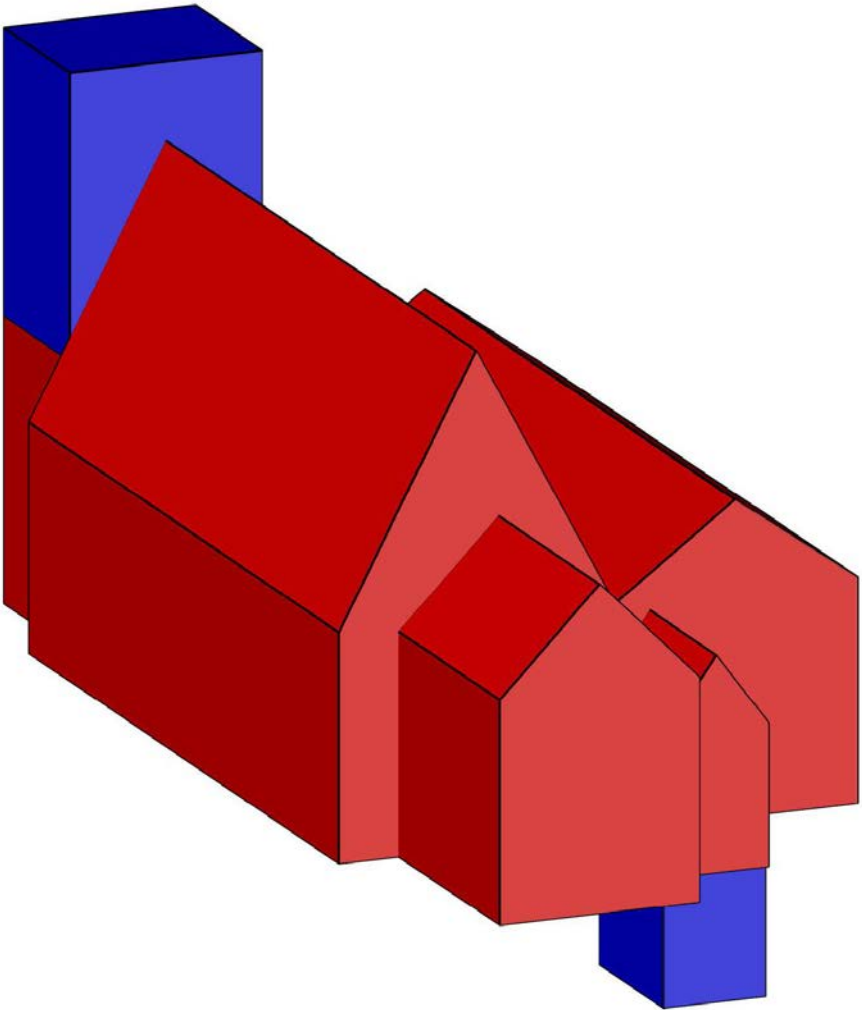


Figure 8:
Heating controls (right).



Figure 9 shows the heated areas of the church in red and the unheated areas in blue. The main areas of the church and the lower section of the tower are heated.

Figure 9:
Heated and non-heated
areas of the church.



3.3 Energy consumption and utility supply

Oil

The existing oil tank is bunded (this means that it has a self-contained tank within a tank construction which offers secondary protection against oil leaks) and has a capacity of 1360l. There is no oil meter, and oil is supplied in one annual delivery. The average amount of oil delivered over the past three years is 940l per year. This is equivalent to 10,102kWh of annual fuel consumption. Note that this figure relates to the combustion of oil. The actual heat provided by the heating system will depend on the plant and system efficiencies. The calculated annual energy consumption for the heating system is 9329kWh.

Assuming that the delivery amount is similar to the actual oil consumption, this equates to annual carbon dioxide emissions of 2780kg. These emissions are for the fuel that supplies the heating system only. The oil-fired boiler does not generate hot water and there are no other oil-fired appliances.

Electricity

There is a three-phase supply to the church, with a cut out with 100A fuse housings, which enters the vestry from below ground. However, only one of the phases is connected, to provide a single-phase 230V supply. The single-phase supply connects to distribution board DB1, which has a 100A main switch. There is a 40A breaker in DB1, which provides a supply to distribution board DB2, located in the tower, as shown in Figure 12.

The church approached the energy provider, SSE in 2020, for a quotation to upgrade the electricity supply and provide three-phase electricity. SSE advised the church of the following costs:

- Supply cable upgrade £79 + VAT
- Meter upgrade £132.31 + VAT.

The electricity consumption is known for the past three years, but the impact of COVID-19 means the church used significantly less electricity in 2020.

Figure 10:
Oil tank and enclosure
(left).

Figure 11:
Electrical cut out and fuse
housings (right).



The average annual consumption for 2018 and 2019 is 280kWh. This equates to annual carbon dioxide emissions of 67kg for the church's electricity consumption.

Figures 13 and 14 show that the energy consumption and carbon dioxide emissions are significantly affected by using oil to provide heating in the church. In this analysis, oil consumption for the heating system is 97.3 per cent of the church's total energy consumption.

Figure 12:
Power distribution layout.

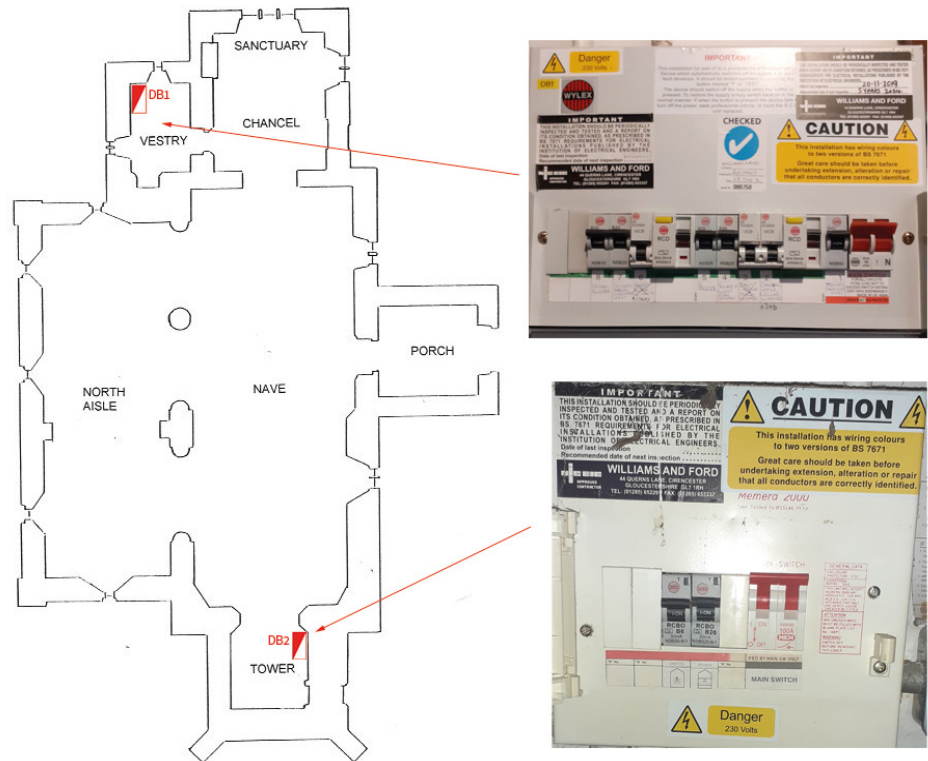


Figure 13:
Existing annual fuel consumption.

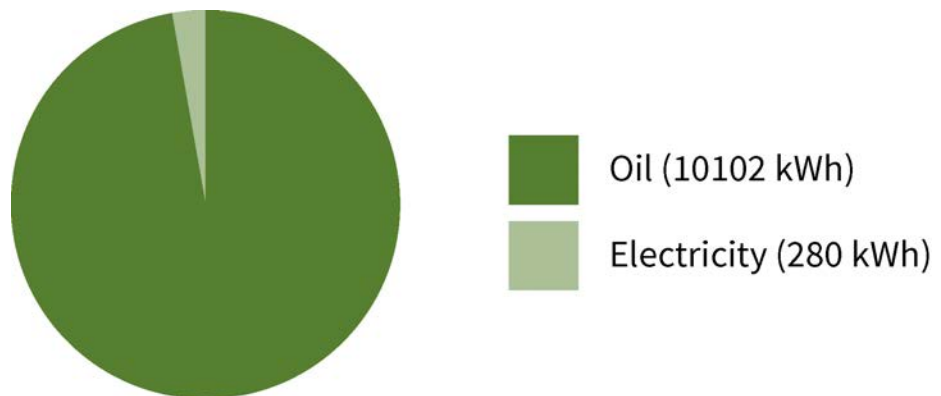
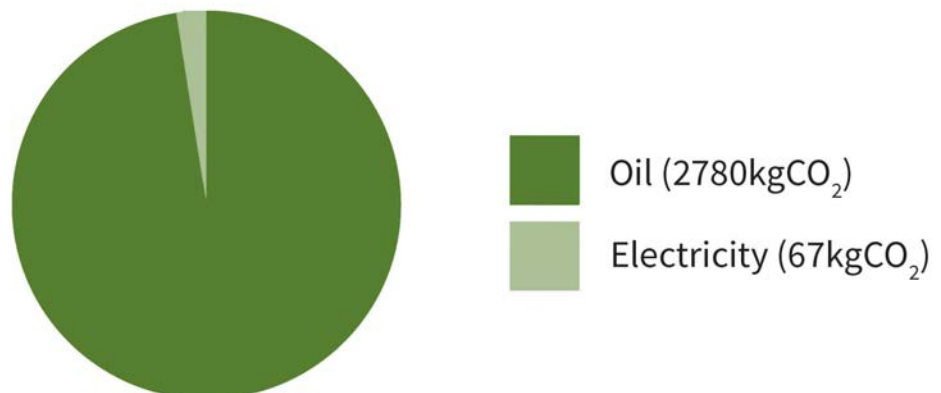


Figure 14:
Existing annual carbon dioxide emissions.



3.4 Current operation and performance

The church building is currently used for worship on Sundays, occasional weddings and weekday funerals, and Christmas/Easter services. The church hopes to expand its operation, and improved levels of comfort from a new heating system would facilitate this.

The current average congregation size for weekly Sunday worship is 17, including the church leader and organist. The church typically has weddings and funerals four times a year, with up to 120 attendees.

The current heating system is reported to take too long to reach comfortable conditions and the users are not satisfied. On the day of the survey, the external temperature was 5°C and the internal temperature was 7°C. The setpoint for the heating system was 18°C. The heating system was switched on at 10 am, and by 11 am the internal temperature had risen only slightly to 9°C.

3.5 Heating system options and viability

It is not recommended that a new piped heating system is installed. This is because the church is not connected to mains water, and there is, therefore, an increased risk of system and plant damage if the water volume is not maintained and the system pressure decreases. The church currently accepts this risk by manually topping up the feed and expansion tank. However, the risk level and potential for damage are not acceptable when considering the significant capital expenditure associated with a new piped heating system.




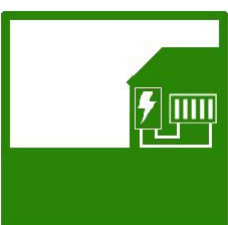

Thames Water could potentially supply a new mains water connection. They charge a fee to provide a full quotation for a new water supply. The estimate for a 20/25mm connection, which was valid until 31 March 2022, indicates that a new water supply to the plant room would cost £8500. Other charges to consider are related to obtaining a soil contamination report, to avoid using a barrier pipe, and possible archaeological costs.

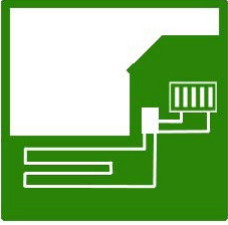

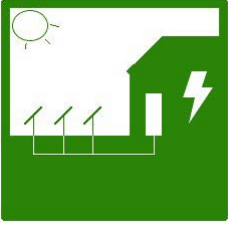


Water authorities are generally understood not to charge churches for their water consumption due to their charitable status. However, our research revealed that some churches are being charged.

Heating technologies and their suitability for the site

Before doing any detailed calculations, this assessment of the technologies was carried out to first consider the suitability of the site for them. This was at a level where it was considered if the technology was technically and practically possible. Photovoltaics, hydroelectricity and wind power were also considered in addition to assessing the heating technologies.

Table 2:
Technology viability
appraisal.

Technology	Site viability assessment	Viable?
Air source heat pump 	<p>An external air source heat pump could be installed in a screened area, in place of the existing oil tank. The acoustics need to be considered. There is currently no available water supply and the estimated installation cost is high.</p>	X
BioLPG 	<p>The boiler room is below ground and there is no alternative location at the church. LPG boilers cannot be located below ground level. There is currently no available water supply and the estimated installation cost is high.</p>	X
Biomass 	<p>There is insufficient space for a fuel store and hopper. Delivering fuel is not easy because of the narrow lane and the distance from the lane to the plant room. The church would need to understand the requirement for regular maintenance. There is currently no available water supply and the estimated installation cost is high.</p>	X
Electric boiler 	<p>There is currently no available water supply and the estimated installation cost is high.</p>	X
Electric heating 	<p>Direct electric heating is possible. If the existing pews are fixed, there would be space available for small pew heaters. There would be a significant shortfall in the heat required even if pew heaters were installed in all of the pews. This shortfall could be overcome by installing wall-mounted electric radiators.</p>	✓

Technology	Site viability assessment	Viable?
Ground source heat pump 	<p>Underfloor heating is required with this technology. The fact that the church is used intermittently is not a good fit for this type of heating system.</p> <p>There is land available for a ground collector if a dedicated area of glebe land was allocated.</p> <p>There is currently no available water supply and the estimated installation cost is high.</p>	X
Hydroelectric power 	No water course at this site.	X
Photovoltaics 	<p>It might not be possible to install a photovoltaic array at the main church site. However, it might be possible, with screening, on a dedicated area of glebe land (see Figure 3).</p> <p>Space for battery storage would be required because the peak solar irradiance will not coincide with the church's demand for heating or other non-heating electrical usage.</p>	?
Water source heat pump 	<p>No water course or lake at this site.</p> <p>There is currently no available water supply and the estimated installation cost is high.</p>	X
Wind turbine 	<p>Planning would likely be an issue. The church is Grade I listed. Daglingworth village is located in the Cotswolds Area of Outstanding Natural Beauty and the conservation area of Daglingworth.</p>	X

Financial and environmental analysis

Detailed analysis of the viable technologies was carried out to include the estimated carbon emissions and costs.

Electric heating is likely to be the most viable option for this church. The comparison of the viable technologies is based on the current average annual heating energy consumption of 9329kWh. The option to provide local electric heating in the form of pew heaters has been included to allow a comparison between heating the church for thermal comfort and providing a level of localised heating. (Appendix B explains this type of heating in more detail.)

Table 3 includes air source heat pumps to allow the evaluation of the payback period associated with installing a new water main along with this technology. The financial and environmental data shown in Table 3 have been determined using detailed calculations. There are a large number of referenced endnotes, which should be read in conjunction with this data.

Table 3:
Heating technology cost
and environmental impact
comparison.

Technology	Estimated annual emissions (kgCO ₂)	Estimated annual fuel cost ¹	Estimated capital cost ²	Heating system capacity ³ (kW)
Existing oil fired boiler	2780	£916	n/a	41
Electric heating	2230 ⁴	£2612 ⁵	£37,467 ⁶	43
				
Local electric heating (pew heaters)	1006 ⁴	£1178 ⁵	£28,212 ⁷	20
Air source heat pump	892 ⁴	£1045 ⁵	£67,554 ⁸	43
				

3.6 Photovoltaic feasibility

Table 2 identifies the red area of land, known as glebe land, as a potential site for a photovoltaic array (see Figures 3 and 15). This proposed location has the following considerations:

- The church acquired glebe land for the purpose of extending the graveyard. If the proposed photovoltaic array is located sensitively and screened off, it would still be possible for some of the land to be designated for grave plots.
- **The Energy Saving Trust** advises a lifespan of 25 years or more for photovoltaic systems, so removing this system in the future would enable more of this land to be allocated for grave plots.
- If any parts of the photovoltaic array are shaded, this will reduce the electricity generated. The positioning of the array should, therefore, consider any seasonal shading that is cast on areas of glebe land from trees to the south and east. If screening is installed around the array to minimise its visual impact, then the shading from this would also need to be considered.
- A new underground electrical cable would need to be installed between the array and the church. The route of the cable would need to take account of existing grave plots and the listed and scheduled monuments in the graveyard.
- Space for battery storage would be required because the peak solar irradiance will not coincide with the demand for heating or most of the other non-heating electrical usage. Removing the oil tank would free up space to erect a temporary structure to house the batteries. Alternatively, it might be possible to use the electricity generated within the properties adjacent to the church in the form of a community power supply.
- There are no known grants available for photovoltaic installations. However, there is a government-backed Smart Export Guarantee (SEG), which allows applications to be made to 14 licensees/energy suppliers. Each licensee can be approached and the financial benefit and contract length is determined on application.
- The cost of the installation depends on the size of the photovoltaic array and the exact route of the buried electrical cable.

Typical domestic installations have a generating capacity of between 1 and 4kW. For some context, the majority of electric kettles use 3kW of electrical power.

Figure 15:
Listed and scheduled
monuments.

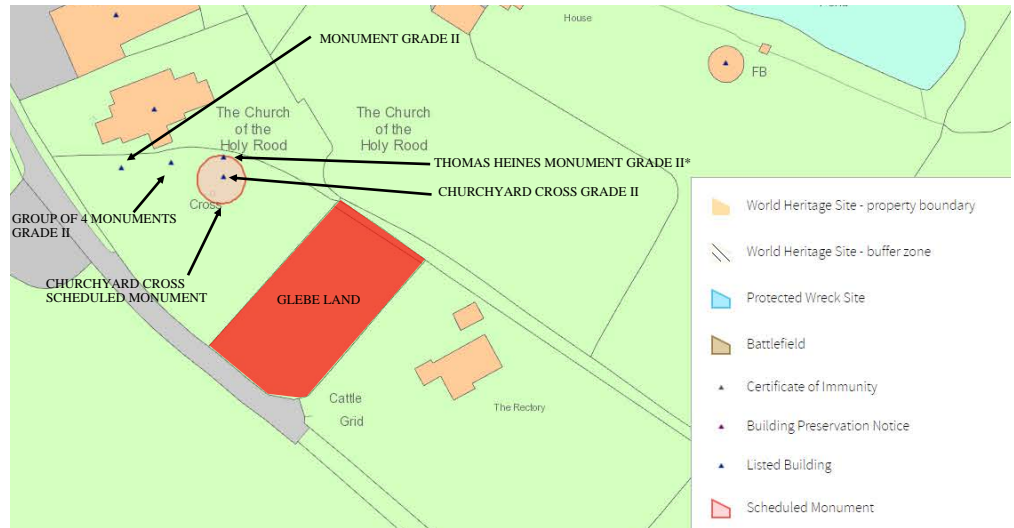
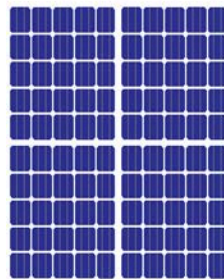


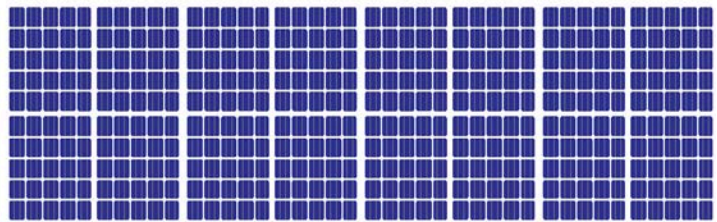
Figure 16:
Typical photovoltaic
arrays.

yesenergysolutions.co.uk

1 kW system
Four solar panels, typically
takes up around 8 m² of space



4 kW system
16 solar panels, typically
takes up around 28 m² of space



The cost of the groundworks and cabling is estimated to be about £8000. (This assumes an excavation distance of 68.5m and excludes any costs associated with archaeology.) As this is a substantial amount, a medium-sized 8kW photovoltaic array has been considered for this site to justify the capital investment. The average size of this array is 56m² and it would typically generate up to 8kW of electricity.

In theory, this could provide up to 8.6 per cent of the electricity required for heating the church, using electric heaters during periods of peak heat loss. Similarly, an 8kW array could, in theory, provide up to 46.5 per cent of the electricity required for heating the church using air source heat pumps.

In practice, the peak period for generating electricity would not coincide with the peak period of heat loss at the church. It is, therefore, recommended that detailed modelling is carried out to consider the benefits of a photovoltaic array.

The total estimated installation cost for an 8kW photovoltaic array with 40kWh of battery storage is £28,648.

Using a simplified solar energy calculator from the Energy Saving Trust, we can determine the following benefits:

Potential emissions saving: 1736kgCO₂
Potential annual benefit: £338
Potential lifetime benefit: £8033
This includes payments from the SEG.

Although the calculator is simplified and does not reflect the use of a typical church, it gives a useful indication as to the estimated performance of a photovoltaic installation at this site. The proposed installation would not achieve financial payback within its anticipated lifetime. However, the potential emissions saving exceeds the estimated heating system emissions for local pew heaters (1006kgCO₂) and air source heat pump (892kgCO₂) heating options (see Table 3).

3.7 Recommendations

Electric heating is the recommended heating solution for the Church of the Holy Rood. As the national grid decarbonises, this proposal will allow the church to achieve the government's net zero carbon target by 2050. It would also be possible for the Church of England's 2030 net zero carbon target to be reached if a green electricity tariff is available.

Air source heat pump and photovoltaic technologies are not the preferred solutions at the current time because of the amount of installation work involved and the associated costs. It is not possible to achieve financial payback for air source heat pumps when compared with electric heating. At present, there are no grants available for heat pump and photovoltaic installations in churches, but this could change in the future.

A trial of the pew heaters that form part of the electric heating proposal is recommended for a dedicated area of the church where pews can be fixed. When the weather is milder, it may be possible to isolate some of the existing radiators or even completely turn off the existing oil-fired boiler, depending on the size of the congregation. This approach could be useful otherwise the benefits of the pew heaters could be overestimated if the existing heating system is operated at full capacity.

The trial will allow a post-occupancy evaluation of this type of heating to learn from the experience of the congregation and church staff that operate the heating. The feedback should include the following criteria:

- Thermal comfort
- Appearance
- Quality of installation
- Ease of operation
- Suggestions for improvements.

4

Church of All Saints, Bisley, and Bisley Blue Coat Church of England Primary School (Category C)

The Church of All Saints, Bisley, is a Grade II*-listed building dating back to the 13th century. Both the church and Bisley Blue Coat Church of England Primary School are located in the conservation area of Bisley and the Cotswolds Area of Outstanding Natural Beauty. There are a large number of Grade II-listed monuments, one Grade II*-listed monument and one scheduled monument within the churchyard.

Figure 17:
The Church of All Saints,
Bisley (left), and the Poor
Souls' Light scheduled
monument (right).



Church Heritage Record
facultyonline.churchofengland.org/church-heritage-record-bisley-all-saints-616003

Historic England listing entry
historicengland.org.uk/listing/the-list/list-entry/1340362

Note: This church was intended to be a Category B church that should already have a three-phase electricity supply. The church currently has a single-phase supply. This means it is one of three Category C churches that have been investigated for this report.

Bisley Blue Coat Church of England Primary School is immediately adjacent to the church and has an interesting local history dating back to 1732. The oldest of the current school buildings, which is Grade II listed, was built in 1854. There is a public right of way through the playground to the church.

Historic England listing entry

historicengland.org.uk/listing/the-list/list-entry/1340367

A non-intrusive survey of the Church of All Saints and Bisley Blue Coat Church of England Primary School was carried out on 22 December 2020.

Figure 18:
The 1854 school building.



Figure 19:
The main entrance to the school and a view of the Church of All Saints.



4.1 Site appraisal

The church site highlighted in yellow and the school site highlighted in red are outlined in Figure 20. The sites are located at a high point, near the centre of the rural village of Bisley. There is a slight downhill gradient to the south of the graveyard. This graveyard is well used, which means there is very little surplus land available for renewable or alternative technologies.

The blue areas show the oil tank locations at both sites. The church oil is supplied either from Church Hill or via the unnamed driveway, and the school oil is supplied from School Road.

The incoming electricity supply for the church enters the meeting room from below ground at the location shown in Figure 20. The below ground route of this incoming electricity supply is unknown. The incoming electricity supply for the school is installed overhead, across the playground from the site boundary.

Figure 20:
Church and school site.

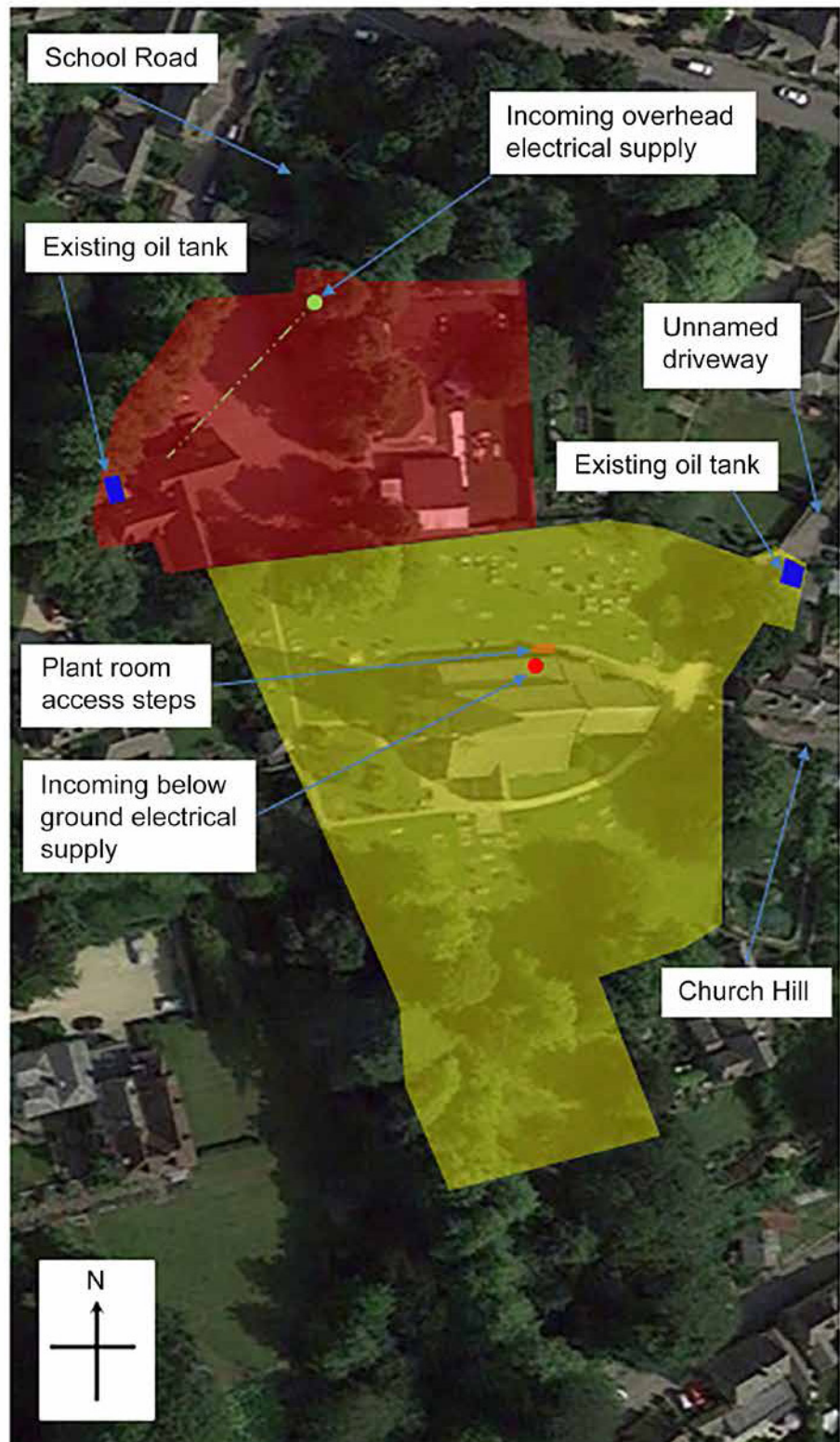


Figure 21:
Severn Trent records
© Severn Trent.

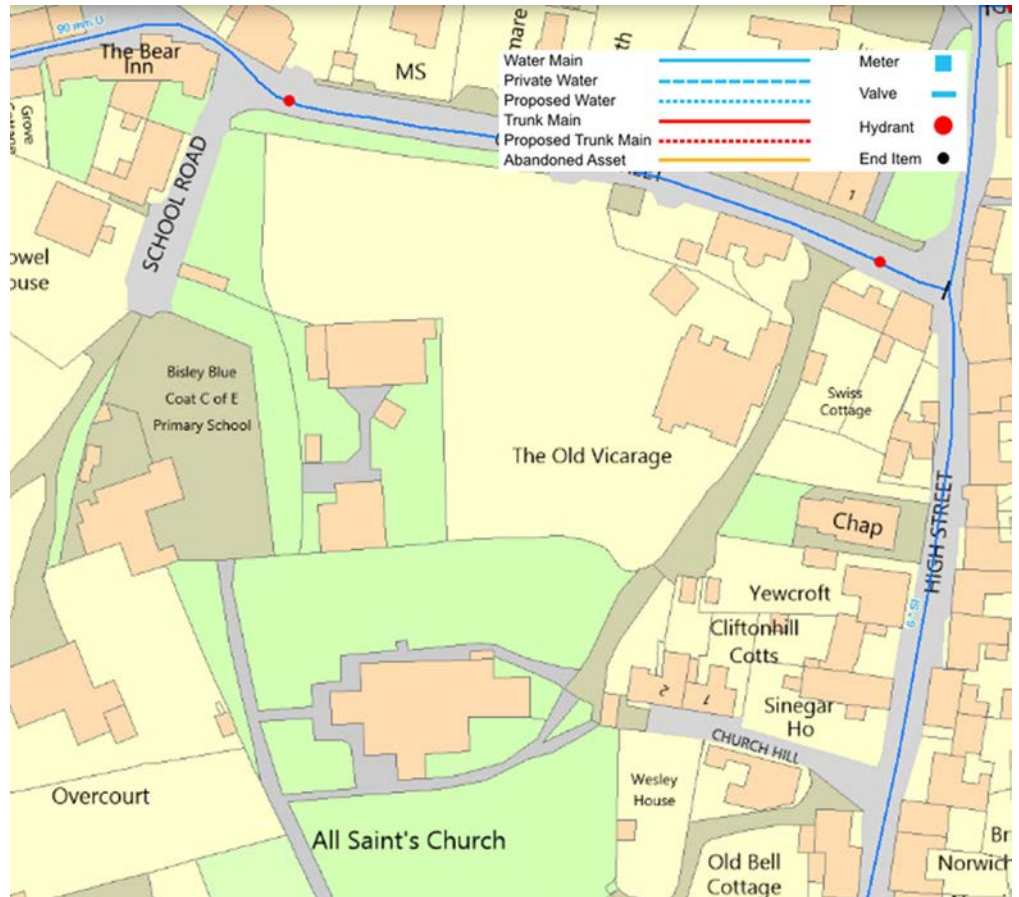


Figure 22:
Church water meter (left).



Figure 23:
School stopcock (right).



Both sites have mains cold water supplies. Severn Trent's records indicate a 90mm water main in George Street, which supplies the school. There is a 6 inch water main in the High Street, which likely supplies the church.

4.2 Existing heating system

Church

The existing heating system is a low temperature hot water system, which uses radiators, large trench heating and a small number of fan convectors. There is also a local electric heater in the vestry. Above this, there are high-level electric radiant heaters in the ringing chamber. The radiators are the column type, and their age is unknown. It is estimated they are at least 15 years-old.

Figure 24:
Column radiator.



The condition of the radiators appears reasonable for their age, but the paintwork has been chipped away in many places. One radiator is positioned behind a display in the Lypiatt Chapel which will prevent this heater from heating the church. The trench heating is installed along half of the length of the nave. A trench is also located along half of the length of the north aisle, but this does not contain any heating pipework. The three Dunham-Bush fan convectors are likely to have been installed in 2011. Two are in the north aisle and the third is in the children's area of the south aisle.

The fan convectors were reported to be performing poorly in terms of heat output and noise. It is understood that they have to be turned off manually during church events because of the noise. As these heat emitters were retrofitted, there are two things that should be actioned. It is recommended that the heating system is commissioned to provide the design flowrate and that the acoustic performance at the lowest fan speed setting is considered. On inspection, the filters on the fan convectors were dirty and needed to be cleaned. One of the fan convectors is installed in the children's area of the church, however there is currently no protection to prevent accidental contact with the supply grille or the exposed pipework. A risk assessment is recommended, and any remedial work should be carried out to minimise the risk of burns.

Figure 25:
Fan convector (left) and
fan convector with cover
removed (right).



The oil-fired boiler is in a basement plant room below the meeting room. A fenced and planted enclosure at the north-eastern site boundary surrounds the existing oil tank. The external oil pipework is installed below ground between the tank and plant room.

Heating pipework is distributed within the floor, making use of the grille-covered trenches that run along most of the length of the church.

Figure 26:
Oil boiler (left) and
insulated heating
pipework (right).



Figure 27:
Trench heating.



The boiler is controlled by a seven-day timeclock. This is located in the meeting room alongside a remote thermostat dial, which is set to 30°C. The associated thermostat is located in the north aisle, and during the survey the church temperature was 11°C. The thermostat setting appears to be too high. However, the church reported that the heating system pump stops when the thermostat temperature is reduced from 30°C.

It is recommended that this configuration is investigated to confirm the correct operation of the heating system. The pump should not cut out until the internal setpoint temperature is achieved. Lowering the setpoint temperature from 30°C to 21°C would reduce energy consumption, particularly during periods when the weather is milder.

The central trench, which contains uninsulated heating pipework, is used to heat the church via four floor grilles. An existing chimney suggests that the church used to be heated by a solid fuel-fired furnace, which would have provided heat via the ventilated trenches (effectively acting as a trench heater).

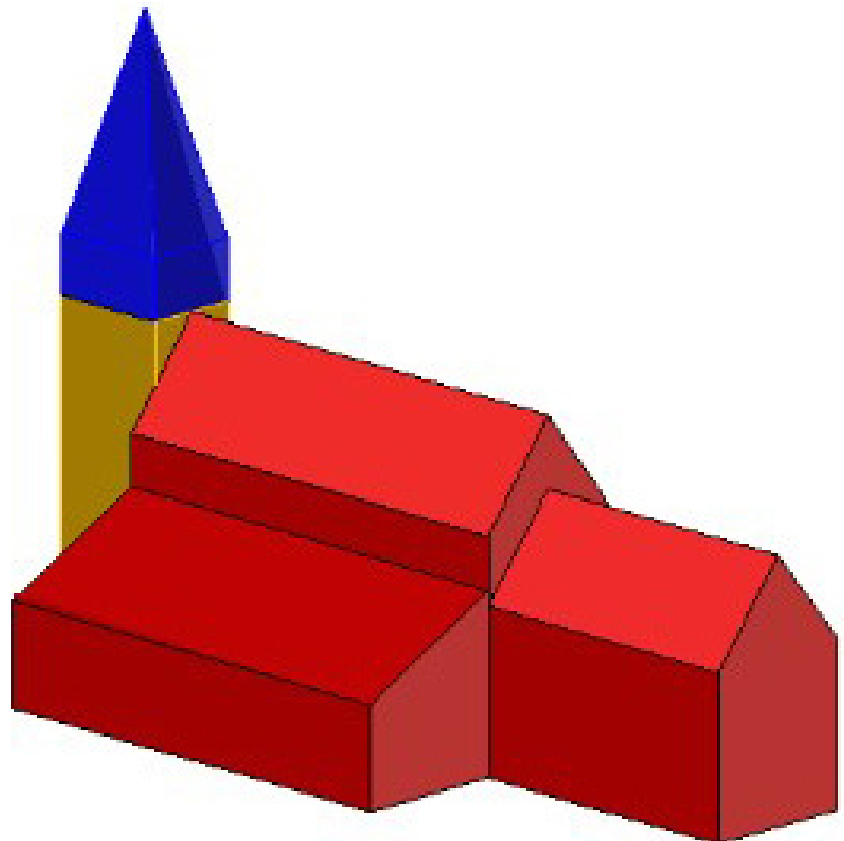
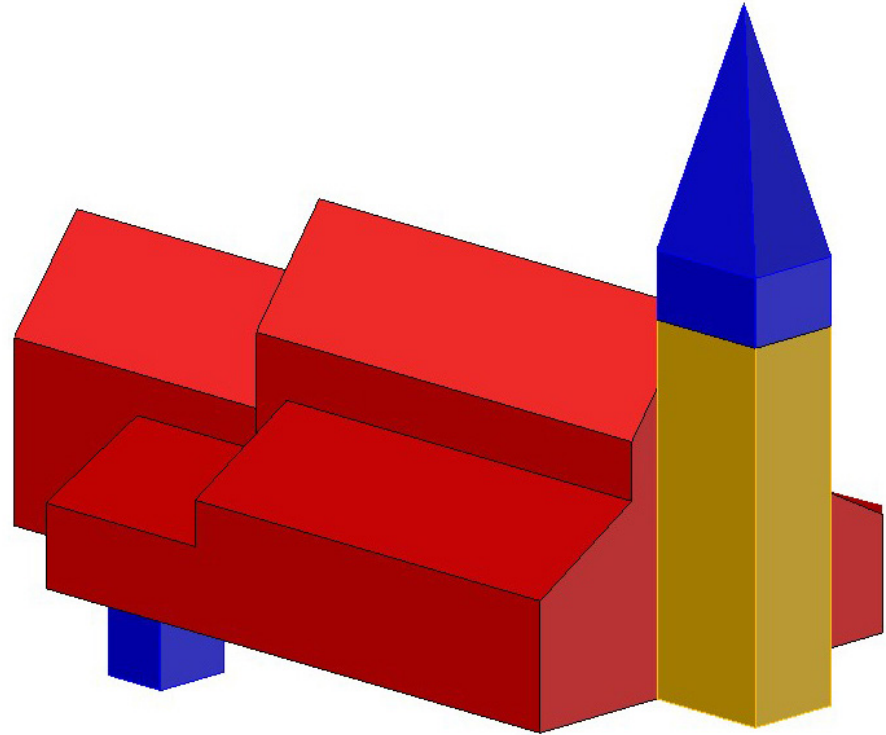
The heat loss for the church is estimated to be 109.8kW, which is significantly above the 65kW capacity of the existing oil boiler. This heat loss estimate has been determined using a rule of thumb calculation. Detailed heat loss calculations should be carried out at the project design stage.

The heat provided by the existing boiler is 22W/m³, which is below the typical heat loss of 30W/m³ for a general building. (Boushear, M (ed) 2001 Rules of Thumb (3rd edition). BSRIA T15/2001.)

From design experience, the typical heat losses for churches are in the range of 35 to 50 W/m³. The church advised that the existing heating system does not heat the church well and that it feels cold.

Figure 28 shows the areas heated by the oil-fired heating system in red and the unheated areas in blue. The orange area of the tower is heated by electric heaters.

Figure 28:
Heated and unheated
church areas.



School

The school provided the drawing shown in Figure 29. It indicates that the school's buildings are heated by two types of heating systems, depending on their location. The oil-fired boiler heats the listed building on the left, or west, of the site. To the east, there are three 'temporary' classrooms, which could be in use for another 14 years. These classrooms are heated by electric night storage heaters.

Figure 29:
School heating system.
© Bisley Blue Coat Church
of England Primary
School.

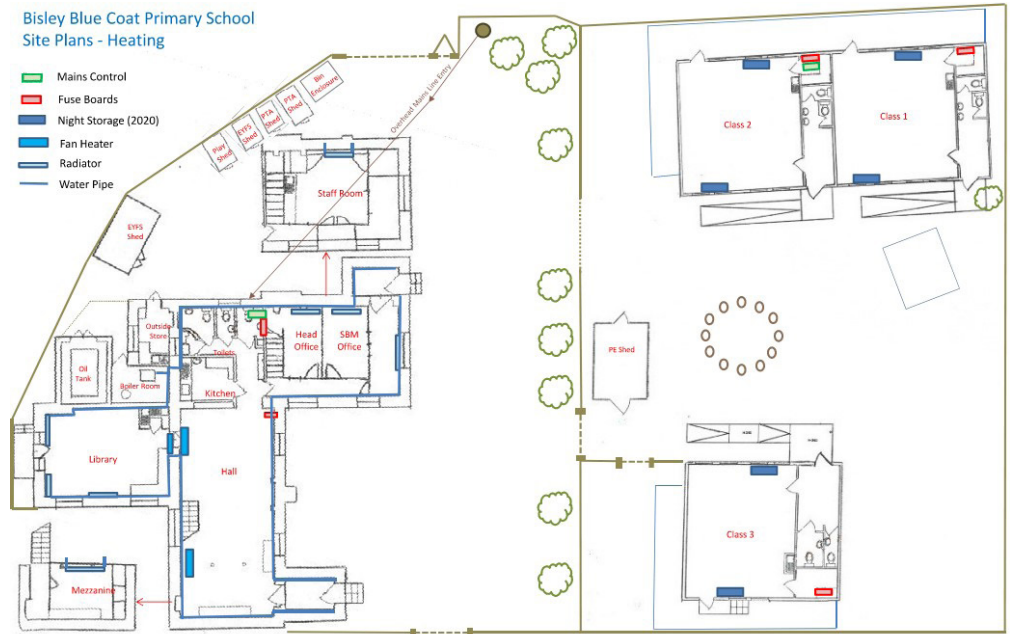


Figure 30:
Plant room and oil tank
room.



The main school building is heated by radiators and fan convectors. The fan convectors are a good method of heating the spaces because there is limited wall area available. The quick response time of fan convectors is good for the hall, which has intermittent use.

The hot water in the main school building is also heated indirectly by the low temperature hot water system.

The oil-fired boiler is installed in a plant room adjacent to a bunded oil tank room, as seen in Figure 30. These plant areas are enclosed by a fence and accessed from the playground.

The boiler flue discharges via the chimney and there is a modern Trend IQ3 building management system installed (automatic controls). The boiler capacity is unknown, but the Ideal Falcon GTE (existing boiler) is available with heat outputs of 50 to 102kW. The oil burner provides 95 to 213kW of heat, so it is likely that the boiler can provide 102kW of heat. The indirect hot water cylinder requires 18.3kW of heat, which leaves approximately 83.7kW available for space heating.

The heat loss for the main school building is estimated to be 47.0kW, which is below the estimated 83.7kW available for space heating. This heat loss estimate and the consequent estimate for the whole school site have been determined using a rule of thumb calculation.

Detailed heat loss calculations should be carried out at the project design stage. It should be noted that the heat input required by fan convectors is often above that required for space heating. If the three temporary classrooms are included in the heat loss calculations, the estimated heat loss for the whole school site is 66.8kW.

4.3 Energy consumption and utility supply

Oil for the church site

The existing oil tank is bunded and has a capacity of 1340l. There is no oil meter, but oil is typically supplied in four annual deliveries. The average amount of oil delivered over the past three years is 2898l per year. This is equivalent to 31,177kWh of annual fuel consumption. Note that this figure relates to the combustion of oil, and the actual heat provided by the heating system will depend on the plant and system efficiencies. The calculated annual energy consumption for the heating system is 28,790kWh.

Assuming that the delivery amount is similar to the actual oil consumption, this equates to annual carbon dioxide emissions of 8579kg. These emissions are for the fuel that supplies the heating system only, because the oil boiler does not generate hot water and there are no other oil-fired appliances.

Figure 31:
Oil tank.



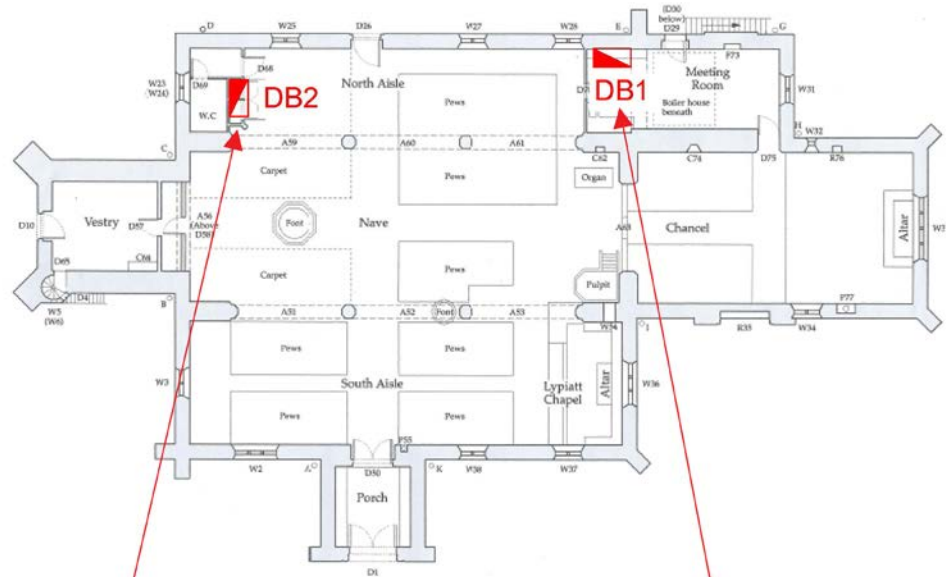
Electricity for the church site

There is a three-phase supply, cut out with 100A fuse housings, which enters the meeting room from below ground. Only one of the phases is connected, to provide a single-phase 230V supply. The single-phase supply connects to distribution board DB1, which has a 100A main switch. There is a 40A breaker in a separate enclosure at this location, which provides a supply to distribution board DB2, located within a cupboard in the north aisle.

Figure 32:
Electrical cut out and fuse housings.



Figure 33:
Power distribution layout.



The electricity consumption is known for the past three years, and the average annual consumption is 4701kWh. This equates to annual carbon dioxide emissions of 1124kg for the church’s electricity consumption.

Figures 34 and 35 show that the energy consumption and carbon dioxide emissions are significantly affected by using oil to provide heating in the church. In this analysis, oil consumption for the heating system is 86.9 per cent of the church’s total energy consumption.

Figure 34:
Existing annual fuel consumption.

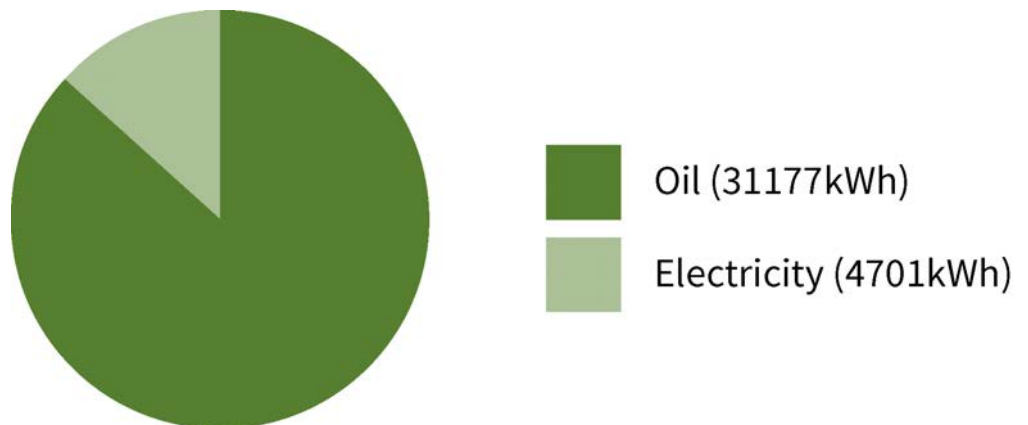
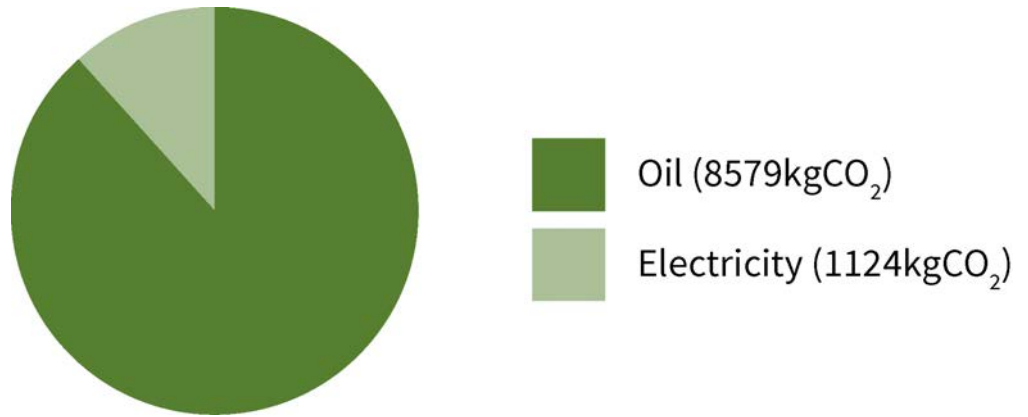


Figure 35:
Existing annual carbon
dioxide emissions.



Oil for the school site

The existing oil tank is bunded and has a capacity of 1000gal (4546l). During the survey, the external oil gauge indicated a volume of 430gal (1955l). The average amount of oil consumed over the past two years is 7035l per year. This is equivalent to 75,673kWh of annual fuel consumption. Note that this figure relates to the combustion of oil, and the actual heat provided by the heating system will depend on the plant and system efficiencies. The calculated annual energy consumption for the heating and hot water system is 69,879kWh.

Assuming that the delivery amount is similar to the actual oil consumption, this equates to annual carbon dioxide emissions of 20,824kg. These emissions are for the fuel that supplies the heating and hot water systems. There are no other oil-fired appliances.

Figure 36:
Oil tank gauge.



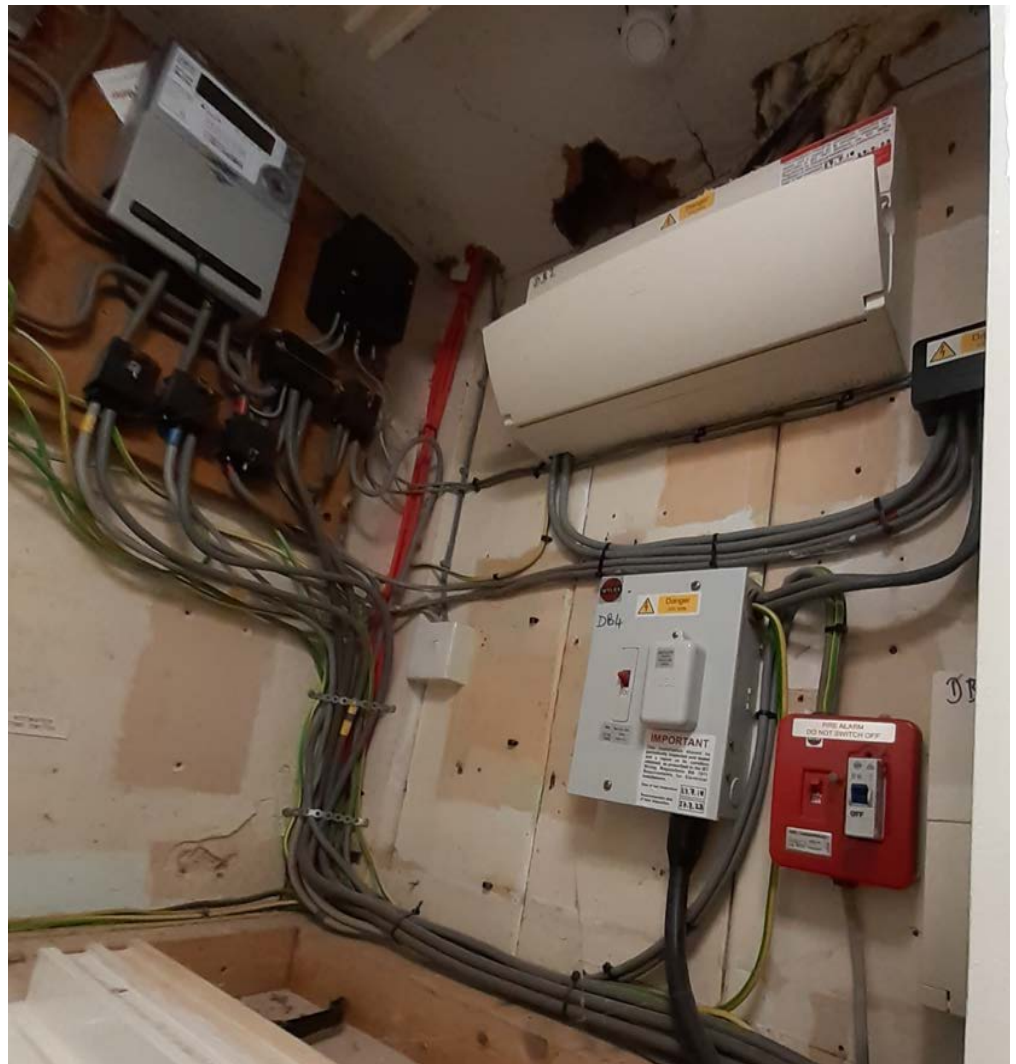
Electricity for the school site

There is a 415V three-phase supply, with 100A fuse housings, which enters the electrical switch room at high level through the external wall. The switch room also contains three-phase power and controls for the night storage heaters in the temporary classrooms and two single-phase distribution boards. The temporary classrooms have three-phase power supplies, with a single-phase distribution board for each classroom. There is also a small single-phase distribution board in the boiler room. This has two circuits.

An electrical load assessment for the school has not been carried out, but it was noted during the survey that there are no spare electrical circuits in the distribution boards.

The electricity consumption is known for the past two years. The average annual consumption for 2019 and 2020 is 28,415kWh. This equates to annual carbon dioxide emissions of 6791kg for the school's electricity consumption.

Figure 37:
Electrical incomer.



Figures 38 and 39 show that the energy consumption and carbon dioxide emissions are largely affected by using oil to provide heating and domestic hot water in the school. In this analysis, oil consumption is 72.7 per cent of the school's total energy consumption.

Figure 38:
Existing annual fuel
consumption.

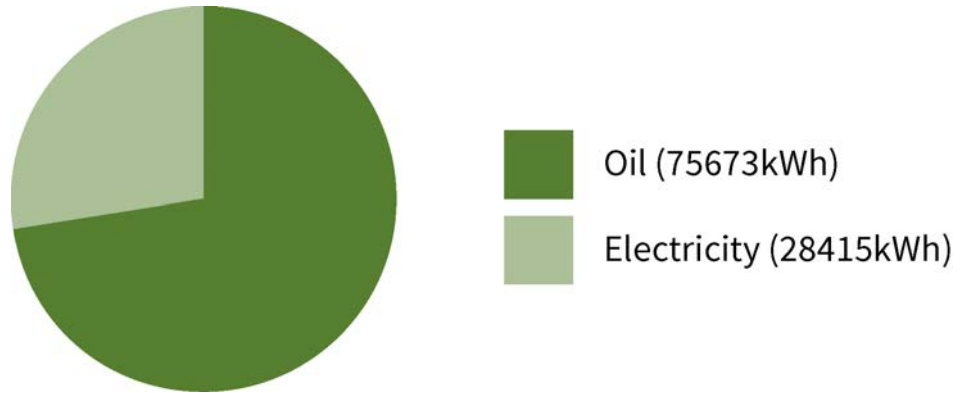
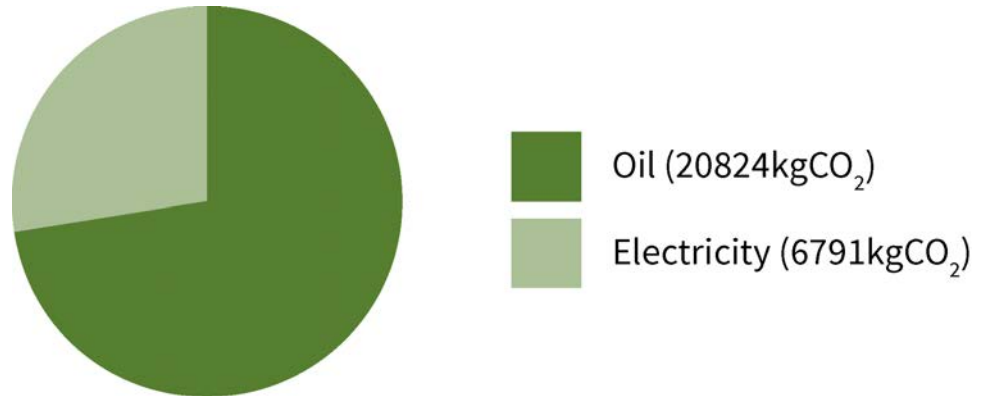


Figure 39:
Existing annual carbon
dioxide emissions.



4.4 Current operation and performance

Church

The church advised that the building is currently used on Sundays for worship and for around 90 minutes after the service every week. The school uses the church for worship regularly, but this is restricted during cold weather because the church is not warm enough. Choir practice and church meetings also take place in the church.

The current heating system is reported to take too long to reach comfortable conditions. There are reports that the congregation are reluctant to attend church because of the current heating system. The church would like to widen the use of the building and believes that a better heating system would facilitate this. Plans include a new heating system that could provide background heating and respond quickly to demand via remote operation. Sustainability and low carbon technologies are a priority for the church. The fan convectors are said to be noisy and intrusive, and the church finds the heating system expensive to run.



School



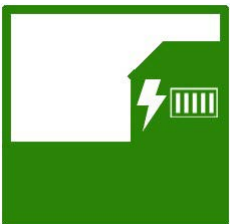
The school has a typical term-time operation and the heating system is reported to work well. There are aspirations to lower the school's carbon footprint. The existing oil tank is due for replacement.

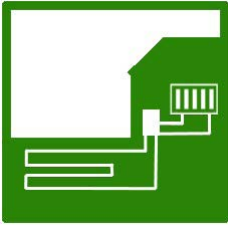

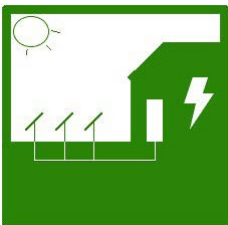
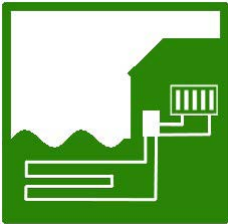
4.5 Heating system options and viability


Before doing any detailed calculations, this assessment of the technologies was carried out to first consider the suitability of the site for them. This was at a level where it was considered if the technology was technically and practically possible. Photovoltaics, hydroelectricity and wind power were also considered in addition to assessing the heating technologies.

Table 4:
Technology viability appraisal.

Technology	Site viability assessment	Viable?
Air source heat pump 	Church An external air source heat pump could be installed in a screened area in place of the existing oil tank. This option would involve buried heating mains. An alternative location would be the site of the previous oil tank (adjacent to the plant room steps), if the graves can be avoided. The acoustics need to be considered. New or additional heat emitters would be required. This technology would not be compatible with the existing fan convectors.	✓
	School An external air source heat pump could be located in the oil tank room, if sufficient ventilation can be provided via louvred doors. Alternatively, it might be possible to locate a heat pump in front of the oil tank room. The acoustics need to be considered. New or additional heat emitters would be required. This technology would not be compatible with the existing fan convectors.	✓
BioLPG 	Church The current boiler room is below ground and there is no alternative location at the church. LPG boilers cannot be located below ground level.	X
	School The external LPG tank would need to be either in the playground or where the existing oil tank room is. The oil tank room would, therefore, need to be demolished. The LPG tank could be fenced and screened. This technology is compatible with the existing heat emitters. Note: 100% BioLPG is not currently available in this region. This could change in the future.	?

Technology	Site viability assessment	Viable?
Biomass	Church Insufficient space is available for a fuel store and hopper. Fuel cannot be delivered easily due to the narrow lane and distance from the lane to the plant room. This technology is compatible with the existing heat emitters. The church would need to understand the requirement for regular maintenance.	X
	School A fuel store could be located in the oil tank room. This location, towards the front of the school, is good for fuel delivery. The chimney should be surveyed to determine if it can be lined and used for the new flue. This technology is compatible with the existing heat emitters. The school would need to understand the requirement for regular maintenance.	✓
Electric boiler	Church This technology could be installed if there is sufficient electricity available. An electric boiler could be installed in the existing boiler room. The surfaces in the boiler room would need to be cleaned and may need local repairs.	✓
	School This technology could be installed if there is sufficient electricity available. An electric boiler could be installed in the existing boiler room.	✓
Electric heating	Church Direct electric heating is possible. There is space available for small pew heaters as the existing pews are fixed. There would be a significant shortfall in the heat required even if pew heaters were installed in all of the pews. This shortfall could be overcome by installing wall-mounted electric radiators and electric fan convectors.	✓
	School Direct electric heating is possible, using electric radiators and electric fan convectors.	✓

Technology	Site viability assessment	Viable?
Ground source heat pump	Church Underfloor heating would be required with this technology. The fact that the church is used intermittently is not a good fit for this type of heating system. There is nowhere to install a ground collector within the church site. However, if the school were to install an adequate ground collector in the playground area, it is technically possible for both buildings to have a heat pump installed, connected to a shared ground collector.	?
	School Underfloor heating would generally be required with this technology. Some smaller spaces could be heated by radiators. The playground is the only area on the school site where a ground collector could be installed.	?
Hydroelectric power	Church/School No water course at this site.	X
		
Photovoltaics	Church/School May not be possible at either site. The only location available for a photovoltaic array is on the roofs of both buildings. Space for battery storage would be required because the peak solar irradiance will not always coincide with the demand for heating or other non-heating electrical usage.	?
		
Water source heat pump	Church/School No water course or lake at this site.	X
		

Technology	Site viability assessment	Viable?
Wind turbine	Church/School Planning would likely be an issue. The church is Grade II* listed and the school is Grade II listed. Bisley village is located in the Cotswolds Area of Outstanding Natural Beauty and the conservation area of Bisley.	X
		

Financial and environmental analysis

Detailed analysis of the viable technologies was carried out to include the estimated carbon emissions and costs.

It is worth investigating air source heat pumps as a heating option for both the church and the school. However, at the school, biomass may be a better option because the heating system outside of the plant room would not need to be changed.

Although it is technically possible to heat both the church and the school using ground source heat pumps, the costs associated with replacing a large amount of the floor in both buildings to install underfloor heating make this option less favourable.

Similarly, it is technically possible to install photovoltaic panels on the roofs of both buildings. A detailed feasibility assessment for this technology has not been carried out due to the planning permissions required for this installation.

Electric heating and electric boilers are possible options in both buildings. The existing heating systems could be heated by an electric boiler, but there does not appear to be sufficient heat emitters in the church to provide a good level of thermal comfort.




The comparison of the viable technologies is based on the current average annual heating energy consumption for each building. For the church, this is 28,790kWh (heating only). For the school, it is 69,878.5kWh (heating and hot water). The option to provide local electric heating in the form of pew heaters has been included for the church to allow a comparison to be made between heating the church for thermal comfort and providing a level of localised heating. (Appendix B explains this type of heating in more detail.)

The financial and environmental data shown in Tables 5 and 6 have been determined using detailed calculations. There are a large number of referenced endnotes, which should be read in conjunction with this data.

Table 5:
Heating technology
comparison for the church.

Technology	Estimated annual emissions (kgCO ₂)	Estimated annual fuel cost ¹	Estimated capital cost ²	Heating system capacity ³ (kW)
Existing oil fired boiler	8579	£2827	n/a	65
Air source heat pump 	2752 ⁴	£3225 ⁵	£186,079 ⁹	136
Electric boiler 	6881 ⁴	£8061 ⁵	£100,216 ⁴	120
Electric heating 	6881 ⁴	£8061 ⁵	£78,229 ⁹	110
Local electric heating (pew heaters)	2484 ⁴	£2910 ⁵	£50,059 ⁷	20

Table 6:
Heating and hot water
technology comparison for
the school.

Technology	Estimated annual emissions (kgCO ₂)	Estimated annual fuel cost ¹	Estimated capital cost ¹⁰	Heating system capacity ³ (kW)
Existing oil fired boiler	20,824	£6861	n/a	84
Air source heat pump	6680 ⁴	£7826 ⁵	£66,853 ¹¹	43
				
Biomass	2726	£4731	£36,500 Heating plant only	50
			£64,274 Heating plant and new heat emitters / distribution pipework	
Electric boiler	16,701 ⁴	£19,566 ⁵	£10,994 ¹¹ Heating plant only	60
			£38,768 ¹¹ Heating plant and new heat emitters/ distribution pipework	
Electric heating	16,701 ⁴	£19,566 ⁵	£20,510 ¹¹	47
				

4.6 Recommendations

Church

Electric heating is recommended for the Church of All Saints, Bisley. As the national grid decarbonises, this option will allow the church to achieve the government's net zero carbon target by 2050. It would also be possible for the Church of England's 2030 net zero carbon target to be reached if a green electricity tariff is available. An electric boiler would be more expensive to install than electric heating, without any significant benefits.

Figure 40:
The Church of All Saints,
Bisley.



The high capital cost for the air source heat pump makes this option less favourable. Also, this technology would not achieve financial payback within the expected life of the plant when compared with electric heating. At present, there are no grants available for heat pump installations in churches, but this could change in the future.

A trial of the pew heaters which that part of the electric heating proposal is recommended for a dedicated area of the church where pews can be fixed. When the weather is milder, it may be possible to isolate some of the existing radiators or even completely turn off the existing oil-fired boiler if the congregation size allows this. This approach could be useful otherwise the benefits of the pew heaters could be overestimated if the existing heating system is operated at full capacity. The trial will allow a post occupancy

evaluation of this type of heating to learn from the experience of the congregation and the church staff that operate the heating. The suggested feedback could include the following criteria:

- Thermal comfort
- Appearance
- Quality of installation
- Ease of operation
- Suggestions for improvements.

School

Air source heat pumps provide a zero carbon heating and hot water option for the school, if the school uses a green electricity tariff. Alternatively, a biomass boiler offers a low carbon option, with a similar capital cost if the heating system is also replaced. The capital cost is substantially lower if the existing heating system is retained. The estimated annual fuel cost for a biomass boiler is the lowest of all the options explored. For this reason, biomass technology is recommended for the school.

Figure 41:
School sign.

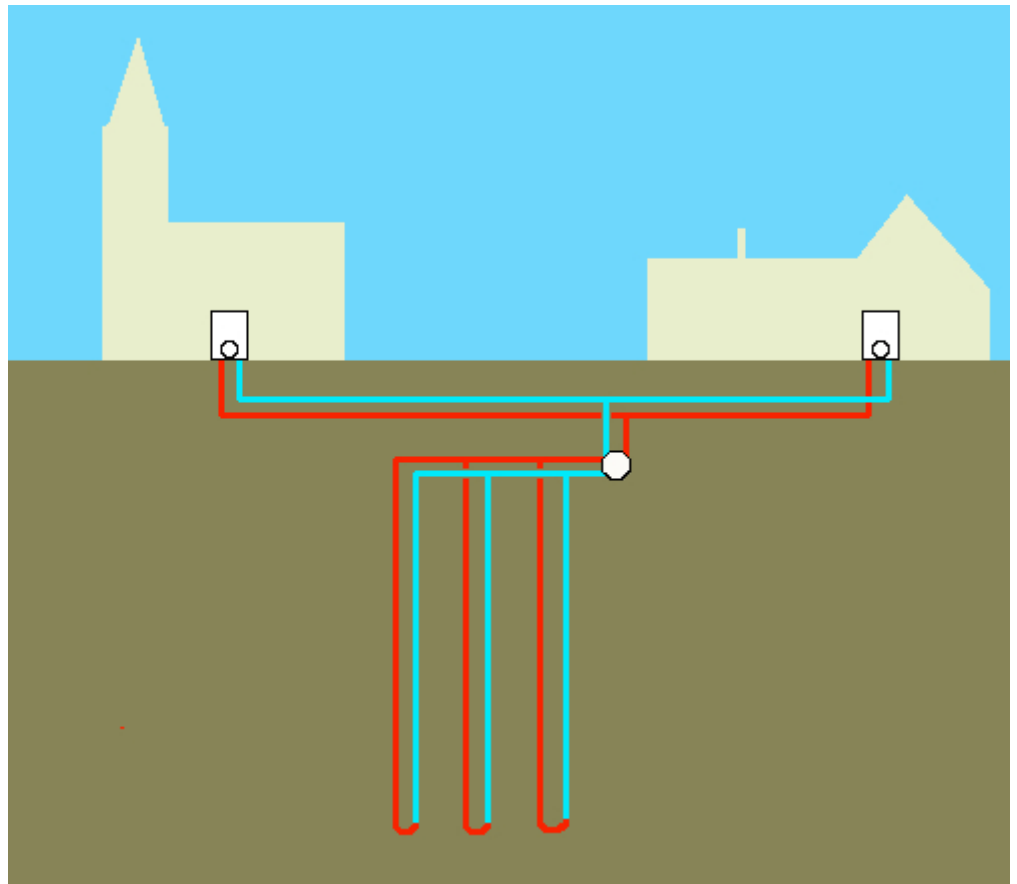


The high estimated running costs of electric heating and an electric boiler mean that these options are not recommended for the school. This is despite the fact that replacing the existing heating plant with an electric boiler is the option with the lowest capital cost.

Comparing an electric boiler with a new biomass boiler (plant only), the simplified payback model, which does not consider inflation or future fuel costs, shows payback for biomass in 1.7 years. The expected working life of a well-maintained biomass plant is 20 years. (CIBSE 2014 Guide M: Maintenance Engineering and Management.) Consequently, even in the short term, this is the most financially viable heating option.

The only low carbon heating technology that could be effectively shared across both sites is ground source heat pumps. A shared ground collector would need to be installed in the playground.

Figure 42:
Typical community
ground source heat pump
diagram.



This option is appealing from a technical and community perspective. However, it involves a significant amount of capital investment, outlined below:

- Underfloor heating in the church would only be viable if there was a major reordering, to include replacing the floor. The church would also need to be used more by the community throughout the week for this type of heating to be effective.
- The floor would need to be replaced within the majority of the school building
- A ground collector would need to be installed and the playground resurfaced
- Groundworks would be required along a suitable route to connect the ground collector to the church

This option should only be explored further if there are significant building works planned for both sites.

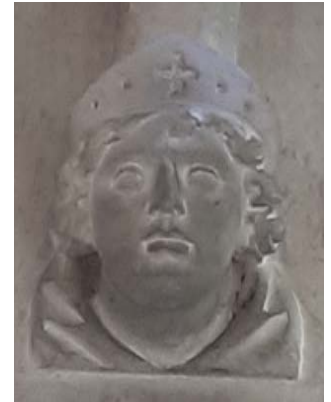
Before considering these options in full, it is recommended that an electrical load assessment is carried out for the school site by a suitably competent person. This assessment will be required for all options except biomass. Quotations should be obtained for any electricity supply upgrades that are required.

5

St Michael and All Angels, Poulton (Category C)

The Church of St Michael and All Angels, Poulton, is a Grade II-listed church dating back to the 19th century. It is located in the conservation area of Poulton.

Figure 43:
Church of St Michael and
All Angels, Poulton (left),
and stone details (right).



Church Heritage Record
facultyonline.churchofengland.org/church-heritage-record-poulton-st-michael-all-angels-616324

Historic England listing entry
historicengland.org.uk/listing/the-list/list-entry/1153465

A non-intrusive survey of the Church of St Michael and All Angels was carried out on 23 April 2021.

Figure 44:
Inside the church.



5.1 Site appraisal

The church and graveyard highlighted in yellow on Figure 45 are situated in the centre of the rural village of Poulton. The site is relatively small and level. It shares a boundary with the cricket club to the west; other boundaries are residential. The graveyard is at or near capacity, with no surplus land available for renewable or alternative technologies.

Thames Water's records indicate a three inch water main located in Cricklade Street (Figure 46).

Figure 45:
Church site.

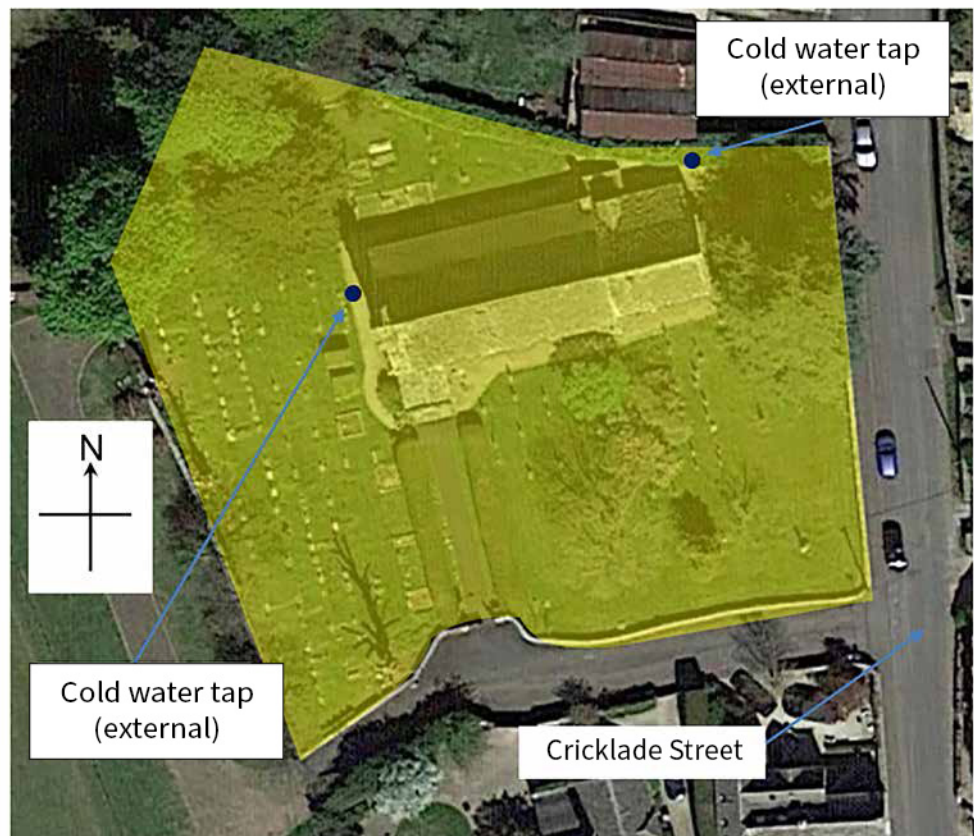
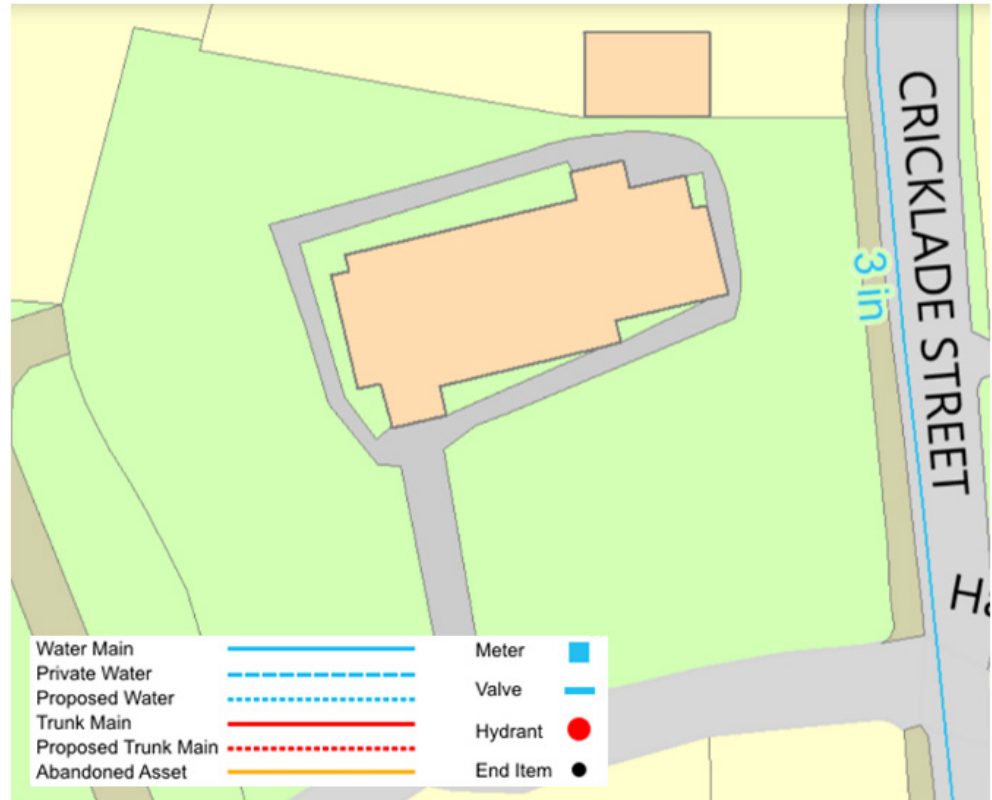


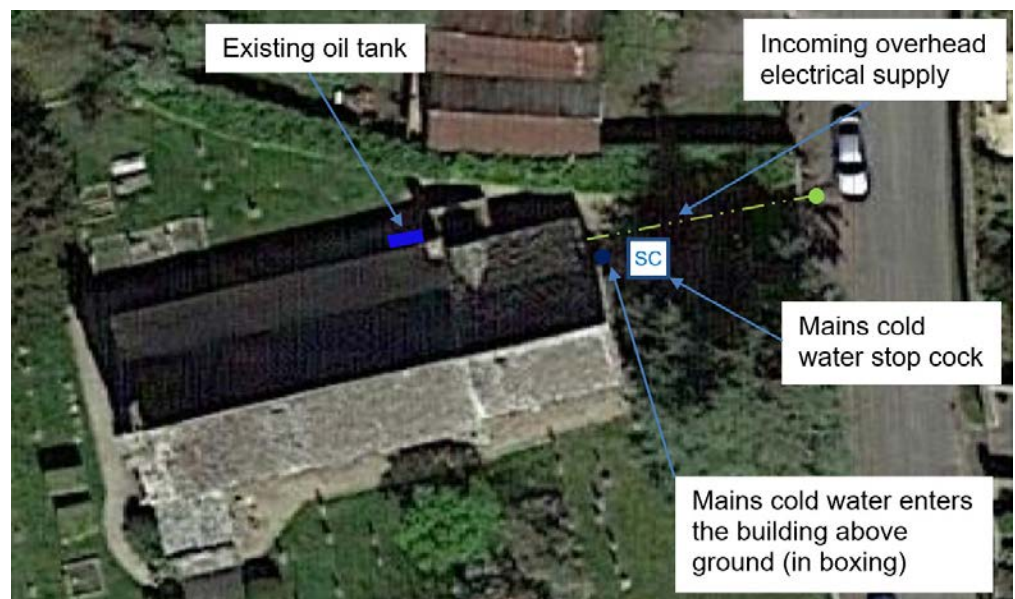
Figure 46:
Thames Water records.



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The incoming electricity supply enters the vestry via an overhead cable from a pole at the site boundary (Figure 47).

Figure 47:
External plant and utilities.



5.2 Church survey

A three-dimensional survey of the church was carried out using a Matterport camera.

This allows precise measurements to be taken, and the building layout and building services installation can be easily viewed.

Figure 48:
Column radiator (left) and
view from the south-west
corner (right) using the
Matterport survey.

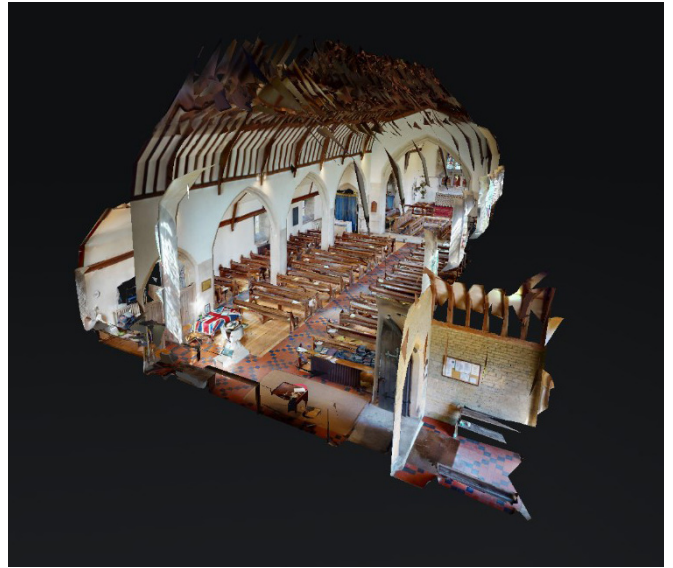
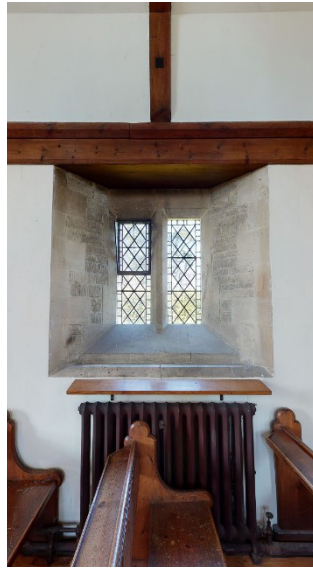
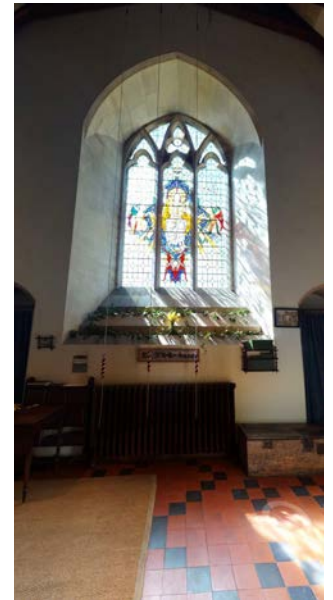


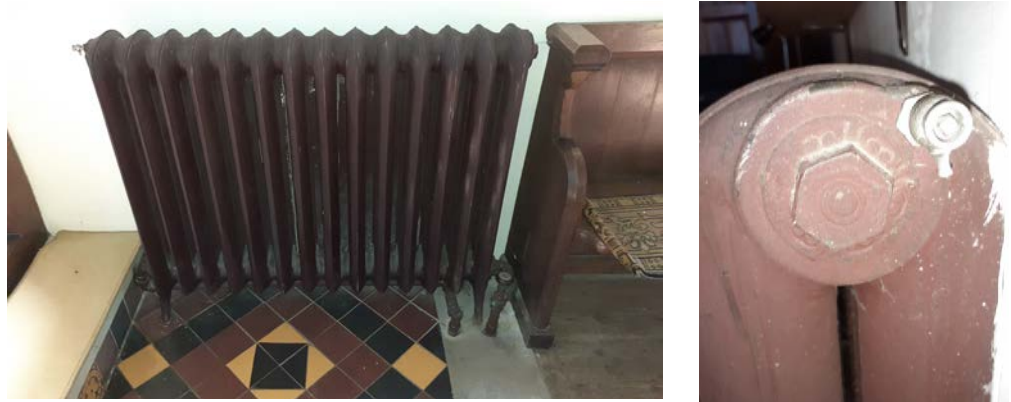
Figure 49:
View from the north-east
corner (left) and west
window (right).



5.3 Existing heating system

The existing heating system is a low temperature hot water system, with column radiators located throughout the church. The radiators are the Princess model, manufactured by Beeston and they are the column type. Generally, they are in reasonable condition, although there is some evidence of leaking valves. The vestry does not have a radiator. Here, a very short pipe coil provides some background heating.

Figure 50:
Beeston column radiator.



The altar is likely to be one of the coldest areas in the church because there is only one radiator in the nearby pews.

The oil-fired boiler is in an external plant room, adjacent to the vestry entrance door. The plant room is a stone wall construction, to match the church, and the bunded oil tank is located behind the plant room, installed on concrete blocks. In the kitchenette, there is a plug-in, radio-signalled sensor, which indicates when the oil level is low. Pipework is distributed within the floor and at low level. The existing boiler flue discharges via the chimney. An existing chimney suggests that the church used to be heated by a solid fuel-fired furnace, possibly using historic trenches where the three areas of timber floor are installed.

Some of the pipework within the plant room is not insulated. High-level air bricks provide a small amount of ventilation. The boiler is controlled by a seven-day timeclock, located inside the main church area by the internal vestry door. There is also a thermostat by the organ, which is set to 74°F (23.3°C). It may be possible to turn the thermostat down to 70°F (21°C) without thermal comfort being adversely affected.

This would reduce energy consumption, particularly during periods when the weather is milder.

The heat loss for the church is estimated to be 65.2kW, which is slightly above the 58.6kW capacity of the existing oil boiler. This heat loss estimate has been determined using a rule of thumb calculation. Detailed heat loss calculations should be carried out at the project design stage.

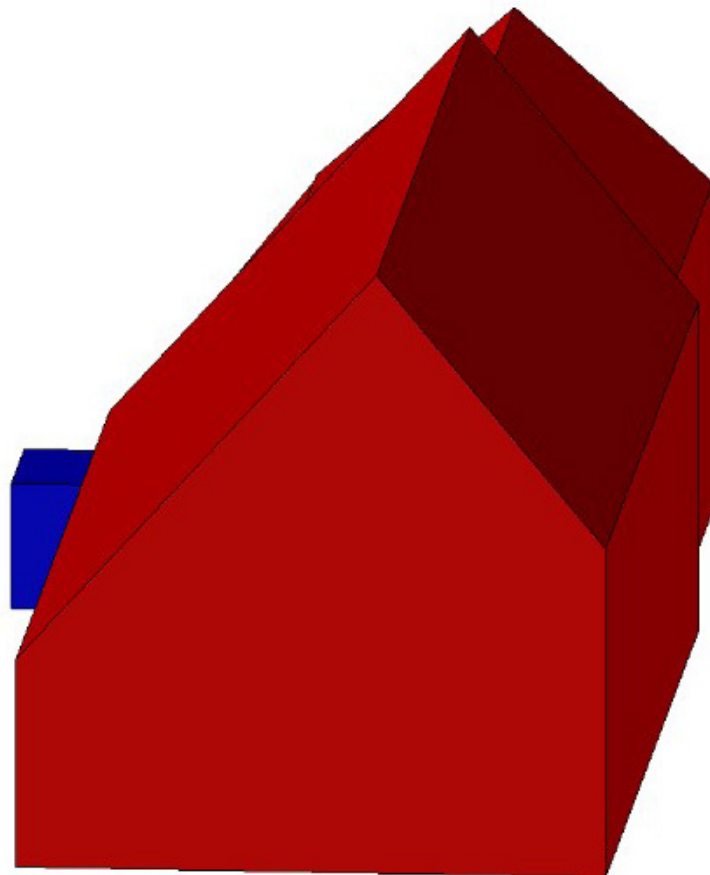
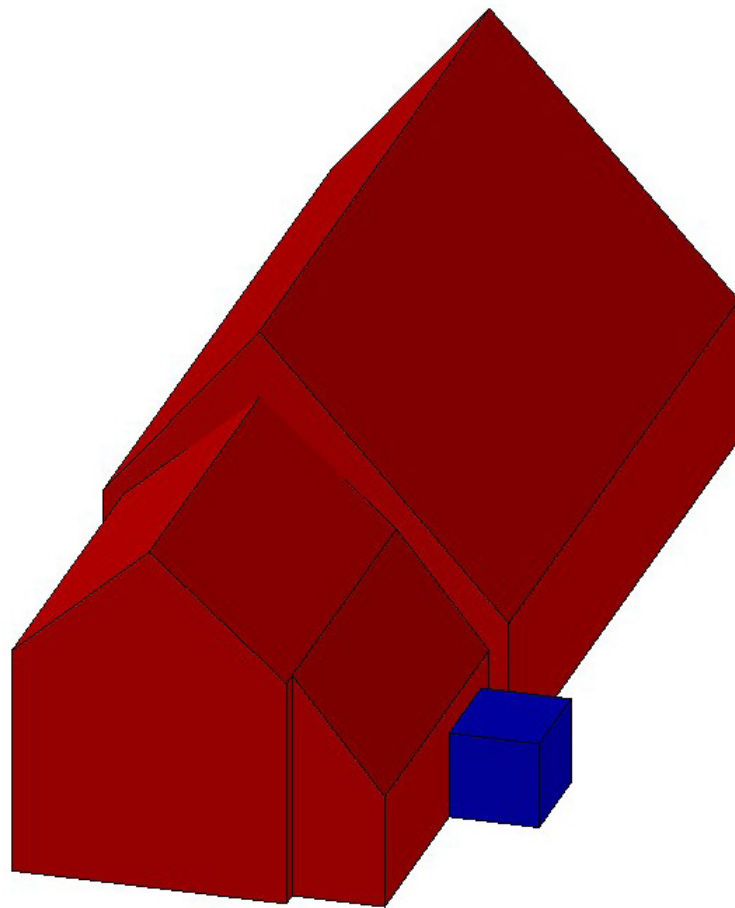
The heat provided by the existing boiler is 31W/m^3 , which is similar to the typical heat loss of 30W/m^3 for a general building. (Boushear, M (ed) 2001 Rules of Thumb (3rd edition). BSRIA TN15/2001.) From design experience, the typical heat losses for churches are in the range of 35 to 50W/m^3 . The church advised that the existing heating system works very well.

Figure 51:
Heating thermostat.



Figure 52 shows the heated areas of the church in red and the plant room in blue.

Figure 52:
Heated and non-heated
areas of the church.



5.4 Energy consumption and utility supply

Oil

The existing oil tank is bunded and has a capacity of 1220l. There is no oil meter, but oil is supplied in three or four deliveries each year. The average amount of oil delivered over the past two years is 1809l per year. This is equivalent to 19,454kWh of annual fuel consumption. Note that this figure relates to the combustion of oil, and the actual heat provided by the heating system will depend on the plant and system efficiencies. The calculated annual energy consumption for the heating system is 17,964kWh.

Assuming that the delivery amount is similar to the actual oil consumption, this equates to annual carbon dioxide emissions of 5353kg.

These emissions are for the fuel that supplies the heating system only. The oil-fired boiler does not generate hot water and there are no other oil-fired appliances.

Figure 53:
Oil tank.



Electricity

There is a single-phase supply to the church, with a 100A fuse housing, which enters the vestry at high level through the external wall. The existing meter is only rated to a 40A maximum current. The single-phase supply connects to distribution board DB1, which has a 45A main switch. There is also a 60A isolator, which supplies distribution boards DB/2A and DB/2B. Both distribution boards have a 100A main switch. DB/2A is located behind the organ and DB/2B is by the main entrance, as shown in Figure 55.

The electricity consumption is known for the past three years. The average annual consumption is 526kWh. This equates to annual carbon dioxide emissions of 126kg for the church's electricity consumption.

Figure 54:
Electrical incomer.

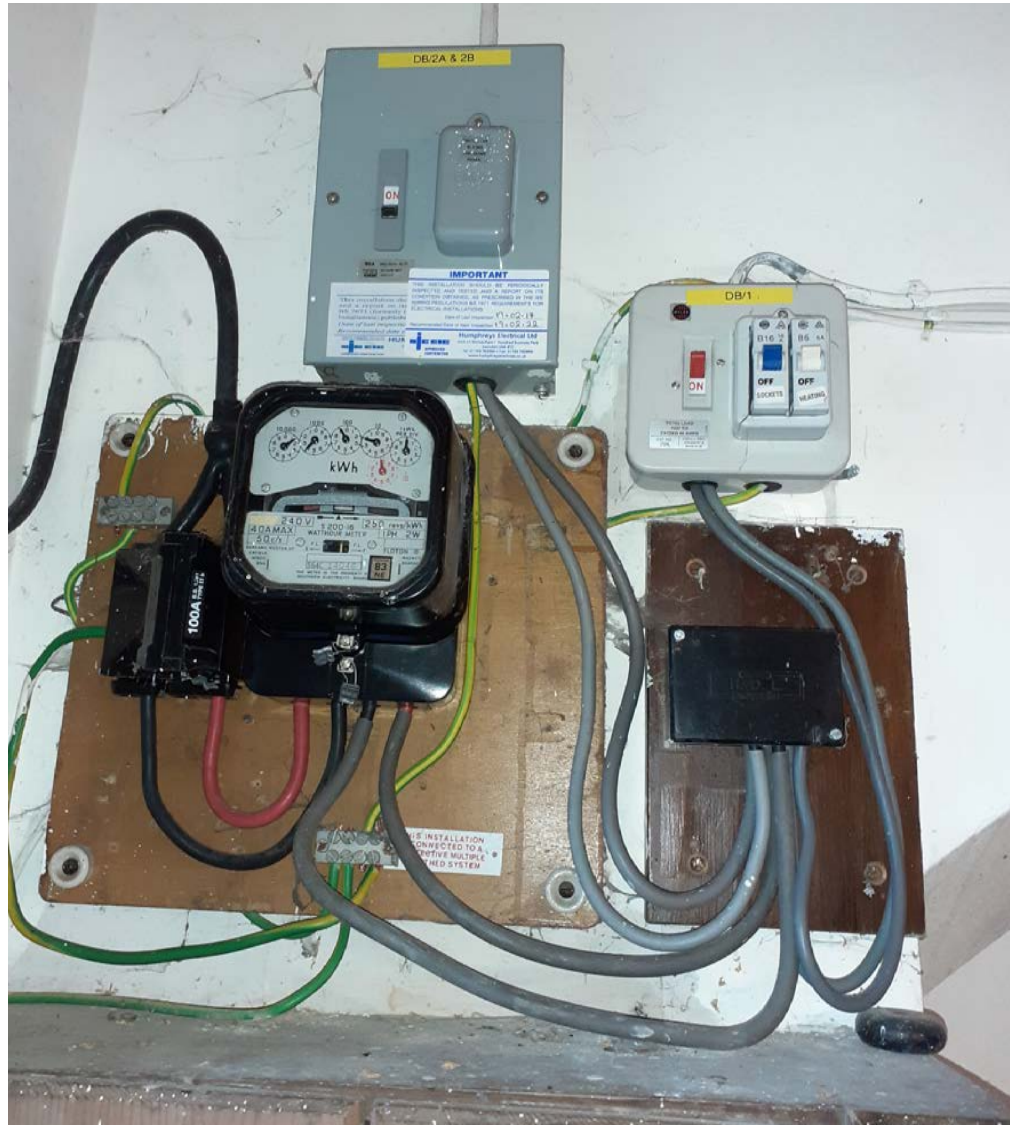
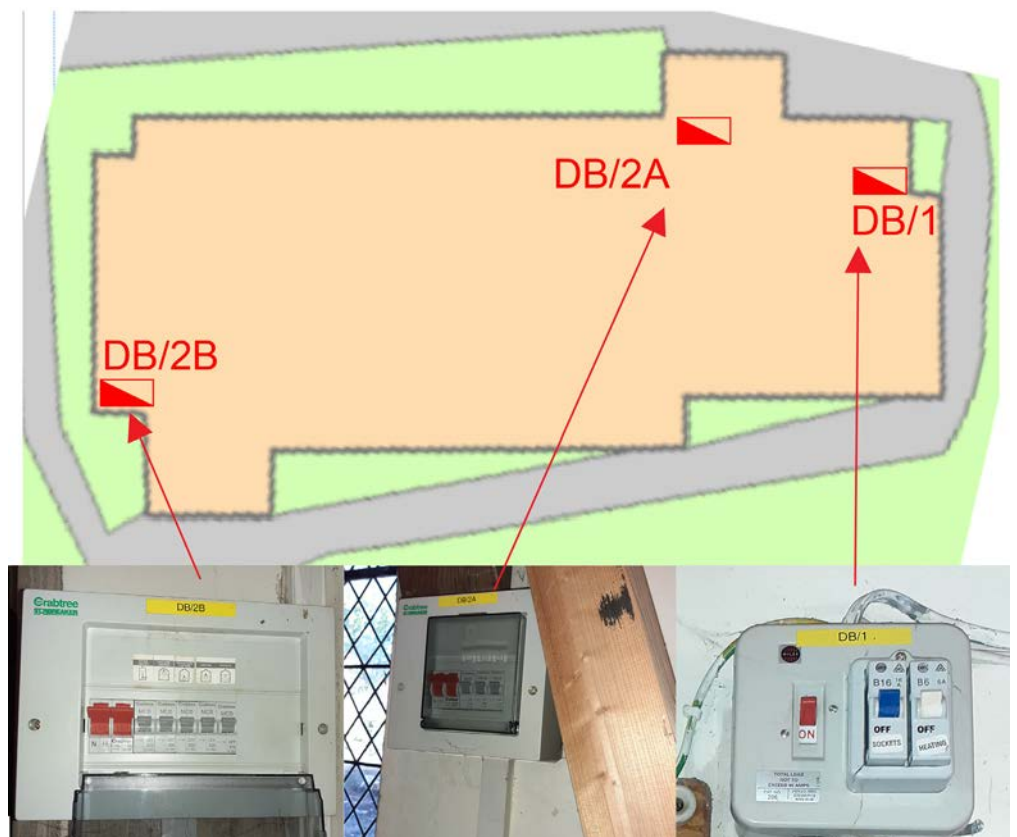


Figure 55:
Power distribution layout.



Figures 56 and 57 show that the energy consumption and carbon dioxide emissions are significantly affected by using oil to provide heating in the church. In this analysis, oil consumption for the heating system is 97.4 per cent of the total energy.

Figure 56:
Existing annual fuel
consumption.

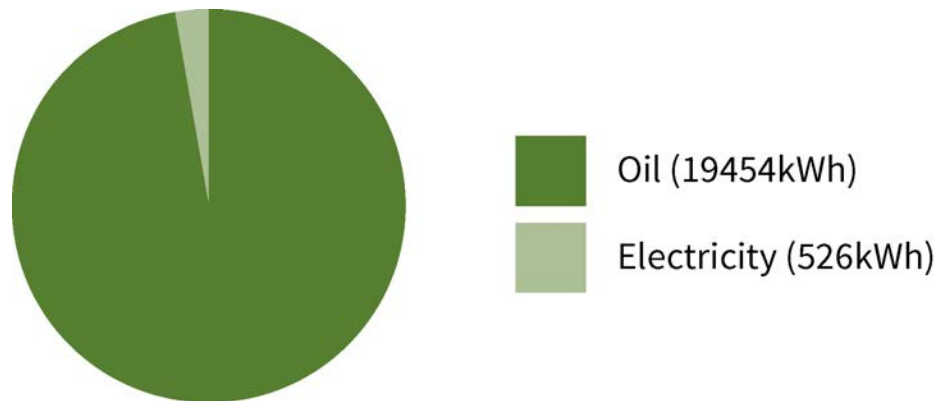
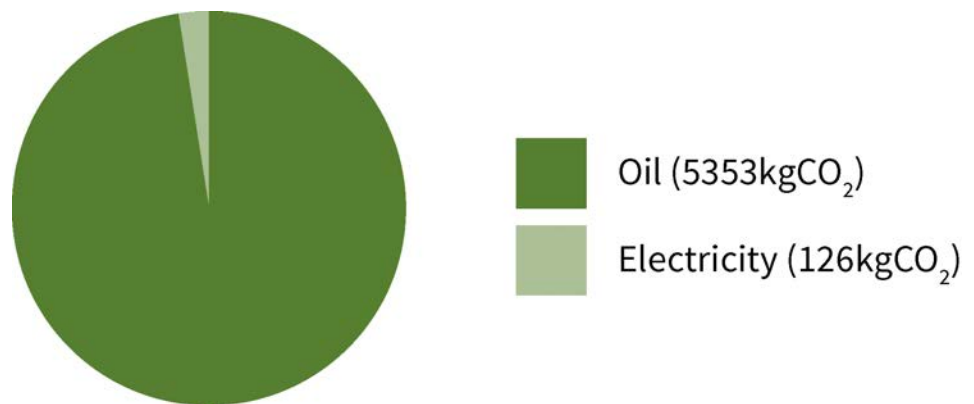


Figure 57:
Existing annual carbon
dioxide emissions.



5.5 Current operation and performance

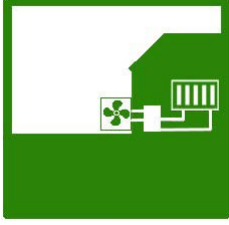




The church building is currently open every day for visitors, and there are two Sunday services every month. Other uses include funerals, weddings, baptisms and the occasional concert.

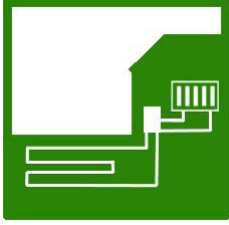

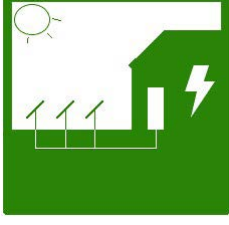
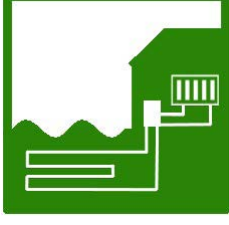

The current heating system has a warm-up time of between five and seven hours. Feedback regarding the performance of the existing heating system is very positive. The church reports that the heating system works very well in winter and is better than that provided in other churches.

5.6 Heating systems options and viability

Before doing any detailed calculations, this assessment of the technologies was carried out to first consider the suitability of the site for them. This was at a level where it was considered if the technology was technically and practically possible. Photovoltaics, hydroelectricity and wind power were also considered in addition to assessing the heating technologies.

Table 7:
Technology viability
appraisal.

Technology	Site Viability Assessment	Viable?
<p>Air source heat pump</p> 	<p>An external air source heat pump could be located in a screened area in place of the existing oil tank. The acoustics need to be considered. New or additional heat emitters would be required.</p>	✓
<p>BioLPG</p> 	<p>A BioLPG tank could be located in a screened area in place of the existing oil tank. Note: 100% BioLPG is not currently available in this region. This could change in the future.</p>	?
<p>Biomass</p> 	<p>A biomass boiler and hopper could be installed in the existing plant room. A fuel store could be located in a screened area in place of the existing oil tank. The chimney should be surveyed to determine if it can be lined and used for the new flue. This technology is compatible with the existing heat emitters. The church would need to understand the requirement for regular maintenance.</p>	✓
<p>Electric boiler</p> 	<p>This technology could be installed if there is sufficient electricity available. An electric boiler could be installed in the existing boiler room. The surfaces in the boiler room would need to be cleaned and may need local repairs.</p>	✓
<p>Electric heating</p> 	<p>Direct electric heating is possible. There is space available for small pew heaters as the existing pews are fixed. There would be a significant shortfall in the heat required even if pew heaters were installed in all of the pews. This shortfall could be overcome by installing wall-mounted electric radiators.</p>	✓

Technology	Site Viability Assessment	Viable?
Ground source heat pump 	Underfloor heating would be required with this technology. The fact that the church is used intermittently is not a good fit for this type of heating system. There is no location for a ground collector within the church site.	X
Hydroelectric power 	No water course at this site.	X
Photovoltaics 	May not be possible. The only location available for a photovoltaic array is on the roof. Space for battery storage would be required because the peak solar irradiance will not always coincide with the demand for heating or other non-heating electrical usage.	?
Water source heat pump 	No water course or lake at this site.	X
Wind turbine 	Planning would likely be an issue. The church is Grade II listed. It is located in the conservation area of Poulton.	X





Financial and environmental analysis

Detailed analysis of the viable technologies was carried out to include the estimated carbon emissions and costs.

The comparison of the viable technologies is based on the current average annual heating energy consumption of 17,964kWh. The option to provide local electric heating in the form of pew heaters has been included to allow a comparison to be made between heating the church for thermal comfort and providing a level of localised heating. (Appendix B explains this type of heating in more detail.)

The financial and environmental data shown in Table 8 have been determined using detailed calculations. There are a large number of referenced endnotes, which should be read in conjunction with this data.

Table 8:
Heating technology
comparison.

Technology	Estimated annual emissions (kgCO ₂)	Estimated annual fuel cost ¹	Estimated capital cost ²	Heating system capacity ³ (kW)
Existing oil fired boiler	5353	£1764	n/a	59
Air source heat pump	1717 ⁴	£2012 ⁵	£95,784 ⁹	68
				
Biomass	701	£1216	£41,000 Heating plant only £79,244 Heating plant and new heat emitters/ distribution pipework	65
				
Electric boiler	4294 ⁴	£5030 ⁵	£12,367 ⁹ Heating plant only £50,611 ⁹ Heating plant and new heat emitters/ distribution pipework	65
				
Electric heating	4294 ⁴	£5030 ⁵	£42,734 ⁶	65
				
Local electric heating (pew heaters)	2997 ⁴	£3511 ⁵	£34,330 ⁷	46

5.7 Recommendations

Biomass is the recommended heating solution for the Church of St Michael and All Angels and this provides a route to low carbon emissions. Electric heating and electric boilers are also feasible and should be considered because they have the potential to achieve zero carbon emissions.

Air source heat pumps are expensive to install for this church compared with the other heating technologies. At present, there are no grants available for heat pump installations in churches, but this could change in the future. Air source heat pumps would provide a zero carbon heating and hot water option if the church uses a green electricity tariff. However, this technology would not achieve financial payback within the expected life of the plant when compared with electric heating.

The advantages of biomass are:

- Lowest fuel costs
- Compatibility with the existing heating system.

The advantages of electric heating and electric boilers are:

- Allows the church to be net zero carbon by 2050, as the national grid decarbonises
- Possible for the Church of England's 2030 net zero carbon target to be achieved if a green electricity tariff is available
- Estimated capital cost for electric heating includes a new heating system
- No on-site emissions from the combustion of biomass.

A trial of the pew heaters that form part of the electric heating proposal is recommended for a dedicated area of the church where pews can be fixed. When the weather is milder, it may be possible to isolate some of the existing radiators or even completely turn off the existing oil-fired boiler, depending on the size of the congregation.

This approach could be useful otherwise the benefits of the pew heaters could be overestimated if the existing heating system is operated at full capacity.

The trial will allow a post-occupancy evaluation from the congregation and church staff. The feedback should include the following criteria:

- Thermal comfort
- Appearance
- Quality of installation
- Ease of operation
- Suggestions for improvements.

The option with the lowest capital cost is replacing the existing heating plant with an electric boiler. Comparing this option with a new biomass boiler (plant only), the simplified payback model, which does not consider inflation or future fuel costs, shows payback for the biomass boiler in 7.5 years.

The expected working life of a well-maintained biomass plant is 20 years. (CIBSE 2014 Guide M: Maintenance Engineering and Management.) Consequently, over the longer term, this is the most financially viable heating option.

6

Church of St Mary, Bibury, and Bibury Church of England Primary School (Category B)

The Church of St Mary, Bibury, is a Grade I-listed building dating back to the mid to late 11th century. Both the church and Bibury Church of England Primary School are located in the conservation area of Bibury and the Cotswolds Area of Outstanding Natural Beauty. There are a large number of Grade II-listed monuments and one Grade II*-listed monument within the churchyard.

Figure 58:
Church of St Mary, Bibury
(left), keyhole plate (top
right) and Saxon stone
detail (bottom right).



Church Heritage Record
facultyonline.churchofengland.org/church-heritage-record-bibury-st-mary-616310

Historic England listing entry
historicengland.org.uk/listing/the-list/list-entry/1155770

A non-intrusive survey of the Church of St Mary, Bibury, was carried out on 5 May 2021.

Note: Historic England was informed that the Church of St Mary, Bibury, had a single-phase electricity supply, which would have made this a Category D church as defined in Section 3. However, during the surveys, it was discovered that both the church and the school have three-phase electricity supplies. This means St Mary's is a Category B church.

Bibury Church of England Primary School is a Grade II-listed building dating back to the 19th century. The school shares a significant boundary with the churchyard at the southern end of the site.

Historic England listing entry

historicengland.org.uk/listing/the-list/list-entry/1341802

A non-intrusive survey of Bibury Church of England Primary School was carried out on 7 April 2021.

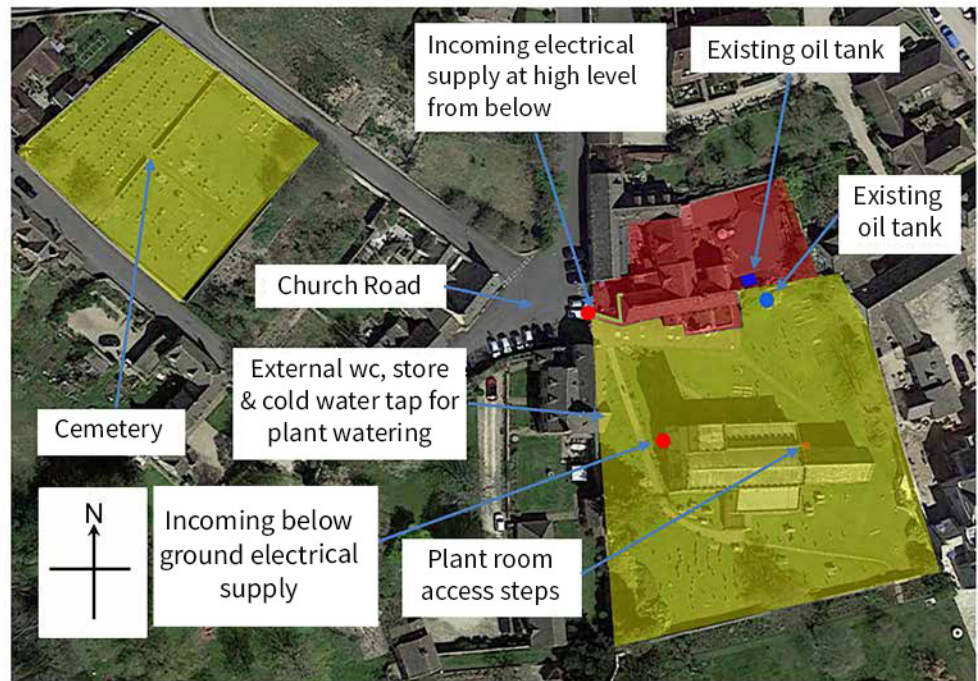
Figure 59:
Bibury Church of England
Primary School.



6.1 Site appraisal

The church site highlighted in yellow and the school site highlighted in red are shown in Figure 60. They are located in the centre of the rural village of Bibury. The church site is approximately 40 metres north of the River Coln. Both sites are on level ground and the church has a separate cemetery on land that has a gradient. The cemetery has some capacity for additional graves, but neither site has much land available for renewable or alternative technologies.

Figure 60:
Church and school site.

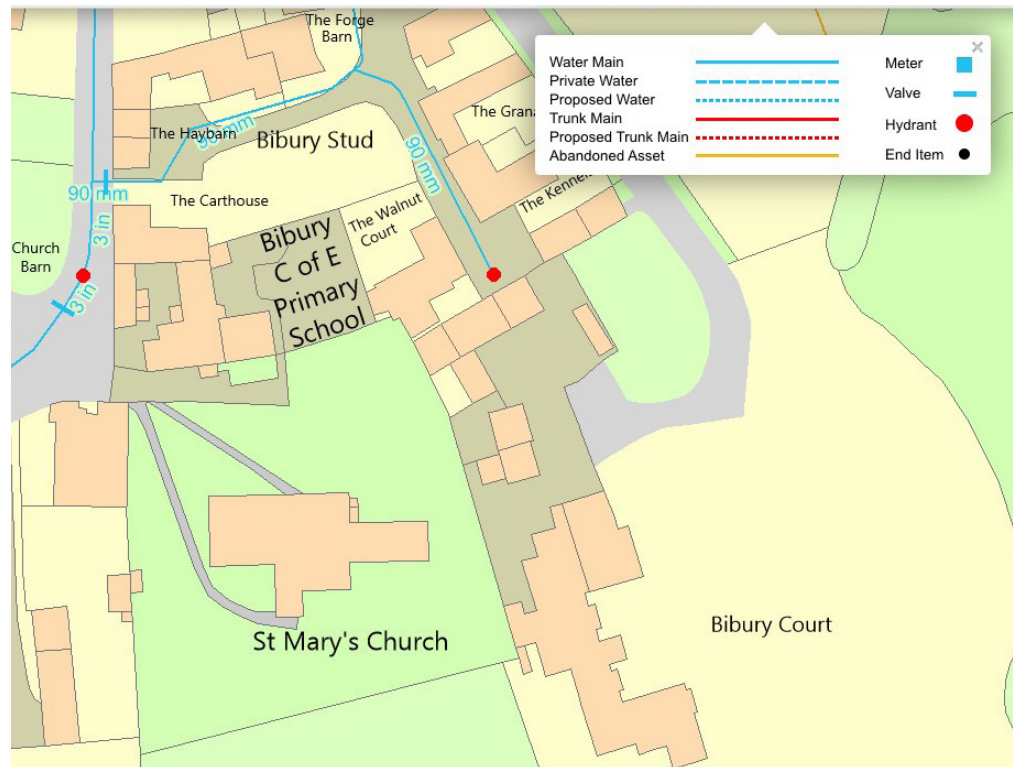


The blue areas show the oil tank locations for both sites. Oil is supplied via Church Road.

The incoming electricity supply for the church enters the tower at high level, after rising externally from below ground (Figure 60). Similarly, the incoming electricity supply for the school is installed externally on the wall, after rising from below ground at the site boundary in Church Road.

Both sites have mains cold water supplies. Thames Water's records indicate a three inch water main in Church Road at the boundary to both sites.

Figure 61:
Thames Water records.



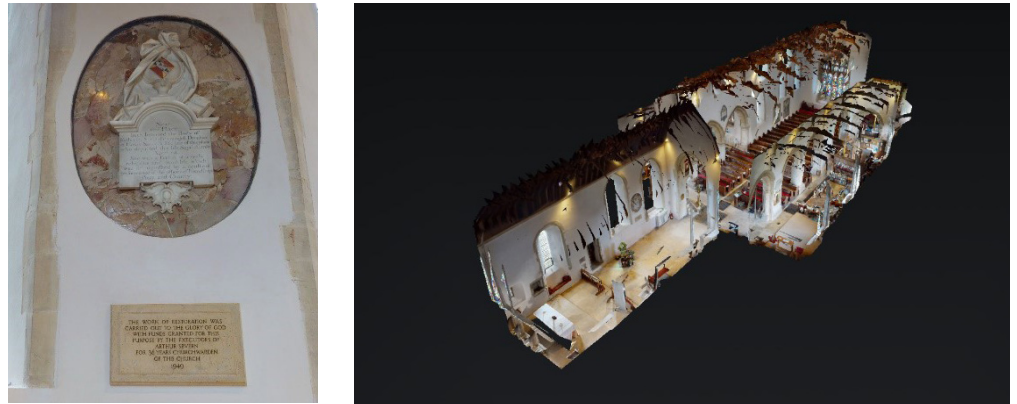
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6.2 Church survey

A three-dimensional survey of the church was carried out using a Matterport camera.

This survey allows precise measurements to be taken, and the building layout and building services installation can be easily viewed.

Figure 62:
Commemorative plaques (top left), view from the north-east corner (top right) and view along the nave (bottom) using the Matterport survey.



6.3 Existing heating systems

Church

The existing heating system is a low temperature hot water system, with radiators and trench heaters. About half of the pews also have electric pew heaters, and there are local electric heaters in the vestry and tower. The radiators were manufactured by the National Radiator Company, which was a subsidiary of The American Radiator Company. They are ornamental three column radiators, likely dating from the early 1900s. Their condition appears

Figure 63:
Column radiator.



reasonable for their age, but the paintwork is chipped in many places. Some valve heads are missing and there was some noise, which could indicate air trapped in the system.

One radiator is positioned directly above the boiler room behind a curtain and so is not heating the church. The radiator at the west end of the church was reported to be not working well. It is recommended that all the radiators are bled to see if air is present in the system. If the performance of the radiator at the west end does not improve, then commissioning is recommended to balance the flowrate through all the heat emitters.

Figure 64:
Panel pew heaters.



The electric pew heaters are predominantly the radiant panel type which are fitted to the rear of the pews. They are unusual in that they have a wooden front panel. This means they are quite discreet (apart from the electrical conduit). The age and manufacturer of the pew heaters are unknown.

These pew heaters are probably near the end of their expected lifespan. When they are turned on, you can feel the heat on your knees when seated. It is, therefore, apparent that they would work well with the radiators and trench heaters. It was possible to keep your hand on the pew heaters, thus indicating that their surface temperature was not hot enough to cause burns.

The main church area has five trench heaters, with decorative grilles in various sizes. There is a good variety of heat emitters, which generally suit their current locations. The glazed lobby at the main entrance enhances the effectiveness of the heating system. It helps reduce heat loss and, combined with the trench heaters, improves the comfort of the congregation. It is a good example of what is possible in a Grade I-listed church.

Figure 65:
Glazed entrance lobby
(left) and trench heater
(right).



The oil-fired boiler is in a basement plant room, accessed via an external staircase. It was installed in 2018. The oil tank is located on the northern site boundary between the church and the school. It is installed on a concrete base and there is no screening. The external oil pipework runs below ground between the tank and plant room.

Heating pipework is distributed at low level and within the floor, making use of the grille-covered floor trenches.

The boiler flue is unusual in that it terminates approximately 305mm above ground level. This results in a visible plume at low level in the churchyard. Debris was found in the flue terminal due to the upward-facing flue termination. Although this flue termination is unusual, it meets the minimum height requirement (300mm above ground) stated in the Building Regulations Approved Document J.

There does not appear to be any fresh air provision for combustion because the boiler room is not ventilated and the flue is not concentric. This is a statutory requirement, and it should be investigated by a competent heating engineer at the earliest opportunity.

Figure 66:
Boiler flue termination
(left) and flue plume
(right).

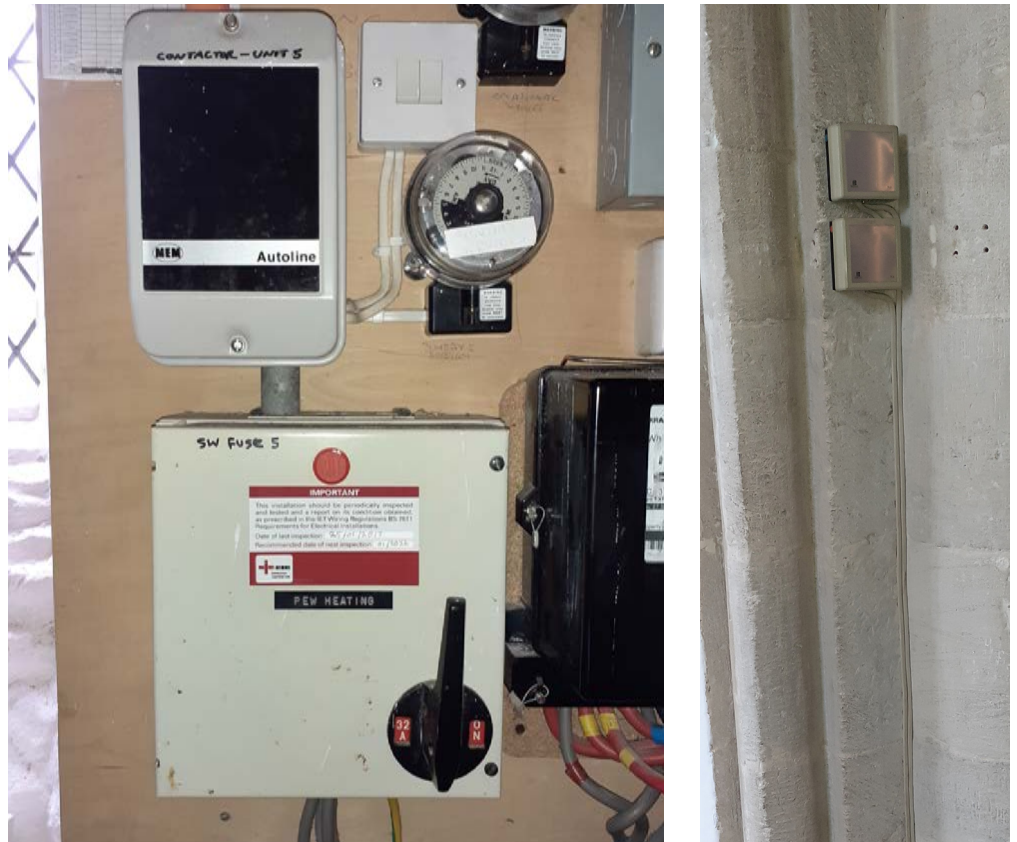


The lack of ventilation may be the cause of the deposits that have blackened the distribution board (Figure 67). This electrical equipment is positioned above the oil burner. An alternative location for the electrical installation is recommended to avoid damage from overheating.

Figure 67:
Boiler room electrical installation.



Figure 68:
Pew heater power and control (left) and
thermostats (right).



The pew heaters are controlled using a timeclock in the tower.

There are two adjacent thermostats for the low temperature hot water system and heating system. They are presumed to be a room thermostat and a frost thermostat. The heating programmer is in the vestry. There appears to be a wireless thermostat above a radiator near the altar. If this thermostat is connected to the main heating system, it should be moved away from any heat emitters.

The existing chimney and available space for a solid fuel store suggest that the church used to be heated by a solid fuel-fired furnace, which would have provided heat via the ventilated trenches (effectively acting as a trench heater).

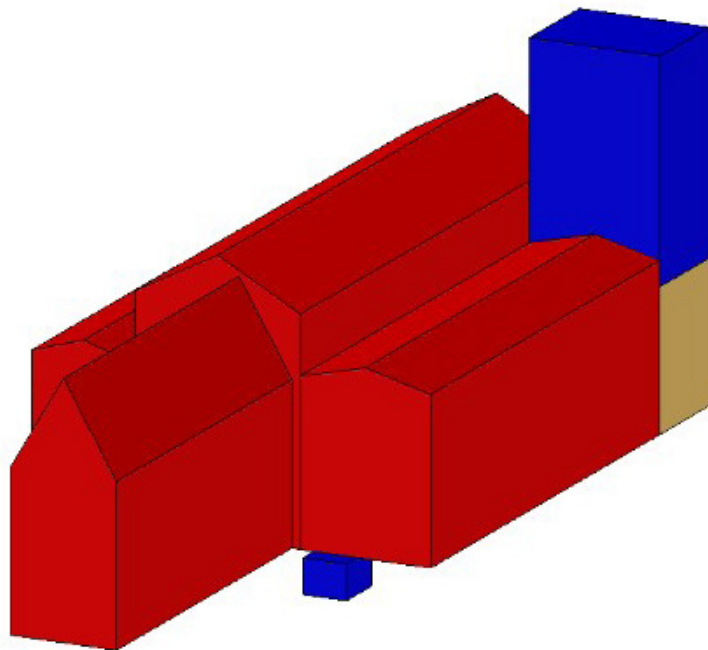
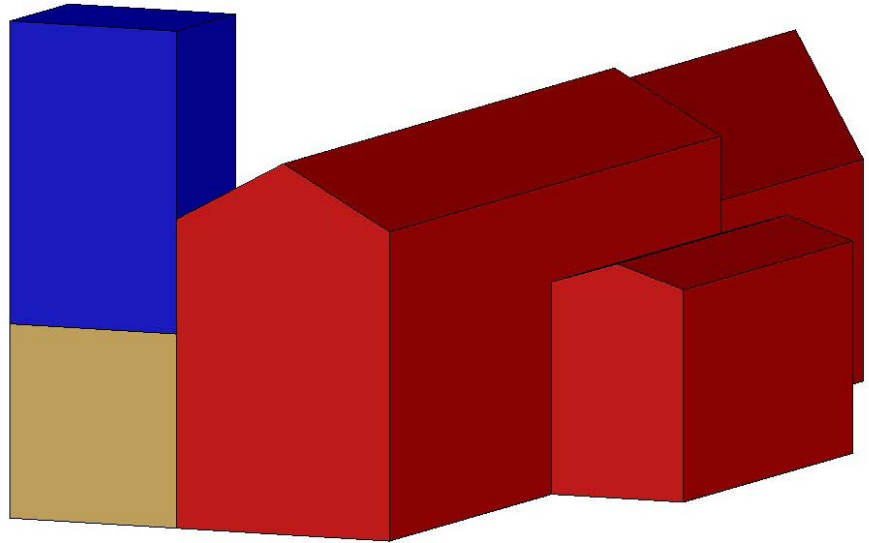
The heat loss for the church is estimated to be 114.5kW, which is significantly above the 44kW capacity of the existing oil boiler. This heat loss estimate has been determined using a rule of thumb calculation. Detailed heat loss calculations should be carried out at the project design stage. The heat provided by the existing boiler is 14W/m^3 , which is markedly below the typical heat loss of 30W/m^3 for a general building. (Boushear, M (ed) 2001 Rules of Thumb (3rd edition). BSRIA TN15/2001.)

From design experience, the typical heat losses for churches are in the range of 35 to 50W/m^3 . Some of this shortfall can be explained by the use of pew heaters and other wall-mounted electric heaters, which could be providing up to 14kW of supplementary heating.

However, the heat provided by the heating system is only 18.1W/m^3 when the supplementary electric heaters are considered. The church advised that the existing heating system works fairly well.

Figure 69 shows the areas heated by the oil-fired heating system in red and the unheated areas in blue. The orange area of the tower is heated by an electric heater.

Figure 69:
Heated and non-heated
areas of the church.



School

The school is heated by a low temperature hot water system, with an equal number of radiators and fan convectors. The three largest rooms are teaching spaces. These are heated by high-level, wall-mounted fan convectors, with the heated air being directed downwards. The classrooms have relatively high ceilings, at around 4.5m, and the school uses ceiling-mounted fans as a method of destratification (to ensure that the temperature has less variation at different heights).

Figure 70:
Fan convectors in a
classroom.



Fan convectors were probably installed because there is limited wall space available. The oil-fired boiler provides the heat for the low temperature hot water system, which is distributed around the school in copper pipework. It is located in a small external plant room, which opens onto the playground. There is no ventilation provision in this plant room, to help prevent overheating. However, the flue appears to be similar in form to a room-sealed concentric flue, so air for combustion is likely to be provided.

Figure 71:
Boiler room.



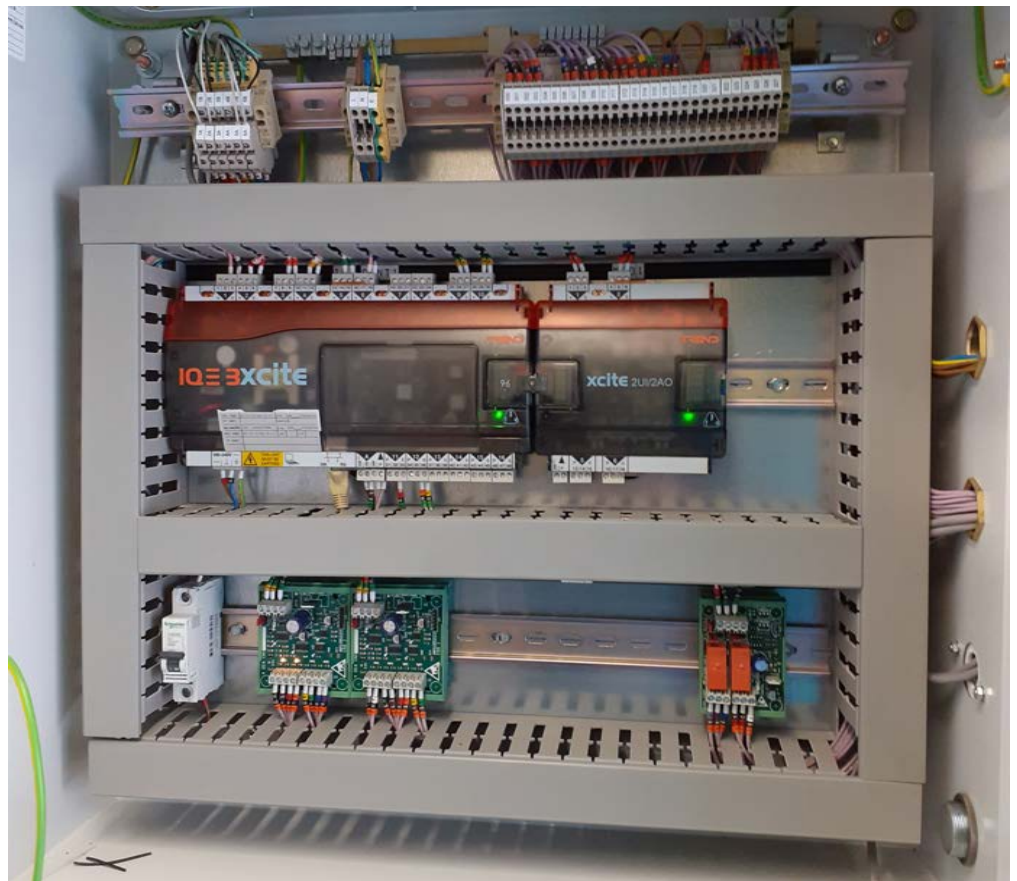
It is recommended that permanent natural ventilation is provided to ensure compliance with Building Regulations Approved Document J and British Standard BS 5410-3:2016.

The bunded oil tank sits on the site boundary, adjacent to the pupil entrance and surrounded by a secure fenced enclosure. It is clear that the oil supply pipe is installed below ground across the playground.

Hot water is provided by local electric water heaters.

There is a modern Trend IQ3 building management system installed, which appears to have a small amount of spare capacity.

Figure 72:
Building management
system.



The boiler capacity is 70kW and the estimated heat loss for the school is 51.5kW. This heat loss estimate has been determined using a rule of thumb calculation. Detailed heat loss calculations should be carried out at the project design stage.

It should be noted that the heat required by fan convectors is often above that required for space heating. This would explain the difference between the existing boiler capacity and the estimated heat loss.

6.4 Energy consumption and utility supply

Oil for the church site

The existing oil tank is bunded and has a capacity of 2455l. There is no oil meter, but oil is typically supplied in four or five annual deliveries. The average amount of oil delivered over the past three years is 7101l per year. This is equivalent to 76,384kWh of annual fuel consumption. Note that this figure relates to the combustion of oil, and the actual heat provided by the heating system will depend on the plant and system efficiencies. The calculated annual energy consumption for the heating system is 70,535kWh.

Figure 73:
Oil tank.



Assuming that the delivery amount is similar to the actual oil consumption, this equates to annual carbon dioxide emissions of 21,020kg. These emissions are for the fuel that supplies the heating system only. The oil boiler does not generate hot water and there are no other oil-fired appliances.

Electricity for the church site

There is a three-phase supply, which enters the church tower through the wall. The size of the fuse housings is unknown. There are two single-phase distribution boards in the tower: DB1 has a 63A main switch and DB2 has a 100A main switch. The pew heaters are supplied by a three-phase distribution board, DB5, which is located in the vestry and has a 100A main switch. DB3 is a single-phase distribution board, with a 63A main switch. It is located behind the organ. The basement boiler room has a single-phase distribution board, DB4, which has a 100A main switch. There is also a single-phase distribution board with a 100A main switch in the external WC building. The locations of the distribution boards are shown in Figure 75.

The electricity consumption is known for the past three years, and the average annual consumption is 5747kWh. This equates to annual carbon dioxide emissions of 1374kg for the church's electricity consumption.

Figure 74:
Electrical cut out and fuse
 housings.



Figure 75:
Power distribution layout
© Church of St Mary,
Bibury.

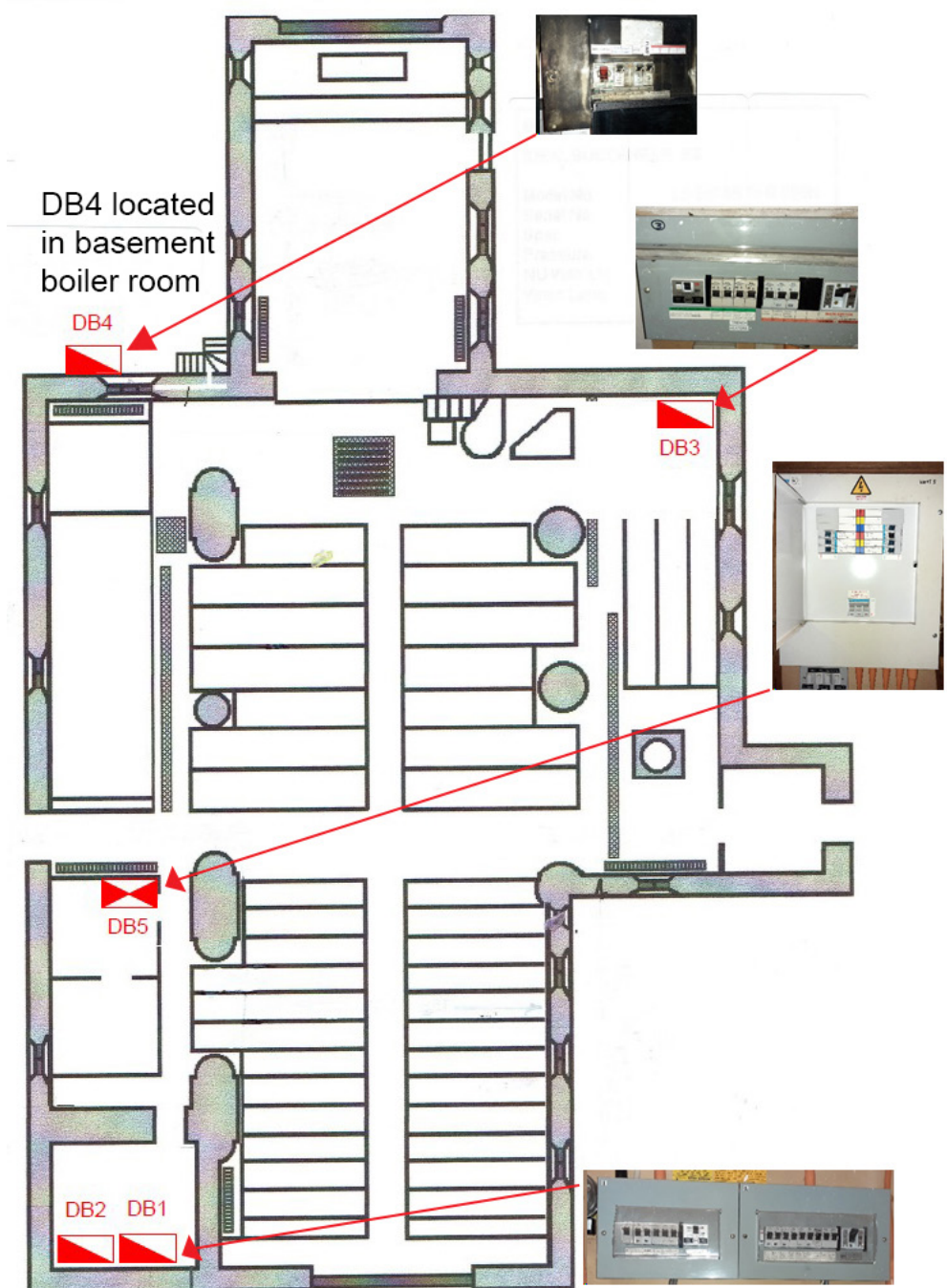


Figure 76:
Existing annual fuel
consumption.

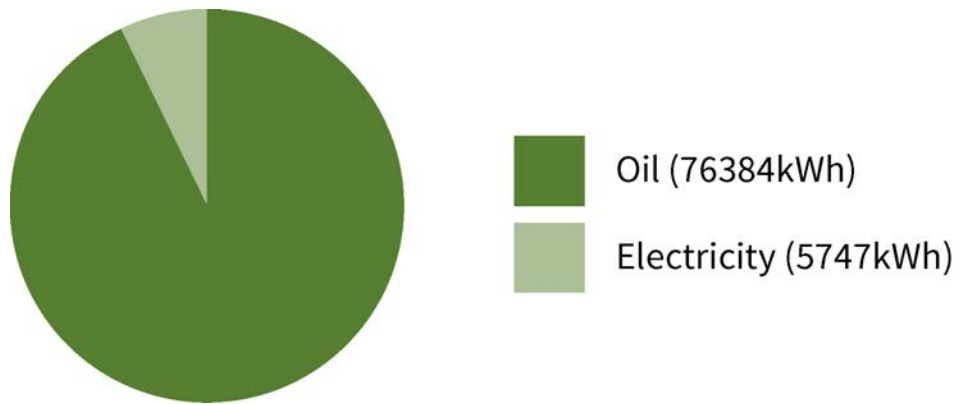
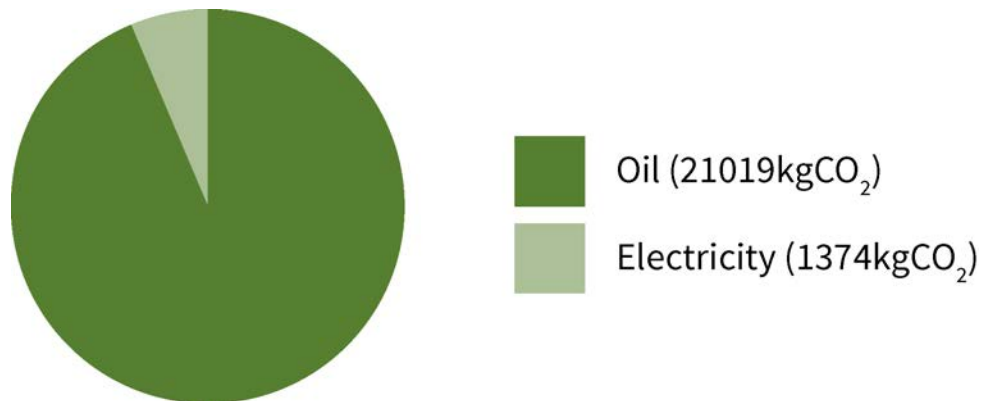


Figure 77:
Existing annual carbon
dioxide emissions.

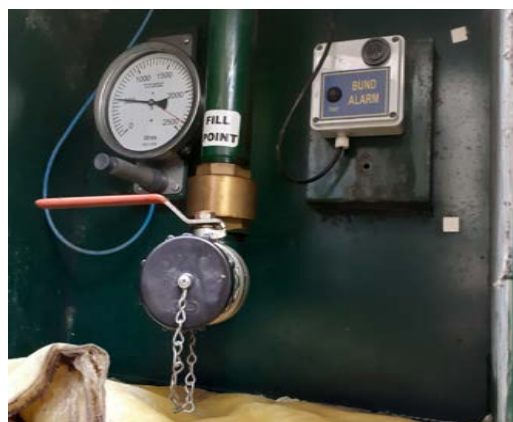


Figures 76 and 77 show that the energy consumption and carbon dioxide emissions are significantly affected by using oil to provide heating in the church. In this analysis, oil consumption for the heating system is 93 per cent of the total energy consumption of the church.

Oil for the school site

The existing oil tank is bunded and the installation has a bund alarm. During the survey, the oil gauge indicated a volume of 500l, with a capacity of 2500l. The average amount of oil consumed over the past two years is 2804l per year. This is equivalent to 30,164kWh of annual fuel consumption. Note that this figure relates to the combustion of oil, and the actual heat provided by the heating system will depend on the plant and system efficiencies. The calculated annual energy consumption for the heating system is 27,855kWh.

Figure 78:
Oil tank gauge.



Assuming that the delivery amount is similar to the actual oil consumption, this equates to annual carbon dioxide emissions of 8301kg. These emissions are for the fuel that supplies the heating system only. There are no other oil-fired appliances.

Electricity for the school site

There is a 400V three-phase supply, with 100A fuse housings, which enters the store room at high level through the external wall. In an adjacent store room, there is a high-level cupboard that contains four distribution boards. DB/P1 and DB/H1 are three-phase distribution boards, with 100A and 125A main switches, respectively. DB/SD and DB/P2 are single-phase distribution boards, with 100A main switches.

Figure 79:
Distribution boards.



In the outside store, there is a single-phase distribution board, DB/P5, which has a 63A main switch that is supplied from DB/P1. DB/P4 is a single-phase distribution board, with a 100A main switch, located by the staff entrance. It is also supplied by DB/P1.

An electrical load assessment for the school has not been carried out. However, it was noted during the survey that there are a few spare electrical circuits available in some of the distribution boards.

The electricity consumption is known for the past two years. The average annual consumption is 12,019kWh. This equates to annual carbon dioxide emissions of 2873kg for the school's electricity consumption.

Figures 80 and 81 show that the energy consumption and carbon dioxide emissions are largely affected by using oil to provide heating and domestic hot water in the school. In this analysis, oil consumption is 71.5 per cent of the total energy consumption of the school.

Figure 80:
Existing annual fuel
consumption.

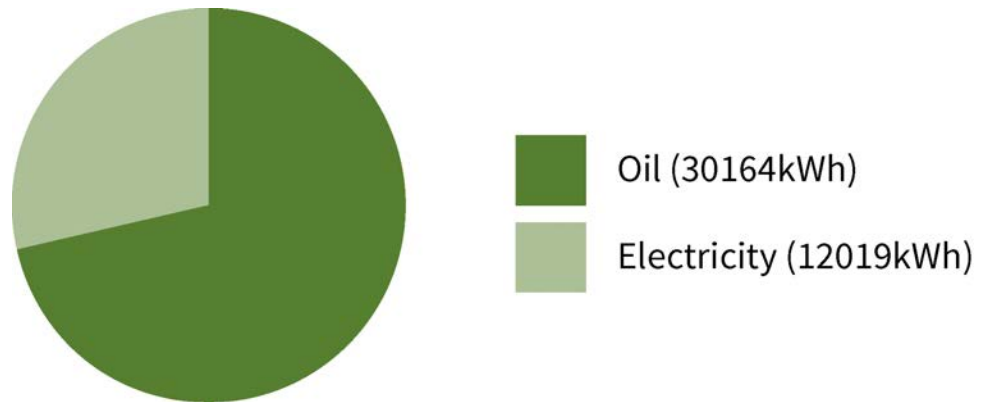
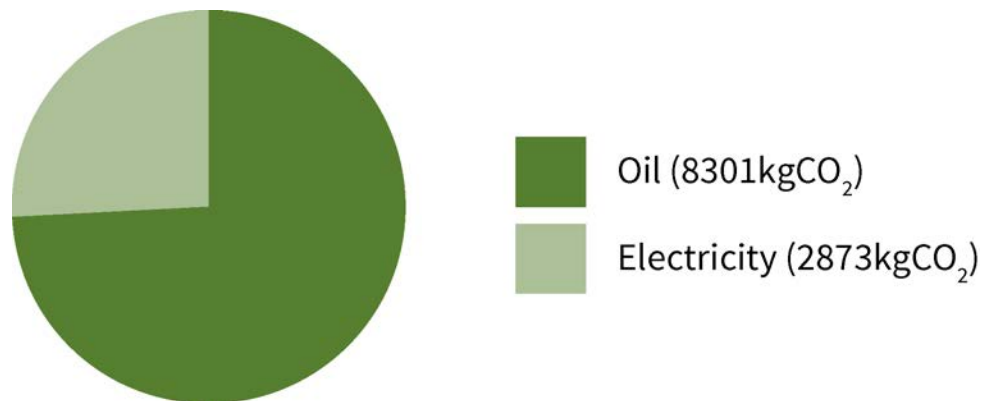


Figure 81:
Existing annual carbon
dioxide emissions.



6.5 Current operation and performance

Church

The church advised that the typical congregation size is around 25 to 30 people and that the heating system works fairly well. From about mid-October onwards, the heating system is switched on for two hours in the morning and two hours in the afternoon. On Sundays, the system operates for a longer period – for the weekly service. The school makes good use of the church for half an hour every weekday morning during term time.

The only reported issue is the radiator at the west end of the church.

The church is interested in removing the pews at the west end. These pews do not have any form of pew heater installed.


School




The school has a typical term-time operation and the heating system is reported to work reasonably well. The classrooms are described as cold and taking a long time to reach the desired room temperature. Using ceiling fans improves the room temperature. The slow response time is unexpected for fan convectors. Consequently, a commissioning exercise is recommended to include a review of the fan convector sizes. There are aspirations to improve the performance of the heating system, with a focus on energy efficiency.


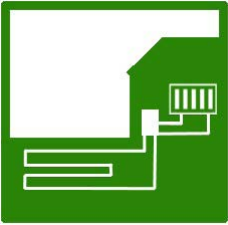
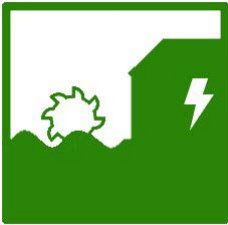
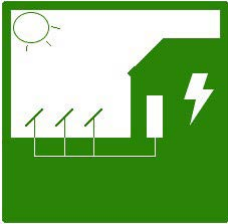
6.6 Heating system options and viability

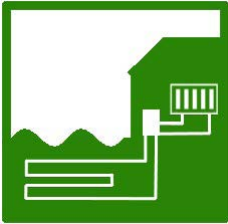

Before doing any detailed calculations, this assessment of the technologies was carried out to first consider the suitability of the site for them. This was at a level where it was considered if the technology was technically and practically possible. Photovoltaics, hydroelectricity and wind power were also considered in addition to assessing the heating technologies.

Table 9:
Technology viability
appraisal.

Technology	Site viability assessment	Viable?
Air source heat pump 	Church An external air source heat pump could be located in a screened area, in place of the existing oil tank. Alternatively, it could be closer to the church, at the site boundary to the east or immediately outside the plant room. This option might involve buried heating mains, depending on the plant location. For cost purposes, it is assumed that the heat pump is located by the plant room. The acoustics need to be considered. New or additional heat emitters would be required.	✓
	School An external air source heat pump could be located either in the playground or in place of the existing oil tank. The air source heat pump could be fenced and screened. The acoustics need to be considered. New or additional heat emitters would be required. This technology would not be compatible with the existing fan convectors.	✓

Technology	Site viability assessment	Viable?
BioLPG	Church The current boiler room is below ground and there is no alternative location at the church. LPG boilers cannot be located below ground level.	X
	School An external LPG tank could be located either in the playground or in place of the existing oil tank. The LPG tank could be fenced and screened. This technology is compatible with the existing heat emitters. Note: 100% BioLPG is not currently available in this region. This could change in the future.	?
Biomass	Church There is no suitable location for the flue. The current oil boiler flue terminates at a very low level (305mm above ground level), and this is not suitable for biomass technology. Fuel delivery is not easy to facilitate because of the distance from the road to the plant room.	X
	School This technology could be installed if the fuel store is located in the playground. However, there are a number of significant disadvantages to using biomass at the school, as outlined below: <ul style="list-style-type: none"> ■ The boiler room would likely need to be increased in size to accommodate a biomass boiler. ■ The location of the boiler room is adjacent to a private residential property and playground. The local air quality would be negatively impacted by this technology at this location. ■ Fuel delivery would need to cross the playground, and safe access during school hours would not be available. 	X
Electric boiler	Church This technology could be installed if there is sufficient electricity available. An electric boiler could be installed in the existing boiler room. The boiler room requires general natural ventilation, which will assist with overheating. Surfaces need to be cleaned and may need local repairs.	✓
	School This technology could be installed if there is sufficient electricity available. An electric boiler could be installed in the existing boiler room. The boiler room requires general natural ventilation, which will assist with overheating.	✓

Technology	Site viability assessment	Viable?
Electric heating	Church Direct electric heating is possible. There is space available for small pew heaters as the existing pews are fixed. There would be a significant shortfall in the heat required even if pew heaters were installed in all of the pews. This shortfall could be overcome by installing wall-mounted electric radiators, electric fan convectors and electric trench heaters.	✓
	School Direct electric heating is possible using electric radiators and electric fan convectors.	✓
Ground source heat pump	Church Underfloor heating would be required with this technology. The fact that the church is used intermittently is not a good fit for this type of heating system. There is nowhere to install a ground collector within the church site. However, if the school were to install an adequate ground collector in the playground area, it is technically possible for both buildings to have a heat pump installed, connected to a shared ground collector.	?
	School Underfloor heating would generally be required with this technology. Some smaller spaces could be heated by radiators. The playground is the only area on the school site where a ground collector could be installed.	?
Hydroelectric power	Church/School No suitable water course at this site. The River Coln is approximately 40m due south of the church site. However, this is shallow and has a gentle current.	X
		
Photovoltaics	Church/School May not be possible at either site. The only location available for a photovoltaic array is on the roofs of both buildings. Space for battery storage would be required because the peak solar irradiance will not always coincide with the demand for heating or other non-heating electrical usage.	?
		

Technology	Site viability assessment	Viable?
Water source heat pump 	Church/School No suitable water course or lake at this site. The River Coln is approximately 40m due south of the church site. However, this is too shallow.	X
Wind turbine 	Church/School Planning would likely be an issue. The church is Grade I listed and the school is Grade II listed. Bibury village is located in the Cotswolds Area of Outstanding Natural Beauty and the conservation area of Bibury.	X

Financial and environmental analysis

Air source heat pumps are likely to be the most viable heating option for both the church and the school.

Although it is technically possible to heat both buildings using ground source heat pumps, the costs associated with replacing a large amount of the floor in both buildings to install underfloor heating makes this option less favourable.

Similarly, it is technically possible to install photovoltaic panels on the roofs of both buildings. A detailed feasibility assessment for this technology has not been carried out due to the planning permissions required for this installation.

Tables 10 and 11 consider electric heating and electric boilers, which are technically possible in both buildings. The existing heating system could be used with an electric boiler, but there does not appear to be sufficient existing heat emitters in the church to provide a good level of thermal comfort.

The comparison of the viable technologies is based on the current average annual heating energy consumptions for each building. For the church, this is 70,535kWh. For the school, it is 27,855kWh. The option to provide local electric heating in the form of pew heaters has been included for the church to allow a comparison to be made between heating the church for thermal comfort and providing a level of localised heating. (Appendix B explains this type of heating in more detail.)

The financial and environmental data shown in Tables 10 and 11 have been determined using detailed calculations. There are a large number of referenced endnotes, which should be read in conjunction with this data.

Table 10:
Heating technology
comparison for the church.

Technology	Estimated annual emissions (kgCO ₂)	Estimated annual fuel cost ¹	Estimated capital cost ²	Heating system capacity ³ (kW)
Existing oil fired boiler	21,019	£6925	n/a	44 (58kW including the existing electric pew heaters)
Air source heat pump	6743 ⁴	£7900 ⁵	£158,077 ⁹	127.8
				
Electric boiler	16,858 ⁴	£19,750 ⁵	£80,826 ⁹	120
				
Electric heating	16,858 ⁴	£19,750 ⁵	£45,166 ^{12,9}	114.5
				
Local electric heating (pew heaters)	3321 ⁴	£3891 ⁵	£22,800 ¹³	22.5

Table 11:
Heating technology
comparison for the school.

Technology	Estimated annual emissions (kgCO ₂)	Estimated annual fuel cost ¹	Estimated capital cost ²	Heating system capacity ³ (kW)
Existing oil fired boiler	8301	£2735	n/a	70
Air source heat pump 	2663 ⁴	£3120 ⁵	£84,804 ¹¹	51.5
Electric boiler 	6657 ⁴	£7799 ⁵	£10,994 ¹¹ Heating plant only £55,061 ¹¹ Heating plant and new heat emitters/ distribution pipework	60
Electric heating 	6657 ⁴	£7799 ⁵	£22,744 ¹¹	51.5

6.7 Recommendations

Church

Electric heating or air source heat pumps are the recommended heating solutions for the Church of St Mary, Bibury. As the national grid decarbonises, these proposals will allow the church to be net zero carbon by 2050. It would also be possible for the Church of England's 2030 net zero carbon target to be achieved if a green electricity tariff is available.

The high capital cost for the air source heat pump option is not favourable, unless you also consider the estimated annual fuel costs. A simplified payback model, which does not consider inflation or future fuel costs, shows that air source heat pumps will payback in 9.5 years when compared with the electric heating option. The expected working life of a well-maintained heat pump is 15 years. (CIBSE 2014 Guide M: Maintenance Engineering and Management.)

Consequently, over the longer term, this is the most financially viable heating option. There are currently no grants available for heat pump installations in churches, but this could change in the future.

School

All of the technologies provide a zero carbon heating option for the school if a green electricity tariff is used. The recommendations are similar to the church in that electric heating or air source heat pumps are the most viable options. The simplified payback for the air source heat pump in the school is, however, longer – at 13.3 years – when compared with the electric heating option. This is still within the 15 years expected working life of a well-maintained heat pump.

Before considering these options in full, it is recommended that an electrical load assessment is carried out for the school site. Quotations should be obtained for any electricity supply upgrades that are required.

Figure 82:
Church of St Mary notice
board (left).



Figure 83:
School sign (right).



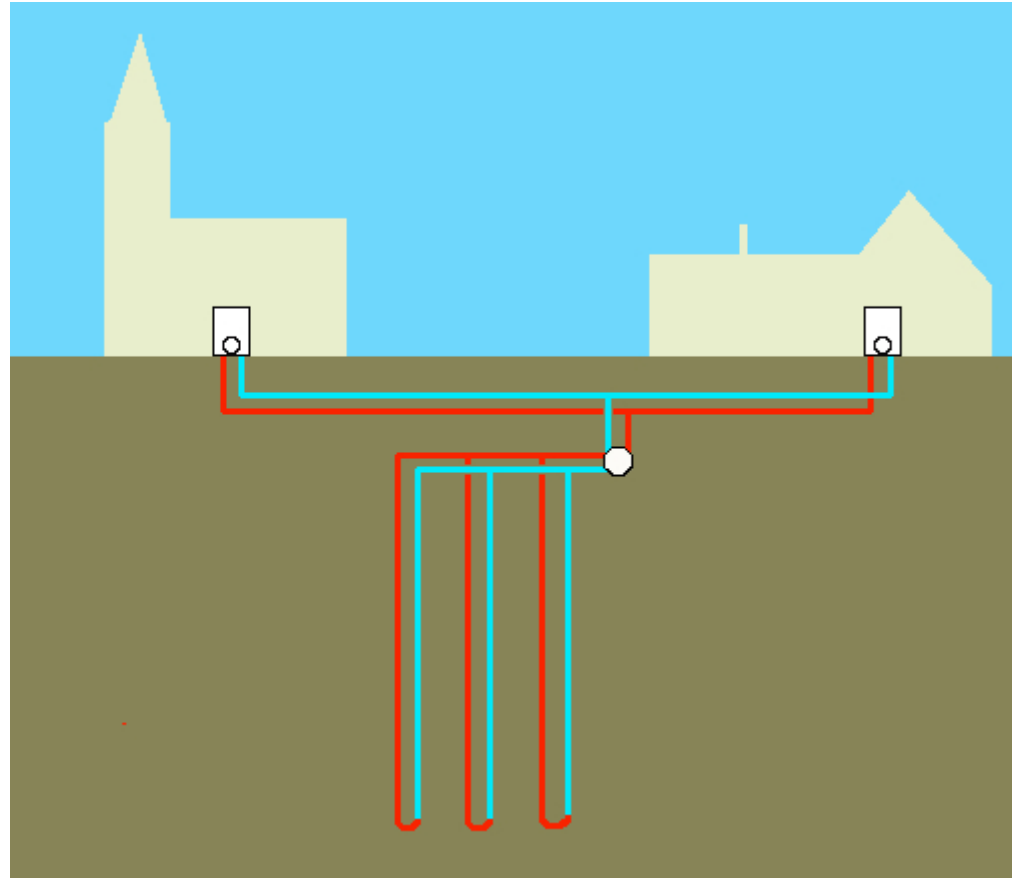
One low carbon heating technology that could be effectively shared across both sites is ground source heat pumps. A shared ground collector would need to be installed in the playground.

This option is appealing from a technical and community perspective. However, it involves a significant amount of capital investment, as outlined below:

- Underfloor heating is required for this technology. In the church, underfloor heating would only be viable if there were a major reordering, to include replacing the floor. Note that the church would also need to be used more by the community throughout the week for this type of heating to be effective.
- The floor would need to be replaced within the majority of the school building.
- A ground collector would need to be installed and the playground resurfaced.
- Groundworks would be needed along a suitable route to connect the ground collector to the church.

This option should only be explored further if there are significant building works planned for both sites.

Figure 84:
Typical community
ground source heat pump
diagram.



7

Comparison of existing energy consumption and heating capacity

Section 7 details each church's current energy consumption and the heating capacity of their existing systems. The purpose is to learn more about the energy performance of historic churches. The energy performance of the schools has not been appraised, because only two sites were visited and one of the schools used its oil fired-boiler for indirect domestic hot water generation.

Table 12:
Churches' existing energy consumption.

Church	Average annual oil consumption			Average annual electricity consumption		Estimated amount of electric heating (kW)
	(kWh)	per unit floor area (kWh/m ²)	Per unit volume (kWh/m ³)	(kWh)	Per unit floor area (kWh/m ²)	
Daglingworth	10,102	65.4	10.5	280	1.8	1
Bisley	31,177	75.2	10.7	4701	11.3	5
Poulton	19,454	76.3	10.4	526	2.1	0
Bibury	76,384	208.6	23.8	5747	15.7	14
Average	34,279	106.4	13.9	2814	7.7	5

The electricity consumption of each church varies widely. One reason for this variation is likely to be the amount of electric heating that is installed in each church. The Church of St Mary, Bibury has a large number of electric pew heaters and the Church of All Saints, Bisley has electric heating installed at two floor levels in the tower.

The oil consumption is reasonably consistent per unit area and volume for three of the churches. The Church of St Mary, Bibury, is the exception, using considerably more oil. This could be because this church is occupied on most days.

Based on a typical heating season and how often each church is occupied, the oil consumption per unit area for every hour of operation can be estimated.

Table 13:
Churches' existing oil consumption for every hour of operation.

Church	Average annual oil consumption per unit floor area and every hour of operation (kWh/m ² h)
Daglingworth	0.179
Bisley	0.144
Poulton	0.313
Bibury	0.252
Average	0.222

Table 13 demonstrates that the Church of St Mary, Bibury, has the highest oil consumption because it is used more than the other churches. If the oil consumption for this church had been the highest for every hour of operation then this conclusion could not have been made. The Church of St Michael and All Angels has the highest oil consumption for every hour of operation. This reflects the fact that this church received the most positive feedback regarding the performance of its existing heating system (Table 14).

Table 14:
Churches' existing heating system capacity.

Church	Existing heating system capacity			% of estimated heat loss	Church feedback on heating performance
	(kW)	Per unit floor area (kW/m ²)	Per unit volume (kW/m ³)		
Daglingworth	41.0	265.3	42.7	94.7	Slow response
Bisley	65.0	156.8	22.4	59.2	Slow response/ poor comfort
Poulton	58.6	229.8	31.5	89.9	Works very well
Bibury	58.0 ⁱ	158.4	18.1	50.7	Works fairly well
Average	56.0	202.6	28.7	73.6	

ⁱ This capacity includes an estimated 14kW of electric pew heating in addition to the 44kW oil-fired boiler.

The Church of All Saints, Bisley, has the lowest oil consumption per unit area for every hour of operation. Similarly, this reflects the fact that this church received the most negative feedback regarding the performance of its existing heating system (Table 14).

Table 14 shows that the existing heating system capacities for the churches in Daglingworth and Poulton are similar to the estimated heat loss calculations. The negative feedback regarding the performance of the existing heating system at the Church of All Saints, Bisley, is reflected by the existing boiler only being able to deliver 59.2 per cent of the estimated heat loss. The unexpected finding is that the existing heating system at the Church of St Mary, Bibury, is reported as working fairly well but it also provided the lowest percentage of the estimated heat loss.

8

General observations

Section 8 outlines some of the observations resulting from this research, which do not relate to the scope.

8.1 Boiler capacity and fuel consumption

Half of the churches surveyed were found to have existing boiler capacities that are significantly below the estimated heat losses calculated for each church (see Section 7). This is important to note because it provides an insight into the link between how the existing heating systems performed and the size of the existing boilers.

A comparison of the existing fuel consumption and associated carbon dioxide emissions shows that the oil used by the heating systems had the most significant impact in all of the churches. This was expected and justifies the scope for this research. Electricity use had a much smaller impact on the overall energy consumption and associated carbon dioxide emissions.

Table 15:
Existing fuel consumption.

Church	Fuel consumption as a proportion	
	Oil	Electricity
Daglingworth	97.3%	2.7%
Bisley	86.9%	13.1%
Poulton	97.4%	2.6%
Bibury	93.0%	7.0%

8.2 Pipework insulation

Uninsulated heating pipework used by heating systems that have oil-fired boilers will typically emit between 50 and 200W of heat for every metre of exposed pipework. For reference, a typical radiator output will be between 1500 and 3000W.

The annual cost of heat wasted by uninsulated pipework can easily reach hundreds of pounds. The quality of thermal insulation to the heating pipework and plant within the church boiler rooms was varied. In some churches, the insulation was incomplete, in poor condition or non-existent. The notable exception was the Church of All Saints, Bisley, which had nitrile insulation. The Church of St Mary, Bibury, had lengths of well-insulated pipework. However, the valves and heat exchanger at this site would benefit

from insulation. Although the heat loss from uninsulated pipework in boiler rooms is relatively small when compared with the boiler capacity, this is wasted heat that can easily be avoided. It is relatively cheap to rectify.

Figure 85:
Uninsulated pipework.



8.3 Sensors and controls

Only half of the churches had plug-in remote oil tank sensors. These low-cost ultrasonic sensors monitor the amount of heating oil stored in the tank. They can facilitate the financial planning of future oil deliveries until the existing heating systems are replaced.

All of the oil tanks at the churches and associated buildings were bunded to protect the environment against oil leaks.

Both of the Church of England schools had reasonably modern Trend building management systems to control the heating. However, the churches had domestic heating controllers with timeclocks. There was no difference in heating system complexity or zoning that would explain these contrasting levels of controls. It is possible that the schools benefit from a local authority requirement for control systems to have fault signals, improved standards of installation and remote connectivity.

Figure 86:
Oil tank sensor.



The churches and schools provided utility bills, answered questionnaires and gave access for surveys. Historic England is grateful for their engagement with this research and is interested in being updated as the oil-fired heating systems are replaced.

9

Conclusion

All of the historic buildings surveyed have low and zero carbon heating options that would allow the 2030 net zero carbon target set by the Church of England’s General Synod to be achieved. Perhaps the biggest challenge is the scale of the work required and the associated financial considerations, considering that the Church of England has more than 16,000 church buildings in England.

Below is a summary of the recommended heating technologies for the historic buildings surveyed in this research. These recommendations consider the use of the building, as outlined in each of the case studies.

Table 16:
Recommended heating technologies.

Building	Recommended heating technology	Other viable heating technologies
Church of the Holy Rood, Daglingworth	Electric heating	None
All Saints Bisley	Electric heating	None
Bisley Blue Coat C of E Primary School	Biomass	Air source heat pump
St Michael and All Angels, Poulton	Biomass	Electric heating Electric boiler
St Mary’s Church, Bibury	Air source heat pump	Electric heating
Bibury C of E Primary School	Air source heat pump	Electric heating

The key observation is that no single heating technology is recommended for all of the buildings or even for each building type. In this small sample of historic buildings, there is an equal split between air source heat pumps, biomass and electric heating. This highlights the need to carry out a detailed technical feasibility study at the early concept stage of a project involving the replacement of a heating system in a historic building.

The recommended heating technology was influenced by many factors, including the building’s site, location, size and form; the use and operation of the building; the condition of the existing heating system; and the existing utility infrastructure. The heating options for the church at Daglingworth were impacted by the lack of a mains water supply and the associated costs of providing one.

From a technical perspective, a good design engineer always aims for the most efficient use of any fuel. Air source heat pumps use electricity effectively to generate heat, but come with a high capital outlay for the plant. For this reason, air source heat pumps were not recommended for the

church at Bisley. However, the technology was recommended for the church at Bibury because the building is used regularly throughout the week and, therefore, consumes a large amount of energy.

It is hoped that as the market for heat pumps develops in the UK, the cost of air source heat pumps will become more competitive and this technology will become a financially viable option for more historic buildings. Rising fuel prices also help tip the balance in favour of energy-efficient heat pumps. Indeed, since the start of this research, the price of heating oil has doubled. As a result, the need to move away from using heating oil as a fuel is being driven by both financial and environmental considerations.

Biomass would have been a viable option at more sites if they had had space to locate the boiler room and a flue location which would not adversely impact local air quality.

All of the historic buildings investigated have the potential to be net zero carbon. The associated carbon dioxide emissions saved by moving away from heating oil are shown in Table 17.

Table 17:
Potential carbon dioxide emission savings.

Building	Estimated annual carbon dioxide emissions savings (kgCO ₂)
Church of the Holy Rood, Daglingworth	2780
All Saints Bisley	8579
Bisley Blue Coat C of E Primary School	20,824
St Michael and All Angels, Poulton	5353
St Mary's Church, Bibury	21,019
Bibury C of E Primary School	8301

To put these emissions in context, the Department for Transport reported that for 2020, the average carbon dioxide emissions per car in the UK were 0.2214kg per mile. Therefore, 1000kgCO₂ is equivalent to 4517 miles of car journey. Table 17 shows no correlation in emissions for all of the buildings or for each building type. The average potential carbon dioxide emissions savings for the churches investigated is 9433kgCO₂.

The type of existing electricity supply was considered to see if it affected the recommendations. The cost of upgrading the electricity supply, where required, for the different heating options varied from £211 to £16,944. This was influenced by the type of existing supply cable, the amount of cable being replaced (where applicable) and the installation method (above or below ground). Despite the range of upgrade costs, this did not significantly influence the recommended heating technology.

Table 18 shows that three churches have very similar costs for air source heat pump heating per unit floor area. This demonstrates that the estimated costs are not significantly influenced by the type of existing electricity supply for this small sample of churches.

Table 18:
Air source heat pump
costs and type of electrical
supply.

Building	Type of existing electrical supply	Estimated cost for ASHP heating	Cost per unit floor area (£/m ²)
Church of the Holy Rood, Daglingworth	Category C - single phase Existing 3 phase supply cable with one phase connected	£67,554	437
All Saints Bisley	Category C - single phase Existing 3 phase supply cable with one phase connected	£186,079	449
St Michael and All Angels, Poulton	Category C - single phase Existing single phase supply cable	£95,784	376
St Mary's Church, Bibury	Category B- three phase Existing 3 phase supply cable with three phases connected	£158,077	432

The heritage risks of the different renewable and alternative technologies have been appraised in Appendix A. None of the recommended heating technologies present a significant risk to heritage.

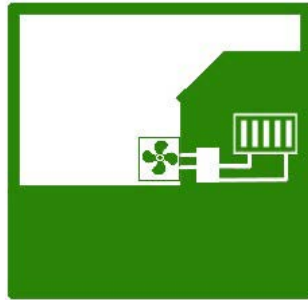
The full scope of the research as outlined in Section 2 could not be achieved because the four categories of church requested by Historic England were not represented. It was only discovered during the surveys that three churches were Category C and one was Category B. As a result, there are no Category A or Category D churches included in our study. This has not significantly affected the outcomes of the research, but the scope has been slightly reduced.

We propose to repeat this study for another diocese and investigate more historic buildings. This will enhance the findings of this research and provide more insight into its conclusions. The reference data in Section 8, regarding the performance of existing heating systems in historic churches, will also be broadened, which will, in turn, increase its usefulness.

Appendix A: Description of renewable and alternative technologies

This appendix describes the available renewable and alternative technologies and provides a high-level appraisal of their advantages and disadvantages. For further reading, refer to Historic England's 'Low and Zero Carbon Technologies' webpage: historicengland.org.uk/advice/technical-advice/energy-efficiency-and-historic-buildings/low-and-zero-carbon-technologies.

Air source heat pump



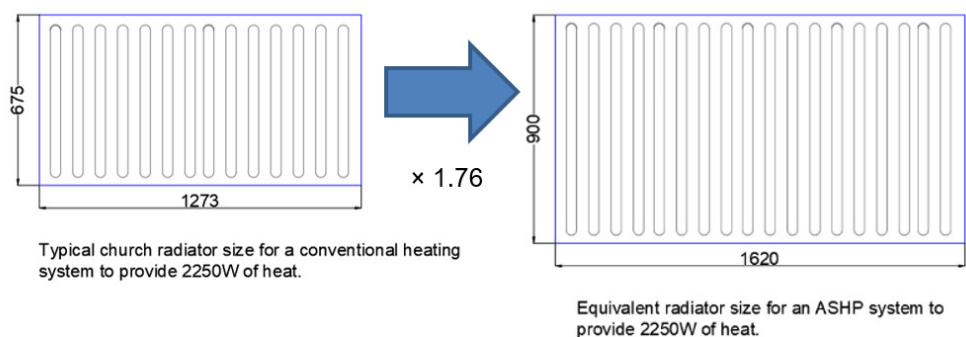
Air source heat pumps (ASHPs) use the low-grade heat from the external ambient air to heat buildings. This is achieved using an electrically powered heat pump.

Before installation, the acoustics of the outdoor unit need to be considered. It is possible to attenuate the external noise using acoustic housings and/or acoustic screens. However, this would incur additional costs.

ASHP technology provides heat at operating temperatures that are ideal for use with underfloor heating systems. It is also possible for ASHPs to be used with warm air systems and larger radiators.

The following example illustrates the limitations of radiator sizes with ASHP technology (dimensions in mm).

Figure 87:
Radiator sizes with air source heat pumps.



A radiator sizing exercise was carried out for a small number of radiators with a similar depth from one manufacturer. On average, radiators for ASHP systems are approximately 76 per cent larger, compared with conventional heating systems. Where it is physically and aesthetically possible to accommodate a deeper triple-panel model, radiators are approximately 55 per cent larger.

Older buildings tend to have a continuous demand for heat during the heating season. This nonstop operation can cause ASHPs to activate their defrost cycle when ice builds up on the external heat exchanger. During the defrost cycle, the ASHP does not provide heat to the heating system. A suitably sized buffer vessel can provide a sufficient thermal store to overcome this issue. Alternatively, the defrost cycle can be accommodated by having some of the heat emitters on permanently with no heating control. However, this could cause discomfort and waste energy.

Historic buildings also experience considerable heat losses, and so the ASHP would often need to operate at a higher than optimum flow temperature. Inevitably, this would reduce the efficiency of this technology.

There are hybrid air source heat pumps available that work with oil-fired boilers. An oil-fired boiler typically operates when the ambient external temperature falls below 10°C. Hybrid air source heat pumps would improve the heating system’s environmental performance and would reduce the overall carbon dioxide emissions, but it is not possible to achieve net zero carbon with this heating technology alone.

For further reading, refer to Historic England’s 'Low and Zero Carbon Technologies' guidance: historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/low-and-zero-carbon-technologies/installing-heat-pumps-in-historic-buildings

Table 19:
Air source heat pump appraisal.

Risk to heritage		LOW
<p>Considerations</p> <ul style="list-style-type: none"> ■ Requires a three-phase electricity supply (single-phase supplies are available for smaller heat pumps up to 14kW heating capacity) ■ Best suited for underfloor heating systems, but can work with larger radiators and fan convectors ■ Suitable external area required for the outdoor unit, which will require a faculty (permission to undertake works in a church building). May be possible to install the heat pump(s) in place of the redundant oil tank ■ Requires internal location for the buffer vessel (where relevant) and associated controls ■ Heating distribution pipework will likely need to be replaced ■ Heat emitters may need to be replaced or supplemented ■ Acoustics for the outdoor unit need to be considered 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ High efficiencies can be achieved, with a SCoP of at least 2.5 ■ No on-site emissions ■ Net zero carbon can be achieved using a green electricity supplier 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Considerable capital cost compared to fossil fuel boilers ■ Underfloor heating is not practical for all churches due to the disruption to the existing floor 	

BioLPG



BioLPG is a low carbon fuel made from a diverse mix of biological feedstocks and processes. It is chemically identical to LPG and as such works with existing LPG plant. BioLPG is an emerging fuel in the UK, and the carbon emission savings are at industry level. As such, they vary depending on the generation source. BioLPG can be purchased from suppliers that offset the carbon dioxide savings using a certification scheme.

Liquid Gas UK is currently working with governmental departments to agree carbon emissions data for the UK market.

For further reading, refer to Liquid Gas UK's 2040 'Vision, Industry pathway to Net Zero' and beyond at: liquidgasuk.org/uploads/DOC5D1B3029E7837.pdf

Table 20:
BioLPG appraisal.

Risk to heritage		LOW above ground tank
		MEDIUM below ground tank
<p>Considerations</p> <ul style="list-style-type: none"> Requires a fuel storage location above or below ground, which will require a facility. May be possible to install the BioLPG tank in place of the redundant oil tank The visual impact of above ground tanks Requires site access for fuel delivery to the fuel store Boiler cannot be located below ground level Carbon emission savings need to be confirmed with the supplier as they will vary according to the fuel source 		
<p>Advantages</p> <ul style="list-style-type: none"> Works with existing LPG plant Will work with the existing heat emitters so can be considered as an oil boiler replacement Has the potential to be a good transitional fuel towards the UK government's 2050 net zero carbon target 	<p>Disadvantages</p> <ul style="list-style-type: none"> Net zero carbon is not possible, but significant carbon savings can be made Not available in all regions. Three LPG suppliers were contacted regarding the supply of BioLPG to this region. Two do not yet offer this fuel and the third typically offers a 40/60 blend of BioLPG/LPG, respectively. This blend has an adverse effect on carbon emission savings 	

Biomass



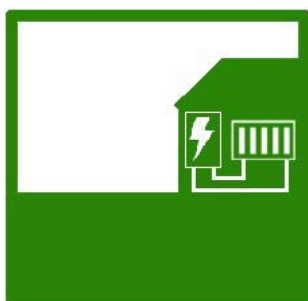
Biomass boilers produce heat by burning wood chip or wood pellets. This results in carbon dioxide emissions and particulates in the products of combustion. For this reason, it can be difficult to obtain planning consent for this technology in urban areas. Biomass technology is considered carbon neutral in that the carbon produced during combustion is offset by the carbon absorbed during tree growth. However, there are still some carbon dioxide emissions associated with transporting the fuel (see Table 1).

during tree growth. However, there are still some carbon dioxide emissions associated with transporting the fuel (see Table 1).

**Table 21:
Biomass appraisal.**

Risk to heritage		LOW
<p>Considerations</p> <ul style="list-style-type: none"> ■ Requires a fuel storage location adjacent to the boiler room; the size of this can be challenging to accommodate and will require a faculty ■ The impact of a new structure to accommodate the plant or fuel storage (where required) would increase the risk to heritage to a medium level ■ Requires site access for fuel delivery to the fuel store ■ Requires internal location for the boiler, buffer vessel and associated controls; the boiler size can be challenging to accommodate ■ Planning permission may consider the local air quality ■ Requires regular cleaning to remove the ash ■ A flue is required to discharge the products of combustion 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ Will work with the existing heat emitters so can be considered as an oil boiler replacement 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ On-site emissions contain particulates ■ There are some carbon dioxide emissions associated with the transportation of fuel 	

Electric boiler

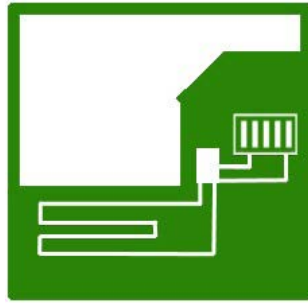


Electric boilers produce heat using electrical elements. Hydraulically, they connect to heating systems in the same way as conventional fossil fuel-fired boilers. Strictly speaking, they are not an alternative or renewable technology. However, if the electricity is provided by a green electricity supplier, then these boilers can operate with zero carbon dioxide emissions. They are less common than conventional boilers due to fuel prices, which, historically, have been high compared with natural gas, LPG and oil.

**Table 22:
Electric boiler appraisal.**

Risk to heritage		LOW
<p>Considerations</p> <ul style="list-style-type: none"> ■ Available power supply will need to be assessed ■ In hard water areas, boilers will need scale protection 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ Will work with the existing heat emitters so can be considered as an oil boiler replacement ■ No on-site emissions ■ No flue installation required ■ Net zero carbon can be achieved using a green electricity supplier 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Less efficient than heat pumps so will have far higher running costs ■ Electricity supplies will usually need to be upgraded due to the high power requirements 	

Ground source heat pump



Ground source heat pumps (GSHPs) use the low-grade heat available from the ground to heat buildings. This is achieved using an electrically powered heat pump. The low-grade heat is provided by solar radiation, which is absorbed by the ground. This heat is taken from the ground using a closed loop ground collector, which can take the form of vertical boreholes or shallow

trenches. There are open loop installations available, but they are less common because they require a licence from the Environment Agency.

GSHP technology provides heat at operating temperatures ideal for use with underfloor heating systems. It is also possible for GSHPs to be used with warm air systems and larger radiators.

The following example illustrates the limitations of radiator sizes with GSHP technology (dimensions in mm).

A radiator sizing exercise was carried out for a small number of radiators with a similar depth from one manufacturer. On average, the radiators for GSHP systems are approximately 181 per cent larger, compared with conventional heating systems. Where it is physically and aesthetically possible to accommodate a deeper triple-panel model, the radiators are approximately 138 per cent larger.

For further reading, refer to Historic England's 'Low and Zero Carbon Technologies' web page:

historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/low-and-zero-carbon-technologies/installing-heat-pumps-in-historic-buildings.

Figure 88:
Radiator sizes with GSHPs.

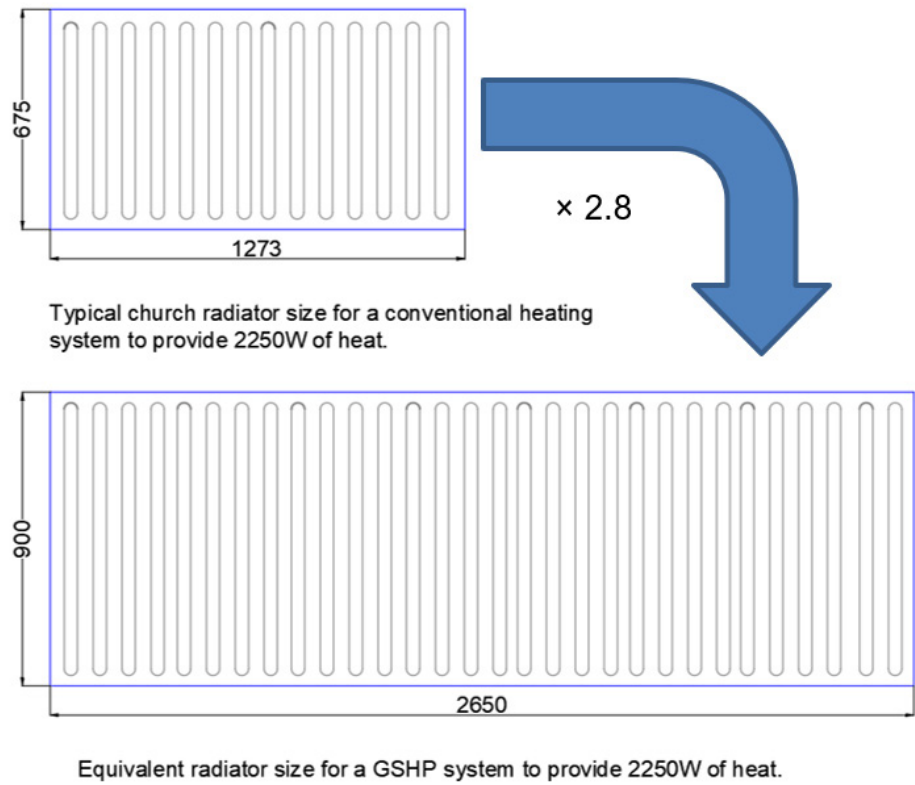


Table 23:
Ground source heat pump appraisal.

Risk to heritage		MEDIUM
<p>Considerations</p> <ul style="list-style-type: none"> ■ Requires a three-phase electricity supply (single-phase supplies are available for smaller heat pumps up to 13kW heating capacity) ■ Best suited for underfloor heating systems which is not practical for all churches due to the disruption to the existing floor ■ Requires suitable external area for boreholes or shallow trenches. May require a faculty for installing the buried pipework and ground collectors (this type of work is not currently described within the List A and List B exemptions) ■ Requires internal location for the heat pump, buffer vessel (where relevant) and associated controls ■ Not practical with most heating systems in historic buildings that use radiators only ■ Site access for the heavy excavation plant ■ May require a full archaeological assessment 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ High efficiencies can be achieved, with SCoP of at least 3.5 possible ■ No external noise ■ No on-site emissions ■ Net zero carbon can be achieved using a green electricity supplier 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ High capital cost 	

Hydroelectric power



Hydroelectric power uses the kinetic energy from flowing water to generate electricity. This technology is only viable where there is a natural water source on site with sufficient head and flow rate.

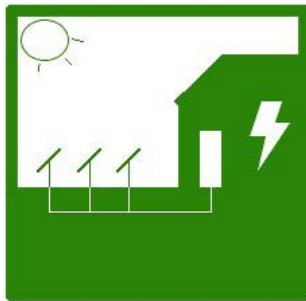
For further reading, refer to Historic England's 'Micro Hydroelectric Power and the Historic

Environment' guidance: historicengland.org.uk/images-books/publications/micro-hydroelectric-power-and-historic-environment/micro-hydroelectric-power.

Table 24:
Hydro appraisal.

Risk to heritage		LOW
<p>Considerations</p> <ul style="list-style-type: none"> ■ Good understanding of water source. Hydro turbines for a site are selected based on the hydraulic head and flow available. ■ Good understanding of climate risks. Flooding or drought will mean that the turbine can't operate so you won't generate any energy ■ In a historic setting there needs to be sympathetic selection to consider the site history and any previous installations ■ Environmental and ecological impacts need to be assessed. Facilities to mitigate the ecological impacts on fish migration by including fish ladders or eel passes. 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ Surplus generated electricity can be exported back to the grid (tariffs are currently low) 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Generated electricity is seasonal and weather dependent – can be subject to drought or flooding 	

Photovoltaics



Photovoltaics (PV) convert the sun's energy into electricity. The most common form of this technology is PV panels, which are most efficient when installed facing south at an inclination of 30° from horizontal. Consequently, the viability of this technology depends on geographic location and the orientation of the proposal. PV panels are often roof mounted, but they can also be installed

at ground level. Planning approval with historic buildings will be required.

It is important to note that the electricity generated by PV panels will not meet the full demand for electrical heating. The generated electricity will, however, contribute towards the electrical demand. Space for battery storage is required because the peak solar irradiance will not coincide with the demand for heating or most of the other non-heating electrical usage.

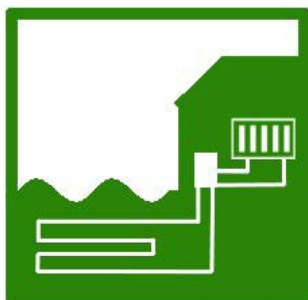
For further reading, refer to Historic England's 'Energy Efficiency and Historic Buildings: Solar Electric (Photovoltaics)' guidance:

historicengland.org.uk/advice/technical-advice/building-services-engineering/installing-photovoltaics.

Table 25:
Photovoltaics appraisal.

Risk to heritage		MEDIUM
<p>Considerations</p> <ul style="list-style-type: none"> ■ Aesthetic impact needs to be assessed within the setting of heritage assets ■ Ecological and environmental assessment may be required. Installation works need to consider bats, birds and other protected species. ■ Assessment of all near and far shading risks ■ Consent will be required for installing any type of PV installation on a listed building or scheduled monument. Planning permission may be required for a building in a conservation area or for installations that affect designated wildlife sites. With roof-mounted installations, you will need to check that the roof can support the additional wind, snow and static load imposed by the PV panels and that it complies with Building Regulations Approved Document A: Structure ■ When installing a new PV system, consideration must be given to the possible effect of a direct or indirect lightning strike ■ Maintenance access if roof mounted ■ Requires internal location for some inverter types and battery (if applicable) 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ No external noise ■ Surplus generated electricity can be exported back to the grid (tariffs are currently low) 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Generated electricity is seasonal and weather dependent ■ Peak periods for electricity generation may occur when there is no heat demand 	

Water source heat pump



Water source heat pumps work in the same way as GSHPs. The low-grade heat is extracted from a body of water, such as a river, sea, pond or lake. This technology is only viable where there is a body of water on site.

For further reading, refer to Historic England's 'Low and Zero Carbon Technologies' webpage:

historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/low-and-zero-carbon-technologies/installing-heat-pumps-in-historic-buildings.

Table 26:
Water source heat pumps appraisal.

Risk to heritage		MEDIUM
<p>Considerations</p> <ul style="list-style-type: none"> ■ Requires a three-phase electricity supply (single-phase supplies are available for smaller heat pumps up to 13kW heating capacity) ■ Best suited for underfloor heating systems which is not practical for all churches due to the disruption to the existing floor ■ Needs a body of water near to the building ■ Ground works from water source to building ■ May require planning permission ■ May require a faculty for installing the buried pipework and ground collectors (this type of work is not currently described within the List A and List B exemptions) ■ Requires an internal location for the heat pump, buffer vessel (where relevant) and associated controls ■ Ecological and environmental may be required - Installation works need to consider bats, birds, water voles, great crested newts and other protected species. ■ Not practical with most heating systems in historic buildings that use radiators only ■ May require a full archaeological assessment; ground distribution pipework will need to avoid graves ■ Open loop systems require abstraction and discharge licenses ■ Site access for the heavy excavation plant 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ High efficiencies can be achieved, with SCOP of at least 3.5 possible ■ No external noise ■ No on-site emissions ■ Net zero carbon can be achieved using a green electricity supplier 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ High capital cost 	

Wind turbines



Wind turbines use the kinetic energy from the wind to generate electricity. Consequently, the viability of this technology depends on the geographic location and the site terrain. Planning approval for historic buildings can be difficult. Even a small wind turbine with the capacity to power two typical heat emitters can be up to 15m in height.

Table 27:
Wind turbine appraisal.

Risk to heritage		MEDIUM
<p>Considerations</p> <ul style="list-style-type: none"> ■ Aesthetic impact ■ Requires a faculty ■ Requires an internal location for the inverter and battery (if applicable) ■ Planning permission will evaluate bird migratory routes ■ Ecological and environmental assessment may be required - Installation works need to consider bats, birds and other protected species. 		
<p>Advantages</p> <ul style="list-style-type: none"> ■ Surplus generated electricity can be exported back to the grid (tariffs are currently low) 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Generated electricity is weather dependent ■ Acoustics need to be fully assessed 	

Appendix B: Description of heating systems

This appendix describes the various heating systems that can be found in churches. There are two forms of heating that need to be understood when reading this appendix.

- Convective heating is the heating of the air in a space. This type of heating is useful in counteracting down draughts and raising internal surface temperatures to reduce the risk of condensation. The fast response time (how long the heating system takes to reach design temperature) is ideal for occupants. However, rapid temperature fluctuations can adversely affect the natural materials within historic buildings. The warmer air encourages evaporation, and there will be an increased amount of moisture in the air when the heating system is turned off, which can condense. Convective heating systems can result in high stratification of the heated air. Some buildings with high ceilings overcome this problem by using ceiling/roof-mounted fans, designed to operate at low speeds. This works from a technical perspective in some buildings, but high-level fans can be aesthetically challenging.
- Radiant heating is the heating of the occupants, fabric and all objects within the field of view by a heat emitter via infra-red radiation. This type of heating has a medium response time, although occupants will quickly feel the warm sensation. Eventually, the air temperature is heated by convection as the air comes into contact with the warmer surfaces. This results in less temperature fluctuation, which is beneficial to historic buildings. High output electrical radiant heaters are not recommended because they operate at high temperatures and, therefore, pose a fire risk.

Both types of heating can damage natural materials, such as wood and leather. The potential damage caused by convective heating is widely recognised, but there is limited available information about the potential damage caused by the drying effect of radiant heating.

Relevant extracts from various publications are included below:

In buildings that are occupied intermittently, such as churches, highly radiant systems can provide rapid and highly localised warming of occupants without significantly raising room air or surface temperatures.

CIBSE Guide B1

The possibility of damage to the fabric due to condensation and structural movement caused by fluctuating temperatures must also be considered. In situations where the minimum temperature is critical, it must be determined by discussion with the client. Otherwise a temperature of 10°C is suggested as a general minimum.

CIBSE Guide A

If all or part of a building is used and heated infrequently the construction remains cold, increasing the risk of severe condensation: that risk is greatest if the construction has high thermal mass and heating is purely convective. If some rooms are unheated then water vapour which moves from other rooms can raise the relative humidity high enough to cause condensation or mould growth. Ignoring the comfort of the occupants, the aim should be to maintain an air temperature above 10°C in all parts of the building that are heated.

BS-5250:2011

Fan convectors

Fan convectors use a fan to draw the room air across a pipe coil or electrical element to heat the space by convection. These heaters can be wall, floor or ceiling mounted or recessed. The noise from fan convectors needs to be assessed. Natural convectors without fans are available, but they have reduced heat output.

Figure 89:
Fan convector.



Fan convectors are not designed to be located near the occupants. The supply grille may reach temperatures that could cause burns.

Typical heat transfer: 100% convection / 0% radiation.

Table 28

<p>Considerations</p> <ul style="list-style-type: none"> ■ Aesthetics can be challenging (some cases have colour options) ■ Can be noisy ■ Often needs to be supplemented with another type of heater ■ Assess location for comfort, protection of the building fabric and proximity to occupants 	
<p>Advantages</p> <ul style="list-style-type: none"> ■ Fast response time (convective heaters take a short time for design temperatures to be reached) 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Requires regular cleaning and maintenance ■ Heated air will rise and the whole church space will be heated

Pew heaters

Pew heaters are available as radiant or convective heaters. They can be positioned below the pew or on the back panel of the pew. They are intended to provide local heating (usually electric) to warm the occupants rather than to heat the entire church. In theory, this type of heating will have lower energy consumption. However, there are four important considerations that need to be factored into the design.

- **Frost protection:** The pew heaters need to be able to heat the internal space to 7°C to protect the fabric, furniture and building services. Supplementary heating may be required in some areas of the church.
- **Condensation:** The same amount of moisture will be produced by the congregation irrespective of the type of heating system. Intermittent operation of the heating system, which commonly occurs in churches, presents a risk of condensation, particularly when the heating system is turned off. This is because the ability of air to hold moisture reduces as the temperature drops. Condensation forms on cold surfaces, such as walls and glazing, when humid air comes into contact with them. The risk of condensation can, generally, be reduced by maintaining an internal temperature of 10°C. Supplementary heating may be required in some areas of the church. There is a case study published in the August 2017 issue of the 'CIBSE Journal' that describes an installation of under pew electric heaters that provided 12kW of heating in a Grade II-listed church. The fabric of this church remained cold, with walls and windows frequently wet with condensation.
- **Risk of burns:** The majority of pew heaters have surface temperatures that can cause burns. Vulnerable people are most at risk, particularly in a public building that may be unfamiliar. The surface temperature is similar to that of a conventional radiator, but it is the close proximity of the pew heater to the churchgoer that increases the risk of burns. This risk can be overcome by installing a guard. Alternatively, the risk can be managed by a risk register, which is maintained by the end user. The aesthetic of the guard and heater may not be desirable in a historic building.
- **Comfort:** Before installing pew heaters, the church needs to understand that this type of heating does not provide the same level of thermal comfort as a conventional heating system. Data from a summary paper published by Dario Camuffo and Antonio Della Valle titled 'Church Heating: A Balance between Conservation and Thermal Comfort' (2007) indicate that pew heaters can provide around 18 per cent of the heat required to achieve thermal comfort. The effectiveness of pew heaters will improve as the external temperature increases. The case study published in the August 2017 issue of the CIBSE Journal reports that the air temperature was adequate when the heating had been on for more than 24 hours. However, the fabric of this church remained cold, and the congregation experienced uncomfortable draughts with electric under pew heating.

Figure 90:
Radiant tube pew heater.



Any churches considering this type of pew heating must check with their insurers because some policies exclude cover for damage caused by electric pew heaters.

Radiators

Radiators come in many forms and despite their name, most will heat the space via convection, with only a small proportion of the heating being radiant. There is a wide variety of both piped and electric radiators, and most will operate at temperatures that would cause burns. (A risk of burns applies to any heater with a surface temperature above 43°C.) A detailed risk assessment needs to be carried out. However, the risk is usually deemed acceptable if the radiators are positioned away from seated areas. In churches that use internal areas as creches or learning spaces, for example, a low surface temperature radiator would be a safer heating option. A suitable aesthetic is more difficult to achieve with low surface temperature radiators than with conventional radiators.

Figure 91:
Column radiator.



Radiators in a piped system can be designed to operate at lower temperatures, particularly those working with an air source heat pump. The lower operating temperature reduces the risk of burns.

Radiators can be positioned to offset down draughts and below glazing to minimise the risk of condensation.

Typical heat transfer: 80% convection / 20% radiation (for radiators with fins).

Table 29

<p>Considerations</p> <ul style="list-style-type: none"> ■ Assess location for comfort, protection of the building fabric and proximity to occupants ■ Carry out a risk assessment to consider the risk of burns ■ Assess size and number of emitters and aesthetics ■ If space permits, consider larger single-panel radiators to increase the proportion of heat transfer by radiation 	
<p>Advantages</p> <ul style="list-style-type: none"> ■ Wide variety of available heaters ■ Cost effective 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Medium response time (it takes a reasonable time for design temperatures to be reached) ■ Heated air will rise and the whole church space will be heated (this stratification can be reduced by using radiators that produce a higher proportion of radiant heat and by installing ceiling/roof fans)

Radiant heaters

There are a range of electrical radiant heaters available that can be used in churches. They should be installed at high level due to their high operating temperatures. The aesthetics of this type of heater are a considerable challenge and there is potential for damage to the church fabric. Their effectiveness in reducing the risk of condensation is limited, unless coverage is extended to all parts of the fabric that are at risk of condensation. Thermal comfort needs to be carefully considered to take into account the imbalance between the air temperature, the mean radiant temperature and the radiant heat provided by the heaters. For these reasons, this type of heater will not be considered as a standalone heating option in this research.

All the churches in this research explored electric heating in detail, including estimated running costs, capital costs and carbon dioxide emissions. Due to the way radiant heaters work, they are not always used to preheat churches when there are no occupants. The associated costs and emissions are, therefore, likely to be slightly lower for radiant heaters compared with other types of electric heaters. One advantage with this type of heater is that it can be effective in heating specific areas of a building where the floor cannot be disturbed and/or where there is limited wall or surface space available for mounting heat emitters.

Typical heat transfer: 0% convection / 100% radiation.

Figure 92:
Electrical radiant heater.



Radiant panels

Radiant panels use a piped (or electric) heat emitter located at high level to heat the space below using radiative heat. This type of heating system requires conventional operating temperatures and, as such, will not work with most heat pumps. Radiant panels directly heat the occupants. This means the air temperature can be uncomfortably low without sufficient warm-up time or supplementary convective heating.

Typical heat transfer: 30% convection / 70% radiation.

Table 30

Considerations <ul style="list-style-type: none"> ■ Requires high level access and mounting to the fabric ■ May need to be supplemented with another type of heater 	
Advantages <ul style="list-style-type: none"> ■ Effective heating for spaces with high ceilings and large volume 	Disadvantages <ul style="list-style-type: none"> ■ Medium response time (it takes a long time for design temperatures to be reached). Note: Occupants will, however, quickly benefit from the warm sensation provided by radiant heating ■ A desirable aesthetic can be difficult to achieve

Trench heaters

Trench heaters use a piped (or electric) heat emitter located within the floor to heat the space above via convection. Fan-assisted trench heaters are also available. Trench heaters are generally found around the perimeter of churches and can be used to offset the down draughts from glazing and high external walls. They are commonly used to supplement underfloor heating.

Trench heaters often have decorative metal covers or grilles in churches, which give a more traditional aesthetic. Exposed heating pipes are often found within large floor trenches; these would have conveyed heated air from a furnace. The heating from such pipes can provide good heat distribution in churches, but control is limited and some heat will be lost to the ground.

Typical heat transfer: 100% convection / 0% radiation.

Figure 93:
Trench heater.

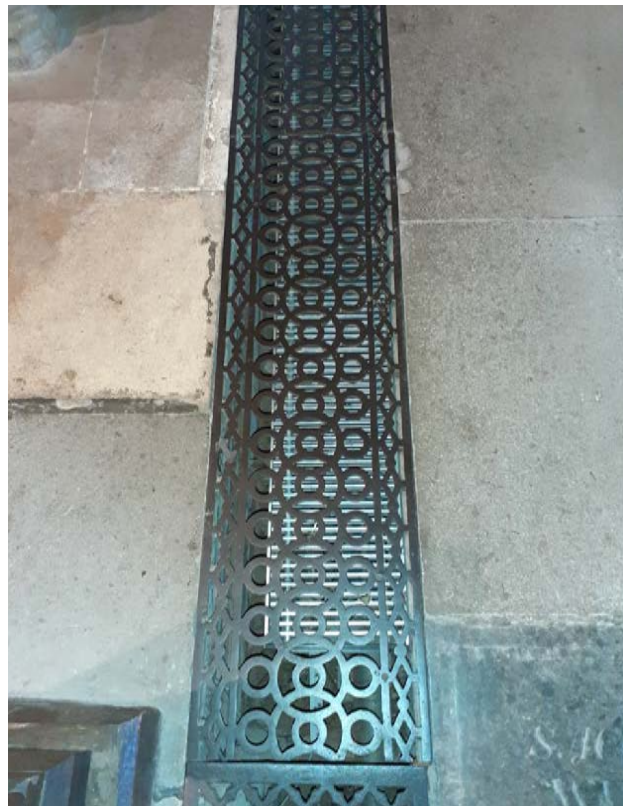


Table 31

<p>Considerations</p> <ul style="list-style-type: none"> ■ May require some disruption to the floor unless trenches already exist ■ Archaeology may need to be involved during the installation ■ Often needs to be supplemented with another type of heater ■ Location is important to minimise the ingress of dirt, leaves and so on 	
<p>Advantages</p> <ul style="list-style-type: none"> ■ Fast response time (convective heaters take a short time for design temperatures to be reached) 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Requires regular cleaning and maintenance ■ Heated air will rise and the whole church space will be heated

Underfloor heating

Underfloor heating systems use a piped heat exchanger within an insulated floor to heat the space above the floor. They work at low operating temperatures, which means they pair well with heat pumps. This type of system can also be installed with a conventional boiler.

Electric underfloor heating systems are available, but no examples of this type of system are known to be installed in churches. This is likely due to the high running cost and resilience.

Typical heat transfer: 50% convection / 50% radiation.

Figure 94:
Underfloor heating.



Table 32

<p>Considerations</p> <ul style="list-style-type: none"> ■ Installation requires the removal of pews and flooring ■ Underfloor heating installations are more viable if significant reordering works are planned ■ Archaeology will need to be involved during the installation ■ Often needs to be supplemented with another type of heater ■ Works best when the church is used throughout the week ■ Using limecrete screed reduces the risk of moisture being driven up adjacent walls and columns 	
<p>Advantages</p> <ul style="list-style-type: none"> ■ Largely heats the occupied zone of the church ■ Low surface temperature of the floor avoids any risk to churchgoers ■ Aesthetics are very good and large areas of the church will be comfortable ■ Allows for a large degree of flexibility in the layout of the church and how it is used 	<p>Disadvantages</p> <ul style="list-style-type: none"> ■ Very slow response time (it takes a long time for design temperatures to be reached) ■ Needs to operate for long periods of time ■ High associated running costs ■ High capital cost ■ Considerable disruption to existing fabric and furnishing

Other heaters

Some churches have historical wet heating systems, such as pipe coil systems. In rare instances, historic furnaces and stoves may be found. If pipe coil systems are in good condition, it may be possible to refurbish and reuse this type of heat emitter.

Other forms of heating occasionally found in churches include direct gas-fired appliances. These have not been explored due to the carbon content of natural gas and the suitability of gas-fired heaters in historic buildings.

Figure 95:
Pipe coil heater.
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Appendix C: Example heat loss calculation

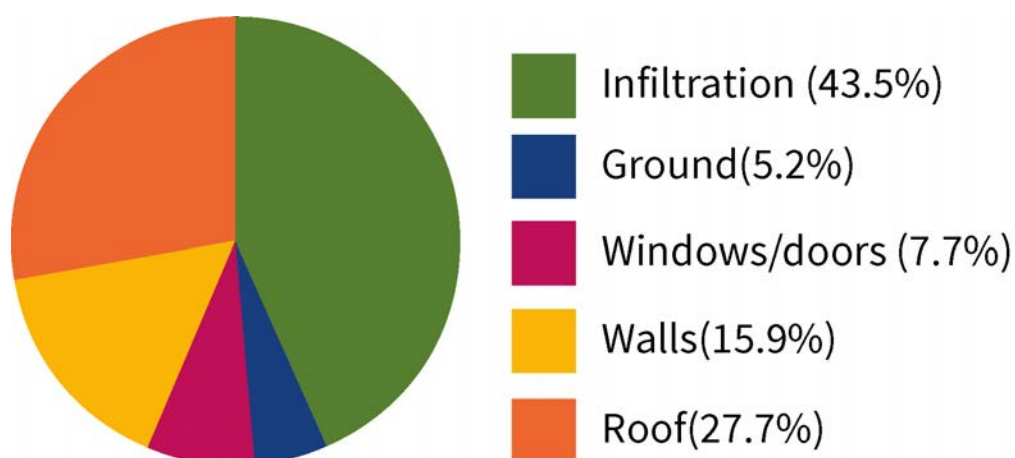
This appendix includes a detailed heat loss calculation for one of the surveyed churches to understand how the internal heat is lost to outside. The Church of St Michael and All Angels, Poulton, was chosen because it had a Matterport survey carried out. This enables accurate measurement of the fabric components. In addition to the physical fabric components, such as windows and walls, through which heat can be lost, there are infiltration heat losses. Infiltration is the air leakage through cracks and gaps in the building envelope.

Some simplifying assumptions about the fabric properties were made to allow a heat loss calculation to be performed. The detailed heat loss calculation was comparable to the heat loss estimate carried out for the investigation.

- Detailed heat loss calculation: 63.2kW
- Heat loss estimate: 65.2kW.

The proportion of the calculated heat loss through each component of the fabric is outlined below.

Figure 96:
Heat losses for the Church
of St Michael and All
Angels, Poulton.



Infiltration is the most significant heat loss at the church in Poulton. One of the other surveyed churches was told that most of the heat is lost through the roof and the windows. They were advised to insulate the roof and provide secondary glazing to the windows. In the example above, glazing accounts for only 7.7 per cent of the heat loss and the roof accounts for 27.7 per cent. If the heat loss through the roof were halved by adding insulation, this would only reduce the overall heat loss by 13.8 per cent.

Similarly, if the heat loss through the windows were halved by adding secondary glazing, this would only reduce the overall heat loss by 3.3 per cent. Although these reductions improve the thermal performance of the church, it is important to note that the benefits of improving the thermal properties of the fabric are overstated. It is also important to consider the impact proposed fabric improvements might have on the aesthetics, historical significance and moisture performance of any historic building.

The form and proportion of the fabric components will vary for every church, which is why a detailed heat loss calculation should always be carried out by a competent person.

The endnotes from the heating technology comparisons carried out in this report are outlined here for brevity.

- 1** The advice in the introduction section relating to the UK energy market and fuel prices should be noted.
- 2** The capital costs outlined are estimates based on typical installation costs and they do not include all project costs such as preliminaries, strip out of redundant services, project development, builder's work and professional fees. It is recommended that a Chartered Quantity Surveyor is appointed to carry out a detailed cost plan.
- 3** The heating system capacity is included to allow a comparison between the existing plant size and the proposals. Some of the plant is only available in specific sizes so the exact design heat loss can't always be provided. This also illustrates the amount of heat provided by the local electric heating option where applicable.
- 4** The emissions could potentially be zero if a green tariff is available. The emissions could be reduced if photovoltaics are installed.
- 5** This cost does not include the annual standing charge of £164 or the electrical consumption for non-heating purposes (such as lighting, small power).
- 6** This cost assumes that pew heaters are installed to all available pews and that the heating is supplemented by additional electric heaters to reflect the estimated heat loss. This cost includes an estimate for upgrading the electrical power supply.
- 7** This cost assumes that pew heaters are installed to all available pews. Note that this option will not provide the same level of thermal comfort as the existing heating system or the other options. This cost includes an estimate for upgrading the electrical power supply. Costs for guards are not included.
- 8** This cost includes estimates for upgrading the electrical power supply and installing a new water supply.

- 9** This cost includes estimates for upgrading the electrical power supply.
- 10** The capital costs outlined are estimates based on typical installation costs and they do not include all project costs such as preliminaries, strip out of redundant services, project development, builder's work and professional fees. It is recommended that a Chartered Quantity Surveyor is appointed to carry out a detailed cost plan. This cost excludes any work associated with the three 'temporary' classrooms.
- 11** This cost does not include for any upgrades to the electrical power supply. No electrical load assessments have been carried out for the school.
- 12** This cost assumes that pew heaters are installed to 50 pews (see endnote 13 for more details) and that the heating is supplemented by additional electric heaters to reflect the estimated heat loss. This cost includes an estimate for upgrading the electrical power supply.
- 13** This cost assumes that pew heaters are installed to 50 pews (there are approximately 144 pews in total). This considers the current typical congregation size of 25 to 30 per week and the church's plans to remove pews at the west end. Note that this option will not provide the same level of thermal comfort as the existing heating system or the other options. The existing supply cable to the church has sufficient capacity. Costs for guards are not included.

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