QODA

Brecon Cathedral

Energy Assessment and Carbon Emissions Review Report

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QODA

Revision Summary

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Contents

1 Executive Summary

QODA was appointed to consider how Brecon Cathedral could improve its overall sustainability by exploring suitable passive retrofit solutions and renewable technology. This means that the building's fabric should be upgraded (to reduce energy use) and energy efficient measures need to be employed, followed by a move away from fossil fuels. A survey of the cathedral was carried out on 13th December 2023.

Feasibility studies were carried out to explore how a non-fossil fuel strategy could be employed. From these studies, it was found that:

- The current total carbon footprint is calculated at around 148 tonnes of CO_2 per year for the cathedral. The space heating is the single largest contributor to this number.
- It was apparent that substantial improvements to the fabric of the cathedral are not viable owing to the historic nature of the building, except to the roof where there are various opportunities for insulation, especially where re-roofing is planned. Draft-proofing should be employed where possible, and the existing porches are an excellent method of keeping the heat inside.

Although it is understood to be difficult to alter the building fabric, changes to the cathedral heating services were examined and the following outcomes were found:

- Replacing the current gas boilers with new and more efficient boilers would reduce the carbon footprint of the building by an estimated 32%, however the cathedral will still be reliant on a fossil fuel.
- Replacing the gas boilers with direct electric heating will reduce the carbon footprint of the cathedral by an estimated 59%, however is likely to dramatically increase the heating bills. It may be a suitable solution for small pockets of the cathedral.
- Ground source heat pumps (GSHP) are examined within this report and are the most effective system at reducing the overall operation carbon emissions (88% reduction). However, the financial case is poor and there are a number of other unknowns to be explored, such as archaeology and geology.
- Air source heat pumps (ASHP) are proposed as an alternative heat pump to GSHP. ASHPs reduce the carbon emissions by a similar degree (85%), however pose visual and noise issues.
- PV deployment is highly recommended within the report because there is the opportunity to install high power PV panels, facing south. However, the impact on planning regulations and conservation considerations due to their visibility is unknown.
- An interim solution could be a hybrid of an ASHP with the existing gas boilers, operating when outside temperatures are mild and using the existing boilers when it is cold outside. This is called a bivalent system.

The results of the analysis found that overall:

- Achieving zero carbon by 2030 will be incredibly difficult.
- All options apart from a direct replacement of the gas boilers will require significant disturbances and financial commitments.
- Any of the scenarios that move to a majority electricity-based heating system will be the most effective at reducing carbon emissions. This is due to the low, and diminishing, carbon factor of the grid.

Ground Source heat pumps are recommended to provide a substantial carbon reduction, but the capital costs are high, and financial case is poor. If a GSHP is not a viable solution, our recommendation based on the above analysis would be to pursue an air source heat pump system. There is the possibility that this could be installed as a bivalent system alongside the current boilers whilst they are operational, providing a steppingstone for the Cathedral to eventually become fully reliant on an ASHP.

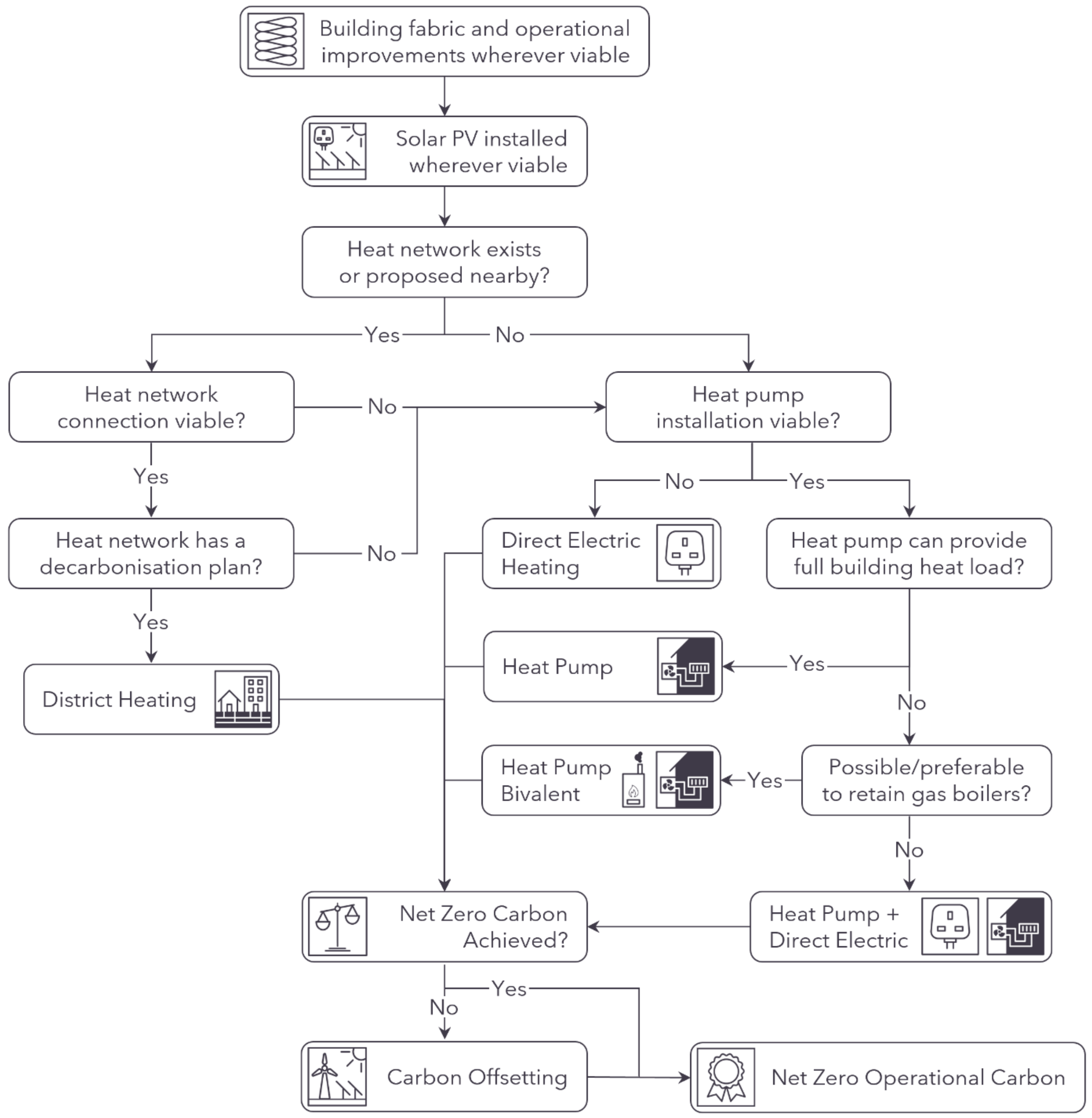

Figure 1: Cathedral Decarbonisation Decision Flow Chart

2 Introduction

In 2020, the United Kingdom passed the Climate Change Act. The background to the above Synod decision is the climate and ecological emergency that has now been clearly identified by many large organisations and governments worldwide, based on a significant body of scientific evidence, most particularly the IPCC special report from 2018[1]. A clear call to action has been made by the global scientific community, along with a clear target from the 2015 Paris Climate Agreement to keep global average surface temperature warming below 1.5°C. This requires global carbon emissions to rapidly decrease, with the IPCC special report targeting a 45% reduction by 2030, compared to 2010.

While the report makes no special case for developed countries cutting emissions harder or faster, others have done so, and the 45% figure above is effectively a minimum global reduction, suggesting those with greater resources should cut harder, given the likely cost. In short, the science and global response justifies unprecedented action on carbon emissions, and ambitious targets by organisations. Figure 2 shows several emissions pathways to a 1.5°C outcome, highlighting the need for particularly rapid reductions in the 2020 to 2030 timeframe, since the earlier emissions are cut, the larger their cumulative effect.

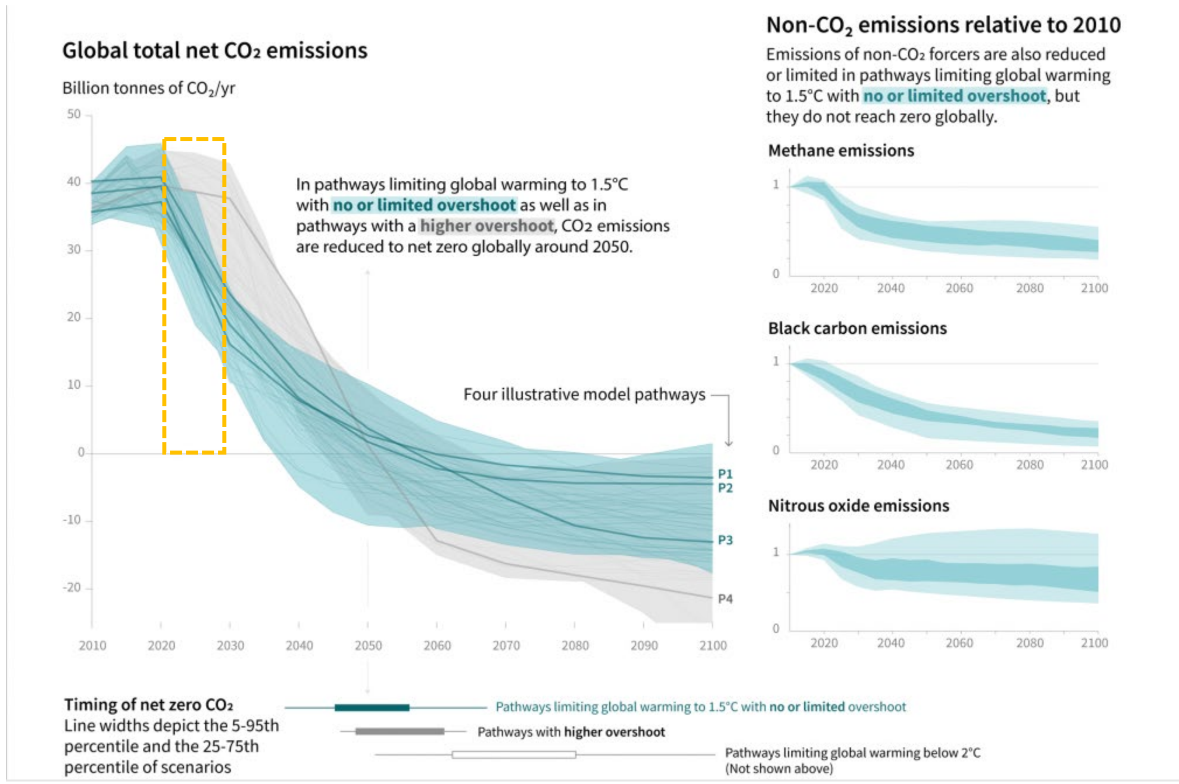

Figure 2: Global emissions pathway characteristics. Source: IPCC Special Report on Global Warming of 1.5°C (2018)3

QODA has been appointed by Brecon Cathedral to evaluate and provide a roadmap to achieving net zero carbon emissions[2] in operation by 2030 or establish a reasonable timescale where 2030 is not possible. The following study is therefore undertaken from the starting point that operational carbon emissions from the cathedral and ancillary buildings need to be reduced rapidly, and to as near zero as possible by 2030. It should be noted that embodied energy and carbon in existing building structures, transport emissions, and biodiversity are outside the scope of the present study; however, in future, it is recommended that these and other wider environmental factors are considered in similar detail.

The present report analyses the feasibility of achieving the above target for Brecon Cathedral. A prerequisite to understanding any upgrade pathways a cathedral is the analysis of the current building operation, energy profile and carbon footprint, building physics and services. The study therefore began with a thorough survey of the building and its surroundings. The aim of the survey was to identify opportunities to dramatically reduce operational carbon emissions, ideally to zero, through a combination of building fabric upgrades, operational improvements, and onsite renewable energy. Within this report, a series of technically feasible opportunities for property improvement opportunities are identified, with a high-level discussion on the practical feasibility and the potential benefits, risks and costs associated with each improvement measure. A detailed quantitative analysis of the potential for improvement associated with these measures is presented towards the end of this report.

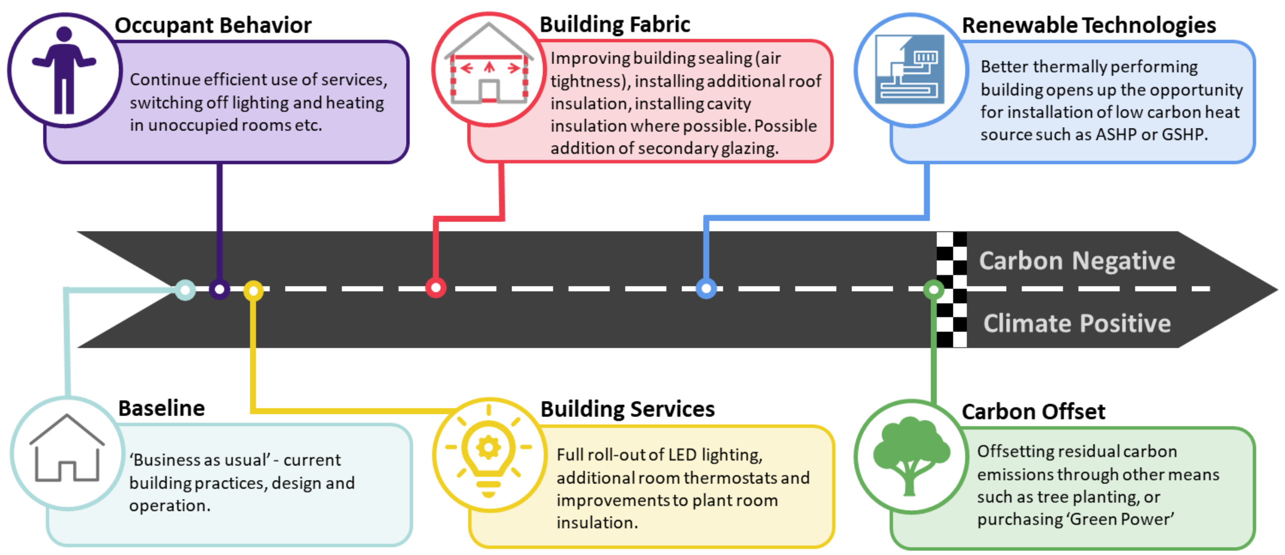

Figure 3: Roadmap to Net Zero Carbon

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[1] Intergovernmental Panel on Climate Change, Special Report 2018 – Global Warming of 1.5°C, https://www.ipcc.ch/sr15/

[2] In this report, we use the terms 'carbon' and 'CO_2' interchangeably to refer to emissions of carbon dioxide in kg or metric tonnes. This is not strictly accurate, as carbon emissions are also referred to without oxygen by scientists and weigh a different amount, but we have taken the pragmatic view that common, non-scientific usage of the two phrases is interchangeable.

3 The Site

3.1 Context

Brecon Cathedral, located in the town of Brecon in mid-Wales, is a site of historical and architectural significance. Originally a Benedictine Priory, it was founded in the 11th century by the Normans, following their conquest of the region. Over the centuries, it underwent various modifications and expansions, reflecting a mix of architectural styles, predominantly Norman and Gothic.

In the 16th century, during the Dissolution of the Monasteries under King Henry VIII, the Priory was dissolved, and its status changed. It was later restored and elevated to Cathedral status in the 20th century, becoming the seat of the Bishop of Swansea and Brecon in the Church in Wales.

The cathedral and its setting are shown in Figure 5.

Figure 4: Survey photos of Brecon Cathedral

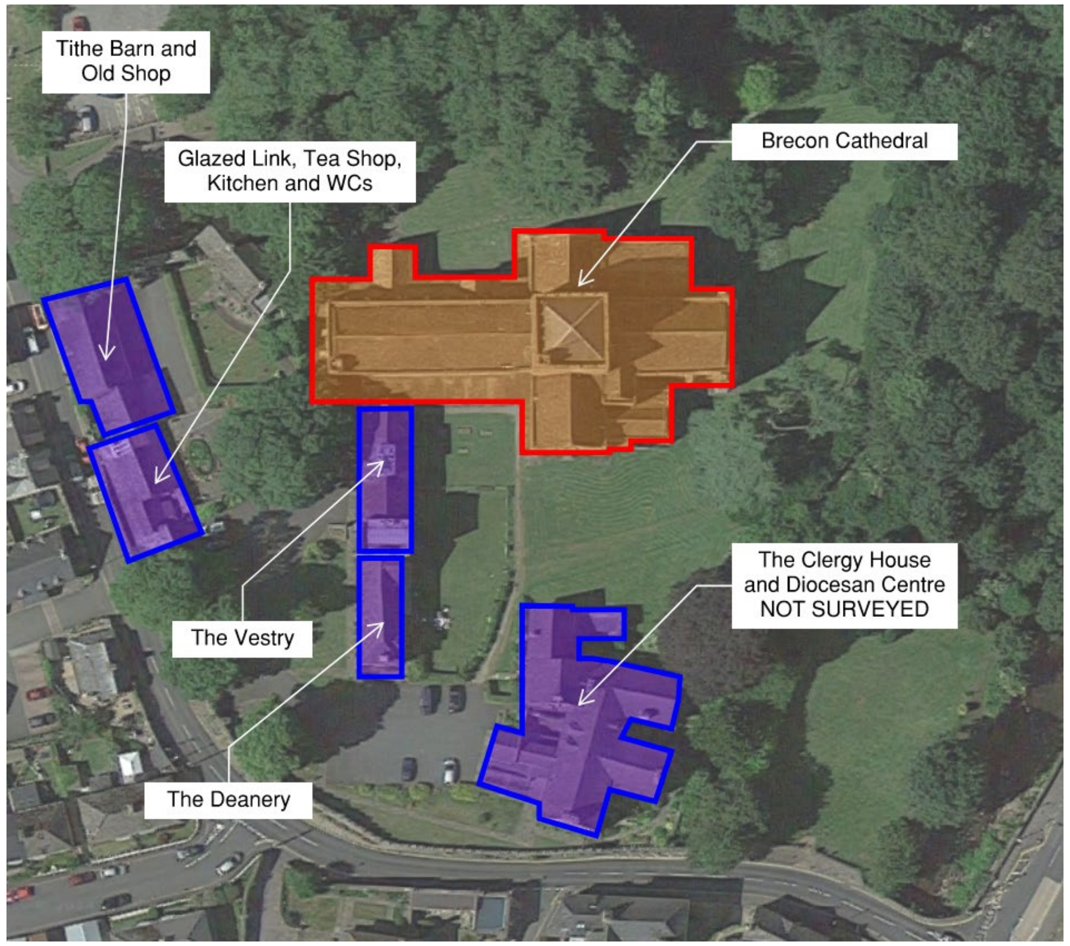

Figure 5: Brecon Cathedral site

3.2 Site Surveys and Current Energy Use

QODA conducted site surveys on the cathedral, and ancillary rooms on 13th December 2023. The surveys were thorough but non-intrusive, and successful in establishing key parameters regarding the building fabric, evaluating the current servicing strategies and in assessing the potential spaces for the installation of low carbon and renewable technologies.

As part of the surveys, informal interviews with cathedral staff were undertaken to provide more information about the thermal and energy performance of these buildings, particularly with regard to the operation of the building's services and user experience.

Current Energy Intensity	Brecon Cathedral
Heating [kWh/m^2]	**319**
Electricity [kWh/m2]	**23**

4 The Cathedral Building

4.1 Building Fabric

On the path to net zero, it is important that energy saving from improvements to the fabric of the buildings and the way it is used are considered before addressing building services.

In the case of buildings as architecturally sensitive as this, the potential for fabric improvements is limited.

4.2 Insulation

The age, appearance, and heritage sensitivities of the Cathedral render opportunities for insulation very limited. Wall and floor insulation must be excluded. Whereas various opportunities for insulating the roof, either alongside imminent or future roof repairs.

Roof Insulation: The Chancel/Presbytery and Organ Chamber could be insulated at ceiling level. The North Transept, South Transept, Havard Chapel are to be reroofed which presents the opportunity to insulate over the rafters. The Crossing could be insulated in the ringing chamber floor. Other roofs including the Nave, Aisles, Porch, Vestry wing, Sacristy and St. Lawrence Chapel could be insulated in future phases of work. The benefit of these measures is that less heat is lost through the roof – where most of the heat transfer occurs. This may result in a somewhat warmer temperature at ground level or allow for less energy to be used to maintain an appropriate comfort environment for people using the building.

4.2.1 Draughtproofing

The building fabric improvement with the most energy saving potential is draughtproofing. Two of the external doors of the Cathedral are sealed; the south one by being accessed via the Vestry; and the north one by its porch, each of which controls draughts coming in from outside, especially where there are large amounts of foot traffic. The proposed new main entrance door at the west end of the Cathedral is to be fitted with an internal draught lobby.

Other external doors are not well-sealed however, and for these and for doorways that do not suit the construction of an internal lobby, or where there is less foot traffic, draughtproofing of the door itself should be explored. As a small word of caution here, reducing draughts may affect humidity levels and or damp, so this may need to be monitored after the work is done.

Figure 6: The north door already has a porch

4.3 Glazing Improvements

The large decorative windows account for a good proportion of the heat loss from the building. In other circumstances, double or secondary glazing might be considered, but here clearly, double glazing can be ruled out and internal secondary glazing is not feasible due to the complicated nature of fitting, the potentially detrimental effects on the condition of the glass, and on the visual impact.

Although not likely to be currently relevant for Brecon Cathedral, isothermal glazing can provide some energy saving to cathedral windows. Isothermal glazing involves the installation of an additional layer of glass, external to the existing installations, providing a protective layer to the original stained-glass windows and allowing equalized climatic conditions to exist on the internal and external side of the delicate windows. It has been shown to have positive conservation and energy saving effects. It is thought to be unlikely that isothermal glazing will be used anywhere here as the cost of this cannot be justified for carbon saving reasons alone, but it should be considered if conservation work on the windows is being undertaken in the future.

Figure 7: Isothermal glazing

4.4 Fabric Improvements - Summary

Although important as demonstrations of effort and for energy saving and improving comfort levels, the potential fabric improvements in the cathedral cannot make a significant contribution to the overall carbon reduction emissions targets of the cathedral building. For this reason, they are not included within the carbon dioxide reduction analysis of this report.

4.5 Existing Services

4.5.1 Heating and Hot Water

Figure 8: Heating for the Cathedral provided by two 325kW boilers.

Heating for the cathedral is delivered by two 325kW Potterton Derwent gas boilers which were installed in 1995. Both are located in a boiler plantroom at the Northeast end of the cathedral and are controlled via a mechanical plant control panel. It would be advisable to update the control system for a digitalised controller set up to improve the efficiency of the systems and lower running costs. No additional direct electric heating was found on the survey.

4.5.2 Lighting

The lighting can be roughly divided between utility / functional lighting, and lighting for display and illumination. It is understood that a programme of LED lighting replacements has been carried out. The main cathedral areas are now illuminated by part LED/part florescent. The basement is currently installed with fluorescent fittings.

4.5.3 Heat Emitters

Heat is distributed from the principal heating system to the main body of the cathedral via column cast iron radiators. This is served by steel piping as seen in Figure 9. If there were plans to migrate to a heat pump-based heating system from the current boilers, a calculation of the possible output of the existing emitters with a lower flow temperature would have to be undertaken to work out whether modification is required.

In the meantime, the system may benefit from the installation of controlled zoning of the heating system with automated control valves, to allow a more efficient control method accompanied by air temperature sensors within the conditioned areas. High efficiency variable speed pumps should also be considered.

Figure 9: Cathedral heat emitters & distribution system.

4.6 Cathedral Services - Opportunities for Carbon Savings

4.6.1 Towards Zero Carbon Heating - Introduction

The key strategy outlined in this report of achieving zero carbon heating means using electricity to provide heat. Heat pumps and direct electric heating are the available options for this purpose. Timing and a medium-term plan of work should be formulated that considers the life expectancy of the boilers and other plant and controls. Premature replacement should be avoided, if possible, but more importantly plans should be in place early in case of plant failure.

4.6.2 Reducing the demands for energy

General

Saving energy by using it strategically, and with control, is an important starting point to the carbon saving strategy. This means examining how energy is used, installing better technologies and control systems, and by paying attention to day-to-day use and waste. This might include appointing an existing member of staff as an energy champion.

Heating

Strategic questions need to be addressed, such as:

- Can the heating season be shortened?
- Could and should the temperature on the thermostats be lowered by a degree or two?
- Is the heating well-controlled, and who has access to the thermostats?
- Could the heating be used more strategically, and be better targeted?

Lighting

The change from incandescent and other traditional lighting to LED lights will have a big impact on electricity demand.

Motion sensors, timers, and flexible sophisticated control systems for all the functional and display lighting would also make a significant contribution to energy savings.

4.6.3 Ground Source Heat Pumps (GSHP)

Ground source heat pumps are the most efficient heat pumps, as they extract heat from underground where temperatures (typically around 12 degrees) remain fairly constant. Ground source heat pumps can be designed to collect heat from a horizontal array of pipes or from vertical boreholes.

For a ground source heat pump system to be feasible there will need to be:

- Sufficient space for a ground collector (either boreholes or extensive pipework within trenches)
- Plant space for the heat pumps, buffer vessels, control panel etc.
- A large enough electrical supply - normally 3-phase
- Suitable heat emitters, or the ability to upgrade them to be suitable for heat pumps.

Ground Collector options

At Brecon Cathedral, the lawn area to the south and southwest of the cathedral presents an opportunity for a ground collector. This is because they are both relatively close to the plant room, have access for plant and machinery to get to the area, and have minimal obstructions such as trees and monuments. There may also be potential on the lawn to the north of the cathedral, however the access route to the current plant room is less obvious. While there is likely to be insufficient space for the lower cost horizontal-type collector (consisting of pipework laid in trenches), there may be room for a vertical system, known as boreholes. Installing borehole heat collectors is marginally less intrusive and they can take up less space. However, there are several other factors that need to be considered for boreholes:

- Local geology: will affect the depth of boreholes required (we have assumed pessimistic ground performance)
- Archaeology: given the historic nature of the area, the lawn may have archaeological value, likely requiring an archaeological survey and ongoing monitoring.
- Drilling boreholes generates a significant amount of spoil which will mar the appearance of the grass until it eventually heals. Trenching would similarly produce scars on the lawn.

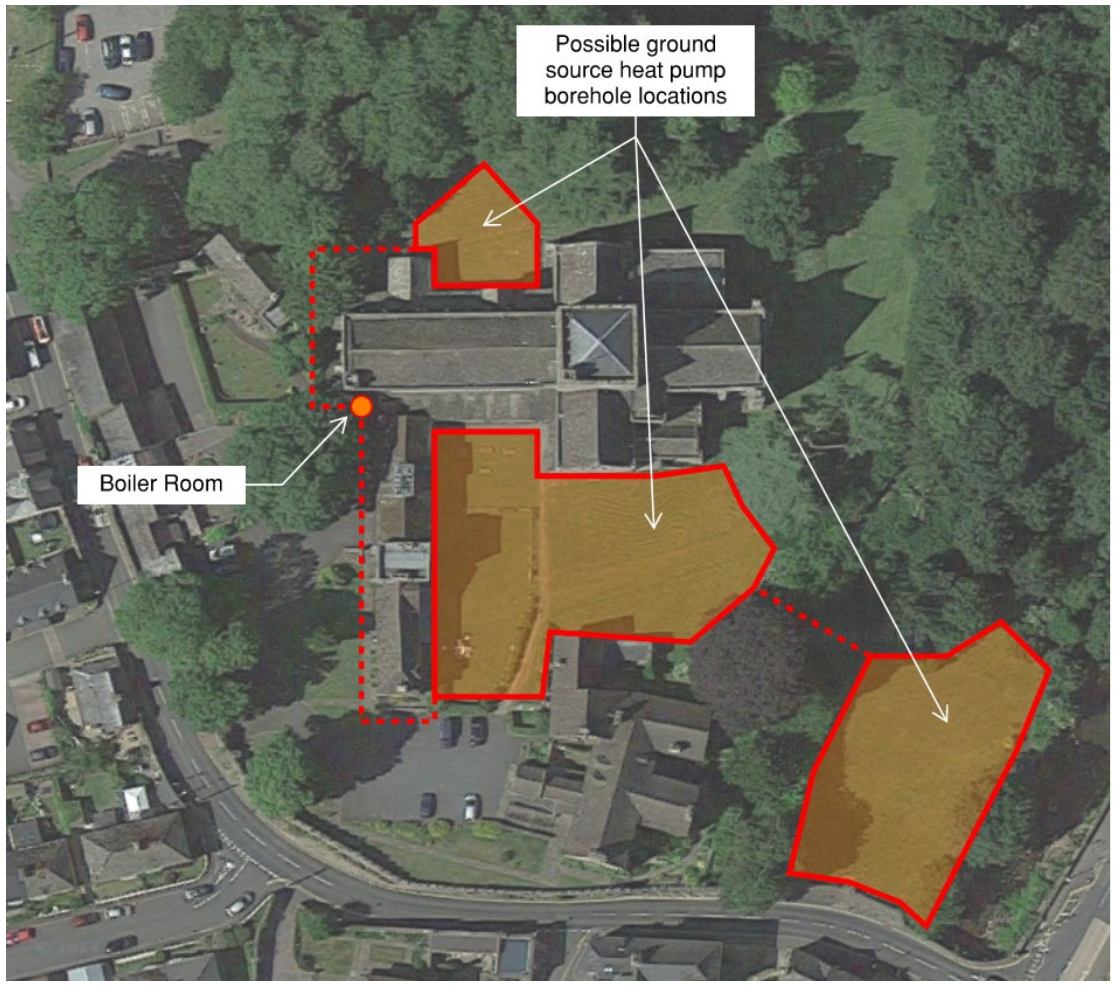

Figure 10: Potential location for a Ground Source borehole array

4.6.4 Air Source Heat Pumps (ASHP)

The most obvious area at Brecon Cathedral for an ASHP is near the road to the south of the cathedral as this area is less likely to be sensitive to noise. Investigation would be required into the size and the visual and aural impacts of the plant – and how this would be seen by planners and users in the context of the cathedral. With normal heat pumps the flow temperature of the heating water is lower than the current systems, thus would require a feasibility study if linked to the existing heating distribution systems. The size of the electricity supply to the site will also need consideration to ensure there is enough capacity to include the heating on the electrical load.

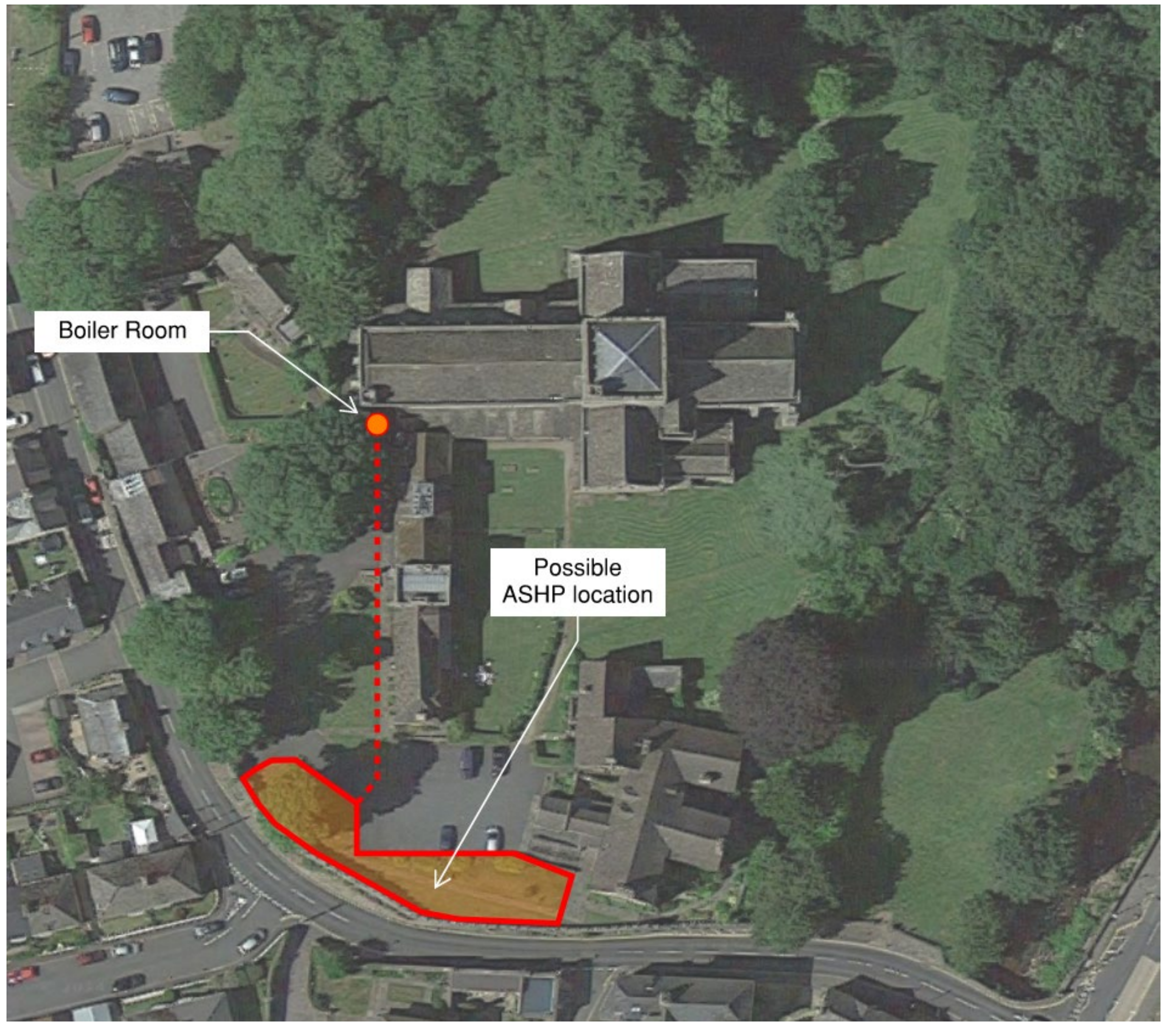

Figure 11: Possible ASHP location

4.6.5 Bivalent System

Although not a site-based net zero carbon option, a bivalent system may ultimately be the only or most practical way forward if existing heating standards are to be maintained. This approach blends the use of heat pumps with existing or replaced gas fired boilers. With this arrangement the heat pump would typically provide space heating when the outside temperature is above 10°C, with the gas boilers taking over during periods of lower outside temperatures. With this approach the modifications to the existing heating's systems are reduced, but at the expense of less carbon emissions savings than by a ASHP alone. This bivalent approach might be a sensible steppingstone to net zero carbon.

4.6.6 Whole site Heat Pumps

Assuming that sufficient space could be made available for the plant, it would be logical to extend the heat pump-based heating system to include other buildings in the vicinity of Brecon Cathedral. As discussed within this report, with this approach the flow temperature of the heating water would be lower than the current systems, and thus would likely require modification made to the existing heating systems. The benefit, however, of deploying a whole site heat pump system would be that capital costs and running costs could be shared between several different stakeholders. This is likely to make the overall cost per unit of heat delivered cheaper. A detailed analysis of which areas could be connected to the systems would need to be undertaken and appropriately sized units selected.

4.6.7 Direct Electrical Heating

Although the running costs of direct electric heating with electric radiators or storage heaters is likely to be high, there are some advantages to this form of heating:

- All electric – so can be within the definition of net zero
- Simple installation and potentially a relatively quick response to plant replacement
- Lower installation costs
- Better control and targeted heating
- Off-peak electricity supply and rates can be used.

The size of the electrical supply and distribution cables would be a major consideration.

4.6.8 Renewables Opportunities

Solar Photovoltaics (PV):

Roof mounted solar PV could make a contribution to carbon emissions reduction of the site but would require planning and listed building consent which may be challenging to obtain. A thin-film PV option may have merit in blending with a sensitive heritage context. Annual yield calculations in Figure 12 are based on 330W panels.

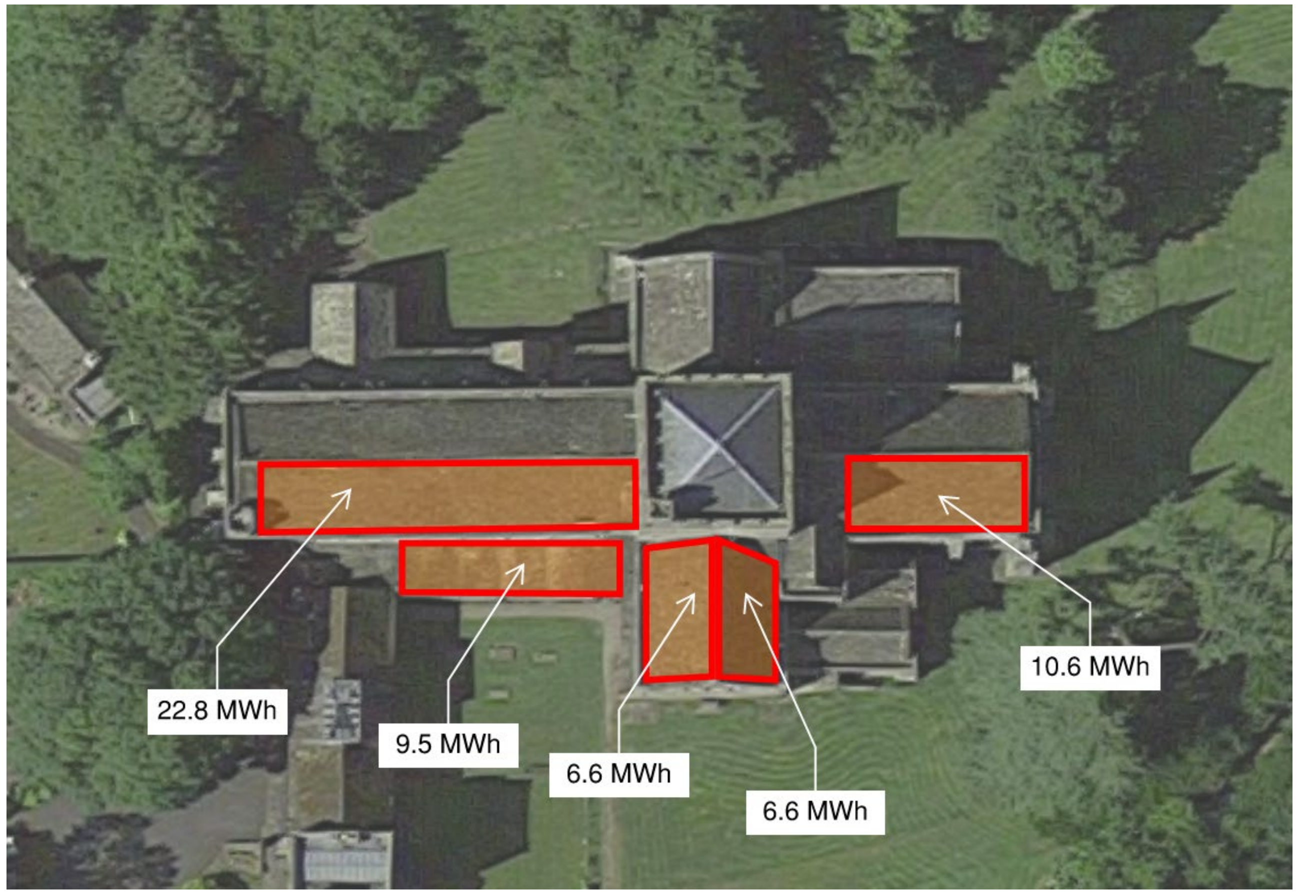

Figure 12: Possible PV array on the cathedral roof

To be a technically viable solution, the following considerations would require further investigation:

- Suitability of the roof structure to ensure that the weight of the panels and any associated maintenance, access or framing systems can be sustained. Thin film PV products may be an alternative solution for the property if the roof structure is deemed to have insufficient strength.
- Impact on the aesthetics of the building.
- Potential planning restrictions and listed building consent to be resolved with relevant planning and/or conservation officer.

5 Option Analysis

5.1 Method

Gas and electricity utility data have been collected and collated to understand the overall space heating demand and energy consumption for the cathedral. The review focused on utility bills from 2023. This has been used to benchmark the modelling outcomes with real life consumption data. Instead of modelling the specific building in question, it has been agreed with the Client that energy and cost saving estimates are based on previous modelling experience.

By understanding the seasonal efficiency of different heating options being suggested, an estimation of the energy use compared to the 'baseline' or current energy use can be estimated. By creating different scenarios or 'options' of heating systems, an estimation on the capital cost, operational cost and present and future carbon emissions can be compared to the cathedral's current situation.

Although estimates are made at a high level, they are good at categorising the actions recommended against a current baseline. We suggest that further modelling should be carried out at the next stage when a general strategy is agreed. This is to ensure that highly accurate financial models are developed to explore an option further, and other specialist surveys are carried out if necessary.

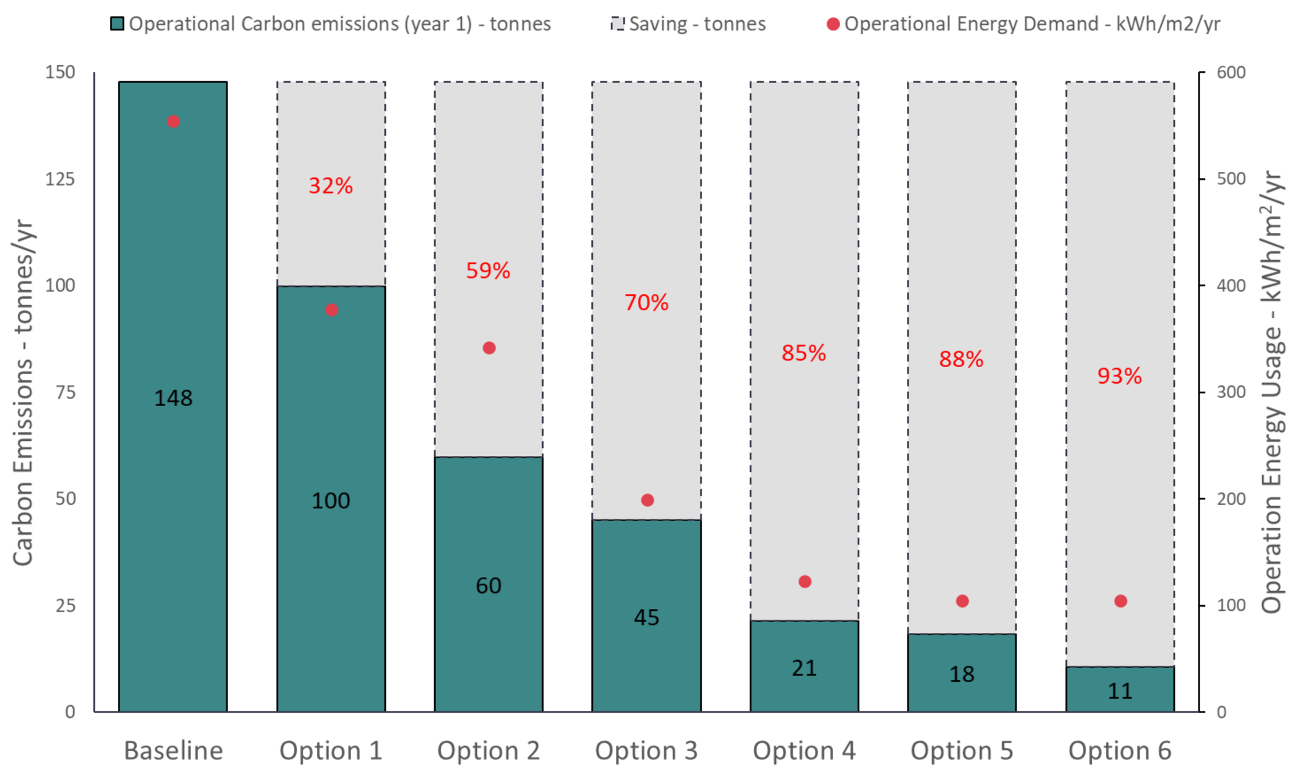

Figure 13: Theoretical carbon savings made if instantaneously switched to each option.

Description	Infographic
Baseline No improvements made to building the cathedral services	
Option 1 Replace boilers with new and more efficient boilers.	
Option 2 Direct Electric Heating only	
Option 3 Bivalent System relying on both the current gas boilers and an ASHP run at the most efficient flow temperatures	
Option 4 ASHP	
Option 5 GSHP	
Option 6 GSHP with the addition of solar PV	

Table 1: Options Calculated with Analysis

As a means of illustrating the effectiveness of the options, Figure 13 shows the carbon reductions of each option if the action is immediate and subject to 2023 carbon intensity values. What is initially clear is that none of the options are getting the cathedral to net zero carbon using today's national grid carbon factors. Even Option 6 (GSHP with solar PV), cannot quite accomplish net zero carbon (achieving an estimated 93% reduction in emissions). The following points are apparent from Figure 13:

- Simply replacing the current old boilers (assumed 60% efficient) with new boilers (assumed 90% efficient) (shown in option 1) is calculated to reduce emissions by 32%. Although a significant improvement, this is still a fossil fuel-based heating system, and therefore does not take advantage of the reducing carbon factor of the grid.
- Moving to a direct electric system now (option 2) would have a dramatic effect on the carbon emissions, however heating bills would increase considerably due to the cost of energy. Although likely not suitable to cover the whole cathedral heat demand, direct electric heating can be a good solution for specific areas of the cathedral, where comfort conditions may be required on short notice.
- Option 3 explores the possibility of adopting a bivalent system. This shows a relatively high carbon reduction, as the heat pump is able to take up a large portion of the heating season, with the boilers contributing only when external temperatures are particularly low.
- Options 4 and 5 are very effective at reducing operational carbon emissions for the Cathedral. However, this assumes that the heat demand can be met from a lower flow temperature and different usage pattern.

Traditional heat pump systems operate at a lower flow temperature but, by running these systems for an extended period rather than on/off two or three times a day, it may be possible to use the thermal mass of the building to bring the building to temperature and keep topping the heating up. Comfort levels when running the heating system at a lower flow temperature can be explored in a series of tests before the implementation of a heat pump. Flow temperature can be controlled via weather compensated setting which allows variation depending on the internal or external temperature. Heat pumps are often a suitable option when paired with areas of direct electric heating, with the heat pump providing a conservation level of heating, whilst direct electric heating can cover areas of comfort heating.

- It should also be noted that the difference between Option 5 and Option 6 (addition of PV) is a 5% operational carbon emissions reduction. In the wider context of getting the UK to a national net zero carbon outcome, solar PV is a vital technology, whose adoption will need to be widespread as part of the total national effort. Therefore, even though the total numerical contribution to carbon reduction at the site is relatively small compared to heat pumps for example, implementation is highly recommended.

Some clear themes are:

- Heat pumps are a part of every best option for carbon reduction.
- A bivalent system would be a good option to provide a 'steppingstone' to net zero carbon.
- A GSHP system produces the lowest operational carbon emissions pathway however there are other factors to consider such as cost, archaeology and geology.
- A heat pump option may benefit from setting up a shared heating system with surrounding buildings that may be interested due to their own objectives in reducing carbon emissions.
- Installation of a PV array on the cathedral using high power panels would reduce the operational carbon emissions.

What must most importantly be noted, is that carbon emissions of all options that rely on electricity to heat the building will drop in line with the grid as it becomes more reliant on renewables.

5.2 Carbon Offsetting

In order to reach net zero carbon without implementing best-performing recommended measures, residual energy that cannot be negated via other means needs to be offset. On-site solutions, such as carbon sequestration through tree planting or using solar photovoltaics, are the most sought-after solutions due to the direct control over the measure. Suitable off-site solutions might include purchase of energy produced by off-site wind or solar farms that is provided by an accredited supplier of 'Green Power' or investment in projects with a measurable carbon impact such as Church-sponsored sustainable woodland. As is discussed above, there is very unlikely to be a pathway to take that will achieve net zero carbon by 2030 without offsetting carbon. Take for example Option 4 (implementation of an ASHP), this option still has a residual emissions rate of 21 tonnes CO_2 emitted to the atmosphere annually, if implemented with today's carbon factors for electricity from the grid. To put that in perspective, it is estimated that 860 trees should be planted annually to offset the carbon.

Figure 15 demonstrates the approximate area of solar PV that would be required at optimum tilt to offset the equivalent amount of $C0_2$ produced annually from Option 4 in 2023. As can be seen, this requires not only the space previously identified as suitable for PV, but a further 600m². It may be possible for the area to be found offsite; however, this is outside the scope of this study.

Figure 14: Area of solar PV required to offset residual CO2 from Option 4

It is clear from Figure 14 that onsite offsetting of residual emissions presents a spatial challenge, and that simply offsetting existing emissions without mitigation measures may not be viable. It is therefore proposed that if any offsetting activity is undertaken, it is taken offsite, and only after maximal pragmatic reductions to onsite emissions have been enacted.

Note also that Figure 2 in Section 1 shows that the IPCC already expects humankind to use what we describe today as 'offsetting' at a massive and unprecedented scale after 2050 to achieve global carbon emissions below zero, having spent the previous 30 years aggressively cutting carbon emissions at source.

While the authors of this report are strongly in support of tree planting globally as a carbon capturing method, this is seen as additional to energy and carbon efficiency, not as a substitute.

5.3 Stand-alone PV

In many instances, installing a solar stand-alone PV system will be the least disruptive measure possible on site. This is because it involves no ground works, does not make any noise when installed and has the lowest capital cost out of all measures proposed. When analysed in isolation, the following high-level conclusions can be made:

- At Brecon, if installed in suggested locations in section 5.11.8 and fully utilised, the array is estimated to save the cathedral £15,200 in the first year.
- Assuming the array costs the cathedral £130,000, and requires an annual service costing £500, payback is expected to be close to 11 years.
- Over 20 years, the array is estimated to save the cathedral emitting 139 tonnes of carbon dioxide.

5.4 Equality of Energy Use

The proposed strategy of heat pumps (possibly combined with some direct electric heating) assumes that the UK electricity grid has sufficient capacity to meet this load. While this is true currently, with the continuing uptake of heat pumps and electric vehicles across the UK, there will be increasing pressure on the grid's infrastructure and renewable generation capabilities. Brecon Cathedral may wish to consider how they can minimise their contribution to this problem. Some options to consider are:

- Improving the cathedral's fabric and use of services before implementing heat pumps- as per our recommendation, to reduce the heat pump size and associated electrical load.
- Battery storage associated with any solar PV installation- allowing stored energy to be utilised during peak periods, instead of the grid.
- Heat generation during off-peak periods- operating heat pumps at times of low grid demand, with larger thermal stores allowing heat to be used later.

6 Conclusions and Recommendations

This report has considered the feasibility of reducing operational carbon emissions of Brecon Cathedral in line with the Climate Change Act. In our survey of the site, and subsequent analysis, we have observed that:

- The building has a high space heating demand as a result of its size, use and thermally poor envelope.
- Occupants of the building have mixed experience of thermal comfort, but there is a general feeling of relative comfort and an understanding of the difficulty to heat a building such as Brecon Cathedral.
- The nature of the fuel used to heat the building and must change in order to reach net zero carbon.

As the cathedral is Grade one listed and of extreme historical importance, extensive fabric improvement measures are not considered for analysis within this report.

Excluding boilers, existing building services are generally efficient and modern, but with room for improvement in some spaces, where we identified some opportunities for improvement including:

- Replacement of remaining non-LED lighting
- Upgrades to pipework insulation
- Improvements to the heating controls
- Improvement of hot water controls by way of time clocks.

A review of the cathedral has identified five opportunities to reduce the carbon emission of the heating system:

- Direct replacement of current gas boilers
- Implementation of direct electric heating
- Air Source Heat Pumps (or bivalent)
- Ground Source Heat Pumps
- Solar PV

The existing gas boilers are at the end of their life and have a poor efficiency. Most cost effective solutions are to directly replace the existing boilers with modern high efficiency condensing boilers.

A ground heat collector array for a ground source heat pump (GSHP) could be drilled beneath the lawns surrounding the cathedral. Its feasibility and possible heat output would be determined by ground performance and below-ground archaeology and infrastructure.

Air source heat pumps can be implemented as a standalone solution or in a bivalent arrangement, i.e., in combination with the existing gas boilers. The bivalent solution offers good carbon emissions reductions for lower capital investment compared to the other heat pump options, though ultimately all gas boilers will need replacing, so costs are delayed rather than removed. A bivalent solution can act as a 'steppingstone' towards further decarbonisation in time, as heat pump technology improves, or further upgrades are made to the buildings.

Unfortunately, the limited government incentives available means that heat pumps do not have a good financial return and coupled with their high capital costs and diminished running costs savings (due to current fuel prices) may not be an affordable solution. Any effort to create a site wide energy centre based around a heat pump with neighbouring buildings would have the potential to reduce capital cost, by sharing installation costs across multiple parties.

Direct electric heating is likely to be the most expensive solution in heating the building if installed as the sole heating system. That said, small pockets of direct electric heating alongside a heat pump can be suitable strategy to heat the building. Areas of irregular use can be warmed to comfort levels by direct electric heating, which is easy to control, and responsive.

Brecon Cathedral has large areas of roof which are south facing, therefore making them highly suitable for PV panels. Large parts of the roof need repairing, therefore and works related to installing PV panels could coincide with this. Although suitable for PV from a technical perspective, the roof surfaces are unanimously visible from the ground, therefore the cathedral should seek advice from the relevant planning and/or conservation officer.

Analysis of the carbon emissions reduction achieved by the various improvement options demonstrates that:

- It will be very difficult to achieve zero carbon for the cathedral by 2030 because there will continue to be carbon emissions associated with electricity used for heat pumps and appliances, or a dependency on a fossil fuel-based district heating system.
- Ground Source Heat Pumps as a single measure provide the largest reduction in annual carbon emissions by 2030 for this site, however present a significant practical and financial challenge.

- There is insufficient space available on site for solar PV to offset these emissions in their entirety.
- To achieve net zero carbon for all options, off-site solutions are required. This could be in the form of local projects e.g., solar PV installations onsite or on other church land, purchasing of zero-carbon certified electricity, or investment in carbon reduction schemes.

Drawing on the above, we recommend the following for the site:

- Pursuing any improvements to the fabric and operation of the building should be the first consideration. Although not analysed in detail in this report, this would be beneficial for comfort, reduction of energy bills and running plant as efficiently as possible.

- Building services improvements including a new low carbon heating system, full roll-out of remaining LED lighting and improvements to pipework insulation and heating controls where possible.

- Ground Source heat pumps are recommended to provide a substantial carbon reduction (around 88%), but the capital costs are high, and financial case is poor. A GSHP option could facilitate setting up a shared heating system with the close buildings in order to coincide with their objectives in reducing carbon emissions.

- If the above is not a viable solution our recommendation would be to pursue an Air Source Heat Pump bivalent system whilst gas boilers are operational, moving to a full ASHP based system in the future.

- Solar PV provides a noticeable contribution to the electricity load of the building.

- Offsite carbon reduction should be considered to offset any remaining CO_2 emissions.

Appendix A - Other Associated Buildings

A.1 The Vestry

The Vestry occupies the location of what was the west range cloister of the medieval Priory and has surviving medieval structure, as well as features from the 17th and 18th centuries. It is Grade I listed and attached to the south side of the Cathedral. It continues to function as a vestry with the various ceremonial garments stored there. WCs are also located on the ground floor.

The Vestry - Fabric

Figure 15 Photos of the Vestry

Component	Summary
Floor	There is a solid floor at The Vestry. Where no floor void exists, adding insulation is considered very difficult, or not feasible as it would either require excavation and replacement or raising the floor to accommodate the layer of insulation.
External Walls	Uninsulated solid stone walls. Internal wall insulation is the only option due to the architectural merit of the façade
Roof	There is a vaulted roof at The Vestry which is thought to be insulated to a poor standard. Consideration could be given to upgrading existing insulation while retaining exposed rafters.
Glazing	All windows are single glazed leaded lights, generally set in timber frames, presenting an opportunity to improve thermally by adding secondary glazing. The glazing is generally in poor repair, resulting in poor thermal insulation and draught exclusion. Therefore, there are opportunities to reduce draughts through replacement of window and door seals, and filling of holes with suitable sealants. It is not deemed possible to replace windows due to the historical and architectural merit.
Airtightness	Significant cold draughts were noted around windows and doors in many spaces, including where daylight was visible through some door frames. A draught lobby could be included within the entrance door. An assessment on whether log burners and open fires are being used should be carried out when occupied. If not used, chimneys could be draught-proofed.

The Vestry – Services

System	Summary
Lighting	The Vestry has little to no LEDs and no intention to move to LEDs throughout.
Heating	The Vestry heating is served by gas boilers and radiators throughout.
Hot water	Hot water is delivered by point of use direct electric water heating units.
Ventilation	Opening windows – no extract ventilation in Kitchens and wet rooms.
Controls	There are no thermostatic valves on radiators. The heating is generally controlled via boiler-based on-off switching and no central thermostat was present

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A.2 The Deanery

The Deanery is the home of the current dean, Dr Paul Scackerley. The building is attached to the Vestry which in turn is attached to the Cathedral. There is a tower at the junction of the Vestry with the Deanery with the second and third floors forming part of the Deanery and the lower floors part of the Vestry. It is Grade I listed with surviving medieval structure and details, as well as features from 17th and 18th centuries, sensitively converted by leading early 20th century architect. Recently it has had a thorough refurbishment at the cost of £1.2m.

The Deanery – Fabric

Figure 16: Photos of the Deanery

Component	Summary
Floor	The floor is largely solid with an area of suspended timber floor at the south end over a small basement area. The insulation to the underside of the basement ceiling is incomplete. The uninsulated area could be insulated between the joists. However, elsewhere where no floor void exists, adding insulation is not considered feasible as it would either require excavation and replacement or raising the floor to accommodate the layer of insulation.
External Walls	Uninsulated solid stone walls. Internal wall insulation is the only option due to the architectural merit of the façade
Roof	We could not get access to the roof; however, we are under the impression that it has been insulated to an appropriate degree recently.
Glazing	All windows are single glazed leaded lights mainly in timber frames with one being stone mullioned, presenting an opportunity to improve thermally by the addition of secondary glazing. It is not deemed possible to replace windows due to the historical and architectural merit.
Airtightness	No draughts were noticed, all doors and glazing are in good condition. An assessment on whether log burners and open fire are being used should be carried out when occupied. If not used, chimneys could be draught-proofed.

The Deanery - Services

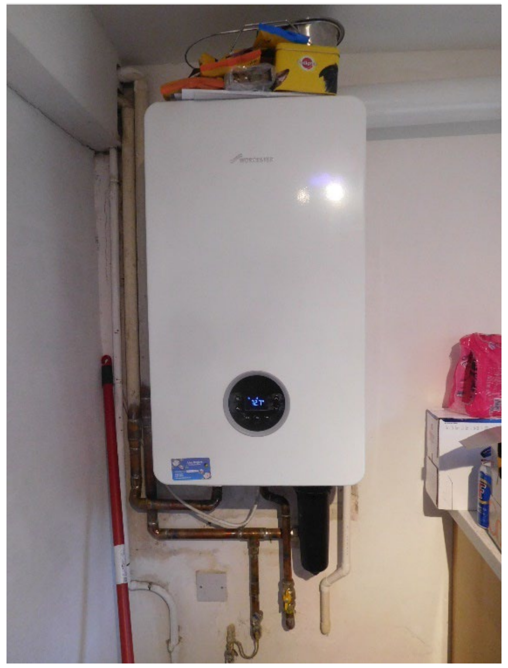


Figure 17: Site Photos of the Services within the Deanery

System	Summary
Lighting	The Deanery has some LED fittings, LEDs are refitted when older bulbs fail.
Heating	The Deanery heating is served by gas boilers and radiators throughout.
Hot water	Hot water for The Deanery is delivered by the main heating system.
Ventilation	Opening windows – no extract ventilation in Kitchens and wet rooms.
Controls	There are thermostatic valves on most of the radiators and the property also has a central thermostat. The heating is generally controlled via boiler-based on-off switching

A.3 Tithe Barn and Old Shop

The Tithe Barn is 17th century Grade II listed and has added significance due to being part of a group of the other listed buildings associated with the Cathedral. The narrower southeastern section, known as the Old Shop, is partially timber-framed and is dated from the earlier 17th century.

Tithe Barn and Old Shop – Fabric

Figure 18: Photos of the Tithe Barn and Old Shop

Component	Summary
Floor	There is a solid floor at Tithe Barn and Old Shop. Where no floor void exists, adding insulation is considered very difficult, or not feasible as it would either require excavation and replacement or raising the floor to accommodate the layer of insulation. The existing flagstones appear modern, so floor replacement may not present a heritage concern.
External Walls	Uninsulated solid stone walls to the Tithe Barn. Internal wall insulation is the only option due to the architectural merit of the façade. Internally the natural stone finish has been painted over. The Old Shop west wall is draughty and admits rainwater being composed of square edge boarding externally and woven timberwork internally. Daylight can be seen through it. The external oak weather boarding could be replaced and insulation incorporated in a renewed wall construction while retaining the existing timber structure. The Old Shop east wall is similar to that of the Tithe Barn and the same comments apply.
Roof	There is a vaulted roof at Tithe Barn and Old Shop which is thought to be insulated but probably to a poor standard. There is the possibility of increasing the insulation thickness and quality while still expressing the rafters.
Glazing	All windows are single glazed, presenting an opportunity to improve thermally by adding secondary glazing. It is not deemed possible to replace windows on the west side due to the historical and architectural merit. However, all the windows and glazed doors on the east side could be replaced in double glazing, as could the entrance doors to the Old Shop
Airtightness	Significant cold draughts were noted around windows and doors in many spaces, including where daylight was visible through some door frames. There was very significant draught through Old Shop west wall – see above. The eaves detail could be improved in terms of airtightness and thermally.

Tithe Barn and Old Shop - Services

System	Summary
Lighting	LEDs have been fully implemented throughout.
Heating	Gas fired heaters.
Hot water	No hot water within this space
Ventilation	Opening windows – no extract ventilation.
Controls	The heating is generally controlled via boiler-based on-off switching and no central thermostat was present

A.4 Glazed Link, Tea Shop, Kitchen and WCs

These building extend to the south of the Old Shop and Tithe Barn and are presumably of more recent construction and lower heritage value, except possibly the stone walls which match the barn. The Tea Shop and Glazed Link appear to be modern infill.

Glazed Link, Tea Shop, Kitchen and WCs – Fabric

Figure 19: Glazed Link and WCs

Component	Summary
Floor	There is a solid floor within the Glazed Link, Tea Shop, Kitchen and WCs. Where no floor void exists, adding insulation is considered very difficult, or not feasible as it would either require excavation and replacement or raising the floor to accommodate the layer of insulation.
External Walls	Uninsulated solid stone walls. Internal wall insulation is the only option due to the architectural merit of the façade.
Roof	There is a vaulted roof at Tea Shop, Kitchen and WCs which is thought to be insulated to a poor standard with the potential to have the insulation upgraded internally. The polycarbonate sheet roof to the Glazed Link could be replaced by an insulated roof with doubled glazed glass roof windows.
Glazing	All windows are single glazed, presenting an opportunity to improve thermally by adding secondary glazing. There may also be the opportunity to replace all windows with better performing double or triple glazing. The area of glazing the Tea Shop east wall could beneficially be reduced with insulated wall or panels raising the sill to say 900mm AFFL.
Airtightness	Significant cold draughts were noted around windows and doors in many spaces. This could be dealt with as part of upgrade to doors and windows mentioned above.

Glazed Link, Tea Shop, Kitchen and WCs – Services

System	Summary
Lighting	The Glazed Link, Tea Shop, Kitchen and WCs all have some LED fittings, LEDs tend to be refitted when older bulbs fail.
Heating	A combination of gas boiler and radiators and gas fired heaters.
Hot water	Hot water for Glazed Link, Tea Shop, Kitchen and WCs is heated by the main gas boiler.
Ventilation	Opening windows – extract ventilation in Kitchens and wet rooms.
Controls	There are thermostatic valves on most of the radiators. The heating is generally controlled via boiler-based on-off switching and no central thermostat was present

A.5 The Close: Fabric & Services Opportunities

Fabric Opportunity	Description	The Vestry	The Deanery	Tithe Barn and Old Shop	Glazed Link, Tea Shop Kitchen and WCs
	Roof Insulation Improvement to any existing insulation layer. In cold loft spaces, provision of an additional 150-400 mm loose lay (e.g., roll) wood or mineral fibre insulation, to be installed at joist level above existing insulation. Efforts to ensure insulation is continuous and covers thermal bridges such as protruding wall elements. In warm loft spaces, provision of insulation at, above or below the rafters.	✓	✗	✓	✓
	Interior Wall Insulation (IWI) Provision of 50-100 mm wood fibre internal wall insulation system. Note that this option is likely to require a complete replacement of internal wall finishes and should be allied to the airtightness measures below. A full condensation risk assessment should be carried out prior to the selection and design of the insulating layers.	✓	✓	✓	✓
	Cavity Wall Insulation (CWI) A masonry cavity is not present; therefore, cavity insulation is not applicable.	✗	✗	✗	✗
	External Wall Insulation (EWI) Provision of 100 mm external wall insulation system. This intervention is not considered viable due to the detrimental impact on the building's façade.	✗	✗	✗	✗
	Airtightness Improving overall building airtightness through sealing gaps. This includes sealing around window and door frames, sealing fireplaces as well as sealing other building fabric junctions (i.e., floor to wall, or wall to ceiling). Pressure tests could be undertaken to ensure the most effective sealing measures are carried out.	✓	✓	✓	✓
	Floor Insulation Where the ground floor is solid, provision of an insulating lime concrete floor above a breathable ground membrane. This option would require excavation of the ground to the required depth. Where ground floors are suspended timber, provision of insulation between joists. This would require lifting any existing floor finishes and potentially raising the floor level. A full condensation risk assessment should be carried out prior to the selection and design of the insulating layers.	✗	✗/✓	✗/✓	✗
	Secondary Glazing / or isothermal glazing Installation of secondary glazing where necessary, focusing on major sources of draughts and/or noise from outside, and windows on the north façades.	✓	✓	✓	✓
	Replacement Glazing Installation of high-performance double or triple glazed windows. This will require a discussion with a Conservation Officer and would incur significant cost.	✗	✗	✗/✓	✓
	Draughtproofing Windows and Doors Overhaul and draughtproofing of existing windows and doors.	✓	✓	✓	✓

Service Opportunity	Site Viability Assessment		The Vestry			The Deanery			Tithe Barn and Old Shop		Glazed Link, Tea Shop Kitchen and WCs
Ground Source Heat Pump (GSHP)  Thermal energy	• In theory, a ground collector array could be installed beneath the lawn area to the south and north of the Cathedral. • Viability would be subject to archeological and financial assessments. • The size of the ground collector may be insufficient to cover the full heat load of the building. A thermal response test would be required to confirm the output / required size of the borehole array.		✓			✓			✓		✓
Air Sourced Heat Pump (ASHP)  Thermal energy	• This solution is less efficient than GSHP, albeit at lower capital costs. • ASHPs lend themselves well to a decentralised approach, i.e., provide individual systems for separate buildings. However, there may be scope to a have a centralised system, connected to the Cathedral ASHP. • AHSPs (and all other heat pump types) can be combined with boilers in a bivalent arrangement. This solution enables the ASHPs to run when it is efficient to do so but reverts to boilers to provide heating when higher temperatures are required which, for example, negates the need to upgrade radiators. • An external location is required for the associated plant items. • Noise produced by the units would need to be considered. • Building heat emitters unlikely to be large enough for conventional heat pump temperatures but can in theory be upgraded. Alternatively, high temperature heat pumps could be considered, as with ground source systems. • Additional internal plant space would be required to accommodate the associated buffer vessels, water heater, pumps, and controls.	✓	✓	✓				✓			
Water Source Heat Pump (WSHP)  Thermal energy	• No watercourse or waterbody on or near the site		✗			✗			✗		✗
PV 	• South, Southeast and Southwest facing roof areas of roof to the buildings technically present an opportunity for PV. • Planning permission and Listed Building consent would be required and may be challenging/impossible to obtain. • Suitability of roof structure would need further investigation but not expected to be prohibitive. Solar PV can also be ground-mounted, this would require an area of the landscaping with little or no shading.	✓	✗	✗				✗			
Direct Electric Heating 	• Direct electric heating is relatively easy to install and can take advantage of off-peak electricity rates. At current prices to deliver existing levels of heat. • Likely to be much more expensive to run than the current system, or a heat pump-based system.		✗		✗		✗			✗	

✓ Feasible ✗ Not Feasible ✗/✓ Feasibility unclear

Appendix B - Property Improvement Possibilities

Here we summarise all the possible interventions and upgrades to old/historic buildings that are technically feasible. Their impact on operational carbon emissions is considered in Section 5 of the report. Technical feasibility is considered across our three primary contributors to total carbon footprint:

1. Building operation, control, occupancy
2. Building physics – the building envelope
3. Building services – systems that make the building work

Note that we use the terminology 'low and zero carbon technologies', or more simply, 'renewables'. This is a term commonly used in the construction and property industries to refer to specific technologies such as heat pumps, solar photovoltaic panels etc that emit no or reduced carbon when compared to fossil-fuelled alternatives. Given that all these systems are part of the building services that make the building habitable and provide energy for this purpose, they could more accurately and simply be called 'low carbon building services' or similar. We stick with convention in this report but are clear that there is not some fundamentally new category, simply better and lower carbon building services and energy systems. These systems, in combination with building operation and building physics, determine the overall carbon footprint, which is the key performance indicator for this study.

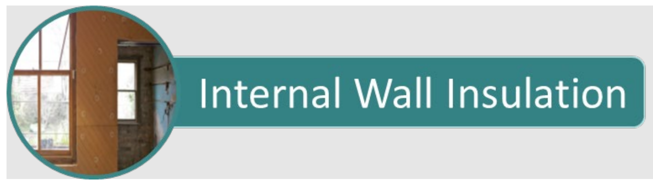
B.1 Building Operation

Interviews with building occupants give a general picture of the operational and occupancy patterns of the buildings. Typically, operational savings can be made through:

- Reductions in thermostatic set points
- Reductions in boiler flow temperatures
- Operational good practice, such as switching off lights, switching to holiday mode when away, etc.

Given the scale of the challenge of driving operational carbon emissions down to zero, it is our view that operational refinements, while generally helpful, have no great part to play here.

B.2 Building Fabric Improvements.



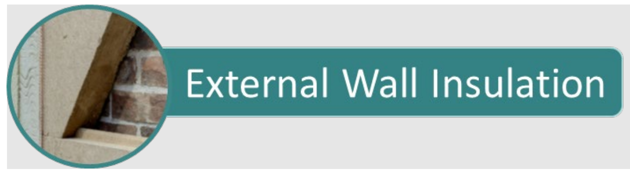
Much of the heat loss through a building is through its walls. Therefore, Internal Insulation (IWI) is an effective insulation method, particularly in settings where external wall insulation cannot be suitably applied. This might because external insulation would adversely affect the appearance of the building (and any relevant heritage requirements), or if the external façade is extremely complex and not conducive to this type of solution.

There are several methods to apply internal wall insulation, however, all involve significant disruption and works to the interior of the house. This includes removal of furniture, including in some cases, built in cabinetry, removal of fittings such as radiators, skirting boards, windowsills and plug sockets which lie on a wall that is being insulated, removal of all internal wall finishes and redecoration required following the installation of internal insulation. IWI improves thermal comfort, however may also reduce the internal size of your room.

There are several methods in which IWI can be applied including rigid insulation boards (some which have pre-attached plasterboard to make installation simpler) or dry lining where battens are fixed to the walls and insulation is fitted between.

Consideration also needs to be given to avoid the potential for condensation to develop within the wall build up.

More information on internal wall insulation can be found at: http://www.greenspec.co.uk/building-design/internal-insulation/



External Wall Insulation (EW) involves adding a layer of insulation to the outside of a building and then protecting this with a layer of render or cladding. It may be considered as an appropriate measure to avoid a loss of space or disruption associated with IWI (explained above). For projects which are already undertaking significant works to the external of a property (such as re-rendering), EWI may be seen as the most reasonable approach to reduce heat losses through the walls.

EWI may require planning permission, in particular for projects that are listed or are located within a conservation area, as it can change the appearance of the building. Some factors to consider if pursuing EWI include, allowing for suitable access (i.e., boundary walls, gardens etc.), ensuring scaffolding can be erected if needed, external fittings such as rainwater pipes, telephone and power cables may need to be removed.

The construction of EWI often consists of rigid insulation fixed to the existing structural wall, followed by a reinforcing mesh which can act as a backing for a base coat of render, followed by a finishing render which will give the building its final appearance. Similarly, with IWI, consideration should be given to avoid the potential for condensation to develop within the wall buildup.

More information on external wall insulation can be found at: http://www.greenspec.co.uk/building-design/insulated-render/

Cavity wall insulation is considered a reasonably 'low disruption' insulation technique for buildings in which the external walls have unfilled cavities at least 35mm wide (generally only buildings built after the 1920s), and where masonry is in reasonably good condition. Similarly, with EWI and IWI, consideration should be given to avoid the potential for condensation to develop within the wall buildup.

The most common way of insulating cavity walls is through drilling a number of small holes into the mortar and injecting or blowing the insulation material (e.g., polystyrene beads or loose glass wool) into the cavity. Once filled, these holes are then refilled and sealed.

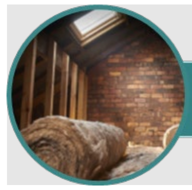
More information on cavity wall insulation can be found here: https://www.cse.org.uk/advice/advice-and-support/cavity-wall-insulation

Under Floor Insulation

Installing under floor insulation is an effective way to reduce energy bills and improve occupant thermal comfort. Depending on the type of construction of the flooring, the amount of disruption caused will vary. For example, if a building has a suspended floor with a large cavity below, that is readily accessible, insulation boards can be fitted between the flooring joists. Alternatively, if the floor is above an unheated basement or cellar, the insulation can be installed above, ensuring that it is secure with netting or other means if required.

If the building has a suspended floor, with a small cavity below that is difficult to access, typically this would require the floorboards to be removed in order to fit the insulation. There are some emerging technologies in this space (i.e., https://q-bot.co/) which make use of robotics to survey the under floor area and spray insulation (thus reducing the need to completely remove flooring).

More information on under floor insulation can be found at: https://www.cse.org.uk/advice/advice-and-support/underfloor-insulation



Roof Insulation

Roof insulation is a reasonably simple building fabric upgrade, when compared to other upgrade opportunities. For buildings with an accessible, an unheated loft space, this is usually a straightforward process which involves laying rolls of insulation over the joists (sometimes on top of existing insulation). For lofts which are not accessible, loose insulation material can be blown into the loft using specialized equipment (usually completed by a professional).

For loft spaces which are heated, insulation needs to be fitted between and over the rafters which can be done with rigid insulation board or using foam insulation sprayed between the rafters.

More information on roof insulation can be found at: https://www.cse.org.uk/advice/advice-and-support/loft-insulation

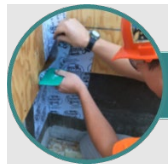
Vacuum Glazing

Vacuum glazing can be included as a suggested upgrade opportunity for these projects. Traditional single glazing does not provide the thermal or acoustic benefits that modern double glazing can offer. While double (and secondary) glazing can provide higher levels of energy efficiency, standard framing systems do not typically work in a heritage setting, largely due to aesthetic reasons.

Standard double glazing requires a space of around 16-20mm which creates a noticeable gap, which can be considered unacceptable for heritage projects. An alternative to this is low sightline slim double glazing, where the gap is reduced to around 5-6mm and creating a visual appearance much more similar to single glazing. This solution, however, has a reduced sealant in the perimeter of the units, which can cause them to be unstable and increase the likelihood of failure.

An alternative is to use vacuum glazing, where the air is extracted from between a pane of low-e glass and clear glass. The vacuum increases the efficiency of these units significantly from other options available in a heritage setting and is roughly a quarter of the thickness (and two thirds of the weight) of a conventional double-glazed unit. These units are available in traditional sliding sash and Richmond casement windows and can maintain the aesthetic integrity of heritage properties.

More information on vacuum glazing can be found at: https://www.gowercroft.co.uk/the-challenge-of-replacing-heritage-windows/



Air Tightness

Air leakage in a home can be a major cause for energy loss and occupant discomfort. Leakage can occur through various aspects of a building envelope including around window and door frames, beneath doors, along the top and bottom edges of skirting boards, around suspended flooring, through the eaves, through gaps in plasterboard, through cracks or holes in masonry, gaps in pipes and flues etc. In order to reduce this leakage, an impermeable air barrier should be applied to the building envelope. Some solutions to achieving this in a retrofit include, sealing and draught stripping existing windows, door sand loft hatches, sealing holes around services, blocking redundant fireplaces, or capping the chimney, sealing cracks in walls etc.

Such improvements must be balanced by the need for the building to 'breathe'- that is, to have sufficient levels of ventilation to maintain a healthy moisture balance. Therefore, we would recommend that airtightness measures are limited to elimination of major draughts rather than the pursuit of a truly airtight building. This can be achieved through measuring building airtightness before, during and after interventions, to make sure that an appropriate level of airtightness has been achieved.

Blower door tests can be undertaken to determine the air changes (and air tightness) in a property. This can also be useful to determine the most effective areas to improve air tightness.

More information on air tightness can be found at: http://www.greenspec.co.uk/building-design/refurb-airtightness/

B.3 Renewable Energy Technologies

Air Source Heat Pump

Air source heat pumps (ASHPs) use the refrigeration cycle to extract heat from the outdoor air and transfer it into a heating fluid- normally water- for use in the building. Electrical energy is required for this process, with typically three units of heat product for one unit of electrical energy input i.e., a Coefficient of Performance (COP) of 3. However, this efficiency is highly sensitive to outdoor conditions (temperature and humidity) and to the temperature the water is being heated to (ideally below 45 C).

As ASHPs heat to a lower water temperature than boilers, they are well suited to underfloor heating. If radiators are used, these need to be significantly (typically 3 times) larger to provide the same output as with a boiler. As ASHPs operate by extracting heat from the outside air, they are located externally, which can make them visually obtrusive. The fans generate noise which must be considered carefully particularly in quiet locations.

Air source heat pumps are problematic for historic properties because of the continuous heat demands which can cause the units to freeze up regularly, triggering 'defrost cycles' where energy must be used to melt the ice. The high heat losses from such buildings also mean that the heat pumps would need to operate at higher temperatures, which greatly reduces the efficiency of air source heat pumps.

Domestic ASHP are generally designed for modern houses and as a result often have relatively low heat output (typically between 5kW and 20kW). Depending on the required heating load of the building multiple external units may therefore be required. Larger, commercial-scale units are available, and it is these that would be required if utilized on the cathedral building, or in a shared system for the Close Houses.

There is less infrastructure associated with ASHPs (no collector arrays required etc.) and it is therefore a lot simpler to deploy them in a decentralised arrangement (when compared to other heat pump types). This is effective for buildings that are divided into different uses and have separate heating systems/requirements or where individual buildings need to be served (especially when they are further apart). Adopting this approach would allow ASHPs to be installed independently for various parts of the site, minimizing disruption and offering better flexibility with sequencing installation.

Bivalent ASHPs

A bivalent configuration generally combines heat pumps with boilers to form a hybrid system, a new heat pump can be connected into the existing heating system to achieve this. There are several ways this can be implemented but in essence the two heat sources work in parallel. Heat pumps are most efficient when the difference in temperature between the source and the heating medium is minimized. A bivalent system therefore works best by letting the heat pump run when the heating load is low and radiator circuit temperatures can be reduced (such as during the shoulder seasons). As the external temperature drops and the heating load increases the boilers are used to increase the temperature of the heating circuit. In this way the heat pump only operates when it is efficient to do so and this results in lower running costs. However, as the system relies partly on fossil fuels there will always be associated carbon emissions. This solution is therefore often used as an intermediate step towards a full heat pump arrangement.

Although the air source heat pump should be sized for the entire building demand, there may be merit in retaining a connection from the existing heating to provide 'top up' during extremely cold periods. This could be particularly useful if it is not possible to upgrade radiators to the size required for the heat pump system or could allow such changes to be carried out over a longer period. In top-up mode, boilers would add heat into the distribution system under peak load – i.e., on the coldest days. This is referred to as a bivalent heat pump system and is described in more detail in the air source heat pump section above. Note that this **top-up** option is different from boilers as a **backup** in case of heat pump failure or outage: we would not consider it necessary for the oil heating to be retained as backup: heat pump technology is highly mature, and many consider it to be more reliable than oil boilers.

An additional advantage of a bivalent system is that the size of the heat pump can be reduced – it is not required to meet the peak heating demand. This results in reductions in capital cost and the installation requires less space which can in turn also offer cost savings. As a bivalent system can operate at the same heating temperatures as the existing system modifications to pipework and emitters is often minimal. To benefit from this the "crossover" point of the system needs to be selected based on the outputs of the heat emitters. As discussed in the Heat Emitters section above this can be tested to determine what heating flow temperatures are required for satisfactory internal conditions.

High Temperature ASHPs

Although the efficiency of a high temperature ASHP is lower than that of a normal ASHP, the benefit of not having to replace all radiators within the property still make this a sensible consideration. At the time of writing, implementation of a high temperature ASHP which can deliver appropriate flow and return temperatures to replace boilers like for like may be difficult. Alternative solutions to this may be including a 'top up' heat system to the buffer vessel such as an immersion heater to deal with the harshest conditions of winter. This has been accounted for in the analysis by assigning a lower seasonal efficiency to a high temperature air source heat pump system.

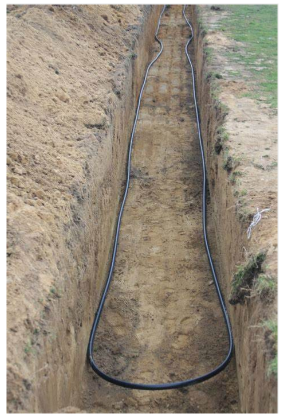
Ground Source Heat Pump

Ground source heat pumps (GSHPs) operate in a similar way to ASHPs, except that they extract heat from the ground instead of air. As the ground below 1m depth has a constant temperature (roughly 10degC in the UK), their performance is more predictable and generally better than ASHPs. Heat is extract from the ground through a ground array or collector which is generally in two forms:

a. a horizontal collector consists of pipework buried in trenches 1-1.5m deep. Fluid containing antifreeze (glycol or brine solution) is pumped through this pipework network at low temperatures, removing heat from the ground.
b. a vertical collector consists of boreholes drilled deep into the ground- typically 100-150m, with a pipe which runs to the bottom of the borehole and returns to the surface.

As the ground is relatively poor at releasing heat, a significant area of collector is required. Boreholes (or trenches for horizontal systems) must be sufficient in quantity and adequately spaced to ensure the ground is not 'over-extracted', which would result in freezing of the ground, and depreciating heat pump performance.

GSHPs are better suited to historic properties because of the stability of their performance, and lower sensitivity to higher operating temperatures.



Water Source Heat Pump

Water source heat pumps (WSHPs) are effectively the same as GSHPs, except that heat is extracted from a body of water – lake, pond, river, or sea- instead of the ground. There are two main types of system:

1. Open Loop System

In an open loop system, water is extracted using a pump, heat is extracted by the heat pump, and the water is then returned to the water body. This approach requires both an abstraction and discharge license from the Environment Agency and may also require planning permission. A key benefit of open loop systems is that there is little in the way of external equipment- most of it is within the plant room. However, as the water being pumped typically contains sediments and debris, a filtration system is required to protect the heat exchanger equipment. This can result in significant maintenance requirements.

2. Closed Loop System

With this system water is not extracted from the water body, but instead the heat exchanger (such as an energy blade system) is itself submerged within the river to extract heat directly. Environment Agency approval is required for this approach too, but are requirements are less stringent than open loop systems. Planning permission may also be required.

Risks Associated with Heat Pumps

Heat pumps are one of the most effective ways of minimising the energy consumption of a building. However, they do provide a number of challenges to implement. Some of these are listed below:

- Cost: Both air source and ground source heat pumps are relatively expensive systems to implement, meaning it is difficult to recuperate the capital costs from the savings in energy. Ground source heat pumps are considerably more expensive to install than air source heat pumps.
- Investments in heat pump technology are now less attractive since the renewable heat incentive has been wound down.
- Heat pumps deliver lower temperature heat, meaning it is likely that heat emitter sizes will need to be increased (see section below).
- Ground source heat pump will cause considerable external disturbance whilst the boreholes are being dug and the lawn in mending.
- Planning permission is likely be required given the noise emitted from new external plant and pipework penetrations through the footings of historic buildings

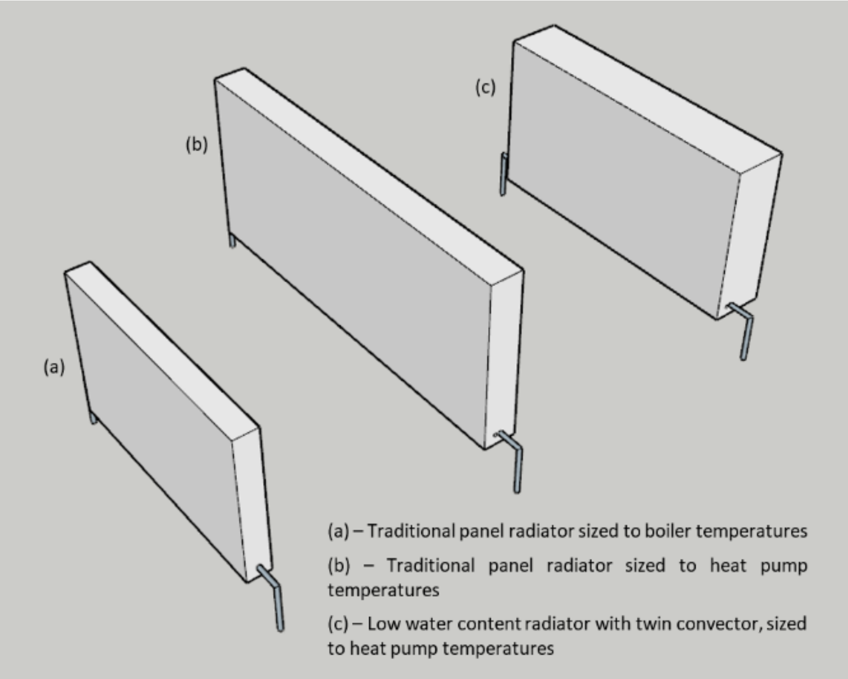
Heat Pumps and Heat Emitters.

When specifying a heat pump for an old / historic property, it is very important that the size of the heat emitters is taken into consideration. As most domestic boiler set up operate at a flow temperature of between 70-80c, whereas heat pumps are between 40 – 50c, heat outputs from small radiators may not meet the heating demand if connected to a heat pump system.

If a low temperature heat pump system was preferred for the property, it is recommended that a full heat loss calculation is performed, and radiators are individually assessed to calculate whether they are an appropriate size or not for the system. If radiators are found to not provide enough heat output at lower temperatures, there are three options to overcome this:

- Upgrade radiators - typically the new radiators would need to be at least two times larger than the existing, although this can be achieved using deeper 'convector' and low-water-content products to minimise their spatial impact.
- Selecting a high temperature heat pump allows the system to continue to operate at higher temperatures, however this has an impact on efficiency which results in higher operating costs and carbon emissions.

Provide supplementary heating to increase the water temperature, typically this is done with a boiler and is referred to as a bivalent arrangement - discussed further below.



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