Otley Parish Church Roadmap to Carbon Net Zero by 2030

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Dear PCC Member

This report is technical in nature because it can be useful for external professionals to gather important details about our church. Please feel free to read all of it and enjoy those details, but don't feel obliged to plough through it all. We really would like you to read and consider the Executive Summary because there are important decisions, listed on page 7, for us to make. Thank you.

Issue date: November 2023

Contents

Glossary

Term	Definition
ACH	Air Change Rate in ‘air changes per hour’. A way of expressing how much fresh air passes into and out of a building.
ASHP	Air Source Heat Pump. A device that provides heat to a building from the outside air.
C of E	Church of England
CoP	Coefficient of Performance. Is a ratio that describes the efficiency of a system and is usually applied to Heat Pumps.
DNO	Distribution Network Operator. The commercial entity that operates the energy distribution grid(s).
Energy Supplier	The commercial entity from which electricity and/or gas is bought
GHG	Greenhouse Gas. A gas that contributes to the greenhouse effect by absorbing infrared radiation. Carbon dioxide and chlorofluorocarbons are examples of greenhouse gases
GSHP	Ground Source Heat Pump. A device that provides heat to a building from the ground around the building
GWP	Global Warming Potential. The potential for an action to add to global warming, expressed as carbon dioxide equivalents.
HGV	Heavy Goods Vehicle
NG	Natural Gas. The fossil fuel.
OoM	Order of Magnitude. The factor of 10 within which a value resides. More generally used to indicate the value is not to be relied upon, but is not incorrect.
OPC	Otley Parish Church
PAS	Publically Available Specification.
PPA	Power Purchase Agreement. Also referred to as a ‘private wire’ is a long-term agreement between an electricity generator and a single consumer
PCC	Parochial Church Council
PV or pv	Photovoltaic (PV) panels are used to produce electricity directly from sunlight.
SME	Subject Matter Experts
VAC	Volts Alternating Current.

Units

Unit	Meaning
kpa	Thousands per year (usually a money value such as £23 kpa)
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
m^3	Cubic metre
m^3pa	Cubic metre per annum
MW	Megawatt
MWh	Megawatt hour
tCO_2e	Metric tonnes of carbon dioxide equivalent
tCO_2epa	Metric tonnes of carbon dioxide equivalent per annum
tpa	Metric tonnes per annum

1 Executive Summary

The purpose of this roadmap report is to capture the work done by the OPC Net Zero Group as we strive to meet the Church of England's ambition to reach Carbon Net Zero by 2030. To aid churches, the C of E has produced a great deal of guidance on the subject, which has been of use to us in preparing this roadmap. It is anticipated that this report will be provided to external service providers, hence it is written in a format that follows the convention of reporting how to achieve Net Zero for organisations.

The OPC Net Zero Group was formed from members of the congregation following the PCC decision to start on the journey towards meeting the C of E Net Zero goal. It is pleasing that there is a strong sense of common purpose and mutual support amongst the local churches from which we have benefitted and in turn would be happy to pass on to others. Information and opinion has also been gathered more widely from the growing body of practitioners in the renewables/Net Zero sector.

Within OPC, we are blessed to have a great deal of information about the fabric of the church and its energy consumption – both of which are key to understanding the current carbon footprint of OPC and how to reduce it towards Net Zero. We found that practically all of the Greenhouse Gas (GHG) emissions attributable to OPC arise from burning natural gas (a fossil fuel) in the church boilers. This roadmap has focussed on achieving Net Zero for the church building. The Chestnuts has a much smaller carbon footprint and will need to be considered separately.

A widely accepted method (also accepted by the C of E) for achieving Net Zero is:

- Reduce current emissions as far as possible (usually by simple changes)
- Then invest in appropriate technology to cease emitting as many GHGs as possible
- Then offset the remaining emissions

To start by identifying where emissions from OPC could be reduced, the group walked around the church building and found areas where energy was being wasted, that could be corrected for minimal or relatively moderate cost. These are detailed in section 6.1 ("Quick Wins") of this report and mostly focus on draught reduction by sealing gaps in the fabric of the building. A little more investigation is required to assess heat loss routes in the difficult to reach parts of the building.

The next step in reducing emissions would be to apply insulation to the building so that less fossil fuel energy is needed to keep it (and its occupants) warm. Some very useful data had been gathered by the Wardens at the end of 2022 that enabled the heat losses to be characterised. We found that it is possible for up to 55% (though more typically 45%) of all the heat put into the church by the fossil-fuelled boilers to be lost through the roof. This makes applying insulation to the roof a high priority. This will not be easy in a Grade 1 listed building in regular use, with limited financial resources. We have started internal discussions with the Diocesan Architect and the PCC to assess what could be done.

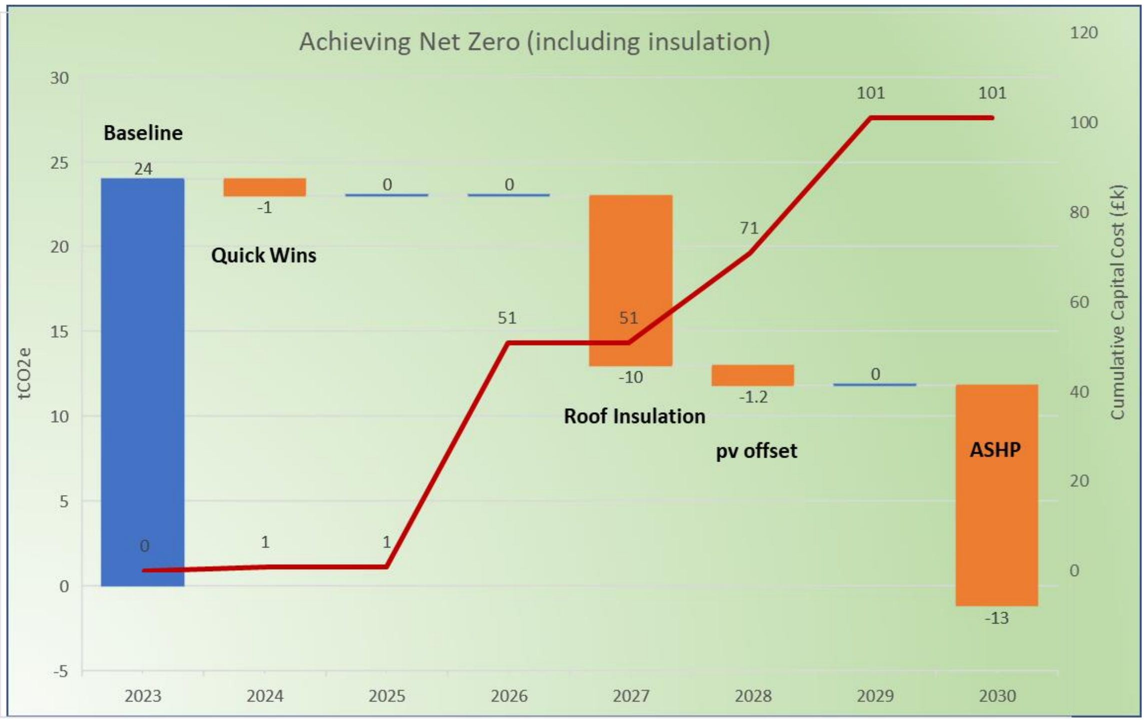
One further point of note is that the church roof is understood to be in urgent need of replacement/refurbishment, which would be an opportunity to install a high standard of insulation at a marginal cost (estimated to be £50,000) during the replacement. If this replacement is deferred, our opinion is that insulation could still be added to the roof by other means, some of which would not change the appearance of the roof, but at greater capital cost and possibly providing a lesser reduction in heat losses. This is another area where more investigation is required.

In order to cease emitting GHGs, the most effective action is to stop burning fossil fuels. In the case of OPC, this means replacing the gas-fired boilers with an alternative heat source that does not emit GHGs. This study concludes that the best solution for OPC is to replace the boilers with an Air Source Heat Pump (ASHP). This is likely to have a capital cost in the region of £30,000 and will triple the consumption of electricity, but as this electricity is renewably sourced, there will be no increase in GHG emissions from OPC.

The church is also responsible for a small amount of residual emissions from, for example, consuming water or the Vicar's car as he goes about the parish on church business. These residual emissions are very difficult to remove individually, so the established approach is to offset these emissions through various means. Unfortunately, there is a great deal of disagreement in the sustainability sector over how to offset GHG emissions, with tree planting schemes in particular being mired in controversy and technological methods in their infancy. One agency that could be considered for this final offsetting is Climate Stewards who are part of the A Rocha group and have links with the church. They could be paid an annual fee to run schemes that sequester carbon on our behalf.

In this study, we explored the final offset problem on the basis that producing electricity and feeding this into the grid, offsets some of the GHG caused by the fossil fuel powered power stations on the grid. The applicable established methods of producing renewable electricity are either wind turbines or photovoltaic (pv) panels. A standard wind turbine would not be appropriate for OPC (though there are some unconventional designs that would work by hiding themselves in the bell tower), so the best alternative would be pv panels. The main problem with pv panels for OPC is their visual impact. The main benefits are they could pay for themselves within 4 to 8 years and thereafter bring a financial benefit to OPC of between £2,000 and £12,000 per year. The initial outlay required would be between £10,000 and £50,000. This range of financial values depends upon the physical area of pv panels that are installed.

The route to Net Zero, if insulating the roof is included, is illustrated below:



This 'waterfall' chart shows the starting point in 2023 as the "Baseline" carbon footprint of 24 tCO2epa (blue column) and zero cumulative capital cost (thick red line). In 2024, the "Quick Wins" have achieved a reduction (orange block) of 1 tCO2epa for a cumulative capital cost of £1000. In subsequent years, further reductions in carbon footprint are achieved in the year (approximately) following the capital expenditure until the carbon footprint reaches zero in 2030.

A similar graph is shown in section 7 for the case where the roof is not insulated before 2030.

This report is fairly technical because this is a technical subject. However, whilst not featured in this report, it is recognised that it is vital to the success of GHG reduction measures that all the stakeholders are involved and can contribute appropriately. Communication is key to this and hence it is suggested that some form of Net Zero group continues into the future. Stakeholder engagement can start with helping to deliver the Quick Wins, such as pruning the foliage that is casting shadows onto the church. Wider community involvement has been found by other churches to be helpful in grant applications, as has all plans being aligned with local neighbourhood plans such as the Otley Town Council plan.

Recommended Next Steps

1. Complete the ‘Quick Wins’, in particular provide finance to enable the clerestory windows in the Nave to be closed and draught proofed. The leaking gutters should also be identified and repaired.
2. Provide finance to investigate the condition of the roof. This investigation to include an invasive study of the structure of the roof with a view to enabling the optimum insulation solution to be identified.
3. Define a new group to take Carbon Net Zero by 2030 forward, as the current group has completed its remit to do initial research and report back to the PCC. The new group should be tasked with; increasing the level of communications about our plans for Net Zero generally, approaching the DAC, English Heritage, Leeds Planners, et sim about the plans towards achieving Net Zero, seeking quotes from suppliers of the recommended capital items (insulation, ASHP and pv panels) and producing the preferred solution to be passed on to the delivery stage. It is likely this group will make use of external professionals and will require a budget to pay for these external services.
4. Start fundraising for; the roof refurbishment/replacement, the roof insulation and the ASHP.
5. Obtain a definitive, considered, decision from the appropriate authorities about the possibility of adding pv panels to OPC.
6. Obtain a definitive, considered, decision from the appropriate authorities about the possibility of adding external secondary glazing to OPC.

2 OPC Brief & Methodology

2.1 Brief

The Church of England has set a target of achieving Carbon Net Zero by 2030 for its substantial property portfolio. In doing so, it has provided guidelines for local PCCs to follow as well as free practical assistance from Subject Matter Experts (SMEs). These SMEs are small in number and have other roles to fulfil, so there have also been other resources made available (contractors and consultants) to assist with the initial stages of the process of working towards Net Zero. The Diocese of Leeds is also providing assistance in the form of procedures to streamline the process, such as the ‘Six Steps’ plan.

To make progress, the Otley Parish Church PCC has formed a small group of volunteers from the congregation to coordinate and focus activities up to the point where professional help from architects and technology providers will be most efficiently procured.

This report will provide the basis of the proposal for achieving Net Zero by 2030 that will be reviewed by the PCC.

2.2 Project Methodology

This section outlines the approach adopted by OPC to meet the brief.

To gain a better understanding of how to achieve Net Zero for OPC, the first steps were to gather information. This included the group’s members improving their knowledge of, for example, the heating and ventilation systems of the church, its history and its performance capabilities. Outside of OPC, the group also sought information from other churches in the area on how they had approached, or were planning to approach the C of E Net Zero target. This included site visits to other local churches and reading their published documents as well as talking to knowledgeable representatives of these churches. Local environmental groups in Otley were also consulted to look for joint opportunities and to share knowledge.

Concurrent with the information gathering, the baseline of OPC’s energy consumption was characterised using billing and smart meter data. This information was used to inform the group about how the church uses energy and which areas should form the initial focus for reducing the church’s carbon footprint.

Related to the understanding of the baseline is the opportunity to reduce this baseline by looking for Quick Wins which can be applied for minimal cost but which would reduce the amount of energy consumed by the church. The group identified and applied some of these Quick Wins as soon as they became apparent and made plans to apply others where minor investment was required (e.g. replace the freezer in the tower bottom).

Next, the group used internal and external sources to begin the process of gathering Order of Magnitude (OoM) cost estimates and to tap into their knowledge. This enabled more informed decisions to be made regarding the roadmap.

Finally, the roadmap report was written, edited and agreed amongst the group.

The project to develop the roadmap for OPC was scheduled to be completed in four or five months, approximately.

The project started with the first meeting of the group in June 2023 and the completed report was delivered in November 2023, with the intention of it being presented to the PCC at the scheduled November meeting.

2.3 Information Gathering

This has been ongoing from many sources throughout the development of the report. Of particular note are:

- The heating data collected towards the end of 2022 by the Churchwardens
- OPC's website and the source documents referred to there
- The smart electricity and gas meters and information provided by the Treasurer
- The C of E websites relating to Net Zero

2.4 Site Visits

Site visits to the following locations were used to meet fellow travellers on the journey to Net Zero and to see the relevance of their experience to the needs of OPC:

- Holy Trinity Skipton
- St John's Menston
- All Saints Ilkley
- Baildon Methodist

A visit to York Minster is being planned to see how they have added pv panels to their roof.

2.5 Interim Meetings

The group met formally on 5 occasions (approximately monthly, to maintain direction and report back on progress) and informally on other occasions, such as the cleaning of the Parish Room heaters and air filters.

Other meetings took place with:

1. The church's architect, Carl Andrews, took place on 4 September 2023.
2. Laura Garcia (an architect with Pegasus Group Leeds), lives in Otley and has worked on projects involving English Heritage.
3. Tim Larner (Vice Chair of Zero Carbon Harrogate and friend of Eric Cairns), an enthusiastic advocate for Carbon Net Zero and an early adopter of Passivhaus technology.
4. Keith Wilson and Tom Raper, for the maintenance of trees and bushes in the churchyard.

Community meetings with Otley 2030 were intended to take place but have been delayed. Informal contact has been made, along with a mutually supportive exchange of ideas.

2.6 Roadmap Development

The roadmap and its attendant spreadsheet became a convenient repository for information as it was gathered. The roadmap report is based on the findings from this information and associated calculations. In the end, the number of potential options for reaching Net Zero available to OPC is small and the report becomes a tool in deciding upon the best options.

2.7 Engagement with the OPC Team

Useful conversations and practical assistance were gained from various stakeholders in OPC, including the Vicar, the Treasurer and the Wardens.

2.8 Carbon Neutrality & Net Zero

These two terms are often used interchangeably. In recent years, both terms have come to have a different meaning, governed by independent standards. Details on the differences are shown in Appendix A.

Interestingly, the C of E has its own definition of Net Zero, which is strongly aligned with the principles of Net Zero, but aims to only achieve a reduction in GHG emissions to 10% of the baseline, rather than zero GHG emissions. This C of E definition is also vague about residual emissions (those very difficult to remove numerous small emissions often out of the control of the church) – which probably has a strong bearing on the decision to aim for 10% remaining emissions rather than zero.

This roadmap report follows the C of E approach to Net Zero, but includes the treatment of the residual emissions by applying the principles of carbon neutrality so that OPC's emissions can become effectively zero by 2030.

3 Benchmarking Study

This would normally be a comparison with other local churches and examples in the Church of England literature. However, the group has not found any other church that is truly comparable to OPC.

The baseline energy consumption could be usefully compared to other churches to indicate where in the 'league table' OPC lies. However, this has been deferred for now as it would not be a simple undertaking and, whilst interesting, is not crucial to decision making about OPC.

Some comparisons are possible from the Diocese of Leeds Carbon Emissions Report 2019 which included the average carbon emissions by size of church, as:

- Large churches 32.9 tCO2epa
- Medium churches 12.8 tCO2epa
- Small churches 3.0 tCO2epa

The definition of a large church used in the above data was a floor area of over 650m^2, which means OPC is defined as a large church. The annual carbon footprint of OPC is 24 tCO2epa, making it somewhat better than average compared to other churches. There are quite a few caveats that should be applied to this statement (primarily because we don't know the details of what was included in the Diocese of Leeds figure), but it is possible that OPC's purchasing of all electricity from renewable sources and the adjustments made to the heating regime are putting OPC in a leading position in the diocese.

4 Site Overview

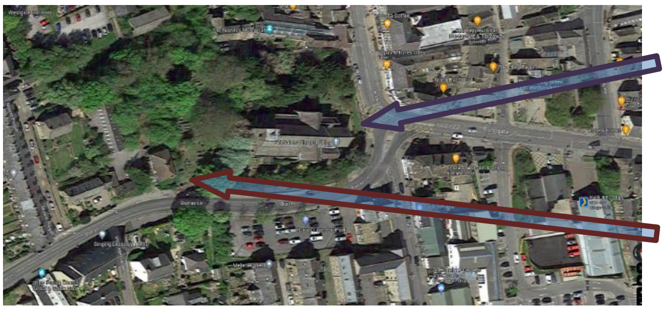
OPC is the oldest building in Otley, with parts of the edifice dating back to Norman times. It is a Grade 1 listed building, which is a welcome recognition of its architectural importance, whilst at the same time a source of complication when needing to make changes to the fabric of the building.

The church is in an elevated position, with busy roads on the east and south sides of the churchyard and public footpaths through and adjacent to the churchyard. Otley itself nestles under a prominent hill 'The Chevin' which is a high foot fall public park. This makes the church a highly visible building that is overlooked from near and far.

The churchyard is a former cemetery (no longer used for burials) but still containing many gravestones and is of public interest and historical value.

Otley is in the diocese of Leeds, North West Leeds Deanery.

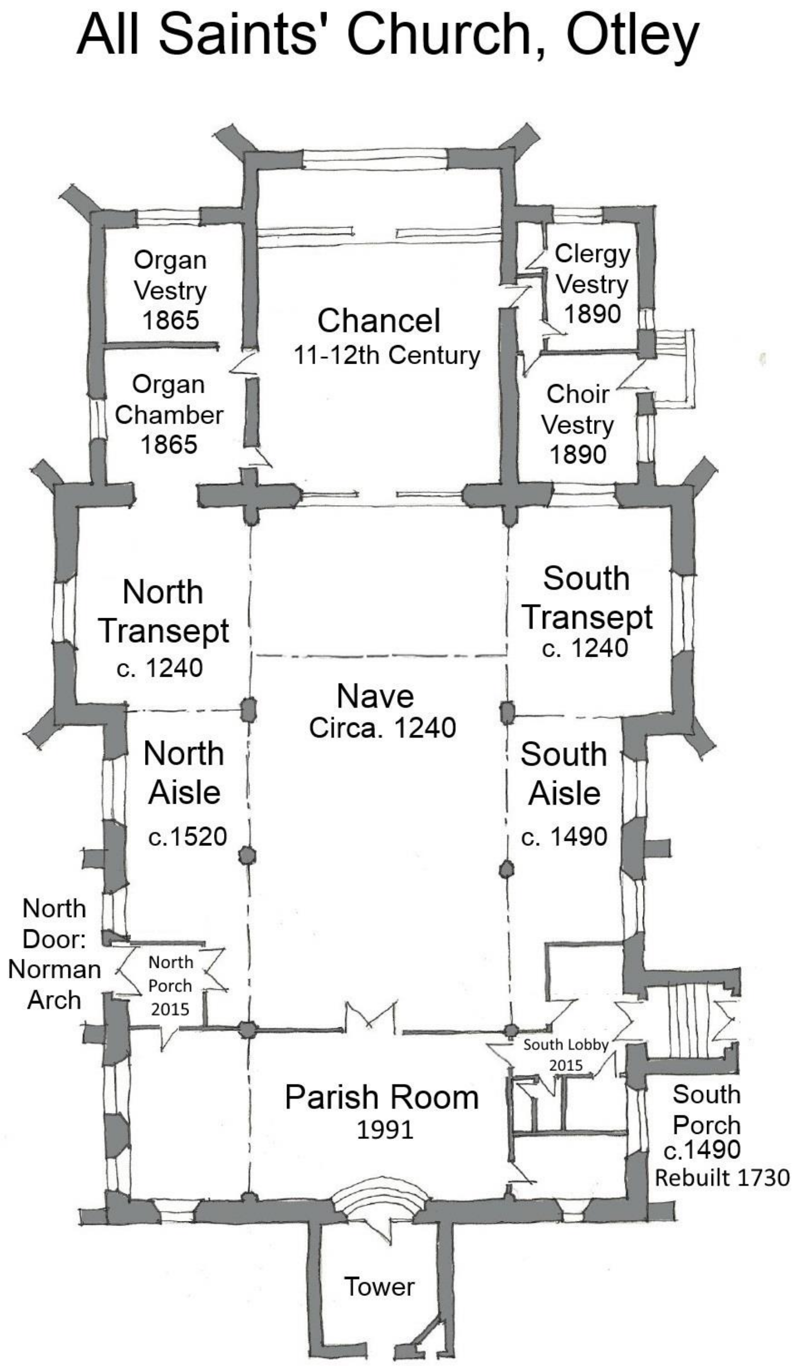
The church office (the Chestnuts) is in a separate building immediately to the west of the churchyard. The Chestnuts is an additional but smaller emitter of GHGs. It is a semi-detached former dwelling that would benefit from better insulation. It already has smart heating controls , installed in January 2023. Whilst it is technically included in OPC's drive to Net Zero, this report has focussed only on the church building and is planning to return to dealing with the far simpler Chestnuts at a later date.



Otley Parish Church – At the Heart of the Community

The Chestnuts

The main components of the church building are shown in the drawing below:



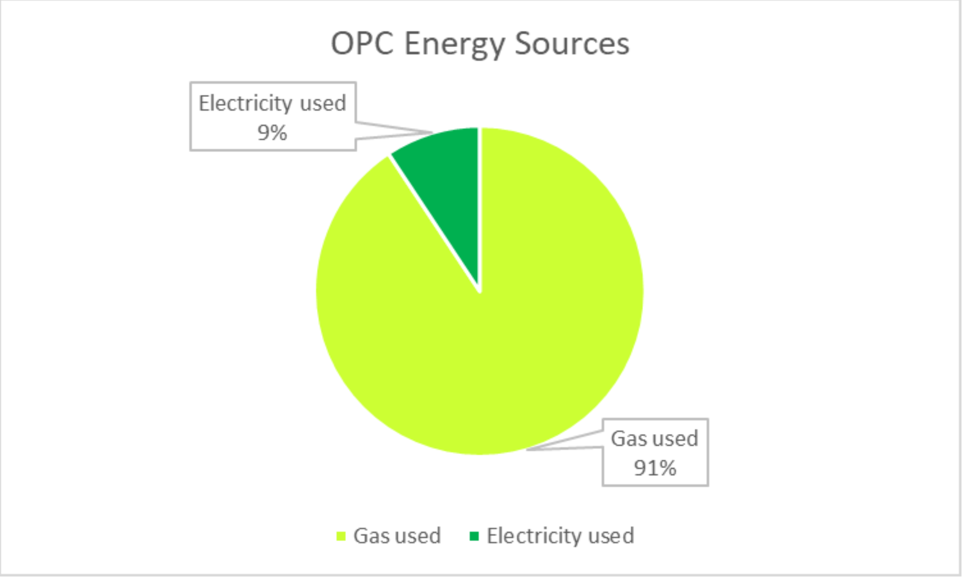
In 2022, the number of people who visited the church was 12,848. This includes the regular weekly services, irregular services (weddings and funerals), special services, such as Christingle, and users of the café and room hire facilities. In total, this use of the building amounted to 1,958 hours in 2022 (or, 22% of the year, or (for context) 82% of the office-based working year).

5 Site Baseline

5.1 Energy Balance

There are two primary sources of energy that supply the church; natural gas and electricity. Both are wholly supplied by grid connections. In common with most church sites, the electricity is certified as being of renewable origin, giving it, theoretically, a Green House Gas (GHG) emission of zero. The natural gas is primarily fossil in origin[1] and therefore has a significant GHG impact.

The gas-based energy consumption is by far the largest component, as shown below:



This is based on the latest annual data (September 2022 to August 2023).

In numbers, the electricity consumption was 13,419kWh and the gas consumption was 130,571kWh. These values are both reduced compared to previous years – by about 10% for the electricity and a remarkable 38% for the gas (attributable to reducing the boiler flow temperature, improved heating management and milder than average winter).

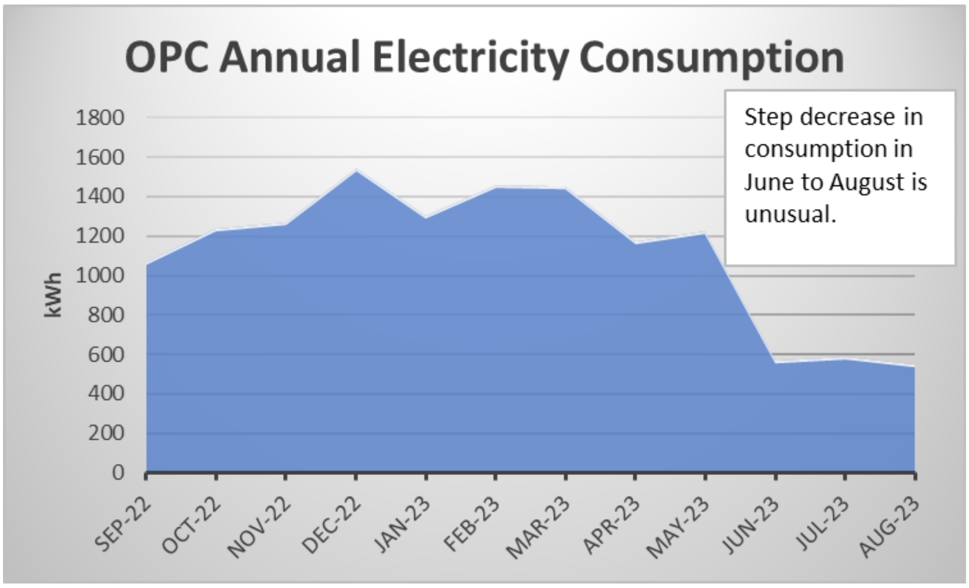
The gas consumption is entirely for heating the church building.

The electricity is consumed for all the other energy uses, the largest of which are considered likely to be; lighting, domestic hot water, café activities, air handling and IT equipment. Lighting, air handling and IT equipment users are relatively low power, but tend to be on for extended periods, whereas domestic hot water and café activities tend to be high power consumers that are only on for short periods of time.

5.2 Electricity Profiles

The electrical demand profile for the church over the last year is shown below:

[1] There is a small but increasing amount of biomethane in the UK grid that is reflected in slight reductions in the year-on-year GHG (Greenhouse Gas) conversion factor (kgCO2e/kWh).



Given the users of electricity at OPC, the shape of the profile is typical of most intermittently occupied buildings. There is a slight increase in electricity consumption in the darker months, but it is in effect a constant consumption year round.

The surprising feature is that there is a step change (decrease) in power consumption from June 2023. This is not explained and should be investigated over time. There are some issues with the smart meters used to gather this data, but it could also be a very welcome change that has been implemented.

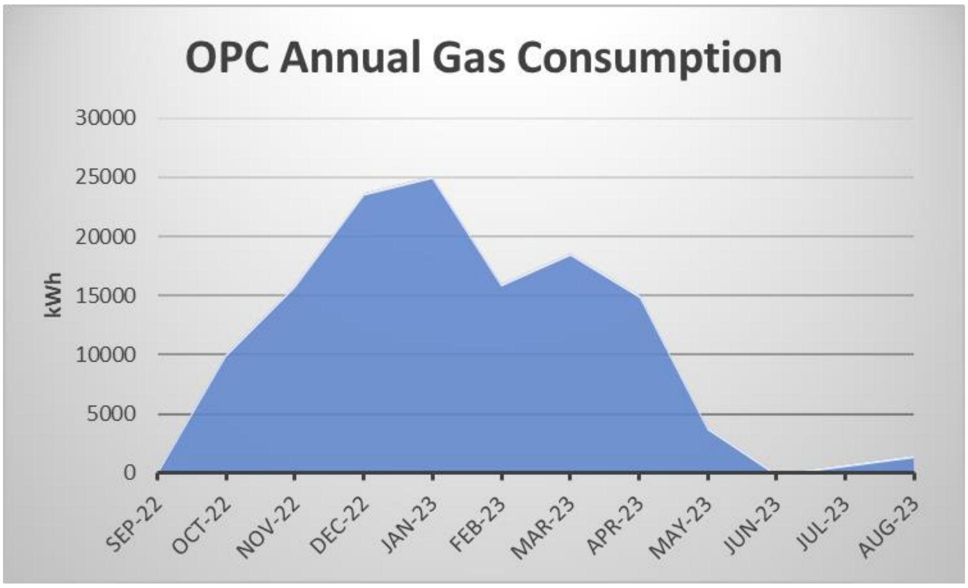
The annual carbon footprint of this electricity is zero tCO_2e.

5.3 Gas Profiles

The natural gas from the grid is primarily utilised in 2 water heaters (hereinafter referred to as boilers), each rated at 100kW. These boilers are controlled such that they take turns in supplying the heat, with the 2nd boiler being used to supplement the first boiler if required.

The boilers provide hot water that is distributed to the various heating appliances around the church (i.e. underfloor heating in the Nave and Parish Room, supplementary heaters in the Aisles, and fan assisted heaters in the Parish Room).

The annual gas consumption is shown below:



This profile is typical of a well-managed building where the gas consumption is only used for heating. A better insulated building would have lower peaks in winter.

The annual carbon footprint of this gas is 24 tCO2e.

Note this footprint is less than the figure given in the OPC 360 carbon footprint tool which showed 44 tCO2e. The reduction reported here is primarily because the annual gas consumption has reduced from 210,000 kWhpa in 2022 to 131,600 kWhpa over the most recent year reported here and there has also been a decrease in the GHG emission factor from 0.211 to 0.1822 kgCO2e/kWh over the last year (as a result of more renewable biogas being injected into the gas grid).

5.4 Current Heating Energy Loss Routes

Given that all the gas consumed on-site is used to heat the building, the way the gas is used can be reduced to a simple look at where the heat goes after it has been created by the boiler. The premise applied here is that the gas meter provides very accurate information on the volume of gas consumed and from that data, the amount of heat put into the church via the boiler and the heating circuit can be calculated. So what we want to find out is, where that heat goes (it must leak out of the building, otherwise the church would become very hot!)

Clearly, this heat input is seasonal – the boiler not being run at all in summer and being worked quite hard in winter. To be more precise, the amount of heat put into the church is controlled by thermostats which call the boiler to run whenever they detect that the temperature in the church is below their target temperature. In summer, the warmer weather keeps the temperature in the church above this target temperature, so the thermostats do not call the boiler to run. In winter, the opposite is true, meaning the boilers are needed to keep the church warm because the weather cools the church down.

To calculate where the heat goes once it has been put into the church by the heating system requires some extra data, over and above the gas consumed by the boiler. Fortunately, the perfect data set for this purpose was gathered by the Churchwardens over 40 days in November and December 2022.

The total gas consumed over this 40 day period was 2,295m^3, which has an energy value of 25,557kWh. In simple terms that energy is equivalent to an average gas consumption of 27kW (though clearly the instantaneous gas consumption will be varying over these 40 days between zero kW and the limit of the boiler which is about 100kW). The OPC boilers are modern and well maintained condensing boilers. It is a good assumption that they are able to convert about 92% of the energy in the gas into hot water for the heating circuit. This means the heat that entered the church from the heating system is 92% of 27kW, i.e. 25kW.

Over this 40 day period, the internal temperature of the church was measured frequently to give an average of 12.6 Celsius. From temperatures recorded by the Met Office over the same period, the average external air temperature was 3.8 Celsius. So, on average, putting 25kW into the church was able to maintain a temperature difference between the inside and outside of the church of 12.6 - 3.8 = 8.8 Celsius. It is this temperature difference that drives the rate at which the heat is lost from the building such that a greater difference increases the heat loss and a lesser difference reduces the heat loss. This is why reducing room temperatures is on the list of Quick Wins (see next section).

Next, use can be made of the concept of “U Values”. These are a convenient way of encapsulating a lot of physics relating to the effectiveness of room insulation into a single constant that has the units of Watts per metre squared per temperature difference (on the Celsius scale). The U Values for different heat loss routes through the fabric of the building are all different, so they can be used to show where the insulation is the worst (indicated by high U Values) and where it is the best (indicated by low U Values).

Whilst U Values are all different for different heat loss routes, many of these heat loss routes have been well researched and there are agreed ‘standard values’ for things like glass windows, floors and walls. Indeed, there are standard values for stained glass leaded windows, limestone walls and stone floors, such as those at OPC. On the other hand, the roof at OPC is a combination of materials (wood, air and slate) and is inaccessible. This means picking a standard U value is not possible and instead, one has to be calculated from first principles, which is difficult without knowing the details of the roof structure.

Apart from heat losses through the fabric of the building, the other significant heat loss route arises from air flowing through the building, i.e. entering the building as cold air, being warmed by the building and then escaping to atmosphere as warm air. This is main reason for sealing gaps in the fabric of the building.

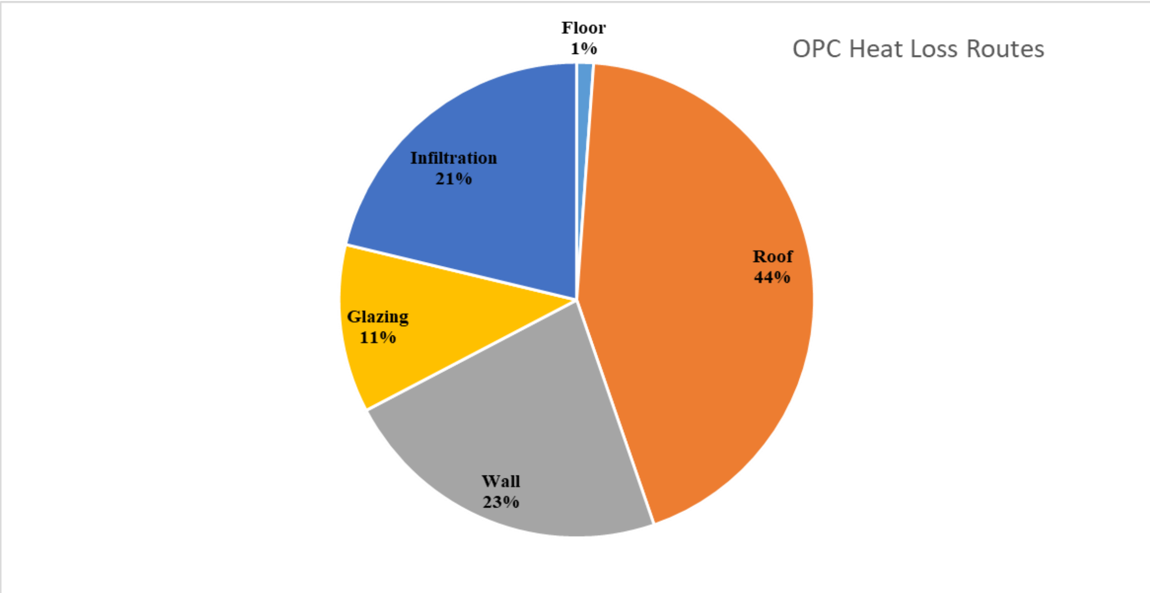
So, to characterise the heat loss routes, we:

- Picked standard U Values for the windows, walls (actually, calculated from its thickness) and floors,
- Calculated from the thermal conductivity of the materials a most likely U Value for the roof,
- Estimated the air volume passing through the building (based on the volume of the building, an allowance for stratification and an informed estimate of air-change-rate).

Notice that U Values depend on the surface area through which the heat flows. If we measure the surface area of, say, the windows, we can calculate the heat loss rate (in Watts) from the standard U Value and the temperature difference. Fortunately, a laser survey of the church exists and this is easy to use to gather the surface areas of all the windows, walls, floors and roofs. The image below shows a screen shot of the measurement of the roof areas, in progress:

Now we have all the required information and just need to crunch the numbers. A spreadsheet was set up to facilitate these calculations and to enable consideration of adding insulation and draught proofing, to be investigated.

The most likely outcomes are shown in the figure below:



This figure is showing that nearly half of all the heat input into the church over the 40 day period was lost through the roof. It is valid to state that outside of this 40 day period, nearly half the heat loss would be through the roof because the data used was comparable for each route. The takeaway message from this is that the roof needs to be insulated. Under some conditions (a windy day) the heat loss through the roof was calculated to be very much higher, whereas on a cloudy still day, it could be a little lower. Until the structure and condition of the roof is investigated, it is not possible to be more precise than to say ‘about half’ of the heat is lost through the roof.

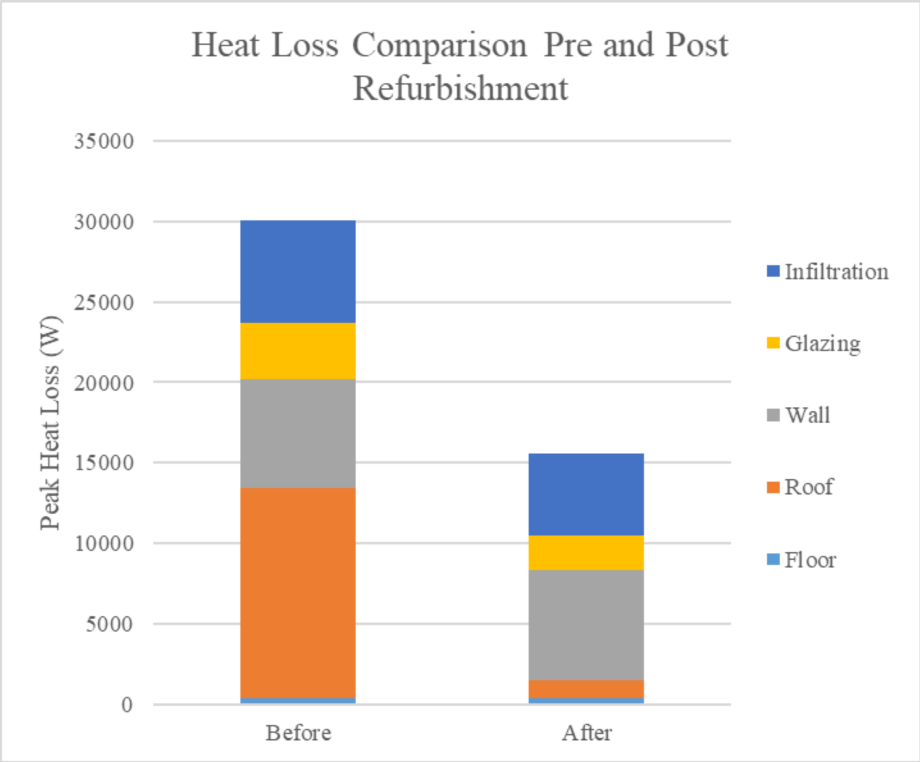
The heat loss rate through the stone walls is comparatively low compared to, say, a terraced house in Otley with solid stone walls, but this is because the OPC walls are rather thick (800mm in parts) and this makes the U Value lower (i.e. a better insulator).

The heat lost through the windows is less than would be expected from a house because the area of the windows in relation to the areas of the walls is quite low. Being single glazed and leaded means the actual U Value is higher than would be expected in a house, so secondary glazing would be worthy of consideration to improve (reduce) the U Value.

The floor area is quite large, but solid floors sitting directly on earth are actually a good insulator and heat loss rates are small when the inside temperature is so close to the soil temperature. Furthermore, it is known that some insulation (crushed glass) was added during the installation of the underfloor heating.

The heat lost to the air flowing through the building (shown on the above pie-chart as “Infiltration”) is significant, but difficult to reduce. This is because, in order to keep the air in the church ‘fresh’ and to avoid mould growth, some air must always be passed through the building – referred to as an ‘Air Change Rate’ or the acronym ACH (air changes per hour).. The recommended levels of the ACH depend upon the occupancy and the activities in the building and can vary from 0.35 to more than 3, sometimes as much as 20. In this analysis, an ACH of 0.5 was the best fit to the available information. A little more detail is provided in Appendix C.

Adding insulation to reduce the heat loss rate brings many advantages (lower energy bills, fewer convection draughts, reduced carbon footprint [whilst still using gas], less chance of condensation, more stable temperatures, easier building management, etc.) and should be done wherever possible. However, adding insulation to OPC as a grade 1 listed building is just not possible to the standards required to meet the most up to date building standards. That said, insulating the roof is probably the least difficult insulation to add. Indeed, if the roof is refurbished and high quality insulation is added, this would go a long way to reducing the heat losses from OPC. Adding secondary glazing to all the windows (recognised to be potentially controversial so only included here for illustration) and improving the air-tightness of the building (as per the Quick Wins) could yield the result shown below:



This means that the boiler power required to maintain the same temperature conditions as the 40 day period is reduced by this refurbishment to around half the current requirement.

One further point of note is that the church roof is in urgent need of replacement, which would be an opportunity to install a high standard of insulation as a marginal cost during the replacement. If this replacement is deferred, insulation could still be added to the roof by various means, some of which would not change the appearance of the roof. This is an area where more investigation is required.

6 Energy Options

6.1 Energy Efficiency – Quick Wins

To move towards Net Zero by 2030, the first stage is to reduce permanently the current energy consumption. This can be achieved by applying basic energy saving measures such as the Quick Wins detailed here and by applying suitable/appropriate insulation.

To identify Quick Wins, the group inspected the church building and arrived at the recommendations for immediate action explained in this section.

6.1.1 Sealing Draughts

The previous discussion on heat loss routes focussed on heat losses through the fabric of the building and should be seen to be the 'steady state' position regarding heat losses. Further heat losses occur from buildings due to air changes (draughts) and evaporation. These further heat losses can be as large as the steady state losses, for example, we have all experienced the effect of leaving an outside door wide open on a windy day.

It was a simple matter to find odd draughts throughout the church. These were places where cold outside air could enter the building and/or warm air could leave the building. Once identified, these draughts were sealed using appropriate means.

Some ventilation is required in any occupied building to maintain the optimum humidity that prevents mould growth or deterioration of important artefacts and the church organ. This is an on-going part of the project, particularly regarding the church organ and the perceived draughts around it, versus humidity requirements.

6.1.2 Cleaning Heat Exchangers

General *control* of humidity should be achieved using the ventilation system that was installed during the refurbishment of the Parish Room in 2011. This ventilation system is in two parts:

1. A conventional extraction system for the toilets and kitchen, triggered by occupancy sensors in the ground floor toilets (with set overrun times). This is intended to maintain the amenity of these rooms by extracting odours. The system discharges the extracted air at the top of the Tower. This is working well.
2. A separate system for the Parish Room.

The ventilation system for the Parish Room was installed with a humidistat (like a thermostat, but instead of switching on the boiler when it detects a low temperature, a humidistat switches on the ventilation system when the humidity is too high). The system draws air out of the Parish Room and replaces it with semi-fresh air from the Tower Base. The system includes a heat exchanger that uses the outgoing humid air to heat the incoming semi-fresh air. This is a good thing to have installed in the Parish Room, particularly given the activities that take place in there and the dampness that arises from the depth underground of the south west corner of this room.

However, it appears not to have worked as intended for some time and has not been adequately maintained.

The group is in the process of restoring the system to optimum operation and has so far regained the ability of the system to transfer air and recover heat from the outgoing air. This is currently not controlled by a humidistat and an interim solution (a manual switch) has been put in place. Going forward, the system will need regular maintenance (cleaning) to keep it operational.

6.1.3 Reducing Room Temperatures

As mentioned in the discussion of U Values, reducing the inside temperature of the building is a very effective way of reducing heat loss rates. However, after a discussion with the group, it was agreed that the target temperatures (i.e. the thermostat settings) are already quite low and provide comfortable temperatures for the coat-wearing attendees that are the norm in the church.

It is recommended that the temperature set points are maintained as is, but that this position is kept under review as other improvements are made (for example, reducing draughts).

It is also noted that the positioning of the thermostats in the Nave is not ideal because they are affected by the heat rising from the heating water distribution system in the cupboard below them. For optimum performance, they should be moved.

6.1.4 Repairing Gutters

Whilst not an immediately obvious way of saving heat, repairing gutters is a very effective way of reducing how wet the outside stonework is. This saves heat because evaporation is a hugely important means of cooling things (for example, we sweat to keep cool – the sweat evaporates from our skin and takes heat away with it). Wet stone is a very effective evaporative cooler, particularly in a solid walled building like the church. There are other benefits to repairing gutters that are well known, so this should be seen as a priority. Leaking gutters were easy to observe around the organ vestry roof but it is possibly occurring in other places that are not so easy to see. A more detailed survey is recommended.

6.1.5 Tree Maintenance

The sun, even in winter is a potent source of free heat. When sunlight falls on walls and roofs it warms them, which means the rate at which heat from inside the church is lost through them is reduced. When sunlight passes through windows, the church acts like a greenhouse and is warmed by the sunshine. However, if the sunlight cannot reach these parts of the church, none of this free heat is gained. There are many trees on the south side of the church that are casting shadows onto the church. If these could be pruned to reduce this effect it would assist the heating of the church.

Meetings with arborists have taken place and a plan of tree maintenance has been drawn up, to be implemented after the summer growing season.

6.1.6 Freezer Replacement

There is a rather old fridge/freezer in the bell tower bottom that is used by the café in the Parish Room. The fridge part has not been used for years but the freezer contains foodstuff that is used by the café. The age of this device plus the fact the fridge is not used means it is likely to be an extremely inefficient freezer. The electrical power drawn by the fridge/freezer was measured over several days and was found to be at least 3 times more than a new freezer would consume.

It is recommended the use of this fridge/freezer is reviewed and if it is still needed, then a modern replacement freezer should be sought.

6.1.7 Clerestory Window Repairs

The clerestory windows on either side of the Nave have opening sections that are operated via a remote lever system because they are too high up to be opened by hand. This system has seen better days and many of the windows cannot be closed properly. In winter, this will represent a significant heat loss route as well as a provider of many draughts that will diminish the perception of comfort amongst the users of the building. This should be addressed urgently.

6.1.8 Organ Vestry

A draught coming out of the organ chamber has been reported many times by members of the congregation. It is also known that the adjacent, connected, organ vestry is often cold. These have been investigated and surprisingly little reason can be found for these reported draughts. There is a damaged window pane in the organ vestry but nothing else that would be an obvious cause of air leakage. Externally this is where the leaking gutter could be seen, so perhaps this is causing excessive heat loss through the stone walls and thereby cooling the internal air in these rooms. The draught reported from the organ chamber could be attributable to a convection current caused by heat losses through the damp wall, in conjunction with heat losses through the roof and the height of this room. It is also possible that the draughts only occur when the wind is in a certain direction and causes the air vents under the floor of this part of church to force cold air into the Vestry.

The most effective way to find these draughts would be to survey the area using a thermal camera. This is planned to take place when the weather is colder as this enables the camera and its operator to spot even minor draughts.

6.1.9 Energy Management

An energy management system similar to that already in use in the Chestnuts could be applied to the church building. A general assumption of a 5% saving (both heat and money) could be applied to the thermal input energy, from installing such a system.

It is recommended that this is investigated for practicality and cost effectiveness. Again, this may require the thermostats in the Nave to be relocated to avoid the heat rising from the cupboard below them.

6.2 Decarbonisation

The next stage after the energy efficiency improvements is to start to invest in technology with minimal (preferably zero) carbon footprint.

The largest demand for energy at OPC is for heating the building in winter.

Heat can be provided renewably by using renewable electricity in specialised electrically powered boilers[2]/water heaters or by burning renewable fuels such as biomethane, biodiesel, or biomass in an adapted, but otherwise conventional, boiler.

None of these sources of renewable heat is without problem:

- Electrically powered boilers use a lot of electricity, which could be more than the local electricity grid can immediately provide and will be very expensive to run.
- Biomethane is in short supply from the national gas grid making it potentially unavailable to new customers.
- Biodiesel has severe credibility issues when described as carbon neutral, especially if it is sourced from imported plant oils rather than local waste cooking oil. This latter is in short supply.

[2] Technically, a boiler is a device for producing steam, but the term is frequently used to describe a hot water heater (consider your domestic heating system, for example). We will use the term “boiler” to mean the hot water heater used in the heating system.

- Biomass in this case is describing organic material imported to the site that could vary from wheat straw to manufactured wood pellets. It is this variability that brings the problems to biomass as a renewable fuel, but this can be overcome by specifying locally produced wood pellets. The problem then is that manufacturers of wood pellets have to be near the source of wood to maximise the renewable credentials. The Scottish Highlands are a major source of managed wood that could be used to manufacture pellets. However, the transportation of these pellets by diesel powered HGV severely reduces the carbon neutrality of this fuel. There are practical problems with wood pellets too, which will be discussed below.

The least problematic renewable energy source for OPC in terms of reliability of supply, is considered to be renewable electricity. Hence, to achieve decarbonisation, the roadmap is focused on electrically powered devices for providing heat for the building. This is also the only method identified as being capable of directly achieving Net Zero carbon by 2030 for OPC.

A number of options have also been considered in depth and these are presented below.

6.2.1 Electrically Powered Boilers

Electrically powered boilers have been developed in parts of the world with an abundant supply of low cost hydroelectric power, like Norway and New Zealand, but the interest in them has dramatically increased since commitments to achieve Net Zero by a certain date became widespread. This has caused some useful development in the designs of such boilers, but has also caused an increase in their price and a reduction in their availability. This economic effect may self-correct over time, but is an issue for early adopters as OPC would be.

Electric boilers are best understood to be similar to domestic hot water immersion heaters, but on a larger scale. They use heating elements in just the same way, but obviously need a lot more elements to meet the heat load of a heating duty such as OPC (i.e. currently around 100kW, though likely to decrease with improvements in the insulation of the building). These elements generally operate at mains voltage (230VAC per phase) and therefore require large cables to carry the current, making installation slightly more difficult.

Drawing this much power will have an impact on the grid supply and would need to be checked with the DNO to see if it could be added to the grid without incurring a contribution to the upgrading of the grid. The current mains incomer is 3 phase, rated at 100 Amps per phase (i.e. a total capacity of about 70kW – not really enough for an electric boiler without also considerably improving the building's insulation.

It is therefore not recommended that electrically powered boilers are considered any further.

6.2.2 Other Electric Heating Technologies

Electricity can be almost 100% efficient at converting itself into heat and there are many ways of using this fact to warm rooms and/or their occupants. A classic radiant heater (a "3 bar fire", for example) uses a very hot element (over 2000^{o}C) to intensely radiate heat (and light) into a room, making the contents of the room warm. These contents then in turn warm the air in the room, making the room feel warm. To reduce the risk of fires, such radiant heaters must be placed well above head height (or behind significant guarding). In a building such as OPC, placing the radiant heaters above head height would be possible, but the effect on the occupants is to sense an overly heated head and cold feet when near the heater and little warmth when away from the heater. This makes them unpopular. To heat a large space (such as the Nave), the pools of heat created by the heater would need to overlap. That would require a lot of heaters to be fixed in place above head height, making them inappropriate for OPC.

A development of the classic radiant heater is the infra-red heater. This emits heat over a wider area from a lower temperature element (less than 1000^{o}C) and gives a more general, less intense, sense of warmth to the occupants. Infra-red heaters come in a wide range of shapes and sizes and because they emit no light visible to the human eye, they can be less obtrusive than the classic radiant heater. To heat a large space such as the Nave still requires a lot of infra-red heaters, but because each heats a wider area, the contrast between warm and cold zones is less noticeable.

The downside of electric heaters is that electricity is expensive. The amount of heat required in the church would be about the same as the current gas-fired heating system, so with electricity typically costing 3 times as much as gas[3] , the annual heating bill could triple. To fudge around this fact, the marketing people have invented all manner of ruses about how less heat is required because an infra-red heater gives a sense of warmth so less energy input is required ("heats the people, rather than the building"). This is an entirely subjective statement and depends on a huge number of factors. To provide some balance, a group of 5 churches in Craven (led by St Mary's Embsay) carried out trials on different forms of electric heating and asked the congregation to rate them. None of the electric radiant heaters were popular (the favourite heating was under-pew convective heaters).

Another electric heating option is convective heaters. These tend to be small, wall mounted or free-standing units that produce an intense plume of warm air. In a tall building such as the Nave, most of their heat would rise well above the occupants and would be of little use unless it could be blown back down by fans. This is all possible and the design of some fans is almost whisper-quiet, but, by definition, they will produce draughts.

As will be explained in the section on heat pumps, using a heat pump gains much more heating energy from the electrical energy than an electric radiant or electric convective heater. By the measure used in the beginning of this section, heat pumps are 300% efficient or more.

Direct electrical heating in any form (electric boilers, radiative or convective heaters) is not recommended for OPC.

6.2.3 New Biomass Boiler

In this option, a new separate biomass boiler that burns imported biomass (wood pellets have been chosen for the consideration of this option) is installed to replace the existing gas boilers. This would require 27 tpa of wood pellets (about 40 'big-bag' deliveries per year). The cost of the wood pellets is strongly dependent on the locality of the source of the pellets. A specific quote for OPC has not been obtained, but from other sources, the price is around £200 to £250 per ton delivered giving an annual cost of around £6000pa. An additional cost for wood ash disposal should be expected. The capital cost is estimated from previous sources to be £16,000, but quotes from local suppliers must be obtained before any further consideration of this option. This option cannot achieve Net Zero because of the small GHG of biomass (giving 2.1 tCO2epa for OPC's consumption), but it will achieve a GHG saving of circa 22 tCO_2epa, when compared to the current natural gas carbon footprint.

To bring this residual footprint to zero requires additional investment in an alternative renewable energy. One example would be to use pv panels to generate renewable electricity and use this to produce heat in an electrically powered boiler that displaces the use of a fossil fuel. As no such demand exists on the church site, it would have to be used at the Chestnuts or exported to the electricity grid to achieve this offset. To give an idea of the scale of the pv array that would be needed to achieve this offset, the residual GHG of the biomass is equivalent to covering the south facing roof of the aisle with pv panels (an additional capital cost of around £18,000).

Probably the biggest issue that would arise from installing a biomass boiler is the logistical difficulty of providing it with the wood pellets. In January, the peak demand for heat would require 5.2 tonnes of wood pellets to be burned. Given delivery times whilst suppliers are at their busiest, it would be sensible to have four weeks supply stored on site, i.e. around 5 tonnes. That would occupy a space of just over 7 m3 (i.e. 2.4m x 2.4m x 2.4m). Note that wood pellets are less

[3] Recent events have shown how volatile this is. In the long-term, after market reforms, the price of gas will exceed the price of electricity simply because of the wider development of renewable electricity sources, but nobody can predict when this will happen.

physically dense and a lot less energy dense than coal, so the space required is considerably more than the old coal storage area in the boiler room underneath the vestry.

Delivering the stored wood pellets to the boiler presents another space problem. It is normal to use a low level silo to store the wood pellets, which then delivers the pellets with the aid of gravity and a screw feeder to the boiler. In other words, the base of the silo needs to be higher than the boiler. This usually results in the silo being built outdoors, adjacent to the boiler. That would have a visual impact at OPC. Other storage solutions may be possible.

The other logistical problem for wood pellets is how to get them to the storage area. For relatively small consumers such as OPC (i.e. not on an industrial scale, but more than domestic) the delivery is normally in the form of either 'big bags' or a blown system from a lorry tanker. Either way, this requires the lorry to be parked for around an hour close enough to the wood pellet store to effect the delivery. Given OPC's location, that could cause an irritating amount of traffic disruption or actually be impossible due to the distances.

A biomass boiler is not seen as a viable solution for achieving Net Zero at OPC and will not be considered further.

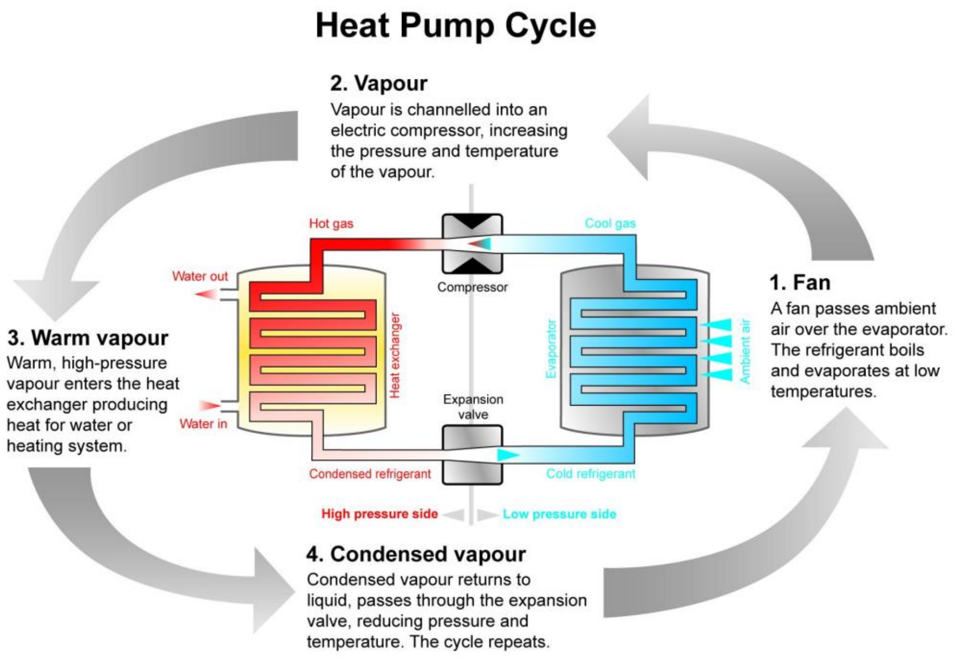
6.2.4 Heat Pumps

Heat pumps are a 'hot topic' at the moment and they are widely seen as a viable way to heat (and cool) buildings. They are probably the best way for OPC to reach Net Zero.

So, what is a heat pump? Every domestic fridge or freezer has a heat pump in it (often referred to as the compressor) and all it does is pump heat from one place to another. In a fridge, it pumps heat out of the fridge and into the kitchen. This makes the fridge cold (and the kitchen slightly warmer). In a freezer, it is exactly the same apart from the heat pump being more powerful and able to lower the temperature in the freezer compartment to well below zero. It takes an amount of energy (provided by an electric motor) to pump this heat from cold (the freezer compartment) to hot (the kitchen) because it is working against the law of physics that says heat flows from hot to cold.

Looking at a fridge slightly differently, if the fridge compartment was opened to the outside air and the kitchen was the room you wanted to keep warm, running the fridge's compressor would warm up the kitchen. This concept has been developed into Air Source Heat Pumps (ASHPs) that use outside air to heat water that is then used to deliver heat to a building using standard central heating components. The key thing to recognise is that the heat pump transfers heat from a cool heat source (the air) to a warm heat supply (the water in the central heating system).

The diagram below explains the vapour compression cycle (also known as the reversed Carnot Cycle or reversed Rankine cycle) that is at the heart of a heat pump.



There are lots of complications and variations on this simple concept, but most of them can be ignored because suppliers of heat pump systems for large domestic customers (i.e. OPC after it has been better insulated) have created efficient, largely off-the-shelf, packaged solutions.

There are two main sources of the cool heat that can be used by a heat pump – the air or the ground. These are briefly discussed in the context of OPC below.

Ground Source Heat Pump

A Ground Source Heat Pump (GSHP) uses a recirculating flow of water running through pipes underground to extract cool heat from the ground to supply the heat pump. These pipes can be arranged to be about 1.5 to 2 m below the surface across a wide area or as a vertical system up and down a borehole. Whilst somewhat different, these two options are taking advantage of the fact that the ground under our feet is always between 10 and 18 Celsius because it is warmed by the sun in summer and the characteristics of soil enable it to retain this heat through the winter. An interesting aside is that the soil is at its warmest in November – if you dig a couple of metres down. This is not geothermal heat, even the borehole variant is not reaching geothermal heat (although a borehole will be slightly warmer if it goes many tens of metres down).

The area or the land required (or the depth of borehole) depends on the energy that needs to be supplied. For a horizontal system to provide 100kW to OPC, the area required is 7000m^2 (0.7Ha or 1.7 acres). That is clearly not possible in the churchyard. With improvements to the insulation and ACH potentially reducing the heat demand to 50kW, the area required is halved, but is still impossible for OPC. For a borehole system, it is likely that more than one borehole would be required. Drilling rigs are large, but could be physically able to be positioned in a few locations. They would all have to drill down around 100m, which gets more difficult. Creating the boreholes would be very expensive and that is before considering the numerous implications of drilling in a graveyard.

For the reasons above a GSHP is considered to be untenable for OPC.

Air Source Heat Pump

An ASHP relies on a flow of air across one of its components (called the evaporator – the shiny bit at the back of the inside of the fridge) to extract heat from the air that the heat pump then uses to create the warm water for the central heating system. Air is an inexhaustible supply of renewable energy that usefully flows easily. This makes it very simple for the heat pump to extract heat directly from the air around it.

There are, though, limitations on how much heat it can extract because air doesn't actually hold as much heat as soil or water (per unit volume). A flow of air therefore has to be provided to the heat pump, which is easily achievable using simple fans. The main limitation is that the air is often quite cool, particularly in winter when the building heating requirement is at its highest. Not only does cool air contain less heat so the fans have to work harder to supply this heat, it also reduces the temperature of the hot water that the heat pump can produce, for a given efficiency of operation. This latter limitation is the main drawback with ASHPs.

To continue to produce hot water at the desired temperature (typically 40 to 60ºC) the heat pump control system will require more electrical energy to drive the heat pump's compressor. This can increase the electricity consumed by an ASHP on the coldest of days 2 or 3 – fold, but is still going to consume less electricity than a simple electric boiler to deliver the same heat to the building.

Most domestic ASHPs are designed to operate outdoors – for easy access to a supply of air and also to avoid the noise of the heat pump compressor and fans from creating a nuisance indoors. ASHPs are not whisper quiet, but neither are they particularly noisy – conversation adjacent to an operating ASHP is not difficult.

The suggested plan for an ASHP at OPC would be to put it in the current boiler room. This means it would have minimal external visual impact (meeting the Grade 1 listing requirements), but would require an air flow to be ducted to it (the suggestion is to use the current openings on the south and east sides to provide the inlet and outlet for this air). The noise externally would be mitigated by the fact it is indoors and it is expected that the robust construction of the church will prevent the transmission of the noise to the occupants.

At this stage of the investigations, we are expecting to only require one ASHP as replacement for the two gas-fired boilers. These gas-fired boilers are understood to alternate their operation (though they can both operate at the same time to provide extra heat). This provides a degree of resilience in case one boiler fails. However, ASHPs are very reliable, so the need to install two ASHPs (one duty, one spare) is questionable. It is anticipated that discussions with the supply chain will assist with answering this question to the satisfaction of all stakeholders.

An ASHP to supply 100kW, as per the current heating system, would be quite a physically large machine. The plan to fit it in the boiler room will need to be confirmed by an expert supplier of such ASHPs. The physical size of the ASHP would be reduced if its heat demand was less than 100kW, so if insulation were fitted to the church building (particularly the roof), the heat demand would be less and the ASHP could be smaller (and consume less electricity).

OPC has a particular advantage over most buildings in that it already has underfloor heating fitted. This type of heating operates at a lower temperature (ideally between 40 and 60 degrees) than a conventional radiator-based system and is more compatible with the lower water temperatures that an ASHP normally produces (40 to 60 degrees at peak efficiency). This means the cost of modifying the central heating system that normally is part of the requirement of fitting an ASHP will not arise.

Altogether, it is considered that an ASHP is a good solution for OPC to meet Net Zero.

6.2.5 Local Renewables – PV, wind and hydro

There is a degree of interest in Otley for producing renewable electricity locally and using either a PPA agreement or a Private Wire to supply consumers. The benefit to the consumers is that this supply would undercut the cost charged by the energy suppliers. The potential for producing this electricity is unclear at this time, but it should be kept under review as a potential way to reduce electricity bills if any of the mooted generation plans come to fruition. It should be understood that this will not actually reduce the carbon footprint of OPC on its own, unless it is used to displace the use of fossil fuels, given that all the electricity currently used by OPC is already renewable.

6.2.6 Dealing with the remaining carbon

With all the consumed electricity being from renewable sources and the replacement of the gas boilers with an ASHP, the main sources of the OPC carbon footprint have been set to zero. Strictly speaking, that is not the whole story because many other activities associated with the life of the church have an associated carbon footprint. This is a complicated area to explore and is outside the remit of this report, but as an example, every cubic metre of water used in the café or the toilets causes the emission of 0.149kgCO2e. A similar number is then emitted by the water flushed down the toilet being treated in the sewage works.

The simple approach to these generally small remaining GHG emissions is to provide a carbon offset. In the past, this offset was provided by planting trees via a carbon offsetting agency, but these have been largely overtaken by big business and have become discredited. One offsetting agency that has maintained a high degree of credibility is Climate Stewards, part of the worldwide A Rocha family caring for God's creation. They provide more holistic solutions to carbon offsetting and are currently charging £25 per tCO2e per year.

A much more direct approach is to produce electricity and feed that back into the grid to displace the remaining use of fossil fuels in the production of grid electricity. This is probably the best approach (for now) to gaining some 'carbon credits' to offset the remaining GHG emissions of normal church activities because there is the opportunity with pv panels to reduce the cost of buying electricity and even the possibility of selling any surplus electricity.

6.2.7 Combinations of Technologies

In reality, reaching Net Zero will be achieved by a combination of technologies. At this stage of the project, there are too many unknowns to make it clear what combination would be most appropriate for OPC. That said, the options are explored further in chapter 7.

6.3 Energy Generation

6.3.1 Wind

Wind power is the original renewable energy source put to work by people to power boats and mills with references going back thousands of years. Things have moved on from the original cloth covered wooden frames to the present day hi-tech plastics and aerodynamics that approach the limits of physics in the amount of energy they can harness from the wind. However, to get the best out of a wind turbine of any design, it needs a ‘clean’ (non-turbulent) flow of air, which is one of the reasons wind farms are built in the middle of the sea. In an urban environment such as that surrounding OPC, a turbine would not deliver its peak performance. Furthermore, there are visual and noise impacts that limit the applicability of a wind turbine in the middle of a town. For these reasons, the use of a normal wind turbine to generate electricity will not be considered further.

However, there is one wind technology that would work rather well at OPC. This is a style of generator known by many names but most generally as a wind harvester that consists of a static device to collect wind that is then ducted to a hidden turbine indoors that drives a generator. These ‘wind harvesters’ are beloved of DIY enthusiasts, but some are commercially available. They work best if the static wind collection device is at the top of a tower. Such a device on top of the bell tower would be almost invisible behind the parapet, could be made to look like the current triangular roof and could duct the captured air down to a turbine-generator just below the roof of the bell tower. As such, it would have practically no visual or noise impact.

This suggestion is mainly made as a token towards advancing the ideas of sustainable generation to inspire others. At OPC, a wind-harvester would be able to generate about 1kW on a breezy day with an annual production estimated to be around 3,000kWh. For context, that is nearly a quarter of the church’s annual electricity consumption.

6.3.2 Photovoltaic Panels

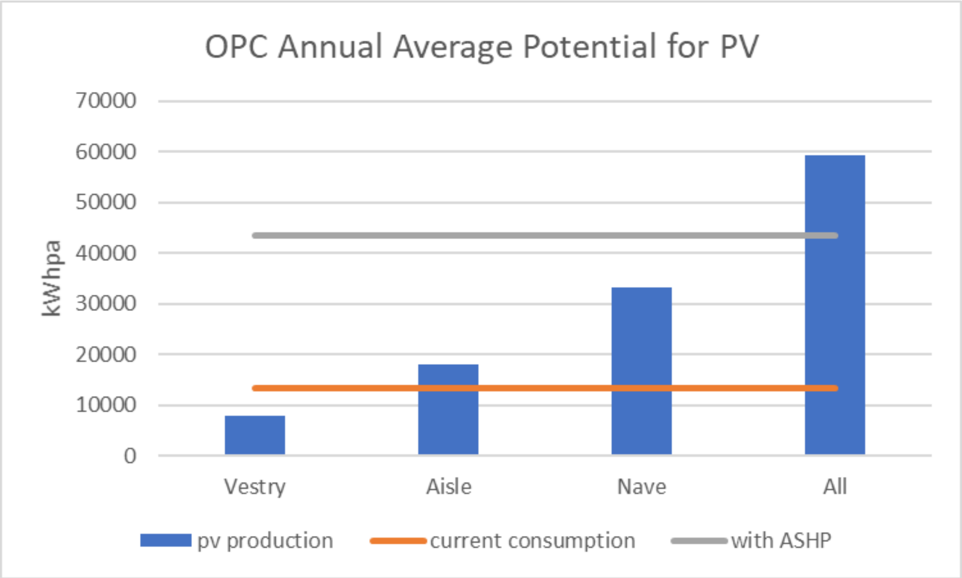
Photovoltaic panels, also known as pv panels or just solar panels, use the physics of semiconductors to convert light into electricity. The technology has been known about for over a century but has seen a huge increase in interest over the last 10 years or so, as a means of generating electricity for off-grid situations in developing countries and as a renewable electricity source to reduce the GHG emissions of developed countries. This upsurge of interest has resulted in the cost of pv panels falling to a third of the price 10 years ago and the amount of electricity produced per square metre of panel increasing significantly. The technology can be considered to be fully established. This is all good news for OPC.

The obvious limitation of pv panels is that they rely on light and therefore produce practically no electricity at night. In winter, when the nights are long and the sun is low in the sky, they produce considerably less electricity than in summer. They are similarly affected by the weather, producing more electricity on a sunny day than on a cloudy day. The seasons and weather combine to reduce the average daily light energy reaching the ground (in London) 7-fold between the peak in June and the trough in December. The installation of pv panels at a suitable angle to the horizontal reduces this difference between summer and winter, but it is still a pronounced difference, especially when weather effects are factored in. A more important installation effect is to mount the panels so they are south facing – this doubles the amount of electricity they produce compared to north facing panels.

In practical terms, panels are most commonly attached to the south facing sloping roof of buildings for optimum electricity production. Panels can be installed in a south facing direction on the ground, which offers lower installation costs, but runs the risk of the panels being overshadowed (particularly in winter) and in urban environments they become more likely to be damaged. At OPC, it is considered that there is no space on the ground that is suitable for installing pv panels.

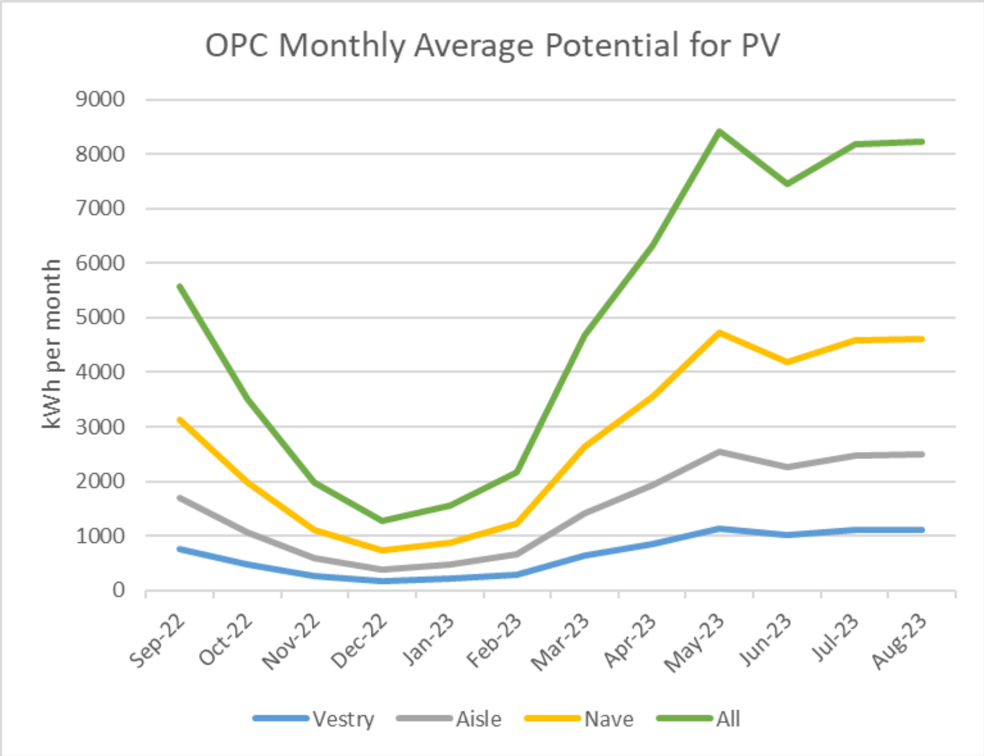
The church building lies east-west which means it has a long south facing roof. This is ideal for pv panels in terms of electricity production.

Based on the roof areas, the headline production figures can be illustrated as shown below:



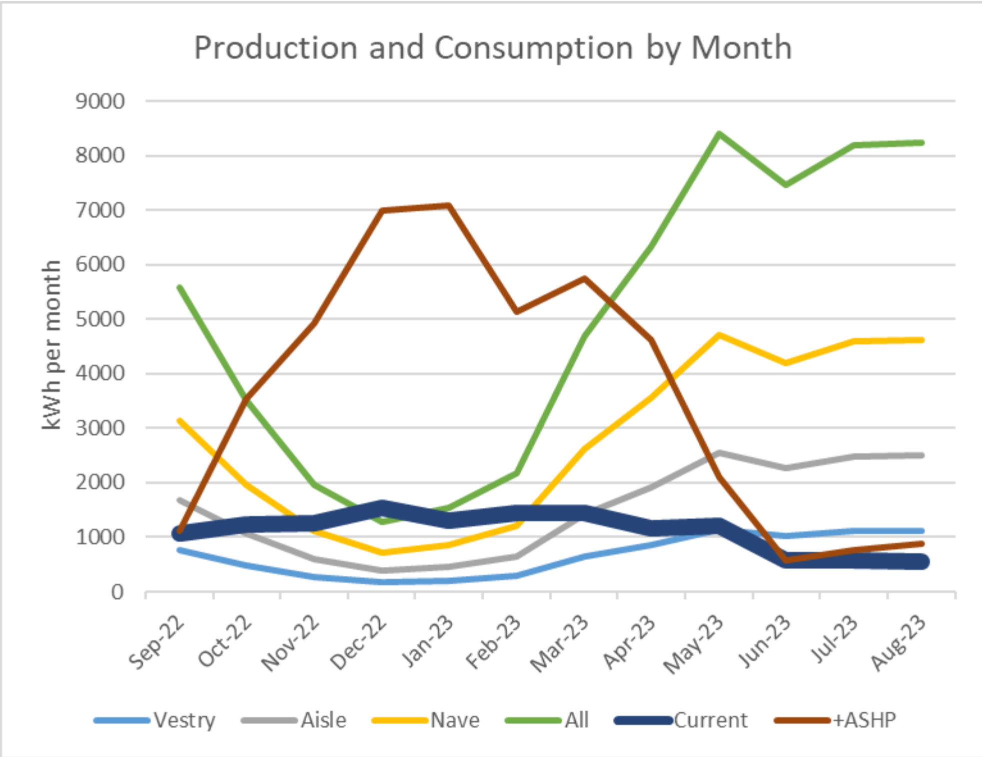
What this suggests is that covering the south facing vestry roof would not supply all the current electricity consumption, but both aisle and nave roofs could supply more electricity than the church needs. Indeed, if the electricity demand of an Air Source Heat Pump (ASHP) is included, covering all the south facing roofs could exceed the total demand for electricity.

This shows the potential, but it is misleading. The seasonal effects then have to be factored in.



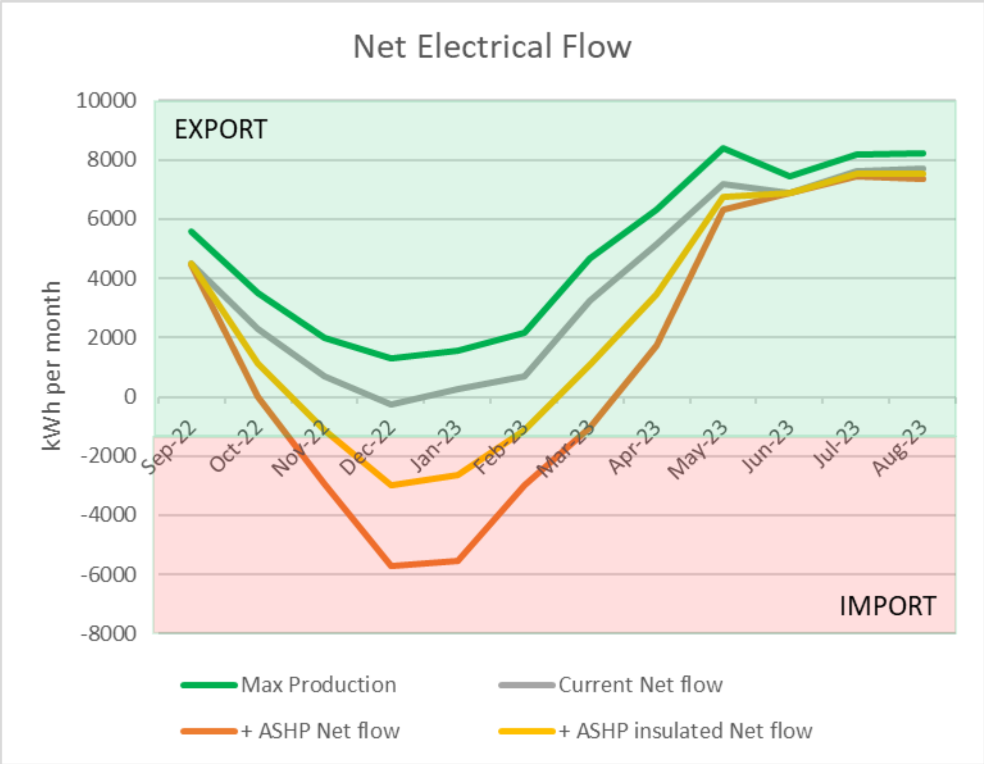
As can be seen in the above graph, the electricity production in the winter months is much reduced because of the low sun and the poor weather (and in summer the production is a lot more than the monthly equivalent of the annual average production).

If we then overlay the production graph with the consumption graph, we can see the times of year when the monthly production meets the monthly electrical demands of the church.



As can be seen there is a surplus of electricity in summer, but a deficit in winter. Even covering all OPC's south facing roofs will not quite meet the current demands (thick dark blue line) in December. Also added to this graph is the electrical power demand of an ASHP that is being used to meet the current heating requirement of the building. Clearly this heating demand is highest in winter, which coincides with the least amount of electricity that can be generated to run the ASHP.

The same information may be visualised more clearly by looking at the net flow of electricity, as below:



This graph shows the production from covering the whole of the south facing roofs, for clarity. Added to this graph is the net flow of using an ASHP after the church roof has been insulated. Clearly, the insulation means the ASHP needs to supply less heat, which means it will use less electricity, which means the pv panels would be exporting electricity for more of the year.

A further complication is that the daily cycle of electricity production rarely matches the daily cycle of electricity consumption. For example, electricity is not produced overnight, but this is when electricity is consumed to operate the lights. Conventionally, this mismatch is overcome by importing electricity from the grid at night, but the advent of much improved battery technology has enabled near self-sufficiency to be achieved when powering, lights, IT equipment, etc. However, for larger electricity demands such as running an ASHP to preheat the church for Sunday morning, the cost of batteries is likely to be prohibitive, so electricity will have to be imported from the grid to meet such demands.

So far, this section has only discussed the potential if various roofs have solar panels fitted on them. The Net Zero group expects that there will probably be significant difficulty in gaining planning permission (or related approvals) to fit solar panels over a large fraction of the roof space of our Grade 1 listed building.

To mitigate the visual impact of solar panels, it is possible to buy pv panels that look like slates. The church has a Westmorland Slate roof, so this is worth considering. Furthermore, as the roof is in need of replacement, using slate-like pv panels instead of slates to replace the damaged slates would be a cost saving. The main downside of these slate-like pv panels is that they cost roughly 3 times as much as the mass produced standard pv panels. The lifetime of all pv panels is expected to be around 25 years, but replacing the slate-like panels is more difficult because they form part of the watertight structure of the roof. The failure issue is compounded by the fact that slate-like panels are very much smaller than 'normal' pv panels, so there are very many more slate-like panels needed (to produce the same electrical power), so there will be more failures to deal with. This would require a more intense (costly) maintenance plan than for 'normal' pv panels, to be put in place.

7 Preferred Options & Cost

This section brings together the ideas discussed above into a plan of how to implement the saving opportunities.

The general approach will be to:

1. Reduce demand in a sustainable manner so that the reduction can be relied upon for the sizing of the next step, which is to;
2. Invest in technology that achieves the goal

7.1 Demand Reduction

7.1.1 Electricity

Electricity purchase represents a significant cost to OPC, so any reduction that can be achieved should be sought. It can be stated with some confidence that steps already taken have reduced the consumption of electricity recently. OPC has already invested fully in the use of LED lighting – the single biggest change it could have made to reduce consumption. Improvements continue to be made - the current measured consumption of 13.4MWhpa is some 10% less than the year before.

The price of electricity has, as we all know, seen some dramatic fluctuations over the last couple of years, but is now stabilising to a figure roughly twice as much as it was a few years ago. If we assume a price per unit for our purposes of 30p per kWh (£300/MWh) that could be a fair reflection of the stabilised market price over the 6 year timeframe of our considerations in this report. That makes the predicted annual cost of electricity consumed around £4,000 pa. Note that standing charges add a considerable amount (about 20% at the moment) to this annual figure, but they are largely outside of the control of OPC, so will not be considered in detail here.

Apart from continued vigilance, maintenance and some of the Quick Wins there is little further that can be done to reduce the electricity consumption of OPC.

7.1.2 Natural Gas

Natural gas is a considerably greater cost than electricity at OPC, because natural gas provides by far the greatest amount of energy to OPC. That said, the consumption of natural gas has reduced markedly over the last year from 210MWhpa to 131MWhpa. This is an impressive achievement.

The price of natural gas has shown similar instability to that of electricity, but for our purposes we can assume a figure of 15p per kWh for the time period here. That means the cost of the 131MWh of gas consumed in 2022/23 was nearly £20,000. Again, standing charges will add about 16% to this but are largely out of the control of OPC.

The consumption of gas can be reduced further by lowering the temperature setpoint (the thermostat setting) or switching the boilers on later and off sooner. However, these approaches lower the comfort value for the occupants of the church and are already widely considered to be as low as tolerable.

Most of the Quick Wins will also reduce the gas consumption. These are simple measures and implementation should be completed as soon as possible as there is virtually no cost involved. The greatest gas reduction amongst the Quick Wins will probably be achieved by closing the clerestory windows.

To reduce gas consumption significantly at OPC requires investment in insulation. As shown in chapter 5, the gas consumption could be reduced to about one half of the present by applying reasonable improvements, particularly to the roof. If this was done quickly, it would reduce the gas consumption by £10,000pa, saving £50,000 over the 5 or 6 years before the Net Zero ambition requires the cessation of the consumption of fossil gas. This figure is about the same as the materials cost for good quality insulation for the roof. Fitting the insulation will probably double the overall cost if carried out as a standalone project, but the cost of fitting will be a marginal cost if done at the same time as replacing the roof. As the roof is considered by the PCC to be urgently in need of replacement, it is strongly recommended that all plans and designs related to replacing the roof include as much insulation as is physically possible and an absolute minimum of 150mm of high quality insulation (note that the latest UK building regulations recommend 300mm thickness of fibreglass insulation).

Fitting secondary glazing to the windows would also reduce gas consumption, though as a means of insulation, this is not actually very effective. Some would argue it has a high visual impact, that would make it unacceptable but others would argue that external secondary glazing would be barely noticeable, given that there is a metal mesh over most of the windows already. For some of the smaller windows it could be done sympathetically with the current appearance, particularly the ones that are high up, because they are difficult to see! However the savings achieved would be rather small simply because the windows are rather small. Indeed the total glazed area of the church building is actually quite small as a percentage of the wall area, so the opportunity for savings by improving the insulation on the windows will never be great.

7.2 Decarbonisation

7.2.1 Electricity

It is expected that the current electricity use on site will continue to be sourced from renewable electricity suppliers, hence there is no need to take any action to reduce the carbon footprint of the electricity consumed by OPC.

It would be prudent to continue to minimise consumption of electricity because of the cost to OPC of buying this electricity, but also to prevent excessive consumption and leave some capacity in the electricity supply system for others.

7.2.2 Natural Gas

To reduce the amount of fossil fuel derived energy used on the site will require the use of the natural gas-fired boilers to reduce. To achieve Net Zero, the use of natural gas will have to stop.

Steps have already been taken to reduce the natural gas consumption by reducing the thermostat settings in the church, implementing the Quick Wins highlighted in chapter 6 (some are still a work in progress) and investigating where insulation is needed. On a year by year basis, these potential reductions are very much dependent on the weather, but it is interesting to note that the gas consumption figure previously published of 210,000kWhpa has reduced to 131,000kWhpa based on the most recent smart meter data. A harsh winter could wipe-out these savings, but it is encouraging to see such a reduction has been achieved already.

Reducing the natural gas consumption to zero will require the gas-fired boilers to be replaced with an alternative heat source. Of all the potential sources discussed in chapter 6, the clearly most appropriate is to use an Air Source Heat Pump. Such a device would require no gas and would use the atmosphere to provide the heat, consuming some renewable electricity in order to achieve this.

To specify the size of the ASHP would need reliable knowledge of the heating demand of OPC. As mentioned above, this demand should be minimised by taking the steps outlined in this report (i.e. the Quick Wins and insulation) and then operated for at least a year to provide reliable sizing data.

If the ASHP is inadvertently undersized, it will be difficult to maintain the desired level of comfort in the church. If it is oversized, it will be more expensive than needed and will physically occupy more space, which will be a problem if it becomes too large to be fitted in the boiler house – its ideal location.

If, as discussed in section 5, the gas consumption is halved, the most likely power rating of the required ASHP will be half the current gas-fired boiler's power rating of 100kW, i.e. a 50kW ASHP would be needed. That is thermal power, not electrical power, such an ASHP would consume around 13kW to produce that 50kW of heat. A 50kW ASHP is estimated to cost £25,000 to install. Note that the optimum location for the ASHP (the boiler room) will require some bespoke installation work, so it is suggested a budget of £30k is allowed for.

7.2.3 Final Offset

The consumption by OPC of fossil fuels (e.g. fuel in the Vicar's car whilst performing his duties and gas in the church boilers) are called direct emissions (or 'Scope 1' emissions) because they are directly emitted by and in the control of the church. By far the greatest of these Scope 1 emissions is the natural gas used to heat OPC. The natural gas Scope 1 emissions would become effectively zero by installing an ASHP, as discussed above.

An electric car would solve the problem of petrol consumption and may be a practical solution, but the emissions will be comparatively small, so it is normal to recommend that these small direct emissions are dealt with instead by offsetting the emissions by doing something to reduce the production of GHGs or to remove GHGs (basically, carbon dioxide) from the atmosphere.

Furthermore, there is an additional carbon footprint of OPC that arises from indirect greenhouse gas emissions. These are emitted as a consequence of the activities of the church but occur from sources outwith the ownership or control of the church (these are known as Scope 2 and Scope 3 emissions – water consumption, for example).

Careful procurement of services and supplies can reduce these Scope 2 and 3 emissions, but this is not a good long-term strategy because suppliers change and some supplies simply cannot achieve zero emissions in the foreseeable future (electronic goods, for example).

Together, these small Scope 1 and the Scope 2 and 3 emissions require what is known as the 'final offset'. The most reliable way to achieve this final offset is to generate renewable electricity that is fed into the grid, causing less electricity to be produced from the burning of fossil fuels in the regional power stations. This would give the church a 'carbon credit' that it could use to eliminate the final GHG emissions caused by its activities.

Using the example of the Vicar's car to provide an order of magnitude for these remaining GHG emissions, we can assume an annual distance travelled of 8,000km in the service of the parishioners. A petrol car would emit 1.2 tCO2e to travel this distance. To offset these GHG emissions would require the production of 6,200kWh of renewable electricity. This amount of renewable electricity could be produced by covering the south facing vestry roof (the smallest suitable roof) in pv panels.

The cost of installing these pv panels on the vestry roof, if standard panels are used, would be around £10,000. If slate-like panels are used, the cost would be around £30,000.

The alternative method of achieving the 'final offset' is to physically remove carbon dioxide from the atmosphere. The man-made technology to achieve this is not developed to a point where it is useful, so the alternative usually applied is to use vegetation (e.g. plant some trees, or more often, pay somebody else to plant some trees). Unfortunately, this is a method that is mired in controversy, poor science and greed. To provide some guidance on what would be required to offset the petrol in the Vicar's car, somewhere between 25 and 150 trees would need to be planted.

Alternatively paying Climate Stewards £25 per tCO_2e every year would be an acceptable way of achieving the final offset if the size of the remaining small emissions can be quantified. This is not easy and may incur extra SME costs (Climate Stewards, amongst others, offer this as a chargeable service).

7.2.4 Timelines

The suggested timeline for achieving Net Zero would be as shown below:

	2023	2024	2025	2026	2027	2028	2029	2030
Implement Quick Wins								
Investigate Insulation Opportunities								
Fund raise								
Apply insulation (as part of the roof replacement)								
Gain new heat demand knowledge								
Investigate approval for pv								
Install pv								
Install ASHP								

Notes on timeline:

- The Quick Wins have already started to be implemented. Some may take longer than shown, but should be bearing fruit by early 2024.
- The insulation opportunities should focus on the roof. This is not only where most of the heat losses from OPC occur, but also has the potential to be tied in with the impending need to overhaul the roof. If the roof replacement is delayed, insulating the existing structure (even as a temporary measure), should be considered.
- Apart from the need to raise the funds, there is no GHG disadvantage to installing pv and starting to offset the electricity costs. The DNO would welcome this. This action could, therefore, be brought forward.

7.2.5 Preferred Energy Solution

It is clear from the discussion above that energy holds the key role in achieving Net Zero. The summarised position is that consuming less energy is a step in the right direction, but stopping the consumption of fossil fuel is essential. The role of electricity generation is more nuanced[4] in all definitions of Net Zero, but it is referred to as an appropriate action in all the C of E's guidance on achieving Net Zero, so is considered in this roadmap.

Or course, generating electricity is not only useful in the journey towards Net Zero – it also reduces electricity bills and can create an income for the church.

From the discussions earlier in this report, the only sensible way of generating a worthwhile amount of electricity is the use of roof-mounted solar pv panels.

To maximise the financial benefit of pv panels, the smallest area of panels (hence lowest investment cost) that offsets the consumption of electricity is needed. This is because the greatest net financial benefit occurs from displacing the importation of electricity. This arises because we buy electricity at 30p/kWh but can only sell it back to the energy suppliers at 5p/kWh, or exceptionally, 15p/kWh. It does get a lot more complicated than this if; the batteries are used for 'peak-lopping', a private wire to Kirkgate Arcade is created, and/or car charging points are included in the considerations, but that would be worthy of a separate study and is not considered here.

To avoid repetitive text, only the smallest and largest options are considered below. For more detail, please refer to Appendix D

Small Array

An array of pv panels that would cover an area of roof of 40m^2 (about the area of the vestry roof), with seasonal effects fully taken into account, would have the cost implications shown below:

Parameter	Units	Result
Annual Production	kWh	8055
Current OPC Annual Consumption	kWh	13419
Net Consumption	kWh	5364
Current cost @ 30p/kWh	£pa	4026
Future net cost	£pa	2070
Future saving	£pa	1956
Future income @ 5p/kWh	£pa	77
Overall benefit	£pa	2033
Array capital cost	£	10000
Simple payback	Years	5

The assumption is that the electricity produced by the pv panels is either used immediately, stored in batteries or sold back to the grid.

[4] There are semi-official definitions of Carbon-Neutral and Net Zero – the former uses electricity generation to achieve neutrality, the latter requires carbon to be removed from the atmosphere to achieve Net Zero, but that is controversial. The C of E's position is that Net Zero means "the carbon emissions of our buildings and travel will be reduced to less than 10 per cent of our baseline levels" – which is not zero or neutral!

The same array when used after OPC's electricity consumption increases as a result of replacing the gas boiler with an ASHP and insulating the roof, is shown below:

Parameter	Units	Result
Annual Production	kWh	8055
Future OPC Annual Consumption	kWh	27292
Net Consumption	kWh	19237
Future cost @ 30p/kWh	£pa	8188
Future net cost	£pa	6161
Future saving	£pa	1956
Future income @ 5p/kWh	£pa	65
Overall benefit	£pa	2092
Array capital cost	£	10000
Simple payback	Years	5

Note that the possible sale price of the surplus electricity could be 15p/kWh rather than the 5p/kWh used above, but the overall effect on the finances is tiny because so little surplus electricity is produced (a surplus is only produced in June, July and August from this small array)

Large Array

An array of pv panels that would cover an area of roof of 300m^2 (about the area of the south facing roof space at OPC), with seasonal effects fully taken into account, would have the cost implications shown below:

Parameter	Units	Result
Annual Production	kWh	59363
Current OPC Annual Consumption	kWh	13419
Net Consumption	kWh	-45944
Current cost @ 30p/kWh	£pa	4026
Future net cost	£pa	78
Future saving	£pa	3947
Future income @ 5p/kWh	£pa	2310

Parameter	Units	Result
Overall benefit	£pa	6528
Array capital cost	£	47000
Simple payback	Years	8

Here, the generation is so large that nearly all the electricity is exported back to the grid (apart from a small amount imported in the middle of winter). This means that the price at which it is sold to the grid is more important. Currently, nearly all energy suppliers are buying pv generated electricity at 5p/kWh, but some companies (Ovo is the most obvious one) are buying at 15p/kWh. If the church sold its generated electricity at 15p/kWh, the net benefit would become £10878pa, giving a simple payback of 4 years.

The same array when used after OPC's electricity consumption increases as a result of replacing the gas boiler with an ASHP and insulating the roof, is shown below:

Parameter	Units	Result
Annual Production	kWh	59363
Future OPC Annual Consumption	kWh	27292
Net Consumption	kWh	-32071
Future cost @ 30p/kWh	£pa	8188
Future net cost	£pa	2154
Future saving	£pa	6033
Future income @ 5p/kWh	£pa	1963
Overall benefit	£pa	7996
Array capital cost	£	47000
Simple payback	Years	6

Again, the large amount of exported electricity needs a sale price of 15p/kWh rather than the 5p/kWh used above, to be considered. This would make the overall benefit £11921pa, giving a simple payback of 4 years.

To sum up, given that replacing the gas boilers with an ASHP is the best way to approach Net Zero and installing some pv panels is the most reliable way of achieving/exceeding carbon neutrality/Net Zero, then, the decision point is how many and where to put the pv panels. Financially, the extremes of the envelope are:

- A future[5] electricity cost reduction of between £2,000pa and £6,000pa

[5] After installing ASHP, but assuming the as-now unit cost of 15p/kWh

- An additional income of between £100pa and £6000pa
- A capital cost of between £10,000 and £50,000.

It is suggested that serious consideration be given to exactly where the pv panels could be fitted and what, if any, mitigation for the visual impact on this Grade 1 listed building could be applied.

8 Roadmap Outcome

There is a lot of detail in this report, but the conclusions are quite simple and follow the best-practice approach of:

- Reducing current emissions as far as possible
- Then ceasing as many GHG emissions as possible through capital investment
- Then offsetting the remaining emissions

The sections on Quick Wins and insulation are all about reducing the current emissions. By definition, Quick Wins cost very little to implement and can be delivered quickly without a lot of specialist assistance.

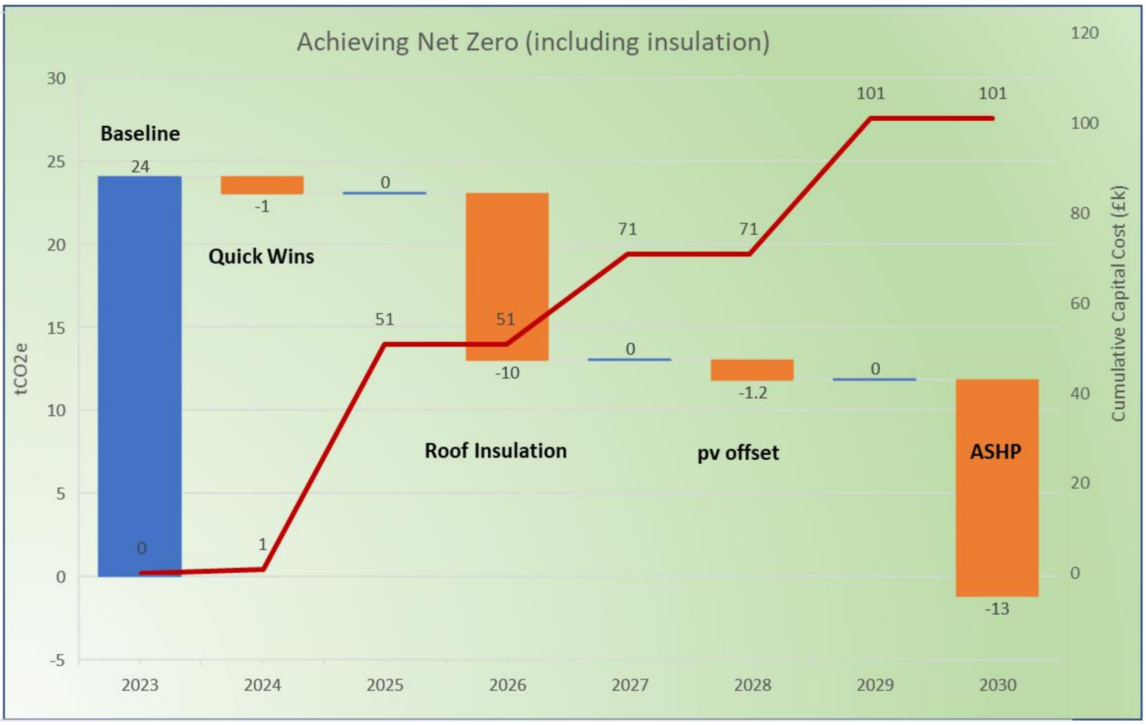
Insulation, on the other hand, will require expenditure and specialist contractors to install it. It is recommended that the church roof be insulated as a priority. This could be tied in with the major overhaul of the roof that is understood to be required imminently or it could be delivered independently of the roof overhaul. The sooner the insulation is installed, the sooner the savings in gas consumption can be realised, but it would be unwise to install insulation in the next couple of years only for it to be removed/damaged/replaced when the roof is overhauled a couple of years later. The timing of the roof overhaul needs to be considered, but it will require the whole church to make the decision.

The main source of GHG emissions at OPC is the gas boiler. To cease these emissions, this boiler must be replaced with something that has minimal GHG emissions. The conclusion in this report is that the replacement should be an Air Source Heat Pump (ASHP) that runs on renewable electricity.

Residual sources of GHG emissions are many and various and are very difficult to eradicate individually. Hence the best approach is to offset those emissions. How that offset is achieved is a controversial topic, but the most certain way is to produce electricity, feed it into the grid and thereby, prevent emissions from distant power stations on the grid. At OPC, this is best achieved by installing solar panels on suitable roof spaces.

The ‘waterfall chart’ below sums up the essential items needed to achieve Net Zero, their capital cost and their timings:

If it can be agreed that insulation of the church roof can be achieved for a nominal sum of £50,000, in the next couple of years, the map to Net Zero would look like this:



Appendix A - Carbon Neutral or Net Zero?

Carbon neutral

The amount of GHGs released into the atmosphere equals the amount removed or avoided through carbon reduction measures and carbon offsetting. Carbon neutrality only includes scope 1 and 2 GHG emissions, with scope 3 emissions encouraged but not mandatory. Offsetting can include environmental and socio-economic projects that “compensate” carbon emissions. Arbitrary reduction targets can be selected by the organisation. There is no requirement to align with science based reduction targets or manage emissions in line with certain climate change trajectories e.g. 1.5ºC etc.

Standards such as PAS 2060 or the CarbonNeutral® Protocol are associated with achieving carbon neutrality.

Net Zero Carbon

Net Zero Carbon is achieved when the amount of carbon emissions (scope 1, 2 & 3) emitted is matched by the carbon emissions removed. Reduction targets must be aligned with Science based targets. Offsetting alone cannot be used to achieve Net Zero carbon status. Offsetting of residual emissions must utilise carbon removal measures only e.g. afforestation and sequestration projects; and not avoidance offsetting mechanisms.

The Science Based Target Initiative (SBTI) released a Net Zero Standard in 2021. This standard sets very clear reduction targets and offsetting allowances. Organisations looking to align with the SBTI Net Zero standard must reduce their emissions along a 1.5ºC trajectory across Scopes 1, 2 & 3.

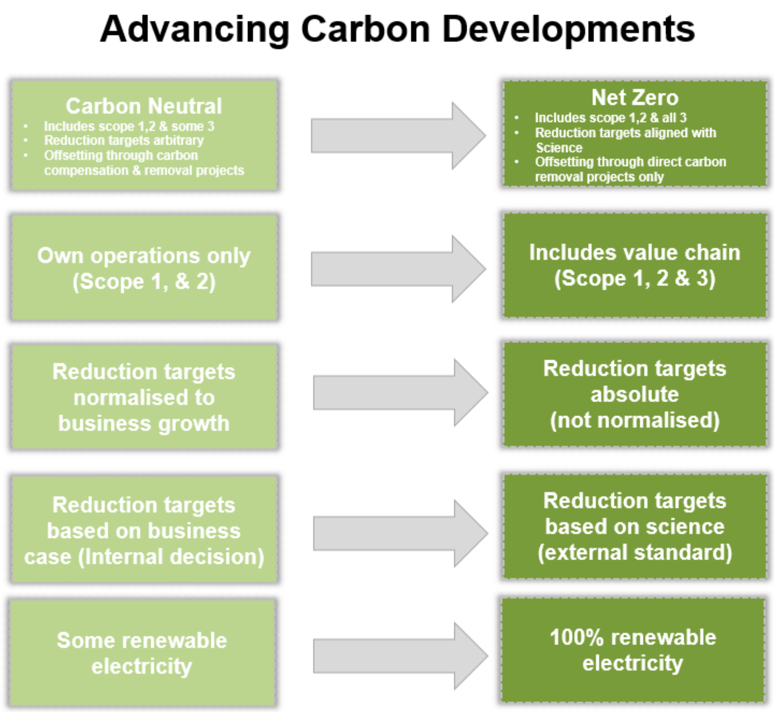


Figure - Carbon Neutral vs Net Zero Carbon

Appendix B - External Contacts

Visits

Holy Trinity Skipton
St John's Menston
All Saints Ilkley
Baildon Methodist

Exchanges of Information

St Chad's Far Headingley
St Mary's Embsay
St John's Ben Rhydding
Chester Cathedral
York Minster

Meetings with people at OPC

Laura Garcia - Architect with Pegasus Group Leeds, lives in Otley has worked on projects involving English Heritage.
Carl Andrews - Church Architect.
Tim Larner - Vice Chair of Zero Carbon Harrogate - friend of Eric Cairns.
Keith Wilson and Tom Raper - Churchyard project

Contact with other people and groups

Jemima Parker - Diocesan Environment Officer
Rob Andrews - DAC Team Coordinator (Church Buildings and Pastoral Reorganisation)
Andrew Howarth - Otley 2030
Andy Boyle - Otley Energy
Dr Eric Peterson – thermal imaging

Appendix C – OPC U Values

In the calculations of the heat loss routes, the chosen U values and ACH for the most likely outcomes, are shown below. In the calculations of heat losses, the average measured internal temperature was used (12.6ºC) and the average external temperature taken from MetOffice records for the actual dates was 3.8ºC.

	Construction	Area (m^2)	U-value (W/m^2K)	Heat loss (W)	Heat loss (%)
Conduction	Floor	711	0.80	341	1%
	Roof	744	2.00	13094	44%
	Wall	551	1.40	6788	23%
	Glazing	71	5.50	3436	11%

Infiltration	4266	0.5	6382	21%
	Volume (m^3)	Rate (ACH)	Heat loss (W)	Heat loss (%)

Total peak heat loss	30042	W
	42	W/m^2

These figures assume a cloudy, light wind day.

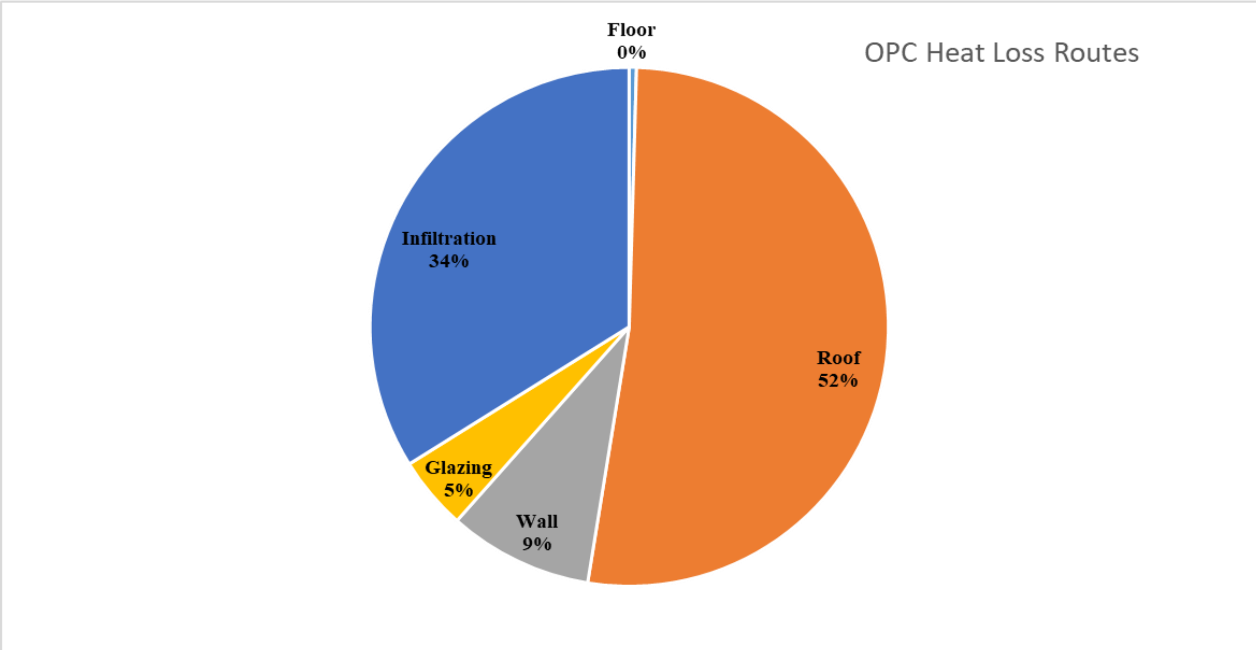
The U value for the roof is calculated from the thermal conductivity of the materials of construction, but critically depends on the air in the gap between the plasterboard ceiling and the roofing slates. Air is a good insulator, but only when it is motionless. Any movement of this air rapidly degrades the insulating properties. However, the air in contact with the plasterboard (and the slates, but they are such poor insulators that this is barely applicable) doesn't move up to a certain depth called the boundary layer. This boundary layer provides some insulation. The depth of this boundary layer depends on (amongst other things) the velocity of the air moving above the plasterboard. On a cloudy, light wind day this velocity is low. This results in a boundary layer of (equivalent) depth of a couple of centimetres, which is enough to give the roof a U Value of 1.3 $W/m^2.K$. On a windy day, with the expected gaps in the tiles, the velocity of air in this gap could be very much higher, giving a boundary layer of only 2mm and a U Value of up to 6$W/m^2.K$. A windy day would also increase the ACH, to say 2 per hour.

The windy day data is shown below:

	Construction	Area (m^2)	U-value (W/m^2K)	Heat loss (W)	Heat loss (%)
Conduction	Floor	711	0.80	341	0%
	Roof	744	6.00	39283	52%
	Wall	551	1.40	6788	9%
	Glazing	71	5.50	3436	5%

Infiltration	4266	2	25528	34%
	Volume (m^3)	Rate (ACH)	Heat loss (W)	Heat loss (%)

Total peak heat loss	75377	W
	106	W/m^2



Notice how the total heat loss is more than twice as great as on a light wind day and is approaching the peak power of the boiler.

Appendix D – Seasonal PV Values

This appendix provides a tabulated example of the calculations used to provide the data shown in the tables in section 7.2.5.

The example used is the small array, without the ASHP or insulation.

Month	Production (kWh)	Consumption (kWh)	Net Flow (kWh)	Current Cost (£)	Net Cost (£)	Income (£)
Sep-22	756	1067	311	320	93	0
Oct-22	477	1234	757	370	227	0
Nov-22	267	1268	1001	380	300	0
Dec-22	174	1543	1369	463	411	0
Jan-23	210	1305	1095	392	328	0
Feb-23	293	1456	1163	437	349	0
Mar-23	636	1450	814	435	244	0
Apr-23	859	1170	311	351	93	0
May-23	1141	1221	80	366	24	0
Jun-23	1012	570	-442	171	0	22
Jul-23	1110	586	-524	176	0	26
Aug-23	1117	549	-568	165	0	28
Totals	**8055**	**13419**	**5364**	**4026**	**2070**	**77**

The current cost is based on a tariff of 30p/kWh.

The possible future income from surplus generated electricity is based on a sale price of 5p/kWh.

The annual saving is the difference between the total Current Cost and the total Net Cost (£1956).

The overall benefit then adds in the total Income to give £2033 per year.

The capex for this 9kWp array is estimated to be £10,000 (installed price), giving a simple payback period of ~5 years.