2020

Reducing the Carbon Footprint of our Churches

RCEF Feasibility Study: Main Report

Authors:

NEP Energy Services

T4 Sustainability

Baytree Energy

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Foreword

By the Bishop of Leicester, The Rt Revd Martyn Snow

In the season of Creationtide, Christians give particular thanks for the abundance of God's gifts through the goodness of the land, the riches of the sea and the rhythm of seasons. In giving thanks for the harvest we are called to cherish and respect our planet and all peoples but also to acknowledge those times when we have misused God's creation.

Across the Diocese of Leicester, we see many ways in which our churches are, through everyday action, demonstrating loving service of their communities and of the world, particularly during this challenging time of global pandemic. This has shown how interconnected our lives are with one another, locally and globally.

I am enormously grateful that the 'Greening Framland' project has taken the initiative, through commissioning this report, to address the impact of energy usage that our church buildings place on the environment and look at ways to mitigate this. I commend the vision behind this report, particularly that it has sought to address a key issue of our times with a local response rather than waiting for a national campaign or a diocesan initiative. My thanks also to the Nottingham Energy Partnership and T4 for producing the report and to the Rural Communities Energy Fund for their grant support that has made it possible.

As we move in Leicester Diocese towards becoming an Eco Diocese with high numbers of Eco Churches, and as the Church nationally seeks to become carbon neutral by 2030, I hope that the findings of this report will help resource and guide our response to achieving those goals. The financial and other pressures brought by corona virus may make implementation of these goals difficult in the short-term for those engaged in local parish church leadership, but as we look to the rest of this decade the contents of this report will I am sure help shape much long-term planning.

Bishop of Leicester, the Rt Revd Martyn Snow.

November 2020

Preface

This feasibility report was commissioned by Framland Deanery with funding from the government's Rural Community Energy Fund. The project began prior to the Church of England's 2030 Carbon Neutral commitment yet has been produced in the context of this goal.

Historic buildings are extremely energy inefficient but can also be complicated to adapt with energy conservation or generation measures. A broad and well-publicised retrofit programme will demonstrate the potential for adapting churches on a grand scale and could act as a catalyst for a comprehensive programme to reduce the carbon emissions of places of worship and other culturally important historic buildings.

Due to the unique nature of the challenge, this report does not strictly follow the traditional structure of RCEF feasibility studies which are designed to cater to community low carbon energy generation projects (the establishment of solar farms, wind turbines etc which have the potential to realise a return on capital investment). This report comprises several parts:

1. This Main Report: this section provides an overview of appropriate measures and technologies for reducing the carbon footprint of church buildings.
2. Appendices: this section provides further information to support the measures outlined in the main report, including information about community engagement, consent and permissions, and delivery options.
3. Assessment Tool: this tool has been developed to allow churches to assess which measures are most appropriate to their church via associated financial and carbon impacts.
4. Supporting Technical Document: this applies the general information provided in the main report to seven churches within the Framland Deanery and demonstrates how to apply the assessment tool to other churches.

As a whole, the report models a range of energy saving measures and assesses their appropriateness when applied to a sample of church buildings within the Framland Deanery; the results of which we hope will be a useful starting point for other churches. As such we have attempted to use accessible language and include explanations to permit widespread dissemination of this report amongst non-specialists, such as the Parochial Church Councils responsible for maintenance and development works to church buildings.

It should be noted that this report does not provide complete solutions for individual churches but provides them with the tools, ideas, and information to develop potential solutions for themselves. It is imperative that Parochial Church Councils are equipped with the knowledge to permit them to plan their own churches' transition to net zero carbon.

Introduction

By Stuart Evans and David Davies, Project Managers

Discussions have been taking place in church groups for a number of years about the general issue of sustainability and our responsibility towards the planet that we all inhabit. There is an active movement of churches working toward the "Eco-church" standard supported by Rocha UK. Others such as 'Caring for God's Acre' are working to promote the sustainable management of churchyards and the enhancement of wildlife.

The launch of the Rural Community Energy Fund in the summer of 2019 provided an opportunity to take a serious look at the energy economy of parish churches. A group came together in the Framland Deanery of Leicester Diocese to prepare a bid. Our initial and continuing hope was that we could develop energy schemes that were financially sustainable and possibly even pay a modest return on capital employed, and reduce net carbon emissions to zero. As evidenced by this report, rural churches are very difficult to heat efficiently and economically on account of their age, location, structure, and patterns of use. The fact that many are listed buildings adds an additional layer of complication, as potential alterations are limited.

We were notified in November 2019 that our bid had been successful. We invited tenders and appointed a consortium led by Nottingham Energy Partnership as our consultants in January 2020. Since then two major external events have influenced the progress of the project.

Firstly, in February 2020 the Synod of the Church of England set the Church a target of becoming carbon neutral by 2030. This is an ambitious target and serves to underline the importance of the work that we are doing.

Secondly, the emergence of COVID-19 and subsequent lockdowns and other restrictions have radically changed the way that the Church operates in many communities. It has not been possible to meet as a congregation and churches have been closed. The longer-term impact of these changes is yet to be felt but may change the way that church buildings are used in the future.

COVID-19 has also had an impact on the way that the project has operated. Gaining access to churches has been difficult. We have needed to hold our steering group meetings online, using Zoom. The overall impact has resulted in the project being extended by several months.

We are very grateful to Nottingham Energy Partnership and T4 for the qualities of insight and professionalism that they have brought to the assessment and analysis of sustainability and rural churches. The results of their work are presented in this report.

We hope that this report will inspire Parishes and their PCCs to address the climate crisis and take action to reduce the carbon footprint of our churches. Individual PCCs need to develop these ideas within their communities. This document should provide them with the tools and outline knowledge to facilitate discussion and allow them, with the appropriate professional support, to make informed decisions.

This report, the supporting technical report and the appendices can be located on the website of the Diocese of Leicester under 'Info for Parishes > Buildings > Environmental Issues' https://www.leicester.anglican.org/info-for-parishes/church-buildings/environmental-resources/.


Proclaim
THE CHURCH OF ENGLAND
Environment Programme
Nurture
Transform
We aim to support, encourage, and enable the whole Church to pray, speak and act prophetically on environmental issues, which threaten the flourishing of the whole of creation
Love
Renew
www.churchofengland.org/environment

Executive Summary

Background

The Church of England has shown an increasing commitment to mitigating the growing threat of climate change. This report has been commissioned by the Framland Deanery of Leicester Diocese, and enabled by funding from the Rural Community Energy Fund (RCEF), to develop practical strategies for reducing the carbon emissions of the church buildings within the Deanery (64 in total). This will enable churches to become more environmentally and financially sustainable. The wider objectives of this report are to develop a model that may be adapted and applied to any of the 16,000 Anglican churches across Britain.

Shortly after this report was commissioned, the General Synod announced the Church of England's commitment to become carbon neutral by the year 2030, lending even greater importance to this report and providing a target against which proposals may be assessed.

This study is based on an assessment of seven churches within Framland Deanery (see Supporting Technical Document). These churches are of different sizes and all bar one is medieval. They show different patterns of usage, different heating systems and different opportunities for energy saving and generation. Taken together they provide a sample of parish churches which offer a range of opportunities to reduce carbon emissions.

This report is written for the whole Church community and we trust that they will find something of value in it.

- Parishes and Parochial Church Councils (PCCs) who are the responsible bodies for the management and maintenance of parish churches and their activities.
- Deaneries which are responsible for guiding and supporting parishes in their work.
- Dioceses which provide local leadership and allocate resources to parishes. The Diocesan Chancellor must authorise any alterations, improvements or major repairs to church buildings.
- The Church of England Synod, which has resolved to achieve carbon neutrality by 2030, and now needs to develop the tools and policies and to find the resources to put this into practice.
- The Church Commissioners who are responsible for Church assets and funds.

Appropriate Technologies

Based on a preliminary assessment of the usage profiles and physical attributes of the selected churches within the Framland Deanery, a number of measures and technologies were identified and explored with regard to their potential to reduce the carbon footprint of the churches. These measures, outlined below, were chosen with an awareness of the heritage and conservation requirements of the buildings. Heating was quickly identified as the greatest contributor to the churches' carbon emissions, therefore measures to reduce the heat load and improve the thermal efficiency of the buildings were prioritised.

- Insulation: generally considered the primary measure for reducing the operational emissions of an occupied building, insulation of historic buildings is a more complex process than the insulation of modern building typologies. Appropriate materials and techniques have been outlined with consideration of the associated risks.

- Spatial Strategy: where spatial requirements are out of scale with the current usage of a building, it is worth reconsidering how the building is used to identify opportunities to reduce heating and lighting requirements. Strategies to partition the space have been outlined where appropriate.

- Energy Generation: whilst much can be done to reduce energy requirements, it is inevitable that a certain amount of energy will be required to enable the operation of the building and the comfort of users. Decarbonising this energy is key to achieving net zero carbon emissions, therefore generating renewable energy which can be used on site or exported to the Grid is a highly effective way to reduce or offset operational carbon emissions.

- Space heating: systems which rely on the combustion of fossil fuels (most commonly gas-powered boilers) are impossible to completely decarbonise at present. Renewable alternatives have been considered including heat pumps and biomass boilers, as well as options involving the re-sizing of boilers to heat the spaces more efficiently and investigating localised and low temperature heating systems.

- Lighting: a relatively straightforward way to make an impact on energy consumption is by upgrading old lighting to LED. This needs little explanation but has been included in the assessment tool in order to quantify potential savings.

- Energy supplier: one of the easiest ways to make a significant impact upon operational carbon emissions is to switch to a 100% renewable energy supplier. Choosing a supplier that generates its own renewable energy and invests directly in renewable technologies makes more of an impact than choosing a green tariff from an energy company that only offsets its emissions.

Summary of findings

Despite the inherent complexities of insulating church buildings, there are significant benefits to prioritising this measure. Insulation is a long term, low maintenance solution which has the added benefit of rendering other technologies more effective. Well insulated buildings have lower heating demands, meaning that heat sources can be smaller and therefore cheaper to install and run. Well insulated spaces are also compatible with low temperature heating systems which can be effectively powered by low carbon heat pump technologies.

The most effective forms of insulation in the context of the church buildings would be wall and roof insulation. Internal wall insulation using sprayed hempcrete would be best suited to many of the buildings surveyed. Roof insulation would ideally be completed in conjunction with planned maintenance work in order to minimise costs and disruption. Floor insulation would be required for any underfloor heating installations and would be worth consideration if floors were being removed for repairs or maintenance.

Simple draught reduction measures such as repairing doors and windows can make a valuable contribution to improving user comfort. More significant measures such as secondary glazing or the introduction of partitions should be considered where draughts have a particularly detrimental effect on perceived temperatures within the space.

Addressing the spatial strategies of the church buildings may be one of the most cost-efficient methods of minimising energy consumption and maximising usability. Partitioning spaces and concentrating insulation and heating measures within these defined areas would require less capital expenditure and would significantly reduce energy demands, as well as increasing building versatility.

There is the opportunity to exploit the large south facing roofs of the buildings to generate energy by means of photovoltaic arrays. Whilst the usage profiles of the buildings are unlikely to correspond with the generation profiles of the photovoltaic systems, exporting energy to the National Grid (The UK's national electricity network) is an effective way to directly offset the churches' carbon emissions.

Where current heating systems do not efficiently facilitate the comfortable use of the church buildings, possible alternatives include low carbon heat sources (such as heat pumps or biomass boilers) and alternative heating systems (such as localised underfloor heating to pews or partitioned spaces). Requirements and recommendations differ depending on the heating requirements of the churches and the existing heating systems in place.

Although not quantified within the scope of this feasibility study, to have the greatest impact on carbon emissions the relative embodied carbon of different measures and technologies should be weighed against the reduction in operational energy associated with their use. For example, whilst natural insulation materials such as hemp can be "better than zero carbon" (i.e. they contain organic materials which have sequestered carbon over their lifecycle), technologies such as heat pumps and PV panels can have significant embodied carbon associated with their manufacture, transportation and end of life disposal.

It is important to bear in mind the potential multiple outcomes of implementing the measures recommended in this report. Lowering the carbon emissions of church buildings must remain at the core of the programme. Financial payback may be a positive driver in the long term, alongside the increased usability and versatility of the church buildings for services and other community functions.

In the long term there is potential for the actions of the Church to have a far wider reaching effect. Demonstrating the Church of England's commitment to act on the deceleration of Climate Emergency and drawing attention to the implementation of a comprehensive sustainability strategy may engage and inspire a broader audience. The potential of the project as a catalyst for communities to take action on climate change is an outcome which is hard to quantify.

Community Support

As detailed in the final recommendations of this report (see Next Steps) engagement at all levels of the Church's organisational structures will be required to provide holistic support throughout the process of implementing the measures required to upgrade church infrastructure to achieve net zero carbon emissions.

At Diocese and Deanery level, guidance must be produced, and steering groups established to take responsibility for and to drive the Church's sustainability agenda. It is proposed that each church be required to produce a Sustainability Report and Sustainability Plan, with the support of the church Architect and associated specialists, and that the implementation of these plans be reviewed through the Quinquennial inspections.

It is crucial that the guidance provides a comprehensive understanding of the faculty process by which PCCs gain permission to make changes to their church buildings. Support and advice must be provided to help churches throughout the application process, and to ensure that the DACs are fully engaged with the church's carbon emissions reduction goals.

At the highest level, there is the need for the Church of England to develop a detailed strategy to provide finance for the implementation of sustainability measures, working closely with the relevant external funding bodies to ensure that sustainability is prioritised. The means by which PCCs can access funding must be as clear and straightforward as possible.

A comprehensive list of advised actions for PCCs, Deanery and Diocese are detailed in the 'Next Steps' section at the end of this report.

Building Retrofit Measures

This section provides a detailed summary of the building retrofit measures that have been considered over the course of this feasibility study with the intention of reducing the carbon emissions of the churches.

It should be noted that the churches included in this study are predominantly medieval buildings. Whilst many of the recommendations are applicable to a wide range of historic church buildings, variations in materiality and construction method may affect the appropriateness of certain measures. As such each church should be considered individually with close attention to its physical and heritage qualities.

The measures that have been considered in this section are:

- Insulation of the building fabric (walls, roof and floors)
- Draught proofing
- Spatial strategy (partitioning the buildings)
- Energy generation
- Heating systems

Whilst the measures outlined in this report are not exhaustive, they have been chosen to provide a comprehensive overview of the energy efficient retrofit measures most appropriate for this context. The retrofitting of buildings is crucial to the pursuit of lowering global carbon emissions, and as such the industry is constantly evolving, with new solutions and technologies being continually developed. Organisations such as Historic England regularly update their guidance concerning improving the energy efficiency of historic buildings, so it is worthwhile consulting the most up to date information when considering retrofit measures.

In addition, the guidance associated with planning permissions and the consents required to make alterations to listed buildings is subject to change over time, particularly with the increasing awareness of the necessity to balance conservation with the urgent need to lower building carbon emissions. The information and recommendations in this report, whilst being as accurate as possible at the time of publishing, will be subject to change over time and should be verified before any applications are made.

Insulating the churches

Insulation is often the first measure recommended to improve the thermal performance of a building, with the greatest effect on reducing energy consumption. Reducing heat loss not only reduces ongoing energy spend; it also reduces the size and cost of any replacement heating system. Historic buildings differ significantly from modern buildings in their construction, materiality, and technical performance, and therefore require an informed and highly considered approach to insulation to ensure the effectiveness and longevity of the measure.

Materials and Processes

Breathability

Historic buildings are predominantly made from permeable materials, in contrast to modern construction methods which prevent moisture movement through the building fabric by means of impervious materials, cavities, vapour control membranes etc. As a result, insulation materials designed for use in modern buildings are often incompatible with historic buildings.

The greatest danger when insulating historic buildings is the risk of condensation between layers of building fabric, known as ‘interstitial condensation’. Whilst historic building materials tend to release the moisture that they absorb through internal and external evaporation, adding impermeable materials to a historic building fabric can cause moisture to become trapped, resulting in elements of the building decaying over time.

It is crucial to maintain the breathability of historic buildings wherever possible, not only to prevent damage to the building fabric but by acting as a buffer to environmental moisture - absorbing it from the air when humidity is high, and releasing it when the air is dry - they regulate indoor air quality and reduce the reliance upon mechanical ventilation systems. Such materials are termed ‘hygroscopic’ and are particularly recommended for historic buildings.

Research has shown that ‘breathable’ materials also prevent the build-up of harmful gases within buildings by reducing levels of indoor pollutants.

Dynamic Thermal Performance

Historic building materials tend to have a high-density building fabric (heavy stone walls, floor etc.) and thermal admittance properties[1] which facilitate the “dynamic thermal performance” of the building fabric. Whereas most modern buildings rely on lightweight materials to maintain internal temperatures, high-density (thermally massive) construction permits the regulation of internal temperatures through the absorption and release of heat (thermal energy). In this way the fabric of a building can act as a thermal ‘battery’, absorbing heat from the sun and from mechanical heating, which it discharges when the environment becomes relatively cooler.

Rather than dynamic thermal performance, however, building thermal modelling is usually based on calculations of the thermal transmittance of the building envelope (walls, roof and floor), commonly referred to as the building U-value. Dynamic thermal performance is less straightforward to quantify and model than thermal performance based exclusively on U-value calculations. However, when approaching historic buildings

[1] Thermal admittance is a measure of a material's ability to absorb heat from, and release it to, a space over time.

it is important to consider the value of the dynamic thermal performance of the existing building fabric, and consider how this can be maintained and enhanced when alterations and additions are made.

Buildings constructed from heavyweight natural materials that have both thermal mass and insulative properties consistently out-perform the U-value based predictions of laboratory tests and computer modelling. Whilst more comprehensive models are in development, these are currently quite complex and not widely recognised; therefore the limitations of industry standard thermal modelling to accurately represent dynamic thermal performance should be taken into consideration when making comparisons between natural and synthetic building materials.

It should also be noted that U-value models of building thermal performance are based on standard, homogenous walls, and do not account for the variations in dimensions and materials present in historic walls. Other factors, such as the presence of water and salts within the wall fabric, can also have an impact on thermal performance yet are not acknowledged in these calculations.

Embodied Carbon

Increasingly the embodied carbon of building materials is facing scrutiny; the government's Committee on Climate Change has recommended that the Building Standards Framework be expanded "to address and drive down the lifecycle carbon associated with buildings, incorporating both embodied and sequestered carbon" (Committee on Climate Change & AECOM, 2019).

Embodied carbon is closely linked to the 'Global Warming Potential' of a material. This equates the energy consumed by all processes associated with the production of a product, from the mining and processing of natural resources through manufacture and transportation to end of life disposal. It takes into account whether component materials are renewable or finite resources, the waste products involved in the manufacture process, and the product delivery.

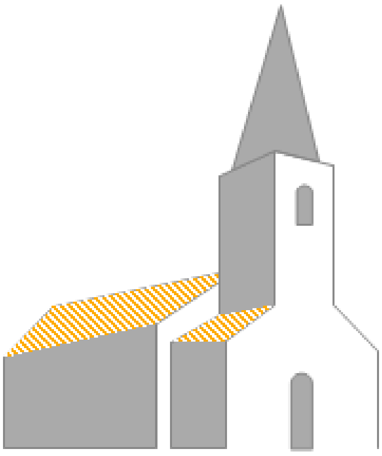
Where Environmental Product Declarations (EPD's) have been produced for insulation products, these offer a straightforward comparison of a materials embodied energy through a CO_2e (Carbon Dioxide Equivalent) value. Whilst synthetic materials used for insulation in the mainstream construction industry can have significant CO_2e values, insulation materials from natural fibres, such as wood, hemp and sheep's wool, can have neutral or even negative CO_2e values (e.g. materials such as hemp, which sequester carbon from the atmosphere as the plant from which they are taken grows).

If insulation is being installed with the intention of lowering a buildings carbon footprint, a comprehensive approach would take the embodied energy of all materials and processes into account alongside factors such as the material's thermal performance.

Aesthetic Considerations

Maintaining and enhancing the historic character of the Churches will be key to gaining the widespread community support required for the Church retrofits to be a success. As such, the materials used must be carefully chosen to integrate with and complement the existing.

A section has been included outlining aesthetic considerations for each insulation type, although ultimately the aesthetic detailing will be specific to each Church.



Insulating Roofs

Typically around 25% of the heat lost from a building's fabric is through an uninsulated roof. This percentage varies according to their shape and construction type. Although there is a level of complexity involved in making alterations to any part of a historic building, roof insulation may be one of the most effective and least disruptive insulation methods to reduce heat loss. It is crucial that natural, vapour permeable materials be used which respect and preserve the building fabric, avoiding the risks of damage to historic fabric through condensation.

1. Above Rafter Insulation

Thermal performance

Fitting insulation above the rafters would be a highly thermally efficient method of insulating the roof. It would allow a continuous, airtight layer of insulation to be applied which would avoid the risk of thermal bridging and reduce air infiltration, offering a considerable improvement in thermal performance. In addition, applying insulation to the external face of the roof structure would reduce the risk of condensation and resulting decay of the timbers, as they would remain within the warmer, drier interior of the church.

Using a material with some degree of thermal mass (e.g. wood fibre board or semi-rigid hemp fibre batts) would have the added benefit of enabling dynamic thermal performance to moderate internal building temperatures throughout the seasons.

Aesthetic and practical considerations

Insulating above rafter level would allow the retention of the original ceiling and associated detailing, such as decorative woodwork, quoins etc.

To install insulation above rafter level would involve removal of the existing roof covering, boards and battens, the addition of insulation boards on top of the rafters (known as sarking insulation) and the replacement of the roof, with cross battening to provide ventilation between the roof and insulation boards. This would require significant financial outlay, including provision of scaffolding and temporary roofing, as well as ensuring that contractors were chosen with high levels of skill and experience in the modification of heritage buildings.

The overall roof level would be raised which would require careful external detailing, particularly at building verges and eaves. Consideration would have to be given to the uneven character of the roofs due to their age, which would inevitably add a degree of complexity to the jointing of insulation boards and sealing of gaps for air tightness.

Figure 1: Above rafter insulation using wood fibre board. Image courtesy Historic England

Figure 2: between rafter insulation. Image courtesy Historic England

2. Between Rafter Insulation

Thermal Performance

Adding insulation between the rafters will provide a level of increased thermal performance. The degree of effectiveness will depend on the depth of the rafters, and therefore the depth of insulation that can be accommodated with the inclusion of a ventilated air space above and ceiling finish below. Assuming that this measure is completed from the internal side of the roof, the exposed rafters would cause a degree of thermal bridging.

Aesthetic and practical considerations

Opting for between rafter insulation involves the installation of a new ceiling, however depending on the depth of insulation chosen, this presents an opportunity to retain visible rafters to the interior of the church, maintaining some of the existing character. In a number of the churches surveyed the original ceilings finishes are no longer present, therefore between rafter insulation finished with lime plaster may be an aesthetic improvement.

There is the potential for this form of insulation to be installed without the need for stripping the roof coverings, dependent upon the type and condition of the existing roof. In this case there would be no impact on the external appearance or visible roof height of the church and no alteration to the internal ceiling height. For churches with exposed internal roof structures, consideration should be given to whether insulation may lead to partial concealment or loss of historic cornices and other details. Careful attention is required for detailing at junctions.

As previously stated, it is imperative that insulation installed between the rafters be vapour permeable and sufficient ventilation be provided to ensure that the roof structure is not subject to vapour build up which could lead to decay in the timbers. Ventilation between the rafters at a point above the insulation requires careful technical consideration.

3. Below Rafter Insulation

Thermal Performance:

A high level of thermal performance could be achieved by insulating below rafter level in a continuous, well-sealed layer. Provided that junctions with wall insulation are carefully detailed, this form of insulation could successfully avoid thermal bridging. A significant depth of insulation could be added subject to aesthetic considerations.

Aesthetic and practical considerations

Below rafter insulation has the advantage of not requiring the external roof height of the building to be increased. However, depending on the existing condition and type of roof covering there may be a need to remove and replace this, for example if an existing roofing membrane is in place which is of an incompatible material or is in poor condition.

Although the installation of insulation below rafter level would affect the internal proportions, where churches have high ceilings it is unlikely that the height difference would have a drastic impact upon the internal appearance of the church.

The more significant aesthetic consideration would relate to the loss of historic features at ceiling level, including the potential concealment of the roof structure, cornices, frames etc. This should be considered carefully in consultation with a historic building specialist to ensure that the character of the church is not unduly degraded.

If below rafter insulation is chosen, sufficient ventilation will be required between rafters above insulation level. Careful consideration must be paid to the movement of moisture in order to ensure that the historic building fabric is preserved to the greatest possible extent.

Materials and Processes

As previously stated, it is of utmost importance to employ natural, vapour permeable materials when insulating historic buildings. Fortunately, there are now a wide range of appropriate materials on the market which reduce the risks associated with condensation, although these materials still require careful detailing with particular attention to ventilation requirements.

Wood fibre insulation board is likely to be the most appropriate material for insulation above or below the rafters. The thermal properties of the material are sufficient to provide a high level of insulation and some degree of dynamic thermal performance. Interlocking boards are available for enhanced airtightness and reduced risk of thermal bridging, whilst being breathable to prevent damage to the building fabric. To fit wood fibre boards to uneven rafters a degree of levelling would be required.

For insulation between rafters, flexible insulation batts (uniformly sized 'slabs' of insulating material) or rolls would be most appropriate to ensure air tightness, particularly where roof structures are uneven. Sheep's wool and hemp fibre insulation are available in these forms and both have hygroscopic properties which would be beneficial to the building fabric.

To the interior of the church it is recommended that the insulation is finished with a breathable lime plaster, which can be pigmented to match other internal finishes.

It is considered inappropriate to install any non-vapour permeable materials within the roof, including vapour barriers, due to their incompatibility with the original permeable construction of the building and the risk of damage to the fabric of the church.

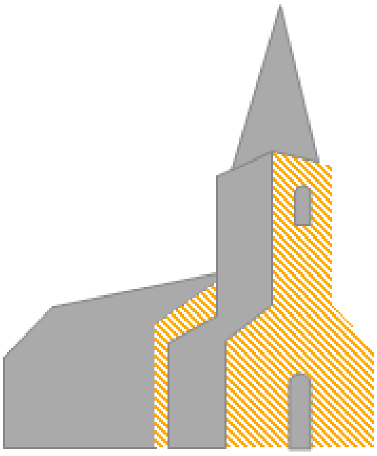
Recommendations:

The most thermally effective roof insulation method would involve a combined approach, the most straightforward being between and below rafter insulation, provided that the roof covering is in good condition and the material is of a suitable type. However, this would require a detailed assessment of the impact upon the historic character of the building and careful detailing by a historic building specialist.

Internal scaffolding would be required for the duration of the work which may have an impact on the normal function of the Church.

If the roof needs replacing in the foreseeable future, it is recommended that above rafter insulation be put in place during the required re-roofing works. This would provide the greatest retention of internal features and a thermally efficient performance which avoids thermal bridging.

All methods would require the inclusion of a ventilated air space which requires careful technical and aesthetic consideration. Vents to the outside should be detailed sympathetically to complement the external character of the building.



Insulating Walls

In general, the largest proportion of the heat lost from a building's fabric tends to be through its walls. In churches this may be reduced to some extent, due to the thickness and material of the walls, which also provide an effective thermal mass to regulate internal temperatures. Provided that any insulation measures maintain the beneficial properties of the walls, introducing **Solid Wall Insulation (SWI)** could significantly reduce energy consumption from heating in the churches.

Internal Solid Wall Insulation

Performance

Adding insulation to the internal walls of the churches could considerably improve the buildings' thermal performance and the thermal comfort of inhabitants. However, the complexities inherent in insulating historic stone walls should not be underestimated.

The breathing performance of any solid wall insulation system will determine the success of the measure. Walls are particularly vulnerable to damp as they are subject to moisture from several sources:

- Rainfall: unlike modern buildings, the fabric of solid wall buildings is exposed to rainfall and relies on evaporation to maintain suitable vapour levels to prevent decay.
- Ground moisture: without a damp proof course, solid walls are subject to rising moisture from the ground which is mitigated by evaporation in breathable constructions.
- Internal moisture from users: moisture is generated by people using the building, which is currently controlled passively by the hygroscopic properties of the solid walls.
- Internal moisture from un-flued gas heaters which can give rise to condensation that may harm the building fabric[2].

As such, it is of utmost importance to ensure that any materials used in repair and maintenance preserve the buildings' breathability. This includes avoiding all impermeable materials, including:

- Cement based products including renders and pointing
- Synthetic insulation materials
- Acrylic based paints, renders or wall coverings
- Vapour membranes

Not only will the use of these materials pose a risk to the building fabric but can be detrimental to user comfort: levels of moisture in the air can have a significant effect on perceived temperature and result in energy intensive behaviours (increasing heating levels or reliance on mechanical cooling systems).

External Solid Wall Insulation

Although there are benefits to insulating the Churches externally, it is considered that as all Churches currently have exposed stonework to the exterior this would change the historic character of the buildings considerably and so in most circumstances would be inappropriate in this context. In cases where the external stonework is in poor condition, it is worth considering external solid wall insulation.

[2] It is highly advised that un-flued gas heaters are **not** used in Church buildings

Aesthetic and practical considerations

Due to the significant surface area of the churches' walls, the costs of insulation will be considerable. In addition, the height of the walls will require the erection of scaffolding in parts of the building and may impede the normal use of the church for the duration of the work.

Most churches were originally constructed with plastered walls. In some cases this became difficult to maintain over the years and has been removed, leaving bare stone walls. In situations where the stonework of the churches is currently exposed, it must be considered that this is unlikely to be the original state of the walls and as such finishing these walls with plaster should be regarded as restoration not a destruction of heritage.

In the case of the churches surveyed, most are plastered internally and therefore the appearance of the church could be largely maintained through using a spray on insulation and finishing this with an appropriately pigmented lime plaster. If the existing plaster is gypsum based, this will need to be removed prior to insulation due to the material's lack of breathability.

This method will permit the organic character of the existing walls to be preserved, and the insulation can be feathered to meet existing details such as cornices and decorative stonework, minimising the concealment of historic features. However, careful detailing will be required to minimise thermal bridging at these points.

Materials and processes

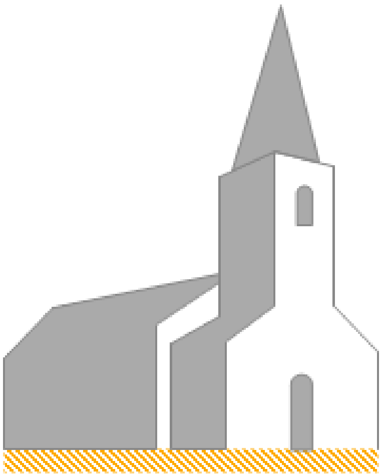
A material with dynamic thermal properties is preferable due to the potential loss of thermal access to the existing walls which provide significant thermal mass to regulate internal temperatures. Most appropriate would be either sprayed hempcrete (hemp-lime) which is recommended by both Historic England and the Society for the Preservation of Ancient Buildings, or sprayed diathonite lime-cork insulating plaster, which can be applied in a thinner layer for less impact on the internal appearance of the church.

The homogenous character of both materials can help to simplify detailing and reduce thermal bridging. Both also possess thermal mass and insulating properties, to compliment the thermal performance of the existing building fabric.

Around 75-100mm hempcrete insulation would be recommended, finished with approx. 12mm lime plaster. This could be feathered to details, around windows etc. Alternatively, between 25-50mm lime-cork plaster would be required.

Figure 4: wall insulation feathered to reveal historical details

Figure 3: internal hempcrete solid wall insulation (UKhempcrete.com)



Insulating Floors

Whilst floor insulation is worth considering to reduce heat loss from the church interior, it should be recognised that the benefits are limited in comparison to other forms of insulation. Churches have solid floors which already have relatively good thermal performance due their thermal mass and contact with stable ground temperatures around 10°C.

In addition, floors in churches are often key aesthetic features and can hold a great deal of historical significance. Great care must therefore be taken when making alterations. Existing floor materials will need to be removed and replaced, which represents a time intensive process.

However, in the event that the floor requires repair or replacement, it may be beneficial to include floor insulation within the scope of works. Should an underfloor heating system be installed, significant floor insulation under this would be essential.

Performance

Typical of their time, church floors are predominantly of stone flags bedded directly onto earth, or clay tiles laid on permeable lime mortar. These materials are vapour permeable and thermally massive, so any insulation materials installed must maintain these properties. The thermal capacity of solid stone floors is particularly significant, and effectively regulates internal temperatures; therefore, lightweight insulation materials are unsuitable for this application as they will reduce the thermal storage capacity of the floor and resulting dynamic thermal performance.

Solid floors can also hold a lot of moisture, which is unlikely to cause damage to the building provided the fabric remains breathable so that excess moisture can evaporate from the entire floor surface. The use of concrete or cement-based products, installation of damp proof membranes, or above floor level insulation which is not breathable can restrict the evaporation of moisture through the floor. This can lead to ground moisture being displaced to the base of walls where it can cause rising damp and result in the deterioration of the building fabric.

It should be noted that any impervious material laid on the floor can cause localised moisture concentration which can lead to damage – e.g. rubber backed mats or carpets. These should be avoided.

Aesthetic and practical considerations

Due to the aesthetic importance of the church floors, as far as possible original floor coverings should be maintained. If the existing floor material requires lifting, this must be undertaken with great care to avoid damage. Prior to the floor being taken up a plan should be made with corresponding labelling of the slabs or tiles to permit accurate re-laying. Appropriate storage of the flooring must be designated for the duration of works.

If a floor is to be excavated a structural survey will be required to ensure that the works will not negatively impact the building foundations. During excavation any exposed archaeology must be carefully recorded.

Materials and processes

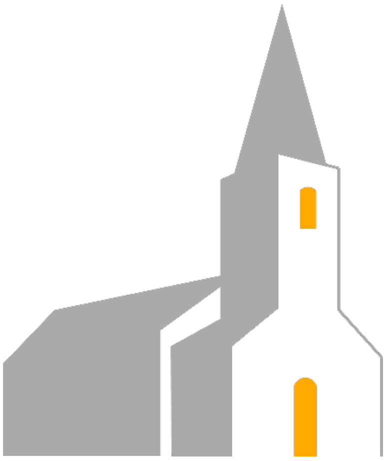
Despite the complexities involved, a number of high-profile places of worship have opted for floor insulation in recent years, predominantly in combination with the installation of underfloor heating systems.

A floor insulation solution which has proven effective in other ecclesiastical applications is a ‘SubLime’ insulated limecrete floor (see appendix 4). This is a permeable system comprising a limecrete floor slab over recycled foam glass gravel, into which an underfloor heating system can be easily integrated. This system requires less excavation than comparable systems, as well as integrating 100% recycled materials meaning that the embodied energy of the system is relatively low.

Notably the solution has been used at Leicester Cathedral, St Margaret’s Church in Ward End, Birmingham, and St John the Baptist Church in Stadhampton, Oxfordshire.

Figure 6: SubLime floor installation at St Margaret's Church, Ward End, Birmingham. Image source limecrete.co.uk

Figure 5:SubLime floor installation at Chrishall Church near Duxford. image source limecrete.co.uk



Draught Proofing

Draught proofing historic buildings is a low-cost way to improve user comfort with little visual impact or risk to the building fabric. The effectiveness of draught proofing measures will vary significantly depending on the building, and the associated energy savings can be difficult to quantify. However, it has been shown that the negative effect of draughts on the perceived temperature of users is disproportionately large, rendering draught reduction measures highly valuable.

Windows

Windows are a hugely important feature of church buildings, not only as an aesthetic feature, but also for their cultural and historical significance. However, they also tend to have an inferior thermal performance in comparison to other elements of the building fabric, therefore reducing heat loss and draughts through and around windows can have a significant effect on user comfort.

Whilst the high thermal conductivity of glass and metal (the primary materials that form church windows) contribute to a building's heat loss, in general a greater proportion of heat is lost through cracks and gaps around the frames, missing or broken panes of glass etc. It is therefore important to assess windows for repair before engaging in any further draughtproofing measures. According to historic England, basic repairs can reduce heat loss via windows by up to a third. However, repairs and alterations to leaded windows involve specialist skills and knowledge, and should only be undertaken by a qualified professional, a list of whom may be obtained through the Institute of Conservation (ICON).

Draught proof Seals

As many church windows do not have moving parts, the potential for sealing against draughts is limited. It may be worth considering sealing the perimeter of windows, however it would be unadvisable to use the impermeable materials typically used for this purpose, due to their incompatibility with the historic building fabric.

Air Permeability:

The air permeability (or draughtiness) of a building is quantified by how much air can pass through the external building envelope. Whilst a certain amount of air permeability is essential to provide building ventilation and prevent condensation and damp, excessive air flow can have a significant negative impact on user comfort, often resulting in energy intensive behaviours such as increasing heating levels.

If the source of draughts is not obvious, fan pressurisation testing may be considered valuable to identify their extent and location. This method can also be employed once draughtproofing works have taken place to assess the effectiveness of the measures.

It is important to consider the passive ventilation of spaces before introducing draught proofing measures, for example unheated spaces in roofs and below floors are often maintained through cross ventilation, and should not be sealed as this would risk moisture build up and could result in damage to the building fabric.

Secondary Glazing

The term 'secondary glazing' refers to an independent window system generally installed to the internal side of existing windows. This measure is likely to be the most effective draught proofing method in this context, simultaneously reducing heat losses whilst preserving the original windows.

In addition to heat losses via uncontrolled air leakage around windows (mentioned earlier in this section), a considerable amount of heat is lost through conducted heat losses via the window unit. Traditional lead and glass windows are poor thermal insulators, so adding secondary glazing can significantly improve the thermal performance of the window element.

The specification of the secondary glazing unit will dictate how effective this measure is: for example using a double-glazed unit, insulated frame or low emissivity glass will have a greater impact than the installation of a single glazed unit. However, in this context the visual impact of the secondary glazing must be taken into account, and a compromise between thermal performance and aesthetic quality may be required. Due to the non-standard forms of church windows and the importance of maintaining visual quality, heritage building specialists would need to be involved in the design and installation of glazing units from an early stage.

Secondary glazing units should be easily openable or removable to allow maintenance of the original windows and to permit adequate ventilation of the interstitial space. It should also be noted that if secondary glazing is installed, this should not be combined with draught proof sealing of original windows as this may cause condensation build up in the 'interspace' between the two layers of glazing.

External secondary glazing, often termed 'storm glazing' or 'isothermal glazing' is often used to protect windows from damage or deterioration. In the context of stained glass windows this can take the form of Environmental Protective Glazing (EPG), a specialist measure requiring a high level of expertise to ensure that the aesthetic properties of the windows are maintained, and that installations do not cause damage to the windows or surrounding building fabric. Whilst this form of secondary glazing may have some thermal benefit, it would not generally be employed for this purpose alone, due to the relative complexity and visual impact[3].

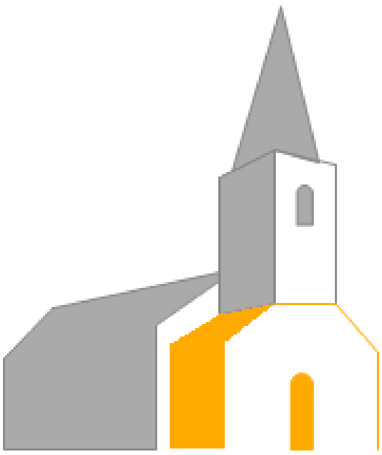
[3] It should be noted that the visual impact of protective glazing may be less than that of protective wire grids which are often employed for this purpose, so may improve the aesthetic qualities of the windows.

Doors & Partitions

Measures to reduce draughts around external doors may also be beneficial. Again, where these features have significant historic value, repairs to existing doors and frames may be most effective and least likely to cause damage to the building fabric. If floors are relatively even it may be possible to install threshold seals or door brush strips to reduce draughts entering below doors, or alternatively installing heavy curtains across doorways would reduce draughts and create a buffer to cold air.

Where doors need replacing, there is an opportunity to ensure that replacements are well fitted and sealed to prevent draughts. If existing partitions do not currently act as thermal barriers (e.g. where these do not extend to the full height of the opening) these could be extended or glazed.

If the churches are to be partitioned as per the recommendations in this report, these measures should also help to prevent draughts, and help to control building ventilation. Open clock towers are a considerable cause of draughts in the church buildings, therefore enclosing their entrances may significantly improve user comfort.



Spatial Strategy

The cost and extent of works involved in insulating and heating the entirety of the churches is considerable. Through discussions with those using the buildings it emerged that there are few occasions where congregation sizes are sufficient to warrant the heating of the whole space. Therefore, it is worth considering ways of increasing building flexibility to better accommodate the present needs of users.

Strategy

Research shows that since medieval times church buildings have been divided into separate chapels, commonly known as ‘chantry chapels’. Whilst traditionally these spaces were defined by archways and rood screens, it would be considered a valid energy conservation strategy to reinstate physically separated spaces within the church which could be insulated and heated individually at far lower (monetary and environmental) cost than the church as a whole.

The uniqueness of each church merits individual consideration of how to ‘partition’ the space to best effect. The space required will be determined by the church architecture and the number and requirements of users. More detail will be provided for the churches surveyed in the process of this study, however the aisles of the churches have in this instance been identified as the spaces which best lend themselves to this purpose. In the partitioning we have not taken into account the locations of the existing organs. It is anticipated that small high-quality organs can be utilised if this is an issue.

Materials and Design

To permit future changes in the use of the space, any separating walls would be best constructed of lightweight materials which could be easily removed, and do not damage the original fabric of the church. These should have a large degree of visual transparency to ensure that the aesthetic impact of the space is not diminished, and so that historical detailing remains visible to the greatest possible extent.

Materials such as timber and glass which interact sympathetically with existing forms and finishes would be most appropriate. For example, carefully designed and crafted high quality oak frames with argon filled double or triple glazing would provide a thermal buffer to the rest of the space whilst maintaining an appropriate aesthetic.

Where visual access is not required to the rest of the church, maximising insulated walls would increase thermal performance. These would once again need to be made of breathable natural materials, for example a timber stud partition with wood fibre or hempcrete block insulation would be appropriate. Finishes should be in keeping with the original, as well as permitting breathability; lime plaster would be best suited for this purpose, and should be pigmented or treated with limewash as opposed to using any acrylic or oil based paint finishes.

Moveable dividers (such as folding doors) could be considered, however the reduced thermal performance, practical implications and increased maintenance requirement of these should be given careful consideration.

Figure 7: partitioned spaces in Churches. image source treskeChurchfurniture.com

Heating and Insulation

If the churches were to adopt the proposed spatial strategy, the smaller 'chapels' could be insulated and heated separately to the main body of the church. The smaller surface area of walls, roof and floor would make the insulation strategies previously discussed more financially viable. If the chapel were housed within one of the aisles of the church, these generally have a reduced height in comparison to the Nave of the church, therefore installation would be more straightforward with reduced scaffolding and access costs. The decreased volume of space being heated would mean that a smaller heating system would be required, with lower installation and running costs.

The most appropriate measures in this case would be:

- Internal Solid Wall Insulation (sprayed Hempcrete or lime-cork plaster)
- Roof insulation between and below rafter level (unless the roof were already in need of replacement, in which case above rafter insulation should be considered).
- Within this smaller space there would be the opportunity to install a SubLime floor with low temperature underfloor heating, provided by an air source heat pump or other energy efficient heat source.
- LED lighting could be installed in tandem with the other works.

It is recognised that on occasion the church would need to be used in its entirety, for example for weddings or Christmas services which draw a larger congregation. For the duration of such services localised heating at pew level may be more appropriate than attempting to heat the whole space of the church. User comfort is more closely related to surface temperature than to air temperature, therefore the following measures should be considered:

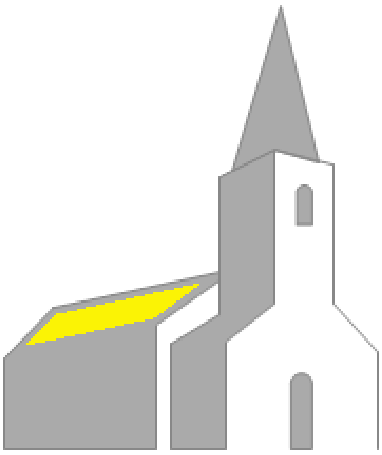
- Provision of pew heaters
- Temporary surface coverings e.g. cushions on pews
- Air to air heat pump systems blowing heated air down onto the users of the building.
- Installing underfloor heating around the area of the pews, particularly if this area is a raised deck which could accommodate underfloor heating without the need for excavation

Conservation of Building Fabric

If the compartmentalisation strategy were to be adopted, it is important that consideration is given to ensuring that the building fabric within the main space of the Church does not suffer from damp due to lack of heating.

Reducing activity within the space will naturally reduce moisture due to human occupation, however it is important that moisture levels in the building fabric are monitored and any problems addressed immediately to prevent deterioration.

As previously stated, maintaining the breathability of the materials will be key to this; in addition, sufficient ventilation must be provided to allow moisture to evaporate, and temperature difference between surfaces minimised to prevent condensation (for example by insulating pipes and ducts).



Energy Generation

Photovoltaic (Solar) Panels are considered the most appropriate form of energy generation for the churches. The East-West orientation of churches means that they have long south facing roofs, which can result in good levels of energy generation, and a large number of churches across the UK have adopted this technology.

Photovoltaic Systems

Due to their large south facing roofs, churches are highly appropriate for energy generation via photovoltaic solar arrays. Photovoltaic (PV) panels, can convert energy from the sun into electricity by means of PV cells.

PV cells do not require direct sunlight to work – some energy can still be generated on cloudy days, however the greater the intensity of the light, the more energy generated. The amount of generation varies throughout the year by a factor of 10. Panels will receive the greatest amount of sunlight and therefore generate the most energy if placed on south facing roofs. Systems on east and west facing roofs will generate less energy per panel, and therefore a system of the same size will have a less significant impact on overall carbon emissions. However, depending on the building usage profile, on-site usage (and therefore bill reduction) could be the same or higher for east / west facing arrays, for example if the building is primarily used in the morning and evening.

A PV system is primarily formed of the following:

- PV panels: connected together these are known as an array.
- Inverter: this converts DC[4] current generated by the panels to AC[5] for use within the building, generally in addition to energy from the National Grid.
- Electrical components: these include isolators, cabling, metering, distribution etc. to connect the system and control distribution.
- Electrical storage: most commonly batteries are used to store electrical energy. These are an optional component where systems are connected to the Grid.

[4] Direct Current
[5] Alternating Current, as supplied to households via the National Grid

PV System Design

Following an onsite roof survey, a solar array can be designed based on the following:

- The size of the roof
- The type of roof (flat/pitched)
- The size of the chosen panels
- Mounting structure requirements
- Wind loading zone (based on height of building)

For this study, only on-roof (above roof level) systems have been considered, however if a roof were being replaced it would be worth considering an integrated (in-roof) system to minimise visual impact. This would however require the roof construction to be carried out in a less traditional way, with a possible impact to the heritage value. In our assessment, ground level systems were not considered due to the cultural and historical significance of the churchyards. Panels have been arranged in landscape or portrait to make best use of the space available, and heavily shaded areas have been avoided.

For the purpose of this study, PV systems were designed and modelled according to Microgeneration Certification Scheme (MCS) guidelines. The use of the MCS method is most relevant in relation to shading analysis, as outlined in the following section.

The location of the cabling, metering, and other electrical components of the PV system will need to be chosen with attention to the importance of protecting the historic fabric of the building. The reversibility of any works must be taken into account, as the lifespan of the PV system will be significantly less than the expected lifespan of the building. This should also take into account the need to access parts of the system for maintenance.

Local authorities will weigh the potential benefits of a proposed PV system against the potential harm caused to the historic building fabric, therefore particular attention must be paid to designing the system to conserve the building and minimise any alteration or destruction of any part of the building. This will include consideration of fixing mountings, ensuring that means of rainwater disposal are not impeded, and that the array does not hinder necessary maintenance work taking place to the church building. More information can be found in the National Planning Policy framework[6].

[6] This can be accessed at https://www.gov.uk/government/publications/national-planning-policy-framework--2

Figure 9: Photovoltaic panels on the roof of the nave at Wing All Saints, Buckinghamshire (Photo: Martin Findlay)

Figure 8: PV mounting on lead roof; mounting system shown from below panels (image source Historic England)

Roof structure and covering

A variety of roof coverings were present on the church roofs, which were categorised into two loose categories; traditional (including slate and historic lead coverings) and modern (predominantly profiled metal). The mounting system and complexity of installation is dependent upon the roof covering – traditional roofs will generally require more labour and extra materials for solar installation, whereas modern profiled metal roofs are well suited to the efficient installation of PV systems.

Historic England, in partnership with the Lead Sheet Association (LSA), have produced guidelines for installing PV systems on lead roofs, including guidance on mounting and passing cabling through the roof. More information can be found in Historic England's publication "Energy Efficiency and Historic Buildings: Solar Electric (Photovoltaics)"[7]

However careful the installer, slates and tiles can be broken during the installation of a PV system; it is crucial that replacements are available prior to works taking place. For roof with slates, stone or handmade ceramic tiles replacements can be expensive and very difficult to find, so this should be taken into consideration when costing and planning an installation.

In addition, the condition and load bearing potential of the roofs would require confirmation by a competent person before a PV array were to be installed. Some roofs may require reinforcement or the replacement of members to ensure that the weight of the array could be safely supported by the roof structure, and that it complies with *Building Regulations Approved Document A: Structure*.[8]

Although theft is rare and PV panels prices have fallen significantly in recent years, security should be considered when planning a photovoltaic installation. This is particularly relevant in circumstances where churches are not subject to natural surveillance, and where roofs are low and easily accessible.

[7] www.historicengland.org.uk/images-books/publications/eehb-solar-electric
[8] https://www.planningportal.co.uk/info/200135/approved_documents/62/part_a_-_structure

Estimate of Generation

In the case of the Framland churches in this study, the presence of shading objects had the most adverse impact upon the feasibility of the systems. Mature trees were often found to the south of the buildings, which in some cases significantly reduced the amount of light incident on the proposed arrays over the course of the day and year. The other major shading obstacle for many of the churches was the tower or spire, due to its height and proximity to the arrays.

Nonetheless, all churches have the potential for PV arrays. Once appropriate arrays had been sized, the panels were separated into 'strings' and the estimated output for each string was calculated via the Microgeneration Certification Scheme (MCS) shade evaluation procedure as follows:

1. Establish the electrical rating of the PV array in kilowatts peak (kWp) from the number and output of the panels
2. Determine the postcode region
3. Determine the array pitch
4. Determine the array orientation
5. Using the postcode, pitch and orientation, lookup kWh/kWp (kK) from the appropriate location specific table
6. Determine the shading factor (SF) using shade factor procedure (set out in MCS document 3.7.7)

According to MCS, the purpose of the standardised procedure is intended to prevent mis-selling and overestimation of PV system performance. This particularly effects the calculation of shade factor, as measurements must be taken from the most shaded point in the array and take into account near shade as having a more significant impact on the efficiency of the array.

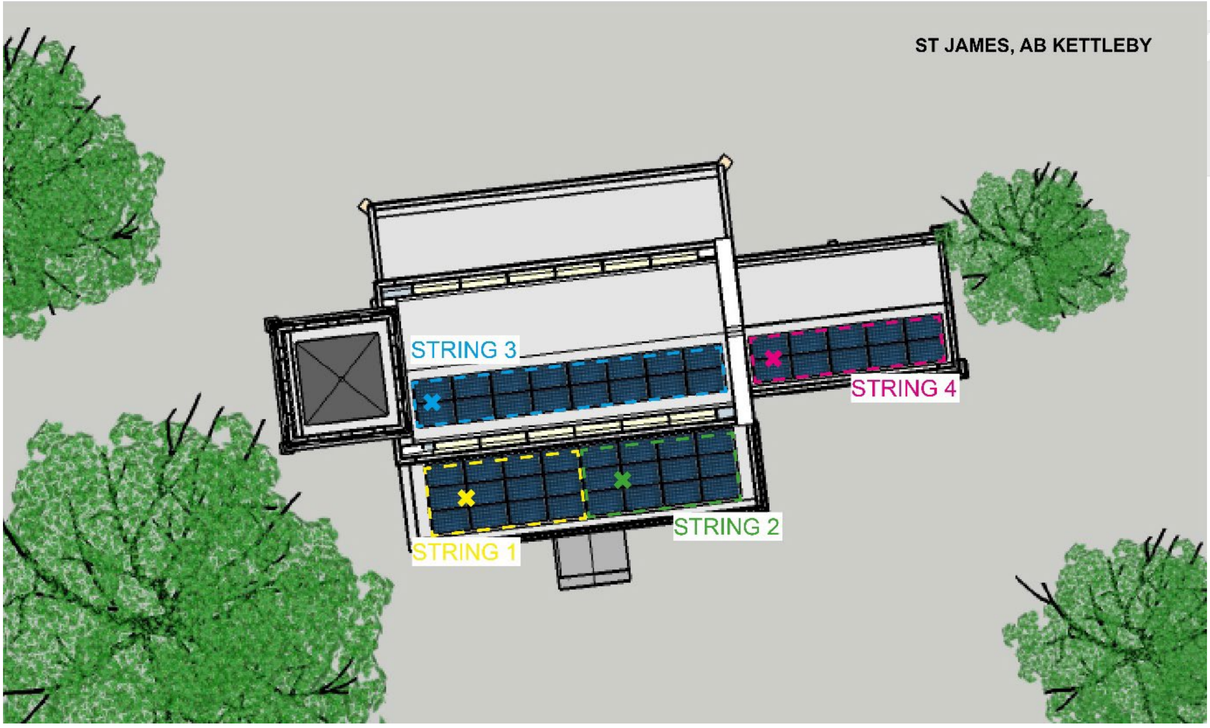
The method is based on a sun-path diagram (see fig 10) which simultaneously shows the position of the sun at different hours of the day and months of the year. The MCS shading diagram is an adaption of a sun-path diagram designed to enable simple shade assessment (see appendix 5).

Shade objects are mapped on the diagram by establishing their azimuth (position on the horizon in relation to south) and altitude (angle above horizon). For the purpose of this study, the churches and associated shading objects were modelled digitally to allow angles to be calculated and mapped to a high degree of accuracy.

The MSC method specifies that objects within 10m of the point on the array should be shown on the diagrams with a semicircle extending to the highest point of the near shade object. Although this has the advantage of ensuring that a system's output is not over-estimated, it can provide a negatively skewed model of potential output; therefore shading factors have been calculated both including and excluding this 'near shade circle' to provide a more realistic picture.

It should also be noted that when a shading object is formed of deciduous trees, the shading effect will be considerably less than shown by the diagram due to the absence of leaves during winter months. This is not accounted for by the shading calculations, however versions of the shading diagrams have been produced differentiating shade from trees (shown in green) from solid objects (shown in grey). Example shown in fig 10.

In addition, there is the possibility of installing module level optimisers to solar panels, which would help to maximise power output, particularly in arrays with significant shading.



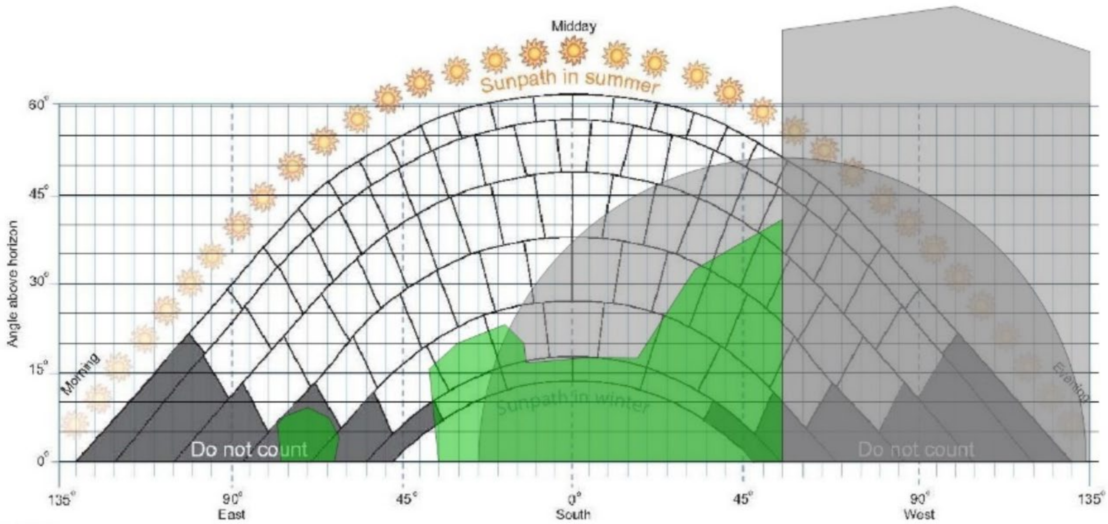


Figure 10: Working Sunpath diagram for Ab Kettleby (PV string 3)

Electricity Distribution and Storage

The way in which the building is used will greatly affect how much of the energy generated from the PV system will be consumed on-site. In the vast majority of cases, churches' electricity supplies will be connected to the National Grid via a main or local distribution board. Therefore, when more energy is required by the building than is being generated through the PV system, electricity will be drawn from the Grid. When the PV system is generating more than is being used within the building, excess energy is either exported to the Grid or diverted to a form of energy storage, for example a battery or hot water cylinder.

From the information provided, the churches are used for very limited periods throughout the week and year, and therefore it is unlikely that the usage profile of the church will correspond closely to the generation profile of the PV system. Buildings which consistently use electricity during daylight hours will be able to make best on-site use of the energy generated, whereas buildings whose main loads are heating and lighting (during winter and evenings) will tend to rely heavily on Grid electricity or energy storage systems.

There is the possibility to divert PV energy not used within the church building to another building in the vicinity. Any buildings fed from the same meter as the church e.g. an adjacent toilet block would be suited to this as they are connected to the church on the load side of the meter. Whilst there may be potential to divert cabling to an adjacent church hall, if this building has its own electricity supply it could not be connected to the church without the original supply being removed. The cost and line losses as well as practical issues such as running cables through the churchyard must all be reviewed if considering this option.

It is worth considering battery storage systems to maximise on-site consumption as well as to take advantage of variable export tariffs. However, due to the relatively low energy usage of the church buildings and the high financial and environmental costs of battery storage systems, it appears unlikely that this would be the best solution in the case of the Framland churches. An alternative means of energy storage worth consideration is diversion to an immersion heater, however again the efficiency of this would depend upon the building's usage profile.

Community Scale Generation and Supply

At the time of this report (October 2020) legislation surrounding electricity supply and distribution prevents small-scale electricity generators from supplying directly to consumers due to prohibitive costs and complex regulation.

The 'People's Electricity Bill' was re-introduced into parliament in June 2020, with the intention of making the costs relating to community-scale renewable energy supply proportionate to the scale of generation. This would allow organisations to sell their energy directly to local people (see powerforpeople.org.uk), so it is worth paying attention to the progress of this campaign and the opportunities its success may offer to the Church.

PV Generation and Energy Demand

Detailed occupancy data was obtained for one of the churches surveyed (St Mary the Virgin, Nether Broughton) to produce a profile of energy usage on the day of a service. This was mapped against modelled energy generation from the proposed PV array to provide a comparison of energy generation against energy usage over the course of a day that the church is in use, for one day per season.

The graphs show energy demand based on the following:

- Room electricity: the electricity required for appliances in the church
- Lighting: the electricity used for lighting the church
- System pumps: the electricity used to power the pumps required for heating systems
- Heating: the electricity required to produce the heat for the church
- DHW: the electricity required to heat hot water for the church
- Generation: electricity generated via proposed photovoltaic array

The resulting graphs (fig 12 to fig 14, p43) demonstrate the disparity between generation and energy requirements throughout the seasons.

- In Winter (January 1st) energy demand is high and relatively consistent throughout the day, however energy generation from PV is low and would only supply a small proportion of the church's energy demand.

- In Spring (April 1st) energy generation from PV is far more significant, however peak energy demand and peak generation are out of step. This means that that still only a small proportion of the energy requirement of the church could be met by PV generation, despite a large amount of generation over the course of the day.

- In Summer (July 1st) the energy requirement of the church is small; a large amount of energy would be generated from the PV array but little of this could be used on site.

- In Autumn (October 1st) energy generation remains relatively high over the course of the day, however again the times between which generation is significant do not correspond with the peak demand.

The graphs demonstrate that, although energy generation via PV can make a significant contribution to offsetting the energy usage of the church, the potential to use the energy directly on-site (at the time of generation) is limited. Exporting excess energy to the Grid is likely to be the most effective means of reducing carbon emissions through energy generation.

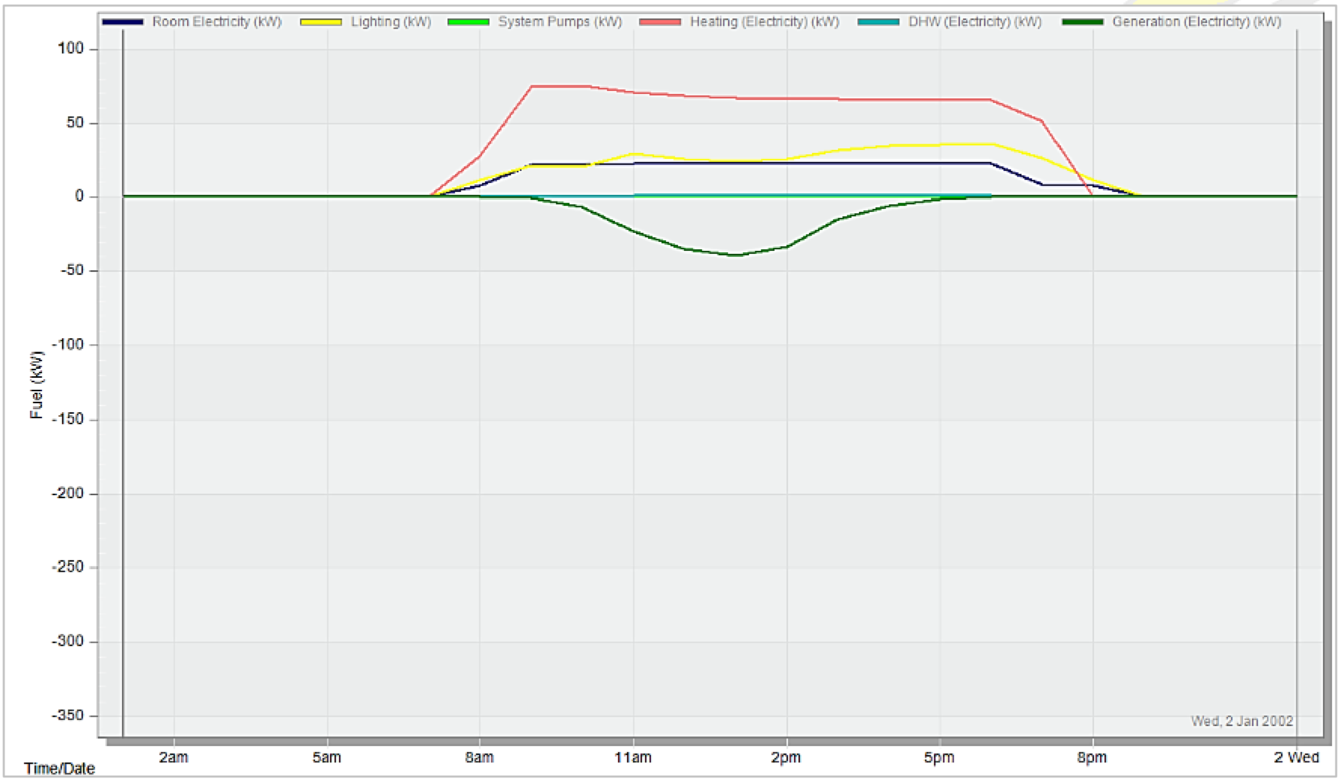


Figure 12: Energy demand and generation, 1st January

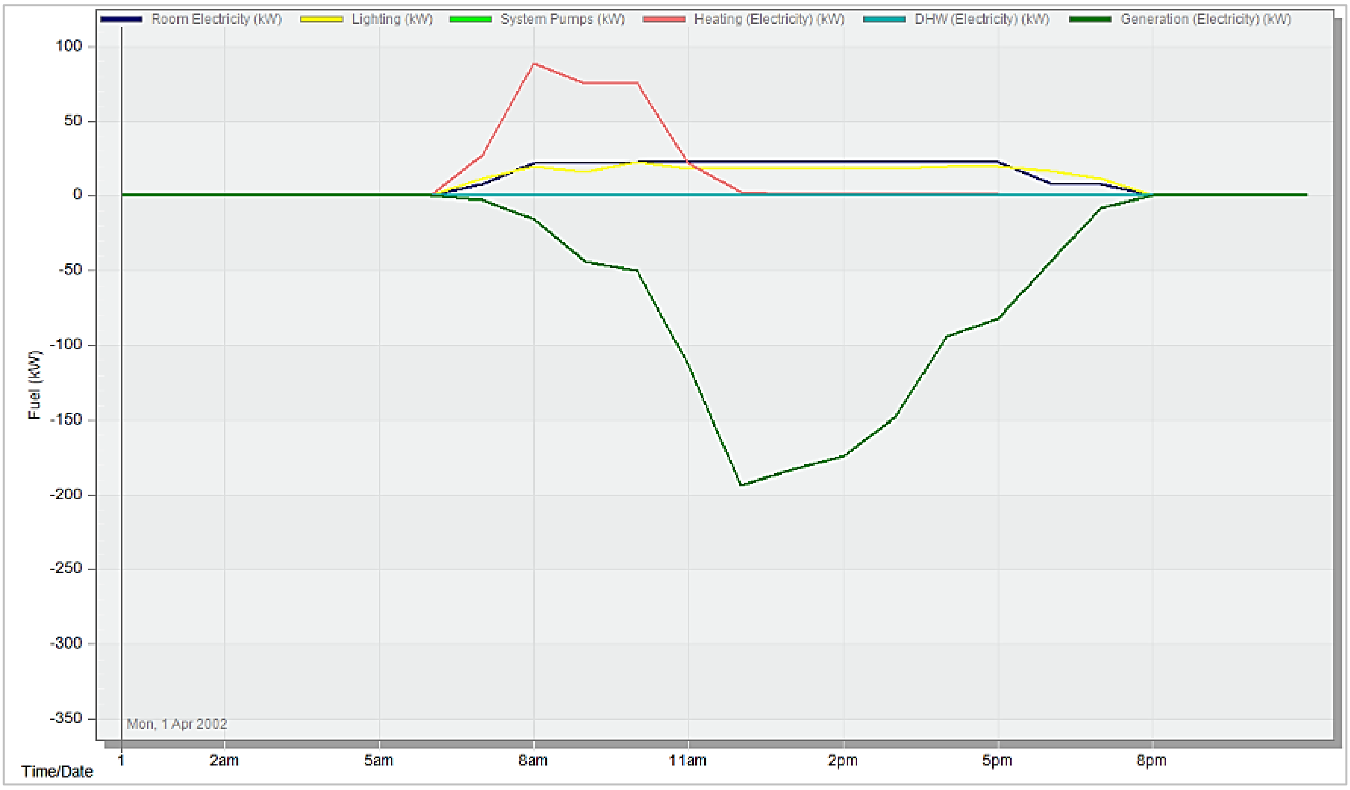


Figure 11: Energy demand and generation, 1st April

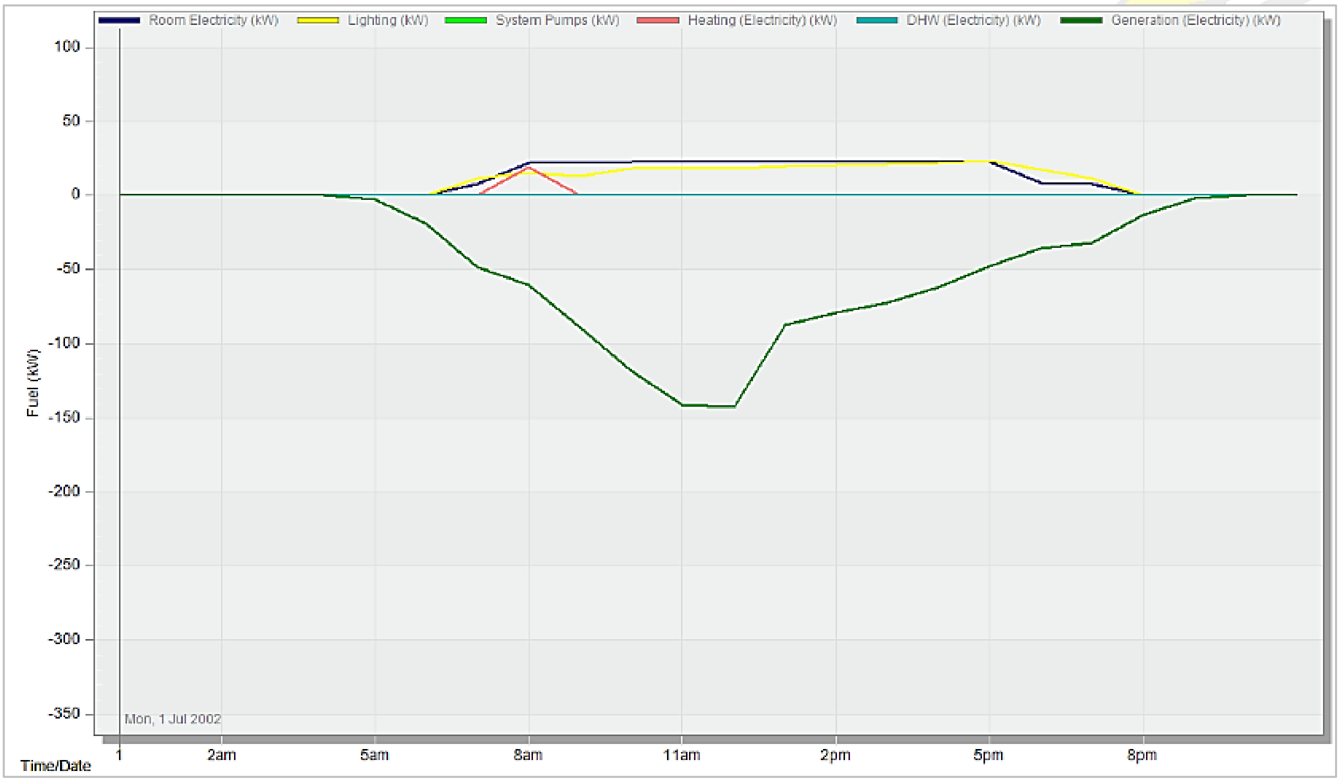


Figure 13: Energy demand and generation, 1st July

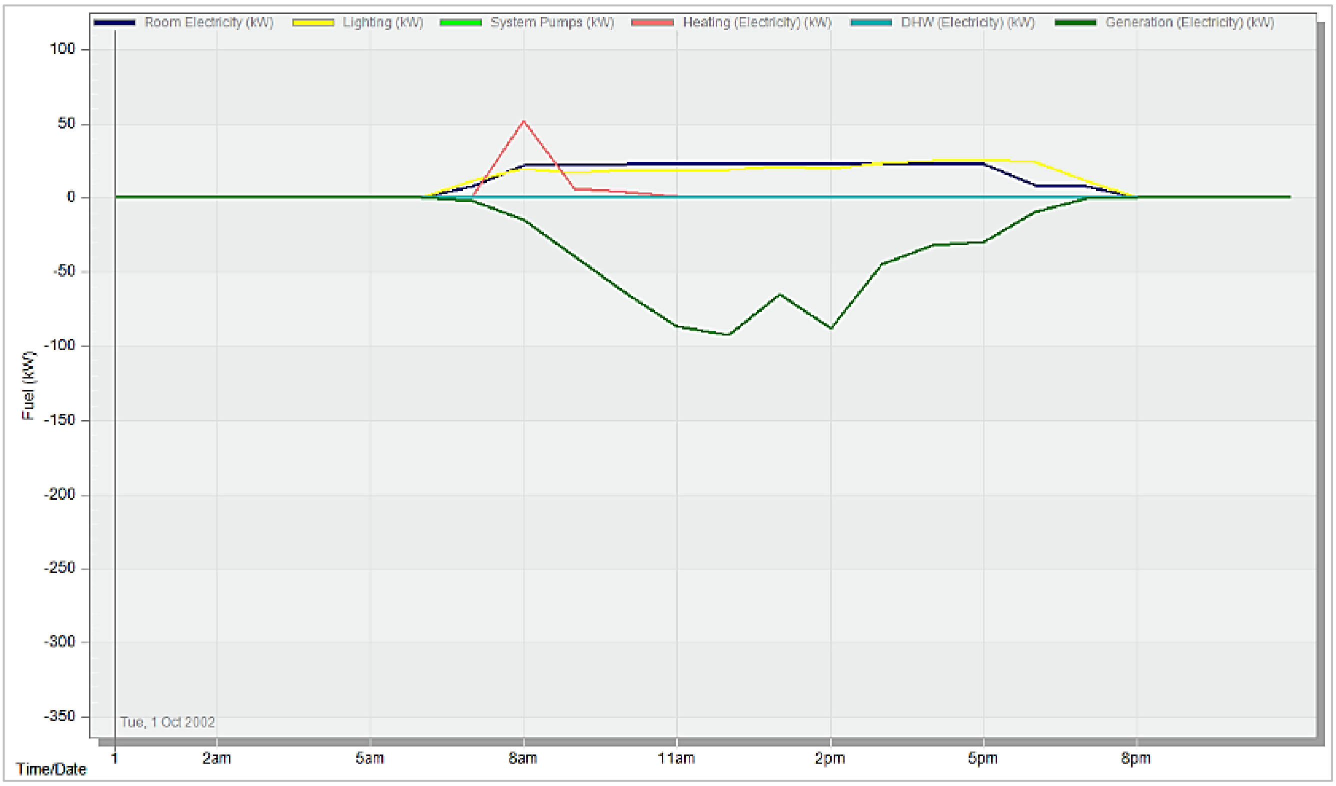


Figure 14:Energy demand and generation, 1st October

Financial Paybacks and Carbon Offsetting

Since the abolition of the Feed in Tariff in April 2019 there have been no significant financial incentives for generating power from photovoltaics. It should be acknowledged, however, that the price of PV panels has reduced significantly in recent years, meaning that the cost of installing photovoltaics is no longer as prohibitive as when the feed in tariff was available.

It is possible that future incentives may become available either in the form of regular payments or capital grants towards installation. Some local authorities and other organisations are currently offering funding for businesses to install photovoltaics, so it is worth researching available financing options in the locality of the church in question, and to stay up to date with relevant government schemes.

Energy suppliers are obliged to offer a smart export guarantee, which pays those exporting energy to the Grid around 5p/kWh – around a third of the cost per kWh of electricity bought from the same suppliers.

At the time of writing this report (October 2020) energy supplier Octopus Energy have recently introduced a variable smart export guarantee which can offer payment at a higher rate dependent upon the demand placed on the Grid at that time. This is most lucrative where renewables are used with battery storage, as this allows customers to export energy when the tariff is high (e.g. 6 pm to 7pm on a weekday) and charge batteries when the tariff is low.

This has some carbon reduction benefit in that it helps to balance the energy supply and demand of the Grid and reduce the overall need for fossil fuel based power generation. However, while the system is in its infancy it is doubtful that the environmental benefit would be outweighed by the significant environmental impact of battery systems.

Financially there may be some advantage to this system, however this varies based upon the specific conditions of each church – please see assessment tool for quantified examples.

In the Church's pursuit of Carbon Neutrality, however, there is a significant benefit of feeding excess electrical energy into the Grid to offset the building's fossil fuel energy usage, and that of Church community activities such as driving to services. The results generated by the assessment tool will demonstrate more clearly the effect of this for the individual churches.

Renewable Energy Tariffs

It is highly recommended that Churches obtain their electricity through an 100% renewable electricity supplier.

Despite claims by many energy companies that their tariffs are 100% renewable, it is worth researching what this means and which energy suppliers actively contribute to increasing renewable energy generation in the UK. Many companies simply pay to offset their emissions or generate only a small proportion of the 'renewable' energy they supply.

The greenest suppliers identified by the Energy Savings Trust in early 2020 were:

- Good Energy
- Green Energy UK
- Ecotricity

More information is available through The Energy Savings Trust and Which.co.uk

Electric Vehicle Charging

Electric vehicle (EV) use in the UK is increasing, with the government aiming to phase out sales of new petrol and diesel cars by 2035. As a consequence, demand for both publicly accessible EV charging points is growing. This may be something that churches could take advantage of as an income source and a more efficient use of excess energy generated from their PV arrays.

The power of a standard domestic charger tends to be around 7kW; these chargers can also be installed in publicly accessible locations such as car parks and outside businesses, for example as part of the D2-N2 electric vehicle charging network across Nottinghamshire and Derbyshire. Fast chargers (typically installed at motorway services e.g. EcoTricity Electric Highway) are often around 22kW. However like PV, an EV charger would require Grid connection permission and 22kW may be too big for rural locations with a single-phase supply.

As EVs have batteries around 20-30kWh, they typically take 1-4 hours to charge from flat to full depending on the size of battery and rate of the charger. EV chargers such as Zappi can be used in 'Eco Mode' to charge EVs only when there is surplus 'free' power that would have been exported. This means it can take longer (days) to charge an EV, but could appeal to local people if the tariff is sufficiently competitive.

Users of EV chargers can pay up to 30p/kWh depending upon the location and rate of the charger - significantly more than domestic electricity rates. As such, if a church bought electricity for 15p/kWh and offered EV charging at 20p/kWh they'd make some income - even at times when no excess energy were being generated from the PV array (e.g. in the middle of the night). Any PV energy which reduced what they had to buy would represent an income to the church.

In certain localities, there may be subsidies or schemes available to help organisations to fund the installation of EV chargers. However it should be noted that where these chargers remain in the ownership of the organisation installing them, opportunities for the church to benefit financially may be limited.

Locating EV charging points

One of the key factors which may prohibit the installation of EV chargers is the availability of off-road parking spaces in close proximity to the church. A church with its own car park would be well suited, provided this is sufficiently close to the church building and can accommodate both EV charging spaces and disabled parking spaces.

In situations where car parks are located at some distance from the church building, consideration must be given to the necessity of running cables. The most appropriate route would be to follow a path, however the expense associated with running cables over a long distance should be weighed against the benefits of installing the charging points.

In the case of the Framland churches surveyed, there was little potential for the installation of EV chargers in the curtilage of the church buildings due to lack of off-road parking. For this reason, financial and energy modelling have not been performed to quantify the possible benefits of this measure.

Heating churches

Due to their construction, historic buildings are generally hard to heat. They are often large (with high ceilings), draughty (due to construction details such as traditional wooden doors), and conduct heat through single glazed windows, uninsulated floors and walls.

Heating Systems

There are a number of effective options available for heating church buildings, all of which have associated merits and drawbacks. Low carbon heating technologies are constantly being developed and improved, and although these can have a high capital cost associated, there are often grants and incentives available to render them more economically viable.

This section provides an overview of the heating technologies that have been considered for use in the context of the churches, and a more detailed breakdown of the technical opportunities and limitations with reference to the churches in the Framland Deanery upon which this report has been based.

Heat Source

Heating systems are based on a heat source (e.g. a boiler) and a heat distribution system (e.g. radiators, underfloor heating).

The heat source requires an energy input. In general, this energy input is either based upon the direct combustion of a fuel (e.g. natural gas, oil etc) or indirectly by electricity generated either from fuel combustion or renewable sources.

Whilst it is impossible or very difficult to decarbonise certain heating sources (e.g. coal or oil boilers), the National Electricity Grid is rapidly expanding the proportion of energy obtained from renewable sources, and even the UK gas network is developing ways to reduce reliance on natural gas in favour of biomethane and hydrogen. Choosing a renewable energy supplier, particularly one directly producing renewable energy (as opposed to offsetting emissions) can effectively reduce the carbon footprint of a heating system.

Heat Distribution

The heat distribution system can take many forms. In the case of the churches surveyed, three main systems prevailed:

- Wet heating systems whereby a heated fluid is passed through radiators (or 'wet' underfloor heating system)
- Radiant heating (e.g. electric panel heaters or infra-red heaters)
- Air blown heating

Unflued gas heaters are also used as supplementary heating in some instances, however these are unadvisable, both for safety reasons and for the potential of creating condensation which can damage the building fabric.

Pew heaters are an economical method of heating the congregation as a supplement to the background heating required to maintain the building fabric.

'Wet' underfloor heating is considered a good option for historic buildings as it uses low temperature 'background' heating to maintain a relatively constant temperature which can help to preserve the building fabric. However, it is important that this type of system be carefully planned in the context of a church, due to the significant works required to the floor, and the risk of indirectly causing damp issues if impermeable membranes are required. Integrating underfloor heating into the area around the pews may be a more appropriate solution requiring less capital expenditure.

Heat Pumps

Heat Pumps use a refrigerant to draw renewable energy from a source (generally absorbed solar energy either from the air, water or ground) and then increase the temperature of the fluid via compression, requiring some electrical input. Heat is transferred from the fluid either to water (for 'wet' heating systems) or to air (for blown air heating systems).

As heat pumps work most efficiently when run on a constant low temperature, they are a good option for maintaining the historic building fabric, and can be considered a low carbon heat source when powered by renewable electricity (either from a 100% renewable electricity supplier, or on site electricity generation via photovoltaics).

Grants and Financial Incentives

At the time of writing this report (October 2020) there are financial incentives available for installing renewable heating systems. The non-domestic Renewable Heat Incentive (RHI) is the most significant of these, although it should be noted that new applications for this scheme close at the end of March 2021.

Non-domestic RHI is a government programme that provides quarterly payments to those with eligible renewable heat installations, based on the amount of heat generated. Potential income from this scheme can be quantified by using the assessment tool that accompanies this report.

It is expected that new incentives will become available following the closure of the RHI scheme; it is likely that these will initially be in the form of a capital grant towards the cost of installation of a renewable heating system, as opposed to regular payments. Ongoing consultations are being carried out to establish ways of increasing the uptake of renewable heating systems amongst businesses and organisations, therefore it is advised that the relevant church organisations stay up to date with developments to be well positioned to take advantage of new financial incentives.

Heat Load

The heat load of a church gives an indication of the power of the heating system required to heat the building to its target temperature (often 19°C) when it is around freezing outside. The churches surveyed had heat loads between 34kW (Holwell) and 160kW (Waltham on the Wolds). Whilst some of the churches have heating systems sized to the building (e.g. 170kW oil fired boiler at Waltham on the Wolds), many of the churches have heating systems that are far smaller than the heat load (e.g. 12kW electrical heating at Holwell). Whilst it is not necessary to heat a church to as high a temperature as 19°C, a boiler capable of reaching these temperatures can heat the building to usable temperatures fairly quickly (rather than having to run overnight to heat the church). This can save fuel as the building spends less time above ambient temperature.

At buildings where it is acceptable to insulate and draught proof the church, the heat load can be reduced, but is still likely to be more than half of the original heat load.

Limitations of Energy Supply

Whilst large heat loads can be met with multiple boilers (e.g. 2 x 35kW gas powered boilers at Stathern), this level of heating cannot be provided via electrical systems, as electrical supplies to the site are limited.

Electricity supplies to churches are typically in the range 13.8kW (60 amps) to 23kW (100 amps) per phase, and supplies are single phase or three phase, giving a range of supply powers to churches from 13.8kW single phase to 69kW three phase. Keeping in mind that some electricity will be used for lighting, kitchen equipment, music making etc, not all of this power can be used for heating.

If we assume that eighty percent of the electricity supply can be used for electric heating, with resistive electric heating elements of various kinds, between 11kW and 18.4kW of heat might be made available.

The amount of heat available from electricity can typically be increased by a factor of between three and five by the use of heat-pumps, but electricity supply still limits the heat available, and heat pumps are subject to Grid connection permission from the District Network Operator.

Gas supply can also limit boiler size. If the gas supply is inadequate, damage to the boiler may result.

Purpose of Heating the Building

Heating a building serves two primary functions. The first is to keep the congregation comfortable enough to enjoy worship and other activities within the Church building, the second is to protect the building fabric by keeping the temperature above the dew point to prevent condensation and fungal growth.

Given the cost of heating the whole Church building, and the environmental consequences of doing so, a key consideration is how to heat the participants in activities within the building, while ideally minimising the unnecessary heating of other parts of the building.

Partitioning building

Efficient distribution of heat within a building typically requires zoning so that only the parts of the building that need to be heated (e.g. the chancel) are heated. Emitters of heat (radiators, fan assisted radiators, underfloor heating etc) need to be chosen to deliver the heat where it will be used most effectively.

A wet heating system (hot water circulated from a heat source such as a gas boiler or air to water heat pump) allows heat to be emitted in a variety of ways and controlled well, but we note that air to air heat pumps powering warm air blowers have been effective in one church in the Framland Deanery (St Egelwin's in Scalford), and this approach might be followed more widely.

Although it is still likely that churches will wish to have boilers big enough to heat the whole building for special services, partitioning the building for other users will reduce the cost of heating, the amount of energy used, and the consequent carbon emissions.

Photovoltaic Energy

Whilst photovoltaic electricity generation can contribute towards the electricity required by a heating system, most electricity is typically generated when heating is least required (summer), and when lighting is not generally required (during the day). Energy storage might enhance the self-consumption of PV energy, but would not necessarily provide a financial or environmental benefit (battery systems are expensive and have significant embodied energy and carbon). Future energy storage products may offer better performance; this technology is developing rapidly. It is possible to use electricity that would have been exported to heat water but not many of the churches surveyed have hot water cylinders.

Any PV energy generated by a church which is not used on site or stored in a battery for later use will be exported to the Grid; measuring the amount of energy exported would allow the emissions saving to be quantified. The church could earn a small income from this export and the electricity will contribute to the decarbonisation of the Grid as a whole. This is consistent with the Church of England's emissions reduction objective.

Next Steps

This details the actions to be undertaken at different levels of the Church community to begin the decarbonisation of church buildings and will be divided into two sections. The first will address those actions the PCCs responsible for individual churches need to take. The second is addressed to a wider community that will need to support the PCCs in their approach. It is recognised that the PCCs will not be able to achieve their sustainability targets if they do not have the support of this wider community.

PCCs

- Any churches not currently using a 100% renewable energy supplier should prioritise energy switching as a simple and straightforward way to reduce their carbon emissions. Churches currently contracted to a '100% renewable' energy tariff should consider switching to a supplier that actively contributes to increasing renewable energy generation in the UK (see information box on p46) rather than those that offset their emissions or generate only a small proportion of the 'renewable' energy they supply.
- All PCCs should as a priority in the next 12 months produce a "Sustainability Report", following guidance to be produced by the Diocese, on their church detailing how they are going to achieve carbon neutrality before 2030. This should include a summary of the current energy systems and the energy usage and short- and longer-term plans as to how the energy consumption is to be reduced or offset by renewable energy generation.
- If a PCC has current plans for capital works these should be reviewed in the light of this report and modified accordingly. For example, if a roof is being replaced this should be replaced with appropriate insulation, or if a door is being replaced it should be replaced with a door that prevents drafts.
- It is anticipated that each individual church architect will have a role in supporting each church with the development of the plans.
- Financing these plans may become a major issue for churches. That should not delay the production of the plans, but the implementation of those plans may need to be adjusted as funding becomes available.
- The PCCs sustainability plan should be widely publicised to the community that they serve.

Other Parties

- Deanery: The Deanery will need to produce material to help PCCs produce these plans. This may be in the form of template for the plan, training on the use of the model and costings of the final plan. They will also need to coordinate and monitor these plans.
- Each Deanery should recruit and train a group of volunteer enthusiasts who will take their church through the process of preparing a Sustainability Plan in a first wave and then be available to support other parishes with the process.
- Diocese: The Diocese should develop policies and associated detailed guidance to support the PCCs to prepare a Sustainability Plan.
- The Diocesan Advisory Committee should revise the criteria for faculty applications to support PCCs to implement their "Sustainability plan".
- The Diocese should amend the specifications for Quinquennial Reviews such that they review the implementation of the plan at each cycle. Note: there are only 2 quinquennial cycles between the issue of this report and 2030.
- Church of England: The cost of these changes will be significant, and a strategy of funding support needs to be developed.
- The Church should engage with those organisations that fund churches' capital programmes to ensure that they support the move to sustainability.
- At local level the Diocese and the Deanery will need to engage with these organisations such that they understand the importance of this work.

It is vital that action is taken with a degree of urgency if the works required are to be completed in time to achieve the Church of England's 2030 target. It should also be acknowledged that the decarbonisation of church infrastructure represents just one part of the impact that the Church can make through this programme. The works undertaken by the Church, and the visibility of these works, have a potentially invaluable influence over widespread behaviour change within the Church community and beyond.

As such it must be acknowledged that the measures undertaken could have far greater environmental impact than the figures directly related to the decarbonisation of the church buildings; it is hoped that by demonstrating the Church of England's commitment to taking action on climate change, those associated with the Church will be inspired to make significant changes in their own lives.

List of Appendices

These appendices can be found on the website of the Diocese of Leicester under 'Info for Parishes > Buildings > Environmental Issues'

https://www.leicester.anglican.org/info-for-parishes/church-buildings/environmental-resources/

Project Contributors

Framland Deanery Steering Group

Rev Canon Dr Peter Hooper: Area Dean, Framland Deanery

Rev Canon John Barr: Rector of the Ironstone Villages and Framland Deanery Prayer and Social Responsibility Enabler

David Davies: Joint Project Manager - St Peter's Kirby Bellars

Stuart Evans: Joint Project Manager – St Mary's Nether Broughton

Penny Clemons: St Egelwin's, Scalford

Vicky Harknett: Parish of the Upper Wreake

Simon Headley: Historic Churches Support Officer, Diocese of Leicester

Peter Stribblehill: St Mary's, Thorpe Arnold

Canon Judith Wells: Deanery Treasurer

Scarlett Tutty: Peter Rogan Associates (from September 2020)

Philip Angus: Nottingham Energy Partnership

Report Authors and Contributors

Paul Chandler: T4 Sustainability

Laura Brain: Nottingham Energy Partnership

John Lancaster: Baytree Energy

John Beardmore: T4 Sustainability

Gavin Fletcher: RCEF

MIDLANDS ENERGY HUB

Bay Tree Energy

Diocese of Leicester

nep nottingham energy partnership

T4 Sustainability Ltd