2020

Reducing the Carbon Footprint of our Churches

Supporting Technical Document

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Introduction

To produce estimates of the financial and carbon reduction impact of the proposed retrofit measures[1] in this context, seven churches in the Framland Deanery were surveyed and a computer model developed (referred to as the 'assessment tool').

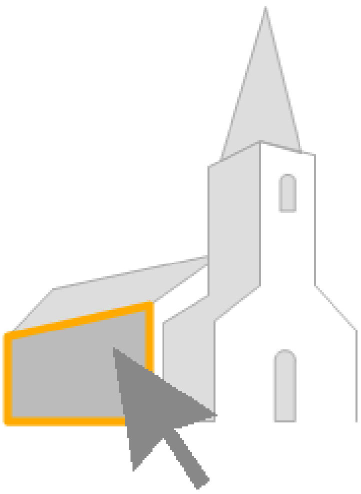
The assessment tool has been used to quantify energy efficiency measures for the surveyed churches. The surveyed churches have been inputted into the tool to give a demonstration of how measures could be applied and combined, and suggest what the associated costs may be, and the carbon savings associated with the measures.

In tandem with the development of the assessment tool, the churches were modelled using 'Designbuilder' software. This was used to judge the accuracy of the assessment tool and to obtain more building specific results based on occupancy data as well as physical building properties.

This document contains a sample of the data acquired through the assessment tool and the Designbuilder modelling. It is intended to equip PCCs with the basic knowledge to assess their own churches, and to identify areas where they would require more specialist input.

This Technical Report is the second part of the Reducing the Carbon Footprint of our Churches Feasibility Study. The main report along with the appendices can be found at https://www.leicester.anglican.org/info-for-parishes/church-buildings/environmental-resources/

[1] Set out in the 'Main Report'



Assessment Tool

An assessment tool has been developed to assess the impact of energy saving measures for a variety of churches. The model automates the calculations of costs and savings for different technical improvements, e.g. lighting upgrade, thermal insulation, boiler upgrade, and the installation of solar PV panels and electricity storage.

Summary

The assessment tool is a spreadsheet which allows the user to estimate costs, and energy and financial savings associated with the retrofit methods described in the previous chapters.

It also allows users to see the interaction between different technologies e.g. if the building is insulated, the required heating system size (and therefore cost) will be reduced, but so will the saving from switching to alternative fuels, as fuel consumption is lower due to the insulation installed.

The assessment methodology is described in detail below, but in brief, comprises the following:

Inputs

- Fuel Consumption
- Electricity Consumption
- Building Dimensions
- Roof Details

Calculations

- Lighting upgrade
- Solar and Battery
- Insulation
- Heating Systems

Summary

- Current energy use
- Estimated cost (for selected measures)
- Estimated savings (for selected measures)

Using the Assessment Tool

The following pages demonstrate the use of the Assessment Tool which has been developed to quantify the costs and savings associated with a range of retrofit methods.

Although the tool is intended for use by those with only a basic knowledge of construction and energy systems, the interface involves a degree of complexity necessary to produce reasonable results. Therefore, it is advised that those using the tool spend time familiarising themselves with this section of this report, and if unclear on any of the required inputs, enlist the help of somebody with a level of professional knowledge.

In brief, the assessment tool uses inputs entered by the user to calculate the costs and energy and financial savings associated with the chosen measures, specific to the building. Energy consumption data and building data are entered into the grey boxes on the ‘client input’ tab. The input data is used to estimate the costs and savings, calculated in the ‘back end’ of the spreadsheet which is hidden from the user. These design tabs refer to the assumptions and look-up tables[2], which are password protected.

Measures can be chosen by the user (tick boxes in ‘summary’ tab) and the resulting cost, saving and payback is displayed alongside the selections. To enable the energy saving from a lighting upgrade to be predicted, an estimate of existing consumption must be entered into the ‘client input’ tab. Estimated electricity consumption is compared with bills to assist with this.

[1]The spreadsheet includes comments which explain calculations to help identify any errors.

Client Input

The first step to using the tool requires some basic information about your church. This can be entered via the “Client Input” tab.

Most of the information required can be found on your appliances, annual utility bills and building surveys. You may also be required to take some measurements yourself, or engage a competent person to undertake a basic measured survey.

Establishing existing and target U-values and air changes may require consultation with a professional, however generic values have been provided which can be used if this is not possible. Equally for the solar calculations, establishing shade factor may require input from a professional, however an estimate can be used.

The following is a breakdown of the required client inputs.

C2 | fx | Old gas

	A	B	C	D	E	F	G	H
1	①	EXISTING HEATING SYSTEM						
2		HEAT SOURCE	Old gas					
3		kW RATING (FROM BOILER)	70	kW				
4								
5	②	HEATING COSTS						
6		COST PER YEAR	£323.15	£				
7		COST PER UNIT	3.59	pence/kWh				
8		STANDING CHARGE	0.00	pence/day				
9								
10	③	ELECTRICITY COSTS						
11		PEAK / OFF PEAK CHARGES	☑					
12								
13			PEAK (DAYTIME)					
14		COST PER YEAR	£260.10					
15		COST PER UNIT	12.78	pence/kWh				
16		STANDING CHARGE	15.93	pence/day				
17			OFF-PEAK (NIGHTIME)					
18		COST PER YEAR	£0.00					
19		COST PER UNIT	1.00	pence/kWh				
20		STANDING CHARGE	0.00	pence/day				
21								
22	④	AVERAGE BUILDING DIMENSIONS (FOR INSULATION)						
23		HEIGHT	7.00	metres				
24		WIDTH	10.50	metres				
25		LENGTH	21.00	metres				
26		REQUIRED AIR CHANGES	3.00	/hour				
27								
28		BUILDING U VALUES						
29		U-VALUE OF EXISTING BUILDING	2.10	W/m^2°C				
30		TARGET U-VALUE	1.10	W/m^2°C				
31								
32	⑤	SOUTH FACING ROOF DIMENSIONS (FOR SOLAR)						
33			LENGTH (M)	WIDTH IN ROOF PLANE (M)	ORIENTATION (DEGREES FROM SOUTH)	PITCH (DEGREES)	SHADE FACTOR (ESTIMATE OR USE MCS DIAGRAM)	
34		AISLE	13	3	0	10	0.1	
35		NAVE	13	3	0	10	0.1	
36		CHANCEL	8	3.5	0	10	0.1	
37		OTHER						
38								
39		ROOF COVERING	metal					
40								
41	⑥	ELECTRICITY CONSUMPTION						
42			RATING (W)	NUMBER	WINTER - HOURS OF USE	SUMMER - HOURS OF USE		
43		HALOGEN LIGHT	250	16	12	16		
44		SPOTLIGHT	150	14	10	16		
45		WIFI						
46		URNS / KETTLE	2400	1	4	4		
47		OTHER						
48		ELECTRIC SPACE HEATERS	1000	1	4	0		
49								
50		TOTAL CONSUMPTION (INCLUDING ELECTRIC HEATING)		1639	kWh			
51		CONSUMPTION FROM BILLS (FOR COMPARISON)		1,580	kWh			
52								

Summary | Client Input | Blank_Sunpath_diagram

EXISTING HEATING SYSTEM		
HEAT SOURCE	Old gas	
kW RATING (FROM BOILER)	Electricity New gas Old gas Biomass Air-Air Heat Pump Air-Water Heat-pump Diesel None	W
HEATING COSTS		
COST PER YEAR		
COST PER UNIT		ence/kWh
STANDING CHARGE		ence/day

1. Select the existing heat source (boiler or other heating system) from the drop down list

EXISTING HEATING SYSTEM		
HEAT SOURCE	Old gas	
kW RATING (FROM BOILER)	70	kW

1a. Enter the kW rating of your boiler (or other heating system). This can be found on the boiler or associated paperwork

HEATING COSTS		
COST PER YEAR	£323.15	£
COST PER UNIT	3.59	pence/kWh
STANDING CHARGE	0.00	pence/day

2. Enter your annual heating costs and cost per unit (pence/kWh) which can be found on your fuel bill or annual statement

ELECTRICITY COSTS		
PEAK / OFF PEAK CHARGES	☑	
	PEAK (DAYTIME)	
COST PER YEAR	£260.10	
COST PER UNIT	12.78	pence/kWh
STANDING CHARGE	15.93	pence/day
	OFF-PEAK (NIGHTIME)	
COST PER YEAR	£0.00	
COST PER UNIT	1.00	pence/kWh
STANDING CHARGE	0.00	pence/day

3. Tick this box if you are on an economy 7 tariff, or pay different amounts for your peak / off peak electricity consumption

3a. Enter your annual electricity costs and cost per unit (pence/kWh) which can be found on your fuel bill or annual statement. Also enter any daily standing charges that you pay.

AVERAGE BUILDING DIMENSIONS (FOR INSULATION)		
HEIGHT	7.00	metres
WIDTH	10.50	metres
LENGTH	21.00	metres
REQUIRED AIR CHANGES	3.00	/hour

4. Building dimensions can be obtained from measured surveys of the church. Try to use values that best represent the overall dimensions of the building

4a. If you are unsure of the ventilation requirements, leave required air changes as 3.00/hour

BUILDING U VALUES		
U-VALUE OF EXISTING BUILDING	2.10	W/m²°C
TARGET U-VALUE	1.10	W/m²°C

4b. Building U-values can be calculated based on the building construction. If you are unable to access professional help to determine your building U-value, leave these figures as existing

SOUTH FACING ROOF DIMENSIONS (FOR SOLAR)					
	LENGTH (M)	WIDTH IN ROOF PLANE (M)	ORIENTATION (DEGREES FROM SOUTH)	PITCH (DEGREES)	SHADE FACTOR (ESTIMATE OR USE MCS DIAGRAM)
AISLE	13	3	0	10	0.1
NAVE	13	3	0	10	0.1
CHANCEL	8	3.5	0	10	0.1
OTHER					
ROOF COVERING	metal				

5. Roof dimensions can either be measured from ground level with the use of a laser measure, or can be calculated from ground level dimensions and estimated roof pitch.

5a. It is only necessary to consider south facing roofs. As most churches are orientated along an east-west axis, the orientation of the most southerly facing roof should be close to zero. The exact orientation can be found by using a compass or an accurate physical or digital map or building plan.

5b. Roof pitch can be estimated, or calculated from a measured survey. Most pitched roofs will be between 15 and 45 degrees.

5c. Shade factor can be calculated by completing the blank sunpath diagram included in the third tab of the spreadsheet. Items that will cause shading such as trees (as seen from the roof facing south) are draw on the diagram. Shade factor is calculated as 1 – number of shaded segments divided by 100. For more information see the MCS shade evaluation procedure (appendix xxx)

Alternatively, a shade rating between 0 (0%) and 1 (100%) can be used (0 is no shade, 0.25 (25%) is light shade and 0.5 (50%) is heavy shade).

ELECTRICITY CONSUMPTION				
			HOURS OF USE PER MONTH	
	RATING (W)	NUMBER	WINTER	SUMMER
HALOGEN LIGHT	250	16	12	16
SPOTLIGHT	150	14	10	16
WIFI				
URNS / KETTLE	2400	1	4	4
OTHER				
ELECTRIC SPACE HEATERS	1000	1	4	0
TOTAL CONSUMPTION (INCLUDING ELECTRIC HEATING)		1639	kWh	
CONSUMPTION FROM BILLS (FOR COMPARISON)		1,580	kWh	

6. Enter the power rating and number of each appliance / device that you have in the building, and estimate the number of hours they are used per month (for winter and summer). The total consumption should roughly equal the consumption from bills.

Summary tab

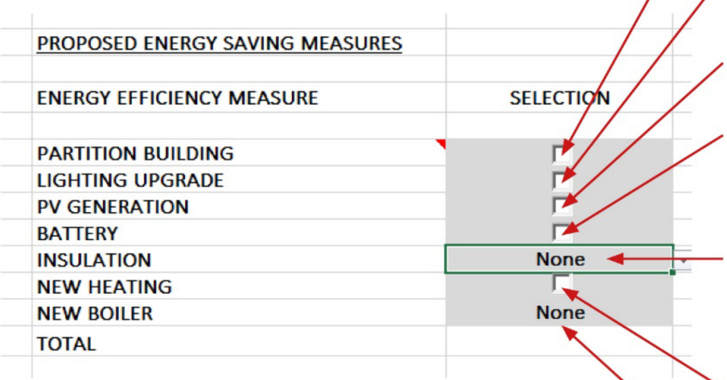
Once the 'Client Input' tab has been completed, the tool is ready to use.

The summary tab provides a breakdown of the measures, and allows the user to select and combine measures to assess the carbon and financial saving that could be achieved by applying them.

It should be noted that the tool can only provide an estimate for these savings. Many factors will affect the accuracy of the estimates, for example changes to energy tariffs, renewable generation incentives and advances in heating technology.

	B	C	E	F	G	H	I
1	CURRENT ENERGY CONSUMPTION						
2							
3		UNITS	FUEL	ELECRICITY	TOTAL		
4	CONSUMPTION	kWh/yr	79,212	1,580	80,793		
5	BILLS	£/yr	£323	£260	£583		
6	CARBON EMISSIONS	$kgCO_2e/yr$	16,231	400	16,631		
7							
8							
9	PROPOSED ENERGY SAVING MEASURES						
10							
11	ENERGY EFFICIENCY MEASURE	SELECTION	Capital Expenditure	Energy Saving (kWh/year)	Bill saving (£/yr)	Income	CO_2 saving ($kgCO_2e/yr$)
12							
13	PARTITION BUILDING	☐	£0	0	£0	0	0
14	LIGHTING UPGRADE	☐	£0	0	£0	0	0
15	PV GENERATION	☐	£0	0	£0	£0	0
16	BATTERY	☐	£0	0	£0	0	-
17	INSULATION	None	£0	0	£0	0	0
18	NEW HEATING	☐	£0	-	£0	0	-
19	NEW BOILER	None	£0	0	£0	£0	0
20	TOTAL		£0	£0	£0	£0	0
25							
26							
27	RESULTS						
28							
29	CARBON SAVING ($KgCO_2e/year$)	0					
30	RESULTING EMISSIONS (KgCO2e/year)	16,631					
31	SAVING & INCOME GENERATED	£0.00					
32	£/TONNE CO_2 SAVED	£0.00					
33	PAYBACK (YEARS)	0					
34							
35	MODEL DOUBLE OCCUPANCY	☐					

Summary | Client Input | Blank_Sunpath_diagram



Partition Building: defined areas of the building would be separated from the main space via sympathetically designed partitions.

Lighting Upgrade: all lights in the building would be upgraded to LED's

PV generation: Solar PV arrays would be added to suitable south facing roofs

Battery: Excess energy generated by the PV system would be stored in batteries to increase the amount of PV energy used on site.

Insulation: Select the level of insulation from a drop down menu. If 'partition building' is not selected, 'partitioned areas only' will return the same result as 'whole building' insulation

New heating: This refers to the addition of a new 'wet' heating system to heat the church

New boiler: Select the desired heating source from the drop down menu.

PROPOSED ENERGY SAVING MEASURES						
ENERGY EFFICIENCY MEASURE	SELECTION	Capital Expenditure	Energy Saving (kWh/year)	Bill saving (£/yr)	Income	CO_2 saving ($kgCO_2e/yr$)
PARTITION BUILDING	☑	£11,025	27,724	£1,386	0	8,115
LIGHTING UPGRADE	☐	£0	0	£0	0	0
PV GENERATION	☑	£11,113	7,317	£84	£236	1,853
BATTERY	☐	£0	0	£0	0	-
INSULATION	Partitioned Areas Only	£53,288	18,600	£930	0	3,811
NEW HEATING	☐	£0	-	£0	0	-
NEW BOILER	None	£0	0	£0	£0	0
TOTAL		£75,426	£53,641	£2,400	£236	13,779

Capital expenditure: this provides an estimate for the upfront cost of the measure.

Energy Saving: this provides an estimate of the annual energy saving (in kWh) that could be made by introducing the selected measure(s)

Bill Saving: this provides an estimate of the annual financial saving (in £) that could be made by introducing the selected measure(s)

Income: this provides an estimate of the annual income that could be generated by installing the selected measures. These figures are based on current tariffs and incentives, and will require updating regularly.

CO_2 saving: this provides an estimate of the annual carbon savings that could be made by introducing the selected measures. This is represented as kg carbon dioxide equivalent, a standardised unit which allows easy comparison of different greenhouse gas emissions

Carbon saving: this shows the difference between the current building emissions and the predicted emissions once the selected measures have been put in place

Resulting emissions: this shows the predicted building emissions once the selected measures have been put in place. A zero or negative result indicates that the church would be carbon neutral, achieving the church's 2030 target

RESULTS	
CARBON SAVING ($KgCO_2e/year$)	13,779
RESULTING EMISSIONS (KgCO2e/year)	2,852
SAVING & INCOME GENERATED	£2,636.74
£/TONNE CO_2 SAVED	£5,282.61
PAYBACK (YEARS)	29
MODEL DOUBLE OCCUPANCY	☐

Saving and income generated: this estimates the annual financial saving that would be made by implementing the selected measures.

£/tonne CO_2 saved: this shows the estimated cost of work per tonne of carbon equivalent saved by implementing the measure

Model double occupancy: selecting this option simulates the relative savings that would be achieved if the church were used twice as much as it is presently

Payback: this figure predicts the financial payback period for the selected measures

Whilst the assessment tool aims to quantify the energy and financial efficiency of the proposed retrofit measures, these should be considered in tandem with an assessment of their impact on the comfort and quality of the user experience and the risk to historic building fabric.

The embodied energy of the technologies is not included in this assessment tool - for example, battery storage currently has a significant associated carbon footprint, which is not represented in the carbon emissions and savings shown using the tool.

Assessment Tool: Detailed Breakdown

Data inputs

The following data needs to be input for each church:

- Existing heating fuel (electricity for conventional electric heating, heating oil, gas, biomass, electricity for heat-pump heating, or none)
- Rating of existing heating system (if not known enter the estimated boiler size)
- Fuel cost per year, cost per kWh and standing charge (can be zero)
- Select if electricity has peak / off-peak tariffs or not
- Electricity cost per year, cost per unit, and standing charge for peak and off-peak
- Building dimensions (external envelope)
- U-Values (leave unchanged if not sure)
- Roof dimensions for up to 5 roofs
- Roof slope and orientation from south
- Number of shaded sectors on MCS sun-path diagram (0 - 100)
- Roof covering - traditional (slate / lead) or modern (sheet metal).
- Number, rating and estimated running hours of lights (leave unchanged if not sure)
- Number, power, and estimated running hours of electric space heaters
- Number, rating and estimated running hours of any electric water heaters

Sun-path diagram: a blank diagram is included in the spreadsheet. Items that will cause shading such as trees (as seen from the roof facing south) are draw on the diagram. Shade factor is calculated as 1 – number of shaded segments divided by 100. Alternatively, a shade rating between 0 and 100% can be used (0 is no shade, 25% is light shade and 50% is heavy shade).

The spreadsheet undertakes basic checks of the input data as follows:

- if the entered boiler size is far bigger or smaller than the estimated size this is flagged
- if the electricity consumption entered is very different to the bills this is flagged

Calculations

Calculations are undertaken on the 'Inputs', 'PV design' and 'Heating design' tabs, which are not visible to the user without a password.

Inputs:

- Heat loss from conduction is estimated from areas of roof, walls, floors and their U-values.
- Heat loss from ventilation is estimated using volume and air change rate.
- Required boiler size is estimated from heat losses.
- Fuel consumption is calculated from bill data.
- Electricity consumption is calculated from bill data.

PV design:

- The number of rows of panels that could fit on the roof (assumes panels in landscape).
- The number of columns of panels that could fit on the roof (panels in landscape).
- Shading calculated from number of shaded segments;
- System size (kW) calculated from number of panels.
- Annual generation calculated using system size, orientation, pitch and shading.
- Self consumption (amount of generation that would be used in the building) estimated based on predicted generation and expected consumption (after energy saving measures).
- Export calculated as generation less on-site usage.
- The self consumption with a battery estimated based on predicted generation and expected consumption (after energy saving measures).
- Export with battery calculated as generation less on-site usage.
- Potential of battery for load shifting (charging with off-peak electricity and discharging during peak times) estimated.

Heating design:

- Heating demand calculated using energy consumption and assumed boiler efficiency.
- Volume of church for heating is halved if partitioning selected.
- Cost and CO_2 emissions calculated from fuel consumption.
- Cost of insulation estimated from wall, floor and ceiling areas, and assumed cost per m2.
- Reduction in energy demand calculated from increase in insulation taking into account proportion of energy that is lost by conduction rather than by ventilation.
- Revised boiler size calculated using reduced heat load due to insulation.
- Fuel consumption calculated taking into account reduced heat load.
- Fuel cost and CO_2 for new heat load calculated.
- Capital cost estimated for new boiler size, and ongoing cost of new fuel.
- Fuel consumption calculated taking into account heating plant efficiency for new fuel.
- Fuel cost and CO_2 for new fuel and heat load calculated.
- Income from Renewable Heat Incentive[3] (if any) calculated.

[3] New applications for the renewable heat incentive for non-domestic buildings will not be accepted after March 2021

Evolution of Methodology

Upon inputting details of some of the church's dimensions and energy usage, issues were discovered with a few of the functions of the spreadsheet, and it was updated accordingly:

- Electricity use: Some Churches had far smaller electricity usage than was expected. The "Look Up Tables" were expanded to provide the required information for more scenarios.

- Electrical heating: Electric heating systems were problematic as the spreadsheet did not differentiate between electricity consumption for light and power and heating. Alterations were made to allow for electrical heating. When an existing electric heating system is selected, the option to input the energy consumption for heating is made available in the electricity consumption tab.

- Additional heat sources: Air to air heat pumps were added as these may be effective and relatively simple to install in buildings with limited numbers of zones. A differentiation between new and old gas boilers was added so that gas boiler upgrades can be modelled.

- Building usage: Energy consumption varies on usage, which can be dependent on how comfortable the building is. At the request of the client, the option to increase (double) the utilisation of the building was added to the spreadsheet. This doubles the energy use (and any associated savings/incomes) which has a significant impact on payback.

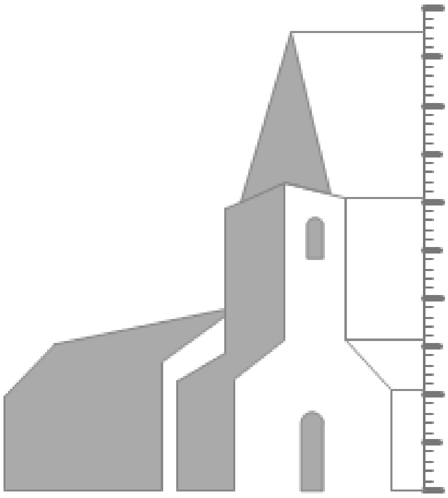
- Partitioning: Early in the project it was identified that in many churches, not all of the building is routinely utilised, and partitioning the building and only using parts of it e.g. holding services in the chancel, would reduce the heating requirement whilst ensuring comfort for users of the building. The churches were modelled with and without (uninsulated) partitions, and the heating requirements compared to produce a ballpark figure for the estimated annual reduction in energy used for heating due to partitioning the church building. The average reduction for the churches modelled was 48%; this was rounded to 50% for the purpose of simplifying the tool. An option to estimate the effect of partitioning was therefore added to the assessment template.

- Draughts, roof insulation and immersion heaters: It would be interesting if draught proofing measures could be modelled but it is difficult to estimate draughts so this has not been added to the model. Whilst it would be useful to model the addition of insulation to the ceiling but not walls, this was felt too complicated for this application. Any church considering insulation could investigate insulating the walls and roof as part of the same design process.

Whilst it would be interesting to model the possible contribution to water heating from photovoltaic systems and immersion heaters, only one church had a hot water cylinder so it was not modelled.

Churches which use hot water every day might consider solar thermal water heating, but this has not been modelled as such sites seem to be rare.

It should be noted that calculations for income are based on schemes available at the time of writing the report (October 2020). The main financial incentive available at this time - the government's Renewable Heat Incentive - will only be available for new non-domestic applications until the end of March 2021. It is likely that this scheme will be replaced in the short term by a grant to reduce the capital expenditure associated with the installation of new low carbon heating systems. It is recommended that before deciding on a new low carbon heating system, it is worth researching the financial incentives available at that time.



Church Surveys

Seven Churches have been surveyed within the Framland Deanery in order to develop and test the Assessment Tool and provide a template for retrofitting churches in the UK. The following chapter provides a breakdown of the surveys, observations and recommendations for reducing carbon emissions and running costs.

Overview

The Seven churches (detailed in the table below) were surveyed between March and July 2020. The surveys were undertaken with regard to potential for improvements to energy efficiency, and the installation of renewable energy systems. The buildings are predominantly medieval in construction, some with later additions and alterations.

Parish	Name of Church	Listing
Waltham-on-the-Wolds	St Mary Magdalene	Grade I
Ab Kettleby	St James the Greater	Grade II*
Nether Broughton	St Mary the Virgin	Grade II*
Old Dalby	St John the Baptist	Grade II*
Holwell	St Leonard	Grade II*
Stathern	St Guthlac	Grade II*
Thorpe Arnold	St Mary the Virgin	Grade II*

To differentiate between the churches for the purpose of this study, each will be identified by the name of it's parish.

Church	Heating system	Electrical supply	Annual energy bill	Estimated annual carbon emissions
Waltham on the Wolds	Oil (air blower)	3 phase	£2,975	10,226 $kgCO_2e$
Ab Kettleby	Electricity	3 phase	£439	811 $kgCO_2e$
Nether Broughton	Electricity	1 Phase	£264	469 $kgCO_2e$
Old Dalby	Old Gas boiler (wet heating)	1 phase	£1,496	5,070 $kgCO_2e$
Holwell	Electricity	1 phase	£384	293 $kgCO_2e$
Stathern	New Gas (wet heating)	1 phase	£647	2,224 $kgCO_2e$
Thorpe Arnold	Old gas boiler (air blower)	1 phase	£800	3,456 $kgCO_2e$

The churches heated by electricity have low energy bills as they do not pay standing charges for gas and because they are infrequently heated, as it is not possible to get them to a comfortable temperature as the heating systems are too small (see next section). It has been suggested that the buildings are less used as they cannot be heated to comfortable temperatures.

The spreadsheet enables modelling of a full range of technologies. Given the varying characters of churches and their energy consumption, not all buildings are suitable for all of the energy efficiency measures and renewable technologies (e.g. large air-water heat pumps require a three-phase supply and a wet heating system).

Observations from the surveys and proposals for systems to be investigated further are given on the following pages. These proposals are to provoke discussions by the local PCCs supported by the Deanery team and by using the model it will enable then to achieve their own solutions to suit the congregation and the budgets.

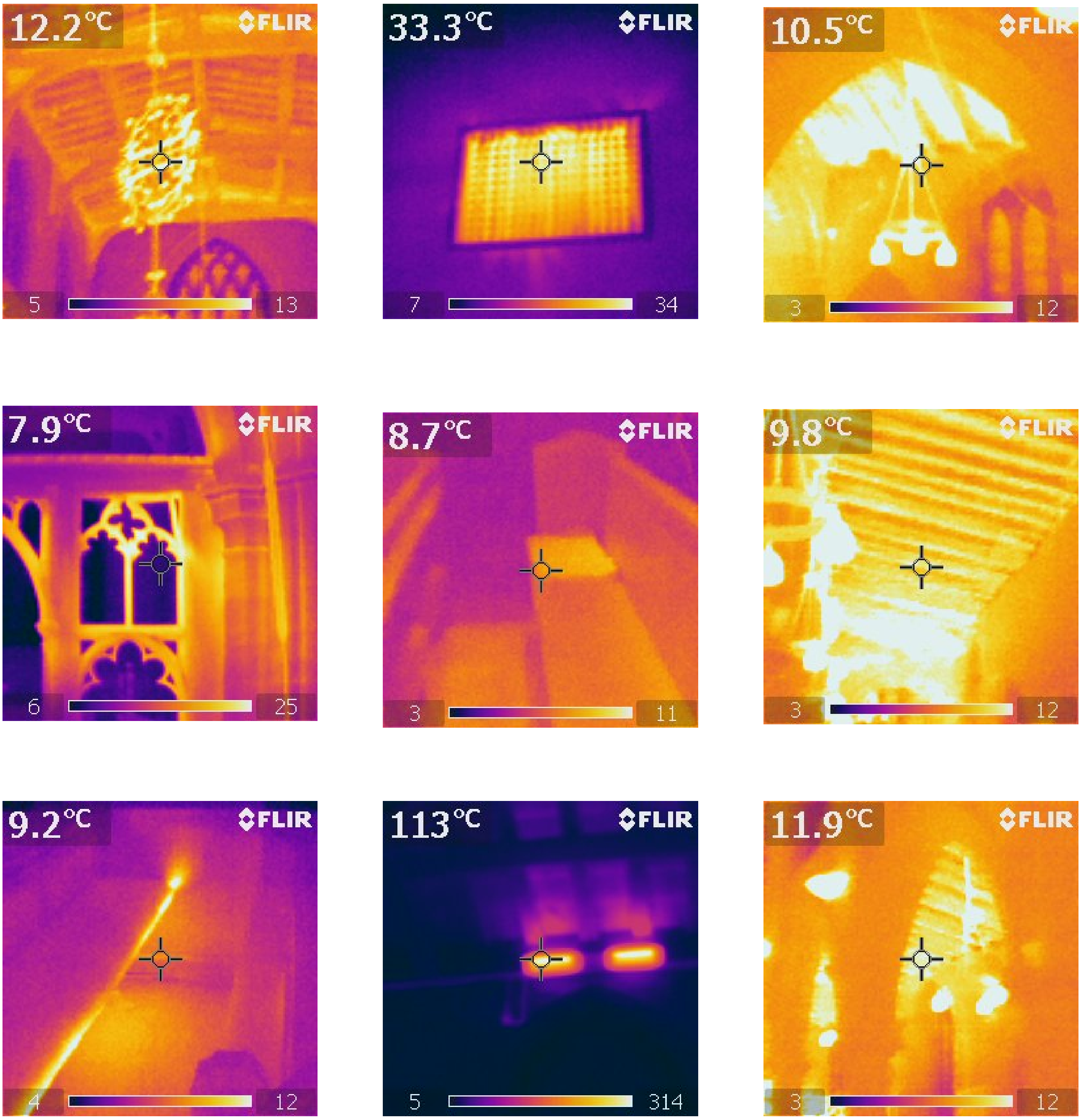


Figure 1: Example images from thermal imaging study of the churches surveyed. The colour scale at the bottom of each image shows the temperature range and associated colour gradient for each image. The temperature in the top left shows the temperature of the centre of the image (shown by the crosshair)

St Mary Magdalene Waltham On the Wolds

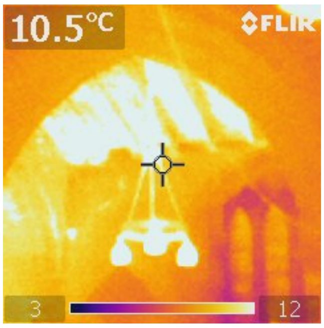


Figure 2:Thermal imaging image; ceiling of Waltham on the Wolds heated by an air blower.

Heating

The church is well used and does not have a gas supply. The church is heated by an oil fuelled air blower which is noisy and ineffective, heating only the top of the church (see Fig 16, p17).

A biomass system was designed and costed for the building (See appendix). Whilst this could use the existing air blowers to distribute heat, adding wet heating (underfloor heating) would qualify the system for income from the Renewable Heat Incentive[4], as well as heat users of the building more efficiently (and quietly) and may enable a smaller boiler e.g. 90kW to be installed. If a biomass system is installed, a suitable location would have to be found for the pellet store. Whilst outside could be considered, it is not advised as the fuel will tend to absorb moisture making it prone to swell and damage the fuel delivery equipment (auger) of the boiler.

An Air-Water heat-pump was also modelled for comparison as the site has a three-phase electricity supply. An Air-water heat pump would cost more than a bio-mass boiler but would have a lower fuel and maintenance cost and would also obtain income from the Renewable Heat Incentive. An Air Source heat pump would require grid connection permission from the Distribution Network Operator.

Lighting

Some of the lights have been upgraded to LED and around half are already energy efficient. The site has had a quote for LED replacement which is in-line (but more expensive) than the estimate from the spreadsheet (£8k for supply only of high-quality dimmable LEDs compared with the spreadsheet estimate of £7k for supply and install).

[4] New applications for the renewable heat incentive for non-domestic buildings will not be accepted after March 2021

Solar PV

The top roof is not visible from the ground, which could make it suitable for PV, but given the profile of the lead roof and the presence of a Lightning Protection System it is not clear without further study whether the roof would be appropriate for PV.

During the survey it was identified that the hot water cylinder installed as part of the new toilet and kitchen appears to be heated by an immersion which is always switched on. If this is the case, electricity is being wasted, and a simple switch or timer should be added.

If photovoltaic panels were added, an immersion diverter could be used to heat water using 'spare' electricity that would have otherwise been exported (thereby offsetting carbon emissions from electricity generation). Such systems cost around £400 and can reduce electricity bills for water heating by around £50 per year in a typical house. In a church the water use (and therefore bill saving) may be lower than this, and payback time may be long (e.g. 20 years) compared with the warranty of the product (2 years).

Spatial Strategy

Due to the scale of St Mary's we would not recommend insulating and fully heating the entire building. Instead, the North aisle offers sufficient space for a community space. The enclosed servery and toilet could be extended. The Vicars Vestry, Vestry, chancel and south transept could all also be separated from the main space to allow individual heating when required.

Timber framed glazed doors between the arches can separate the spaces while still allowing visual connection. They could be open-able to allow the full building to be used for the largest ceremonies.

Insulation

We would not recommend external wall insulation. The stonework is in good condition and the buttresses would make the installation complex. Instead internal wall insulation to the enclosed areas would allow a cost-effective heating strategy.

Breathable hempcrete insulation can be finished with white natural lime plaster matching the existing finish. The roof should then be insulated between the rafters in these spaces so that it ties into the wall insulation.

As the floor has recently be lifted and re-laid it should have a sufficient level of insulation at this stage. The insulation level should be confirmed.

The windows in the insulated spaces should be fitted with internal secondary double glazing. This should be large glazing panels so as to not distract from the original windows.

Summary of recommendations:

Heating: Biomass Boiler with underfloor heating and air blowers, or air-water heat pump.

Lighting: Upgrade inefficient lighting to LED's

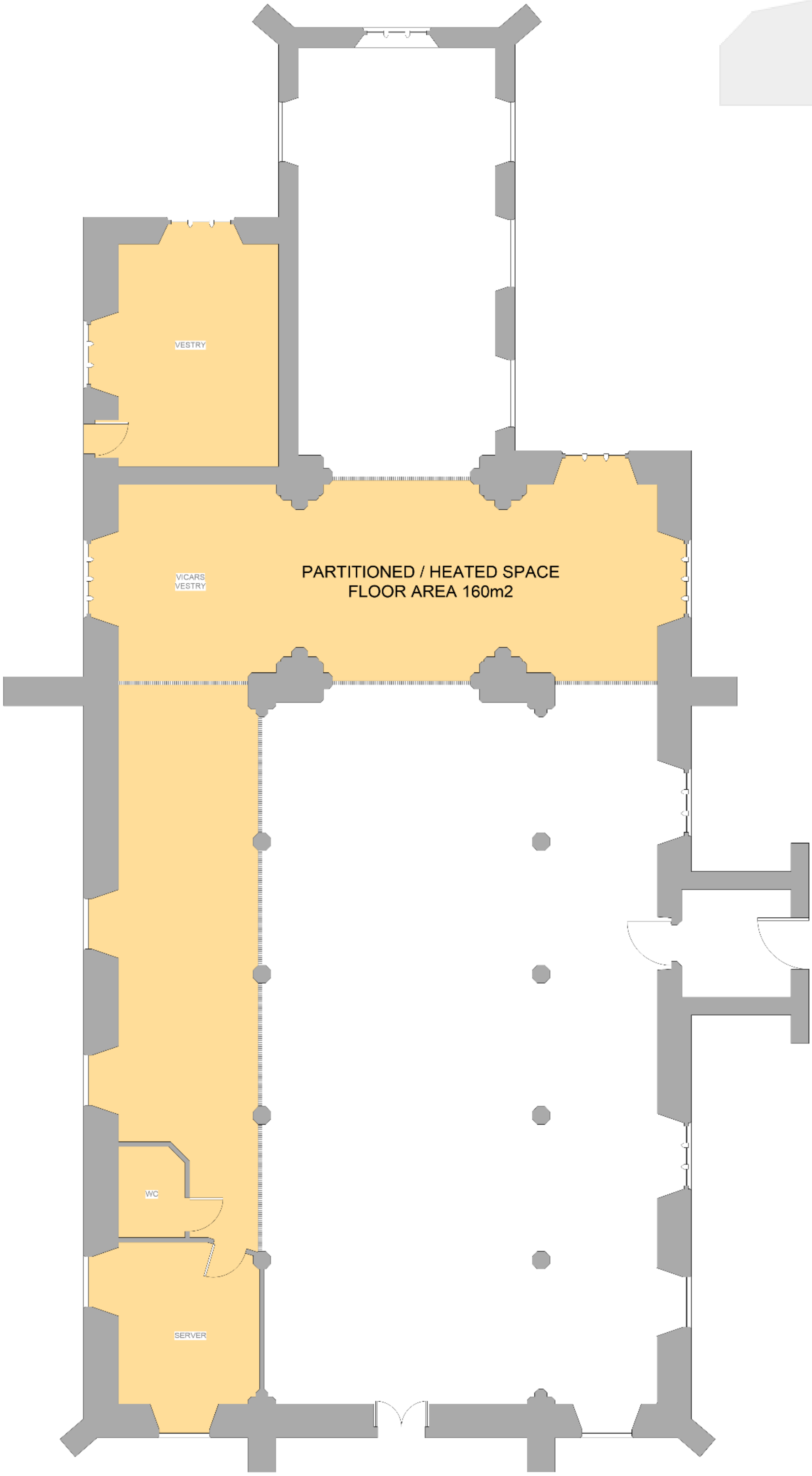
Solar PV: Install a PV system dependent upon suitability of roof

Spatial Strategy: Partition North Aisle, Vicars Vestry, Vestry, Chancel and South transept

Insulation: Add internal solid wall insulation and a minimum of between rafter roof insulation to partitioned areas

Glazing: Consider secondary glazing to windows in insulated areas

Other: Add timer or switch to immersion heater. Consider immersion diverter if PV is installed.


VESTRY
VICARS VESTRY
PARTITIONED / HEATED SPACE
FLOOR AREA 160m2
WC
SERVER

St James the Greater Ab Kettleby

Heating

The church is heated by under pew electrical heating which is sized to 'take the chill off' users of the building rather than try and heat the space (the electrical heaters output power is approximately one tenth of the heat load of the church).

The church has a three-phase electrical supply so a heat pump could be installed. Given the lack of a heating distribution system at the church, an air to air heat pump has been modelled. Such a system would use electricity very efficiently to heat the church through blown air and would comprise an external fan unit, internal air blower, cables to the fan unit (from the consumer unit) and pipes between the fan and air-blower. The system would not benefit from the income from the Renewable Heat Incentive[5] as it is not eligible (as it could be used for cooling as well as heating).

An example of an Air-Air Heat Pump System installed at another church within the Deanery - St Egelwin's in Scalford - is shown in Figure 3 & Figure 4.

Should it be desired to partition the space, other heating systems which are more amenable to zoning should also be considered.

Figure 3: Air Blower at St Egelwins

Figure 4: Fan Unit at St Egelwins

[5] New applications for the renewable heat incentive for non-domestic buildings will not be accepted after March 2021

Space Usage Strategy:

Due to the scale of St James' we would not recommend insulating and fully heating the entire building.

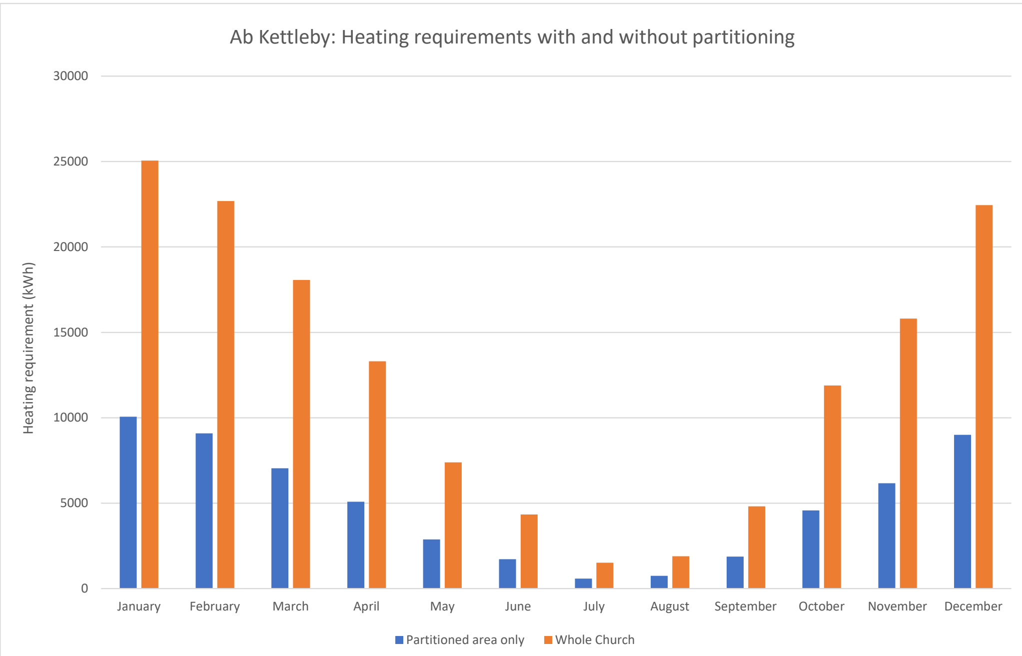
The South aisle offers sufficient space for a community space. The South entrance could be used for separate access. This will allow the nave and chancel to continue to be used at the same time. The community space could be further subdivided into two separate rooms.

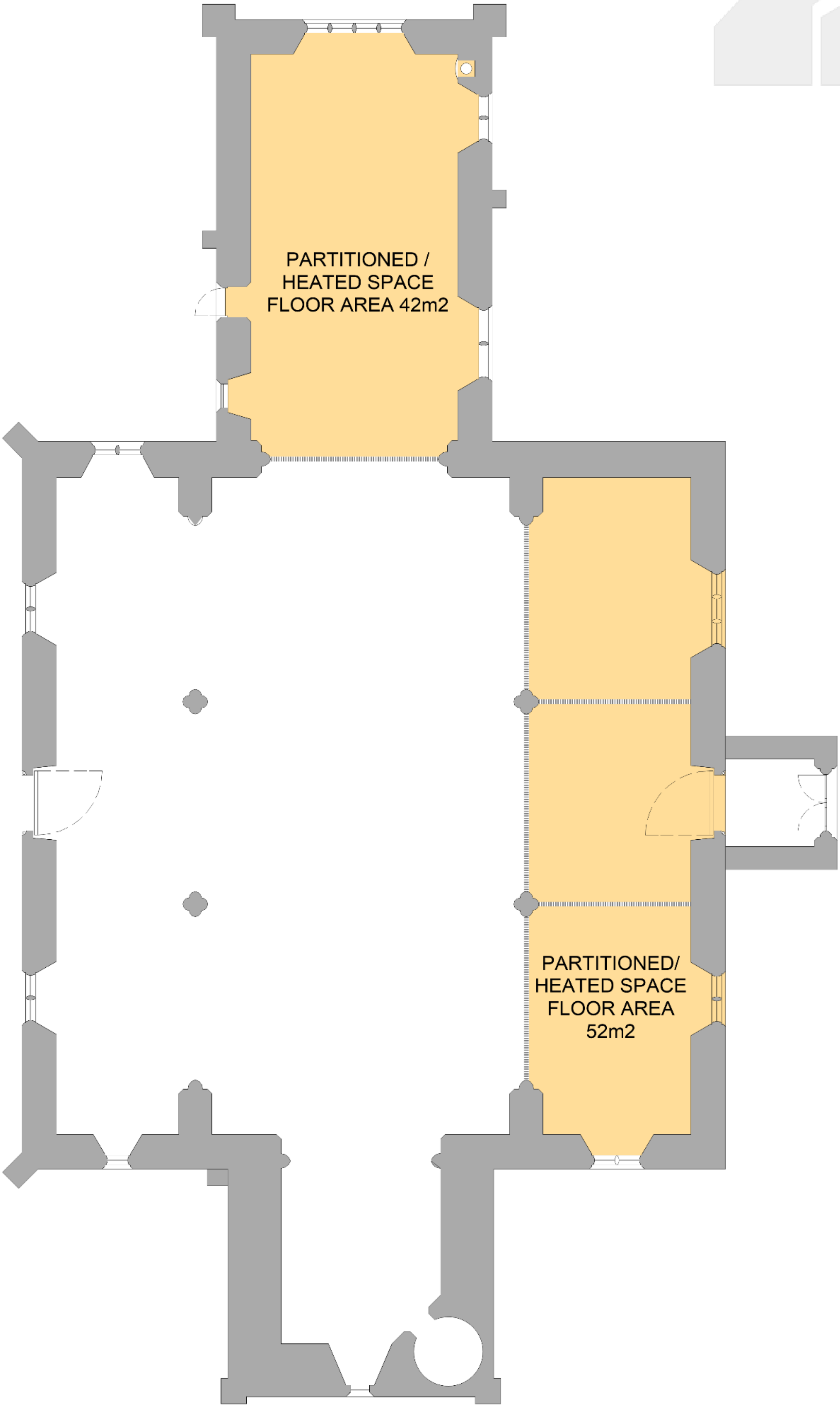
Timber framed glazed doors between the arches can separate the space from the nave while still allowing visual connection. They can be opened to allow the full building to be used for the largest ceremonies.

An internal tearoom and WC could be built in this space.

The chancel could also be separated from the main space. This would allow it to be insulated and heated for small regular services. Folding doors could then be opened up to allow for its reconnection to the nave when required.

The church was modelled using 'DesignBuilder' software, and a comparison made of the heating requirements of the church with and without partitioning (provided that in the case of the church being partitioned, only this space were heated for services). In the modelled scenario, the partitioned space in uninsulated. A graph of the results is shown below.




PARTITIONED /
HEATED SPACE
FLOOR AREA 42m2
PARTITIONED/
HEATED SPACE
FLOOR AREA
52m2

Insulation Strategy

The exterior walls of the church could be insulated with a natural white render finish. However, this would require the entire church to be insulated at great cost.

Instead internal wall insulation to the enclosed areas would allow a cost-effective heating strategy, as per the insulation section of this report. The insulation can be finished with white natural lime plaster matching the existing finish. The roof should then be insulated in these spaces so that it ties into the wall insulation.

Ideally the floor should be lifted to allow for floor insulation and underfloor heating to be installed before they are re-laid.

The windows in the insulated spaces should be fitted with internal secondary double glazing. This should be large glazing panels to not distract from the original windows.

Summary of recommendations:

Heating: Air to air Heat Pump system with blowers

Solar PV: Install a PV system dependent upon suitability of roof

Spatial Strategy: Partition South Aisle and sub-divide. Consider partitioning chancel via folding partition.

Insulation: Add internal solid wall insulation and a minimum of between rafter roof insulation to partitioned areas

Glazing: Consider secondary glazing within partitioned areas

St Mary the Virgin
Nether Broughton

Solar PV

The church has a new (sheet metal) roof which would make the installation of PV relatively low cost and technically simple (fixing to the metal sheet using screws with EDPM washers rather than having to remove slates and add lead or fix to lead without compromising its integrity).

The site has 2 single phase electricity supplies (comprising a single cable with two meters) which have peak and off-peak tariffs. This means that data on the split between daytime and night-time electricity usage should be available. This data would be useful for obtaining a usage profile to use to model electricity consumption from solar energy for this and other churches. During the survey it was found that one of the time clocks is wrong (showing 7am instead of 3pm) so the day / night split of electricity consumption could not be used.

Heating

The building is heated with 8 Infra-Red heaters which provide around 16kW of heating. This is a lot lower than the 48kW heat load of the church. If the two single phase supplies were used to power single phase heat pumps, these would allow the same amount of heat to be delivered at significantly lower cost, energy consumption and carbon emissions; or they might be used to improve comfort by allowing more heat to be delivered within the current electricity supply constraints of the building.

Partitioning

The church could be partitioned into smaller sections so that not all the building has to be heated when only a small number of people attend a service or event. This could be done with glazed timber screens, splitting the space laterally at the column positions; the side aisles are too narrow to form an effective community space, although the chancel might be useable dependent on the size of the congregation. Timber framed glazed doors between the arches could separate the spaces while still allowing visual connection. These could be opened to allow the full building to be used for the largest services.

Partitioning the church into four sections would reduce heat demand to around 8kW for many purposes, which is comparable to the existing heaters (although these are currently spread throughout the church).

Insulation

Given the relatively modest size of the church, insulation would be more affordable than at larger churches. The external stonework is not in the best condition, which makes external insulation worth considering though the aesthetics of this would need careful review. A breathable hempcrete insulation could be finished with white natural lime render, as described in the Insulation section of this report. This should be combined with roof insulation if possible. Insulating the building would reduce the heat load to around 24kW which would be much closer to the existing 16kW electric heating system.

The addition of insulation may not reduce the running costs of the building, but would help make it comfortable for use in cold weather, and would make the building more suitable for use with low temperature heating systems. Partitions may help reduce running costs by meaning that only part of the church needs to be heated when it is used and would also help make the building more comfortable by reducing draughts.[6]

Summary of recommendations:

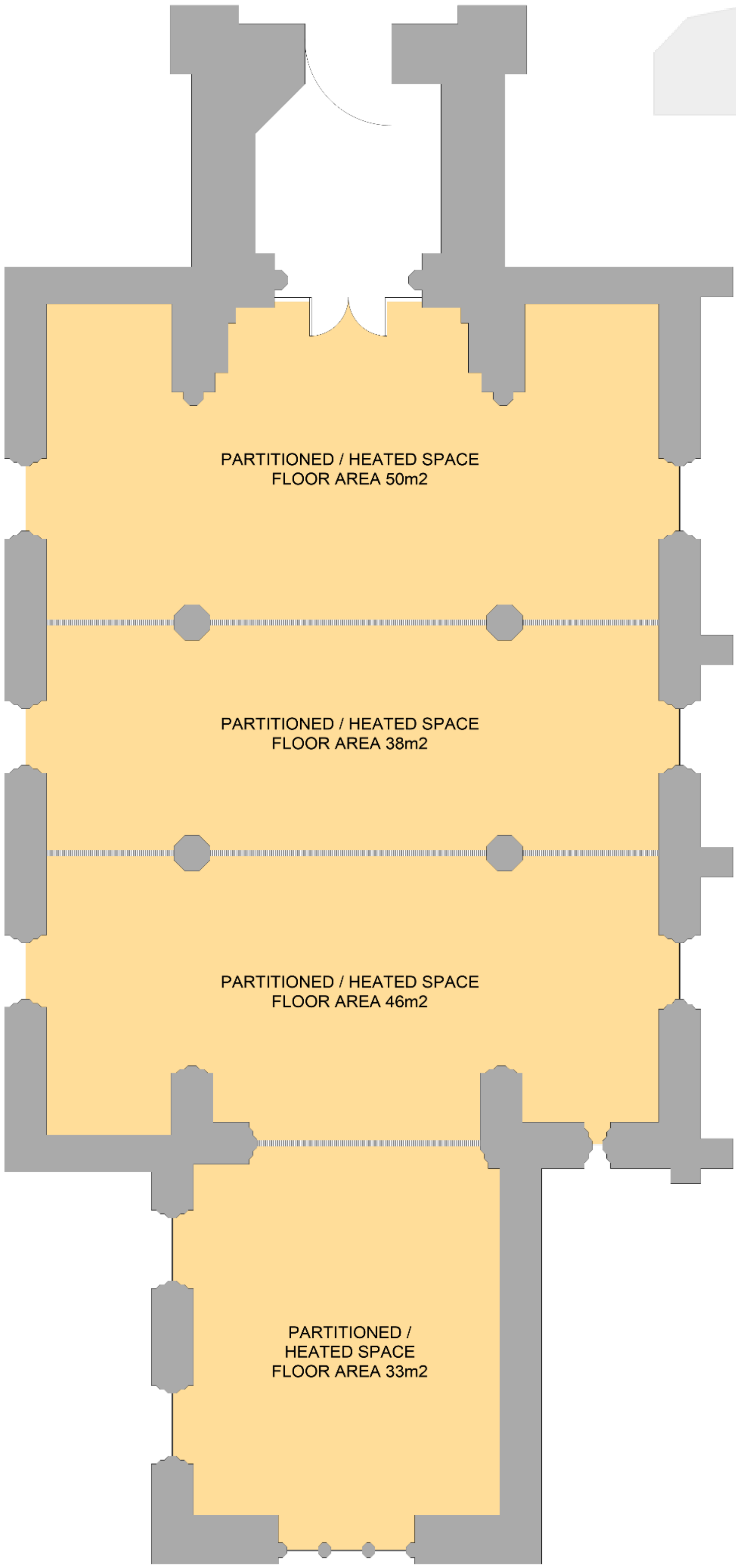
Heating: Install single phase air source heat pumps

Solar PV: Install a PV system on suitable roofs

Spatial Strategy: consider splitting the church into three areas via moveable partitions

Insulation: Add Solid Wall Insulation internally or externally to whole building. More information is required as to existing roof insulation levels.

[6] The lighting system has been fully upgraded to LED’s since the time of the survey


PARTITIONED / HEATED SPACE
FLOOR AREA 50m2
PARTITIONED / HEATED SPACE
FLOOR AREA 38m2
PARTITIONED / HEATED SPACE
FLOOR AREA 46m2
PARTITIONED / HEATED SPACE
FLOOR AREA 33m2

St John the Baptist Old Dalby

Heating & Lighting

The Church is heated by 3 non-condensing gas boilers (30kW each) which is slightly lower than the estimated heat load (110kW). The boilers can heat the building to the required temperature although this can take all night, probably because they are not quite big enough to heat the building. The boilers are relatively old and replacing the boilers with more efficient gas boilers would be a cost-effective way of making a modest reduction to running costs and carbon emissions. The existing gas-supply, boiler room and heating system (around 16 radiators of varying ages) could be re-used and the boilers simply replaced with modern condensing units.

Larger boilers would mean the building could be heated more quickly, and this could result in lower energy use as the air rather than building fabric would be heated before a service, and the building would be heated to above ambient temperature for less time (and therefore have less time to lose heat) prior to services.

Removing the pews and installing a new heating system (under floor heating) was discussed during the survey as a way of increasing the utilisation of the space and the efficiency of heating it. This would deliver the heat to the congregation where it is most needed.

As the site only has a single-phase electricity supply, heat pumps could only be used to a limited extent in this building (perhaps a partitioned space). It is generally accepted that in the next decade, heat pumps should take over from gas boilers as a lower carbon means of space heating. When replacement of the gas boilers is considered, it also be appropriate to consider upgrading to a three-phase electricity supply and using heat pumps for space heating.

The lighting is mostly LED.

Spatial Strategy & Insulation

Due to the scale of St John's we would not recommend insulating and fully heating the entire building.

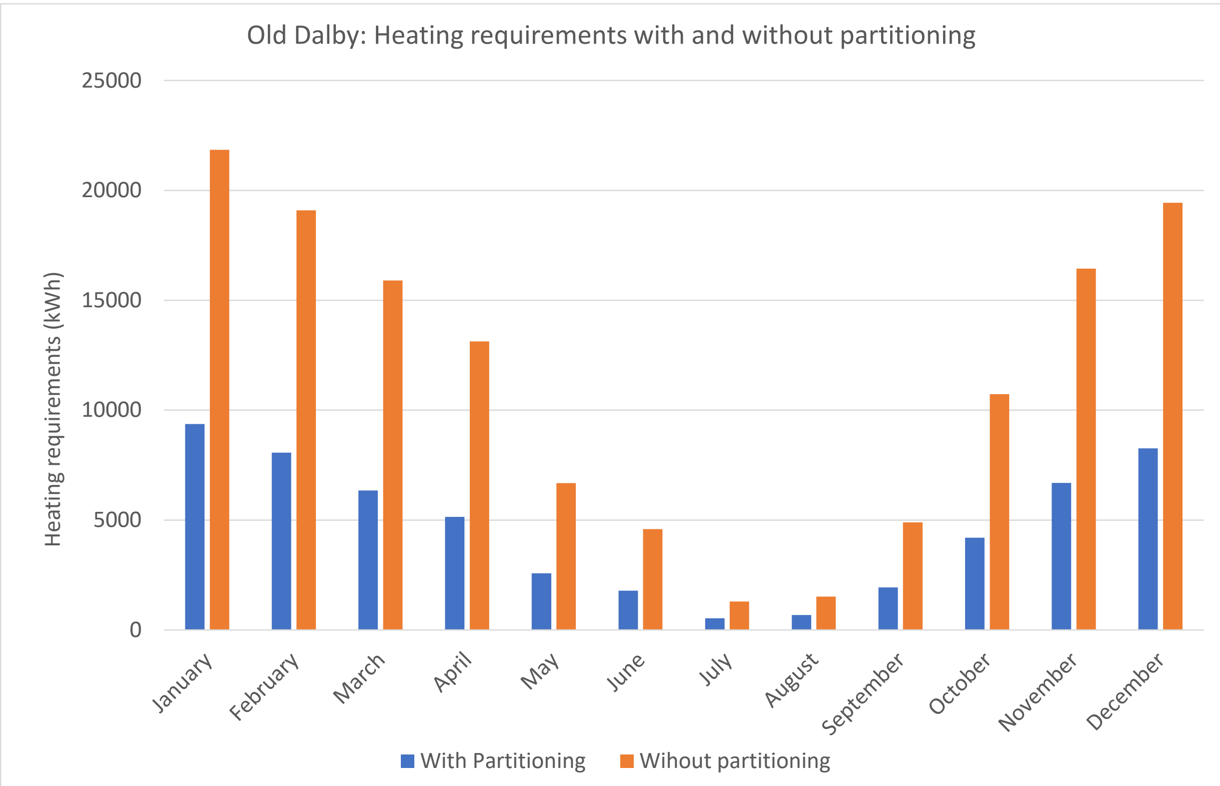
The Church is considering partitioning the tower space so that it can be used for a toilet / kitchen, which would have the added benefit of reducing draughts caused by the tower.

The south aisle offers sufficient space for a community space along with the vestry, so that the second entrance can be made use of. This will allow the nave and chancel to continue to be used at the same time. An internal kitchen and WC could be built in this space.

Timber framed glazed doors between the arches can separate the space from the nave while still allowing visual connection. They can be opened to allow the full building to be used for the largest ceremonies.

The chancel could also be separated from the main space. This would allow it to be insulated and heated for small regular services. Folding doors could then be opened up to allow for its reconnection to the nave when required.

The church was modelled using 'DesignBuilder' software, and a comparison made of the heating requirements of the church with and without partitioning (provided that in the case of the church being partitioned, only these spaces were heated for services). A graph of the results is shown below.



Insulation

We would not recommend external wall insulation. The stonework is in good condition and the buttresses would make the installation complex. Instead internal wall insulation to the enclosed area south aisle would allow a cost effective heating strategy, and corresponding levels of roof insulation should be added. The timber finish below could be restored or a white plaster applied.

Ideally the floor stones should be lifted to allow for floor insulation and underfloor heating to be installed before they are re-laid. The windows in the insulated spaces should be fitted with internal secondary double glazing. This should be large glazing panels to not distract from the original windows.

Summary of recommendations:

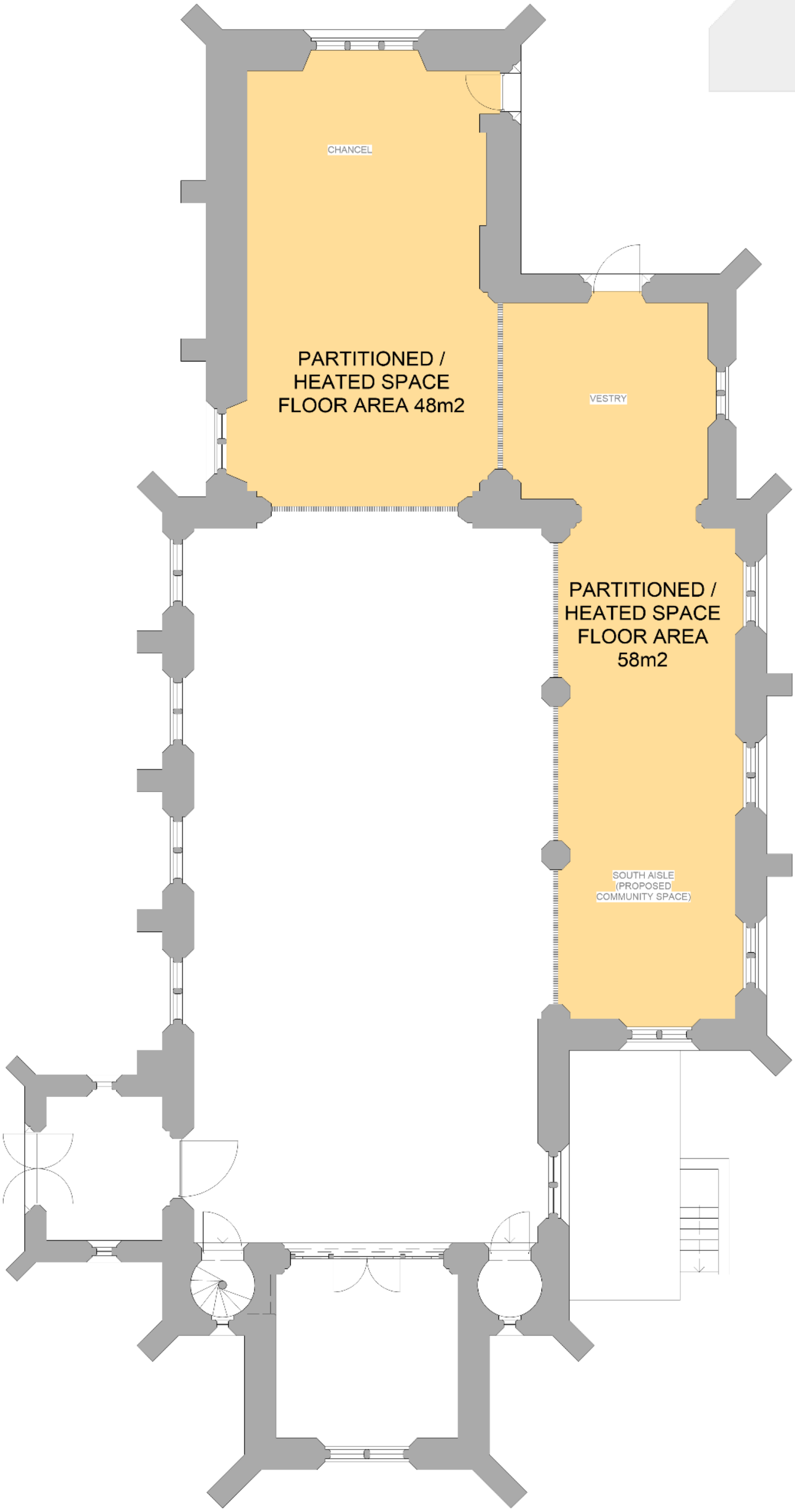
Heating: Consider upgrading gas boilers for greater efficiency, or upgrade to a three-phase electricity supply & heat pumps

Solar PV: Install a PV system on suitable roofs

Spatial Strategy: Partition the south aisle and vestry; consider partitioning the chancel

Insulation: Add Solid Wall Insulation internally to the partitioned area of the building, with corresponding roof insulation. Consider insulating floor and installing underfloor heating to partitioned area.

Glazing: Consider secondary glazing within partitioned areas


CHANCEL
PARTITIONED / HEATED SPACE FLOOR AREA 48m2
VESTRY
PARTITIONED / HEATED SPACE FLOOR AREA 58m2
SOUTH AISLE (PROPOSED COMMUNITY SPACE)

St Leonards Holwell

Roof

The church currently has no roof as the lead was stolen some time ago which gives an opportunity to incorporate solar panels and insulation into the new roof design. This would reduce the costs by sharing the scaffolding between the re-roofing and solar panel / insulation works. It is understood that there is currently discussion about the roofing material to be used. Any insulation would have to be carefully selected alongside the roofing material and attention paid to the design details such as counter battens, membranes and gutters to ensure that the installation of the roof and insulation does not compromise the building structure e.g. by changing the dew point, reducing breathability and facilitating rotting of the woodwork or damage to the stonework.

Solar PV

Solar panels could be incorporated into the roof as part of the re-roof regardless of the materials to be used. The roof timbers and wall-plates should be checked as part of any roof replacement, especially when additional load from solar panels is being added. The roof is easily accessible as the church is not a high building, but the church is in the centre of a village so solar panels should be relatively secure on the roof.

The Church roof is not shaded and therefore considered a good site for solar panel installation. A grid connection application for an 8kW photovoltaic system was submitted to the Distribution Network Operator who confirmed it could be installed without any export limits.

Heating & Insulation

The building is currently heated by 6 x 2kW electric heaters (12kW) which is considerably less than the estimated heat load of the building (34kW). This means that the building cannot be adequately heated. The walls are plastered (which needs repair in places) so the church may be suitable for internal insulation (paying attention to breathability and window details). Insulating the walls and ceiling would reduce the heat load to around 23kW.

Even with the existing electricity supply, single phase air to air heat pumps could be used to deliver substantially more heat than the existing heaters, which in conjunction with additional insulation could make the building a much more useful community asset.

The building does not currently have a three-phase supply although it is assumed that there is three-phase nearby in the village and it understood that the village has a gas supply. The building is perhaps too small to be split into smaller sections, but internal insulation combined with modest number of windows (except south facing) suggests that the building could be heated adequately using the existing heating system if insulated.

Summary of recommendations:

Heating: Consider bringing 3-phase electricity supply from village to install air to air heat pumps

Solar PV: Install a PV system in conjunction with new roof installation

Insulation: Insulate the building internally to all walls. Insulate roof above rafter level in conjunction with re-roofing.

Figure 6: St Leonards has an easily accessible roof

Figure 5: the building appears suitable for internal solid wall insulation

St Guthlac Stathern

Lighting

Stathern church has a bespoke lighting system based on theatre lighting which comprises complicated controls (a leading edge dimmer). If / when the lighting unit fails the church will have little or no light. The lighting system is inefficient, outdated and needlessly complicated. It is suggested that the lights are upgraded with a simpler system (dimmable if necessary) which will reduce running costs. Before the lighting is upgraded it is worth checking that the emergency lighting is adequate for safe egress from the building in the event of a lighting failure.

Figure 7: View of the roof at Stathern Church

Solar PV

The south roof has a lead covering which is alarmed. It is assumed that solar panels could be added to the lead roof, and that the alarm system would continue to operate protecting both lead and PVs, but this would need to be confirmed before and solar panel installation was undertaken. The roof is heavily shaded in places so optimisers may need to be fitted to each panel for the system to be effective.

The church electricity supply is also used to power a local internet connection (approximately 500kWh/year) so this has been deducted from the bills to calculate the electricity used by the church and its associated carbon footprint.

Heating

The church is heated with 2 x 35kW modern gas boilers which is similar to the estimated heat load of the church (74kW). The boilers are used for several hours before services to 'take the chill off' the building.

The electrical supply to the building is relatively small (60A single phase) and therefore not considered adequate to heat the whole building with a heat-pump; this might also be an issue for a large PV system. Consideration might be given however to heating the partitioned space with a heat pump, reserving the gas boilers for the heating of the whole building for larger services and community events.

Spatial Strategy

It appears that this heat load could be further reduced if the chancel were partitioned and the plumbing altered, and heating controls added such that the chancel and the rest of the church could be heated independently.

Summary of recommendations:

Heating: Consider heat pumps to partitioned space, retaining existing boilers for whole building heating.

Solar PV: Consider installing a PV system with optimisers

Spatial strategy: Consider partitioning the chancel from the rest of the church

Insulation: insulate the partitioned chancel area internally

St Mary the Virgin Thorpe Arnold

Figure 8:The chancel already has a partition and separate heat source.

Heating

Thorpe Arnold is heated by 2 x 30kW gas fired air-blowers and a gas convection heater in the chancel. The large burners use gas throughout the year to keep their pilot lights functioning and are described as noisy as well as inefficient. The heating system is correctly sized for the building (around 70kW) and heats the Church in an hour or two before services.

The church has installed de-stratification fans in an attempt to circulate the hot air from the ceiling down to the congregation, but the fans are not used as they are described as too noisy.

Given that there is already a gas supply to the Church new gas-fired boilers (with under-floor heating) could be considered (although an air source heat pump would be cleaner).

Spatial Strategy

There is a village hall (owned by the church) adjacent to the Church, so partitioning of the Church has not been considered in detail as there is already space available for community activities. The chancel maybe suitable for partitioning and already has a heat source (gas convection heater) and wooden partition which could be glazed.

Insulation

The church has previously had the lead from its roof stolen and suffers from damp as a result of leaks from the roof and drainage problems (now repaired). The interior walls are plastered (damaged in places by damp) so it may be suitable to consider the installation of breathable insulation as part of future remedial work.

Summary of recommendations:

Heating: Consider installing new energy efficient gas boilers or air source heat pumps

Solar PV: Consider installing a PV system with optimisers

Spatial strategy: Consider glazing the existing partition to thermally divide the church

Insulation: Consider adding internal solid wall insulation in tandem with remedial works to walls and ceiling

Results

This Section considers how different priorities (financial savings, achieving net zero carbon emissions) may be used to assess the most appropriate works to be undertaken. It is recognised that plans for individual churches will integrate multiple measures to maximise effectiveness and user comfort. Results from this section are based on specific outcomes of the assessment tool as opposed to a holistic consideration of the impact of the given measures.

Zero carbon

By using the spreadsheets to model each of the energy saving measures for each of the churches it has been possible to ascertain the least number of measures that would need to be undertaken to achieve carbon zero or carbon negative operation at each church.

For churches that previously used an electric heating system, PV installation is usually the most effective way to achieve negative carbon emissions. Pairing PV generation with air to air heat pumps also helped to achieve carbon negative operation.

Similar results were found for churches with an existing wet central heating system with the notable difference that in theory these could install air to water heat pumps, taking advantage of the existing infrastructure. In reality this may have to be upgraded, as most existing heating systems are inappropriate for use with a heat pump system as they are designed to operate at higher temperatures than heat pumps operate at and generally need replacing due to age. A new heating system is a cost item in the spreadsheet that can be added to model the addition of a new wet heating system as well as heat source.

The minimum number of measures identified for each church to become carbon negative is given below. Churches with existing heating systems are using more energy than the buildings with electrical only heating and therefore more measures are required to obtain zero carbon.

Church	Measure	Resulting carbon (kgCO_2e/yr)[7]
Waltham on the Wolds	Photovoltaics and biomass boiler	-398 kg CO_2e/year
Ab Kettleby	Photvoltaics	-1,522kg CO_2e/year
Nether Broughton	Photovoltaics	-892 kg CO_2e/year
Old Dalby	New gas boiler, partition building, photovoltaics.	-626 kg CO_2e/year
Holwell	Photovoltaic installation	-840 kg CO_2e/year
Stathern	Photovoltaics, partition building	-530 kg CO_2e/year
Thorpe Arnold	Air-air Heat-Pump, Photovoltaics	-1345 kg CO_2e/year

[7] Negative values indicate that in the given scenario, the church's annual energy generation is greater than its usage

Financial payback

The energy saving measures with the quickest predicted financial payback was identified for each church.

The energy saving measure that most commonly had the shortest financial payback time was upgrading to energy efficient lighting. The payback time for energy efficient lighting installation ranged between eight and forty years. Occasionally it was found that installing PV or installing a new gas boiler also had relatively short payback times, ranging between seven and thirty-nine years.

A summary of the measurers with the shortest paybacks is given below:

Church	Measure	Payback (years)
Waltham on the Wolds	Lighting upgrade	10 years
Ab Kettleby	Lighting upgrade	22 years
Nether Broughton	Photovoltaics	38 years
Old Dalby	New gas boiler	34 years
Holwell	Photovoltaics	39 years
Stathern	Photovoltaics	35 years
Thorpe Arnold	Photovoltaics	29 years

Best value carbon saving

The energy saving measures that have the lowest cost per tonne of carbon saving were identified for each church. These measures identify the cheapest way of reducing the environmental footprint of each church.

For many of the churches photovoltaic installation was identified as it generates considerable energy which displaces fossil fuel generation on the grid. Partitioning was also identified as it could be used to halve the heating energy of buildings.

Church	Measure	£ / tonne CO_2e saving per year
Waltham on the Wolds	Partition building	£4,344
Ab Kettleby	Photovoltaic installation	£7,497
Nether Broughton	Photovoltaic installation	£6,626
Old Dalby	New gas boiler	£9,768
Holwell	Photovoltaic installation	£9,335
Stathern	Photovoltaic installation	£5,825
Thorpe Arnold	Photovoltaic installation	£5,563

This is a range of values for the cost effectiveness of carbon savings for the most efficient measures which depends on the usage of the church as well as the measure.

For some churches, the measures which have the best financial payback also offer the best value in terms of carbon saving (PV at Holwell and Thorpe Arnold new gas boilers at Old Dalby) making them attractive measures from a cost effectiveness point of view.

All of the above figures are relatively high compared to typical figures for the 'social cost of carbon' i.e. the costs are saving could be considered higher than the cost of pollution. Other schemes such as off-site generation i.e. investing in wind turbines and solar panels installed elsewhere may offer better value ways to reduce global pollution.

Solar design

Number of panels

The number of panels that could fit on the roof is estimated by the spreadsheet. Systems were designed for each church and the results are compared in the table below.

The spreadsheet calculates how many panels can be installed based on the dimensions of the roof. This number of panels is either smaller than, or the same as, the number of panels calculated by the designer. The spreadsheet strictly observes the required clearance of the edge of the roof while human judgement can override this limitation. This often means that there is space for an extra row or column of panels.

	Number of panels	
Church	Spreadsheet estimate	Design result
Waltham on the Wolds	70	70
Ab Kettleby	48	50
Nether Broughton	30	36
Old Dalby[8]	80	93
Holwell	18	27
Stathern	36	43
Thorpe Arnold	35	52

The number of panels calculated in the spreadsheet is used to estimate the capital cost. Any solar panel installation would be based on a system design, taking into account site specific factors, and the results from the spreadsheet are considered good enough to estimate system size and therefore cost.

[8] This church has a steeper roof pitch than the others surveyed, meaning that the roof area is larger and therefore more panels can be accommodated

Generation

The generation from a photovoltaic system depends on orientation, shade and pitch. Whilst all of the churches had south facing roofs, pitch varies slightly and shading varied significantly. Shade was calculated by the solar designer using the MCS methodology (ignoring near shade). The results are given below and show which churches offer the best yield i.e. highest energy output per solar panel installed (Holwell offers the best yield as it is not shaded.)

Church	Size (kW)	Generation (MWh/yr)	Yield (MWh/kW)
Waltham on the Wolds	22	11.9	541
Ab Kettleby 50	15.75	7.6	503
Nether Broughton	9.5	5.4	568
Old Dalby	25.2	10.2	405
Holwell	5.67	4.5	794
Stathern	11.3	7.3	654
Thorpe Arnold	11	7.4	673

Heat loads

The heat load (the amount of heat energy required to bring the church to a comfortable occupancy temperature) of the building is estimated by the spreadsheet. Systems were modelled to estimate the heat load of each church, and the results are compared in the table below:

Church	Spreadsheet estimate (kW)	Design result (kW)	Existing heating (kW)
Waltham on the Wolds	160	140	170
Ab Kettleby	138	118	14
Nether Broughton	48	47	16
Old Dalby	83	85	90
Holwell	34	37	12
Stathern	74	76	70
Thorpe Arnold	71	68	60

Note that all of the heating systems (except Waltham on the Wolds) are too small. Most of the gas systems are sized correctly but the electrical heating systems are not big enough for the churches (and this is limited by the size of the electrical supply at around 17kw per phase).

Appendix: Pellet Boiler Heating System Estimate

100kW Simple Pellet Boiler (Arikazan Caria)

This is a rough estimate for supply and installation of a 100kW wood pellet fired heating system to supply heat via a thermal store to underfloor heating (under pews and the children's area) – giving heating where people would get the most benefit. Also included are four floor/wall mounted fan assisted heaters and two high level fan heaters for situations where more heating of the church as a whole is required.

A large hopper is required to store the wood pellets and keep them dry. We assume that this would need to be outside the church and could be clad to make it relatively unobtrusive.

There are three ways of transferring the pellets to the smaller (500litre) side hopper adjacent to the boiler.

1. Manually, if the pellets are delivered in pallet loads of 15kg sacks. This method would only be suitable if the church heating is not required regularly and there is capable person-power available to transfer the pellets by hand.

2. By means of an auger. This requires a straight run from base of main hopper to above the boiler where they drop into the side hopper.

3. Blown feed. This is noisy, but could be done before services, and there is more flexibility in the route taken by the connecting pipe.

As the side hopper should be able to feed the boiler on its own for the duration of a normal service, the supply system could be switched off for the duration, or scheduled to take place only at suitable times.

In order to supply heat to underfloor heating, a thermostatic mixing valve would be required to deliver the correct underfloor heating flow temperature while the boiler and store operate at a higher temperature. The boiler would be run until the store is heated, then switched off until a set lower temperature has been reached in the store. This would reduce the number of stop/starts for the boiler and reduce wear and tear. The size of the thermal store can be chosen to match the space available and the requirements of the heating system. Ideally the thermal store could be placed inside the church adjacent to the boiler outside. If there were a closed off room with the store inside, the heat losses from the heat store would offer background heat to the room, otherwise this heat would be lost in the wider space of the building. Heat stores are typically insulated with 100mm of PU closed cell foam insulation so that losses are minimised.

This price is for a relatively cheap pellet boiler of a type which we know to have run reliably for 3 years. Other more complex boilers may cost up to £30k more.

We have assumed that there would be four separate time controlled areas for underfloor heating of 100m2 each, and that installers could remove the pews, lay insulation and pipes ready for screed to be poured by others, then replace pews afterwards. The design of the underfloor heating would need to be finalised, depending on the situation. As some insulation would be required under the new floor, a solution would need to be found to deal with damp rising naturally from the existing old floor.

A price is included for two high level and four floor mounted fan assisted heaters for areas that may require them, these come supplied with separate remote controls but can simply switch on when a warm flow is detected.

Pipe runs are assumed to be at a high level, dropping down to emitters where necessary. Moving the heat to where it is needed could also be achieved by running pipes in channels below floor level. Buried pipe work should be avoided to reduce heat losses and allow maintenance. All pipework should be thoroughly insulated.

Wood pellets:

The size and diameter of wood pellets is standardised, along with the calorific value.

It should be noted that deliveries by lorry need to be more than 3 tonnes to be worthwhile.

There should be an accessible distance between nearest point for delivery lorry and the entry into the hopper of 30m, no more. Beyond that lorries would need to carry more than the usual amount of pipe and the longer pellets are blown the more they are damaged and degraded.

Heat load:

To transfer 100kW of heat to a building would require many fan assisted radiators, more than there would be space for. If it were achieved there may be some damage to the fabric of an ancient church not designed to be heated. The output of an underfloor heating system is approximately 70W per square metre (in this case, assuming 300m2 = 21kW)

The design of a heating system should not be to heat the entire church, but to keep the congregation / visitors comfortably warm. This could be either by blown air from fan assisted radiators, blown air heated directly, or underfloor heating situated under the feet of those present.

The construction of partitioned spaces within the building would minimise the cost, energy use and emissions required to keep people comfortably warm.

In this case the heating system described would supply 24 + 16 + 21 = 61kW

Energy usage

See:

https://nottenergy.com/resources/energy-cost-comparison/

for a comparison of energy prices

Assuming the church heating were run for 24hrs a week, and at 61kW (all underfloor zones four fan radiators and two wall fan heaters) for 2/3 of the year, the annual energy use would be 24.2MWhr per year, and at boiler efficiencies of 90% this would equate to 2480 litres of oil or 8.6 Tonnes of wood pellet annually.

Cost of oil approx: 64p/litre

Cost of wood pellet: 27p/kg

Cost of oil: £1575/yr

Cost of pellets: £1830/yr

Assuming that the non-domestic RHI is applicable to a church at a current rate of 3.1p/kWhr, income from this would be £738 /yr or £19109 over 20 years.

Estimated Costs:

Item Description	Price
Pellet Boiler – 100kW Arikazan	£11,600
5 Tonne Pellet store, auger and associated parts	£3,500
Heating controls, thermostats and timers for 4 heating zones	£950
Control valves and circulating pumps and temperature control	£1,700
Thermal store	£3,000
Pipe, insulation and plumbing components	£2,150
Flue system (uncoloured) to height to clear the side of church (apse?) to meet building regulations.	£1,600
Four ground mounted, two wall mounted fan assisted heaters	£4,700
Parts and insulation for UFH in four 100m2 zones	£10,500
Labour to install boiler, erect flue, construct pellet boiler, run pipework to 4 locations for underfloor heating	£6,160
Heat meter	£550
Labour to remove and replace pews, lay underfloor heating	£3,360
Commissioning	£560
Total Ex VAT	£50,330
VAT for non-domestic biomass installations @ 20%	£10,066
Total including VAT at 20%	£60,396

Items/works not included in estimate above:

Brick or other shed for boiler. Pellet boiler would require a shelter of dimensions: 2.5m x 3m x 2.6m (WxDxH)

Verify pellet store and boiler have a solid base for support. Pellet store dimensions are 2.4m x 2.4m for 5 Tonne plus units.

Laying screed or lifting/laying of tiles for UFH

Permissions from the diocese for underfloor heating, for running pipes at high level or creating channels for pipe runs.

Other options:

Blown Air: There are pellet boilers available which heat air and blow into the building. These would not be eligible for the RHI, but would not require plumbing throughout the building (instead may require ducting. There may be some noise from the fans, but they could be switched off during quiet parts of a service.

Cascaded smaller boilers: These introduce fault tolerance – while one is awaiting repair there is still heat available (although less), and modern systems will share the workload between boilers, distributing the wear and tear evenly between the boilers. As the heating requirement changes, the boilers would be able to modulate down more easily.

Containerised heating units: These contain a hopper, the controls, the boiler and a flue and can be situated anywhere convenient (by lorry or crane) and can be clad to make them inconspicuous.