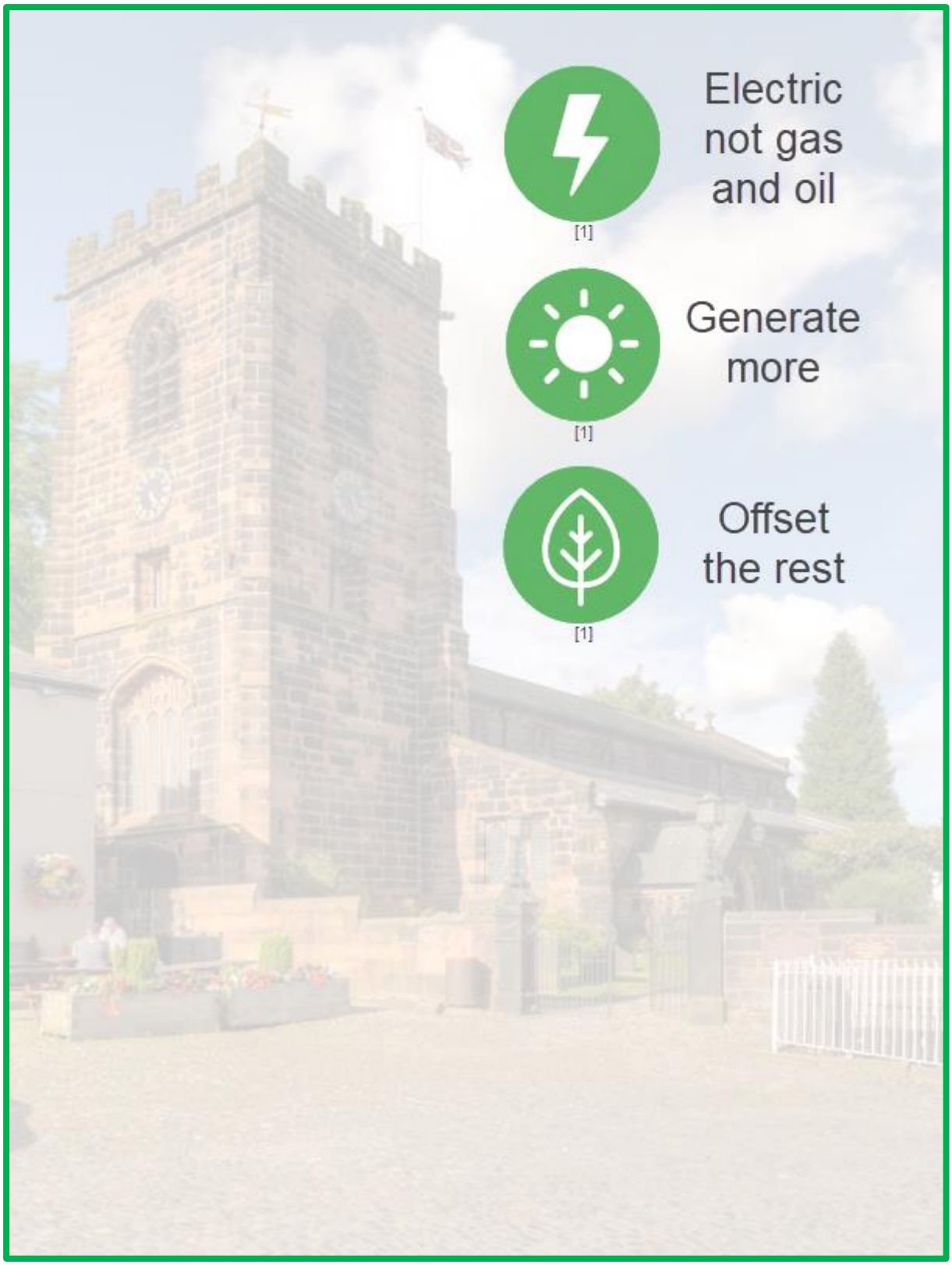

Feasibility study of renewable energy technologies for St. Andrew's Church in NW England

Prepared by Andy Gibbs on behalf of Green Squirrel Energy Ltd

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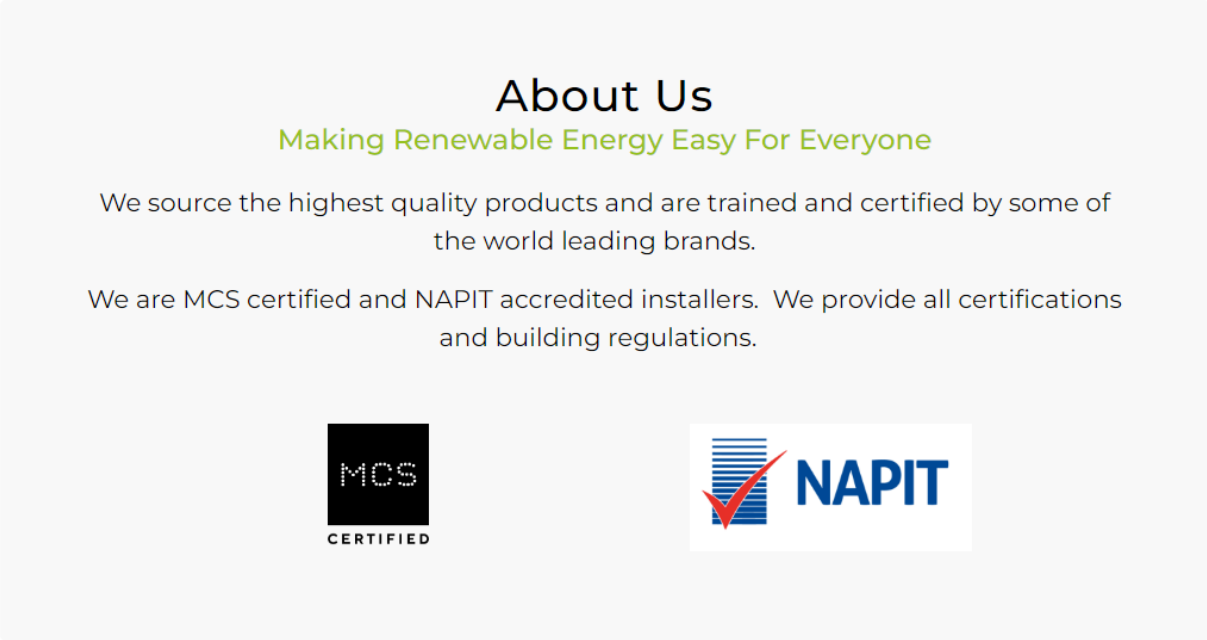
This is an example report created for demonstration purposes only.

Title page image sources:
Icons [1]: https://www.churchofengland.org/resources/churchcare/net-zero-carbon-church

About Green Squirrel Energy Ltd

Mission

Our mission is to give people confidence in low-carbon energy technologies by defining, maintain and improving quality.



Executive summary

The aim of this report is to assess the feasibility of renewable energy technologies for installation in St. Andrew's Church, and help the church reach its net-zero goal by 2030. The report has evaluated five renewable technologies that could be viable to meet space heating demands, prevent interstitial condensation and reach the target of net-zero by 2030. The three most suitable technologies were then analysed in detail, both technically and financially. The key statistics are shown in figure 1, but the headline is that CO_2-emissions are reduced by 88 % by the recommendations. Offsetting to reach net-zero requires and annual investment of approximately £200 through a scheme such as Climate Stewards (https://www.climatestewards.org/).

Recommendations

1. Phase 1 - Install a 70 kW ASHP to meet the space heating requirements.
2. Phase 2 - Install an 18 kWp PV-array on the south-facing church roof.
3. Phase 3 – Offset the remaining carbon emissions through a scheme such as that mentioned in section 3 under *Carbon Footprint*.
4. Phase 4 – Investigate peak shaving by installing an EES-battery, and changing to a flexible tariff, such as Octopus Energy Flux scheme [1] that has a high SEG-tariff.

Figure 1 - The energy and emission savings together with the financial KPIs.

Introduction

The aim of this report is to assess the feasibility of renewable energy technologies for installation in St. Andrew's Church. This project only concerns heating of the church, where the temperature must be maintained between 12-15° C to prevent interstitial condensation. This is also the desired temperature for occupant comfort.

A baseline energy usage (space heating) will first be established for comparison and selection of the different technologies. Local climate, local restrictions and other relevant factors such energy production, demand versus production, environmental impact, CO_2 emissions, and project finances will be evaluated. The report is being produced for The Parochial church council (PCC) of the ecclesiastical parish of St. Andrew's Church. This is desk study supported by data gathered during a site visit in February 2024.

The report is structured as follows:

Section 1: Description of the church and the project scenario.

Section 2: Initial renewable energy resource assessment, investigating potential technologies.

Section 3: Detailed feasibility assessment including energy analysis, cash flow analysis, carbon savings and technically viability.

Section 4: Conclusions and recommendations.

References and bibliography.

Exclusions

Domestic hot water (DHW) consumption is covered by an existing 4 kW Air Source Heat Pump (ASHP) which also heats an annex completed in 2022, both of which are not considered in this report unless they explicitly affect another element e.g. the maximum fuse size for the electricity supply. Discussion of the suitability of the existing heating pipework and radiators, and investment costs associated with this, is beyond the scope of this report. Other improvements such as insulation and upgraded air handling are also beyond the scope of this report. Small-scale hydro is discounted as there is no suitable water course close by. Embodied carbon calculations for specific products are also excluded.

Common Abbreviations

ASHP	Air Source Heat Pump
DHW	Domestic Hot Water
EES	Electrical energy storage
GSHP	Ground Source Heat pump
MCS	Microgeneration Certification Scheme
NPV	Net Present Value
OAT	Outside Air Temperature
PCC	Parochial Church Council
PV	Photovoltaic
ROR	Rate of Return
SEG	Smart Export Guarantee
TES	Thermal energy storage

Section 1: Description of St. Andrew's Church and project scenario

St. Andrew's Church is a grade 1 listed building located within the village conservation area.

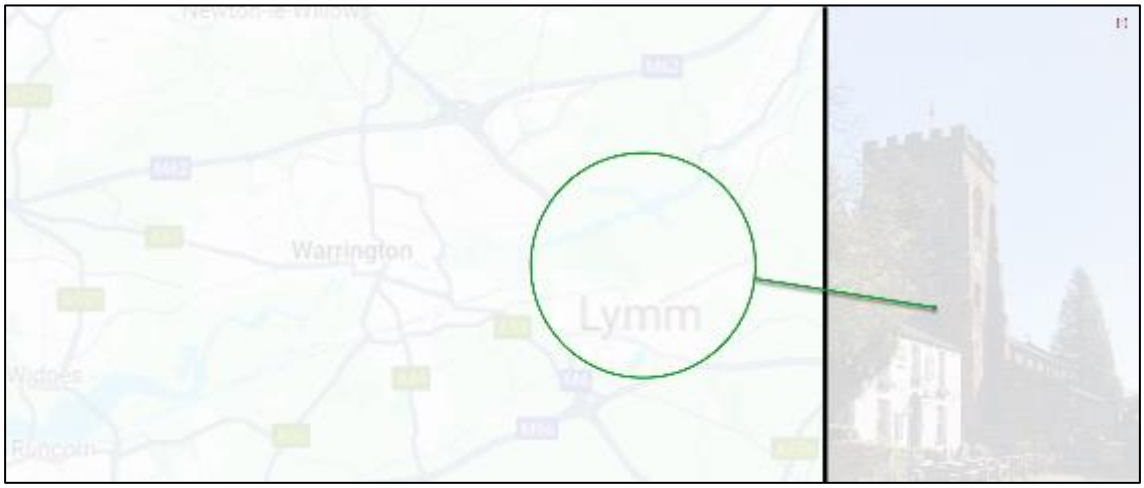


Figure 2 - St. Andrew's Church.
Sources: Map: Google Maps [2]**;**

The PCC's goal is carbon net-zero by 2030. The church has not yet secured funding for a complete solution, so financing will need to come from donations, grants or a loan. The PCC therefore prefer a phased project. The priority is the 40-year-old 66 kW gas boilers, of which only one works. The first phase of this project is thus securing a source of low- or no-carbon heating.

Figure 3 - The only functioning gas boiler installed in the church.

Phase two onwards will be to offset any carbon used by the new heating system by generating electricity and storing any excess energy production for use during periods with no or low production.

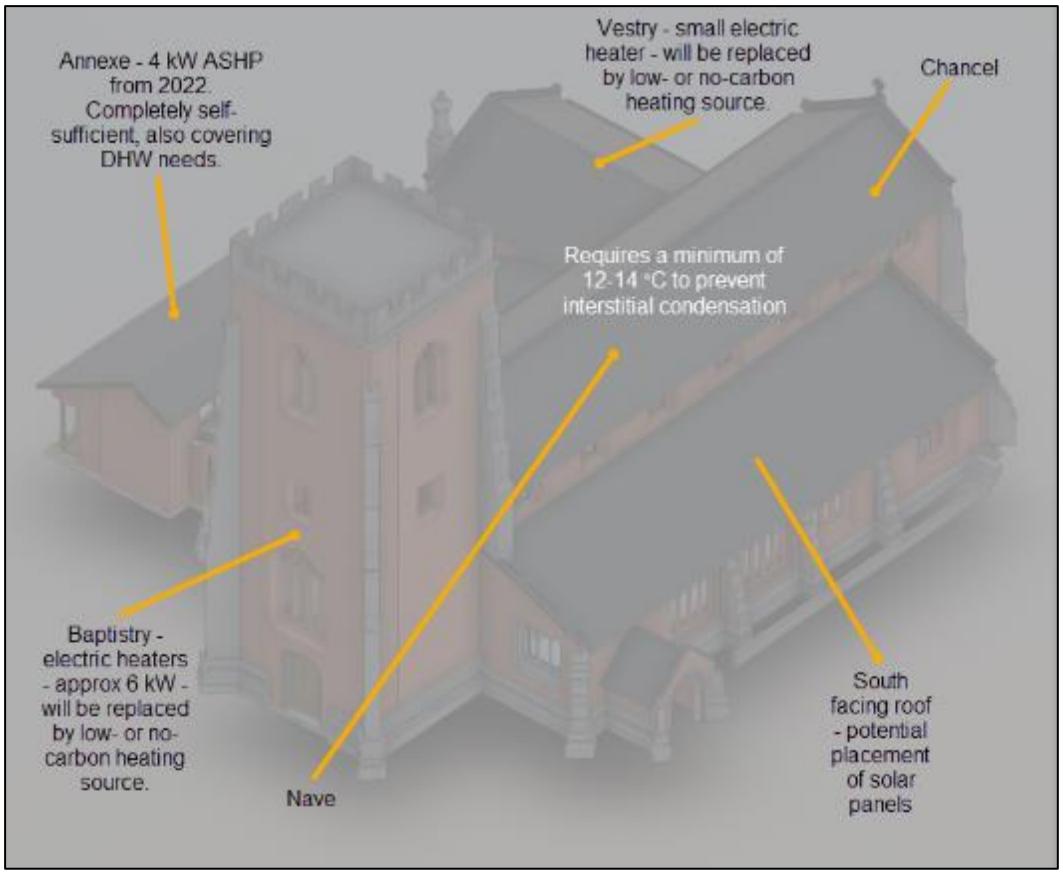


Figure 4 - Some of the key considerations in the project scenario.
Source: 3D image kindly supplied by Kepczyk Pearce Sanderson architects, surveyors & historical building consultants at https://kpsarchitects.co.uk/index.html.

Annual Heating Energy Baseline

After calculation using an adaption of the *T313_Eurohouse spreadsheet* [3], the total net space heating demand is 152 881 kWh yr^{-1}. This is currently met as follows:

Description	Amount	Unit
Water heating	0.0	kWh day^{-1}
Fuel type – Gas	-	-
Efficiency	65	%
Annual fuel consumption – gas	212497	kWh yr^{-1}
Annual fuel consumption - electricity	14757*	kWh yr^{-1}
Total Annual fuel consumption	**227255**	kWh yr^{-1}
Annual CO_2 emissions	**45.6**	tonnes yr^{-1}
Annual fuel cost	**10550**	GBP

Table 1 - Current energy usage by fuel type, annual cost and CO_2 emissions.

The non-condensing gas boiler's efficiency is set to 65 % based on the indication given in section 3.2 *Gas boilers* [4]. There are electric heaters in the bell tower with an output of 6.5 kW. An average of 21082 kWh yr^{-1} has been consumed in the past 3 years so 70 % of this ($21082\ kWh^{-1} \times \frac{70}{100} = 14757.4\ kWh^{-1}$) is assumed to be for heating.

Structure

The church has a complicated structure, so for the calculations, the structure was broken down into basic elements (appendix A), the windows were all considered to be rectangular, and the U-values were estimated as shown in the table below. The building is uninsulated.

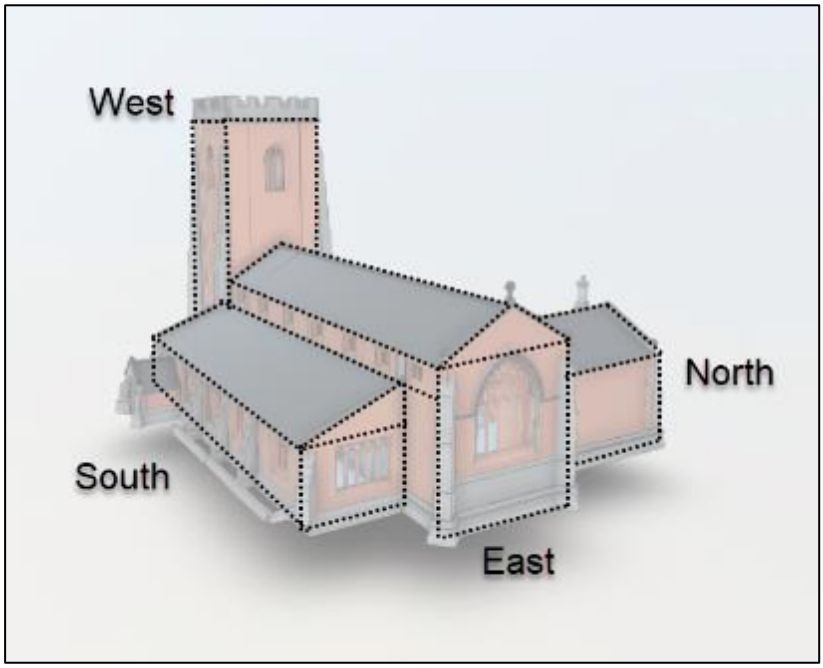


Figure 5 - Breaking down the church into simple elements for heat loss calculations.

Building element	U-value W m^{-2} K^{-1}	Comments	Source
Floors	1.75	Boarding, uninsulated exposed to unheated space.	MCS Heat pump calculator [5]
Roof	3.13	Uninsulated timber with slate tiles	MCS Heat pump calculator [5]
Walls	1.30	1 m thick sandstone for granite or whinstone, the U-value = 3.3 - 0.002 * thickness of wall in mm. Assumed average thickness = 1000 mm	RdSAP and U-values [6, p. 3]
Windows & doors	5.60	Stained glass leaded windows	[7]

Table 2 - Building element U-values used for calculation.

Knowing the U-values, U, (the rate of heat transfer through a material in watts per m^2 per degree Kelvin) and having calculated the areas, A_x, the total fabric heat loss, Q_f, can be calculated by finding the sum, Σ, of fabric heat loss from all elements and multiplying it by the difference between the indoor and outdoor temperatures, ΔT:

$$Q_f = \sum (A_x \times U_x) \times \Delta T \; watts \quad (1)$$

Additionally, ventilation losses, Q_v, are calculated as follows and added to the total heat loss

$$Q_V = 0.33 \times n \times V \times \Delta T \; watts$$

(2)

where *n* is the air change rate, *V* the volume of the building and 0.33 air's heat capacity i.e. 0.33 Wh m^{-3} K^{-1}.

Climate data

The figure below shows the climate data for the area and the further steps to calculate net space heating demand.

Current location		Index	1	2	3	4	5	6	7	8	9	10	11	12
		Months	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Solar radiation														
Daily solar south-facing radiation	kWh/m²/day		4,92	4,26	3,33	2,10	1,31	0,91	0,95	1,68	3,03	4,26	4,98	4,93
1093 m² PV array to meet net demand	kWh/day		5379	4660	3639	2297	1427	992	1039	1841	3308	4652	5443	5386
Annual south-facing solar radiation	kWh/m²/yr		1114											
Temperatures and degree days														
Mean temperature	°C		16,8	16,6	14,3	11,0	7,5	4,6	4,8	5,4	7,0	9,5	12,4	15,1
Days per month			31,0	31,0	30,0	31,0	30,0	31,0	31,0	28,3	31,0	30,0	31,0	30,0
Degree-days/month			0,0	0,0	0,0	93,0	195,0	291,4	285,2	243,0	217,0	135,0	49,6	0,0
Total degree-days per year			1509											
House heat loss and space heating demand														
Gross space heating loss	kWh/day		0	0	0	327	708	1024	1002	936	762	490	174	0
Free heat gains	kWh/day		15	15	15	15	15	15	15	15	15	15	15	15
Useful free heat gains	kWh/day		0	0	0	15	15	15	15	15	15	15	15	0
Total useful free heat gains	kWh/yr		**3650**											
Window solar transmittance (inc.frame)			0,50											
Solar gains	kWh/day		71	61	48	30	19	13	14	24	44	61	72	71
Useful solar gains	kWh/day		0	0	0	30	19	13	14	24	44	61	72	0
Total useful solar gains	kWh/yr		**8407**											
Net space heating demand	kWh/day		0	0	0	281	674	995	973	897	704	414	88	0
Annual total net space heating	kWh/yr		**152881**											

Figure 6 - Calculating the net space heating demand with an adapted version of the EuroHouse spreadsheet [3] . Sources: Daily irradiation and mean temperature data from PVGIS database [8]**.**

Energy prices

The PCC has negotiated a fixed rate gas price of 3.62 p kWh^{-1} and electricity price of 19.4 p kWh^{-1}.

Specific CO_2 emissions

These have been set to 0.20 kg kWh^{-1} for gas and 0.21 kg kWh^{-1} for electricity based on 2023 figures from the Department for Energy Security and Net Zero ([9].

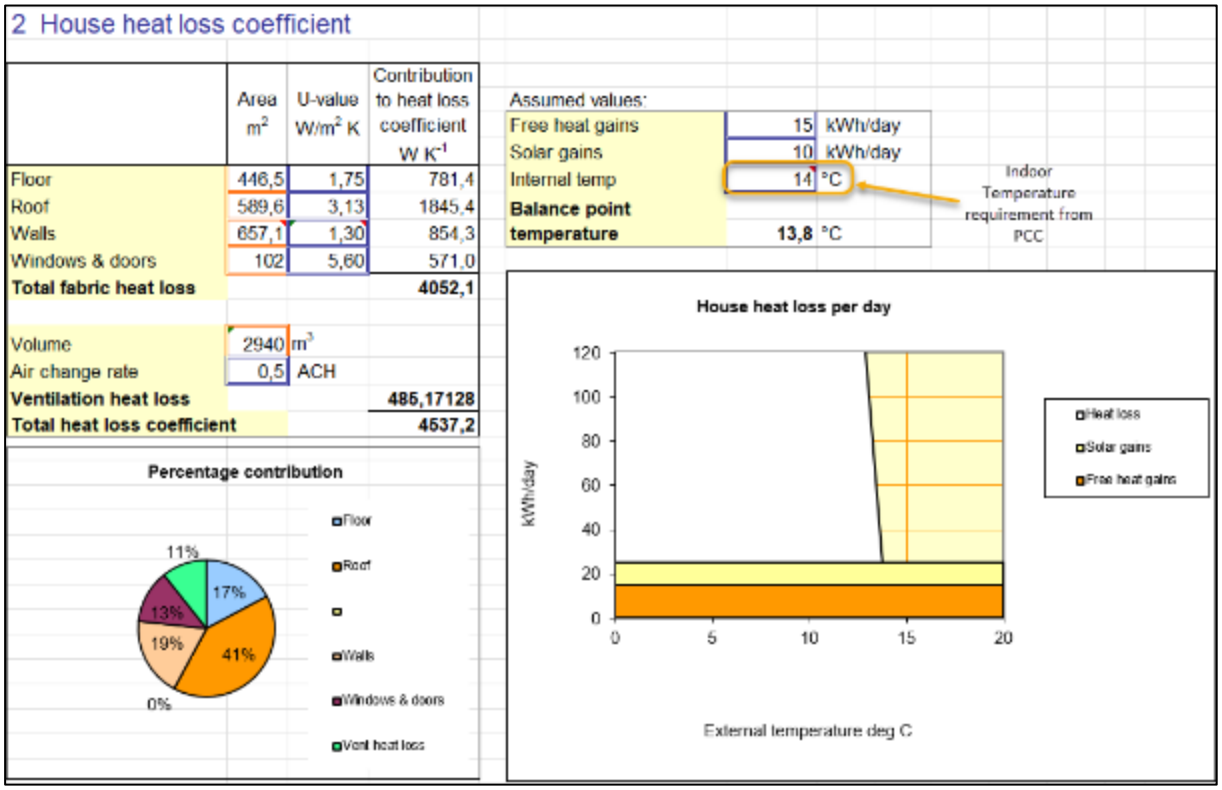


Figure 7 – Heat loss coefficient calculations using an adapted *Eurohouse* spreadsheet [3],

Section 2: Initial renewable energy resource assessment

Solar photovoltaic

Photovoltaics, PV, or '…the conversion of solar energy *directly* into electricity in a solid-state device' [10, p. 115], 'capture' solar energy until electrons 'acquire enough energy to move into a higher energy state […] and move around within the material and thus conduct electricity' [10, p. 121]. The most common types are shown below.

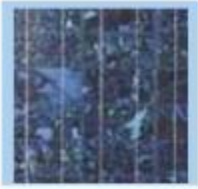
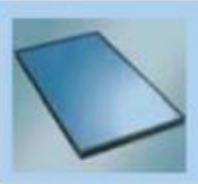
Property	PV cell type		
	Monocrystalline silicon	Polycrystalline silicon	Thin film amorphous silicon
Appearance Current world record (May 2024) is 23.6 % efficiency [2]			
Cell efficiency at standard test conditions[1]	15–17%	14–15%	8–12%
Module efficiency	13–15%	12–14% This figure is approximately 20.0 % [1] in 2024.	5–7%
Area of modules required per kW_p [2]	7 m^2	8 m^2	16 m^2
Area per kW_p [2] of building materials incorporating PV cells	Glass–glass laminates: 8–30 m^2 (depends on cell spacing)	Glass–glass laminates: 10–30 m^2 (depends on cell spacing)	Solar metal roofing: 23.5 m^2 Glass–glass laminates 25 m^2
Advantages/disadvantages	Most efficient but highest cost	Cheaper than monocrystalline but slightly less efficient	Considerably cheaper but about half the efficiency of monocrystalline Offers the widest range of BIPV options
Notes: [1] Standard test conditions (STC) are 25 °C, light intensity of 1000 W/m^2 and air mass (spectral power distribution) of 1.5 and a cell temperature of 25 °C; [2] kWp = peak output power (kilowatts) (solar PV products are rated by their output power at STC)			

Figure 8 - Properties of common types of PV Cell.
Sources: Capturing solar energy KS15 [11, p. 13]**.**
[1] An example PV with 20 % efficiency [12]**.**
[2] Nature Energy Vol. 9 [13]**.**

Figure 8 indicates that approximately $870\ kWh\ m^{-2}\ yr^{-1}$ could be produced from the church roof that the PCC has agreed could be used to site a PV-array.

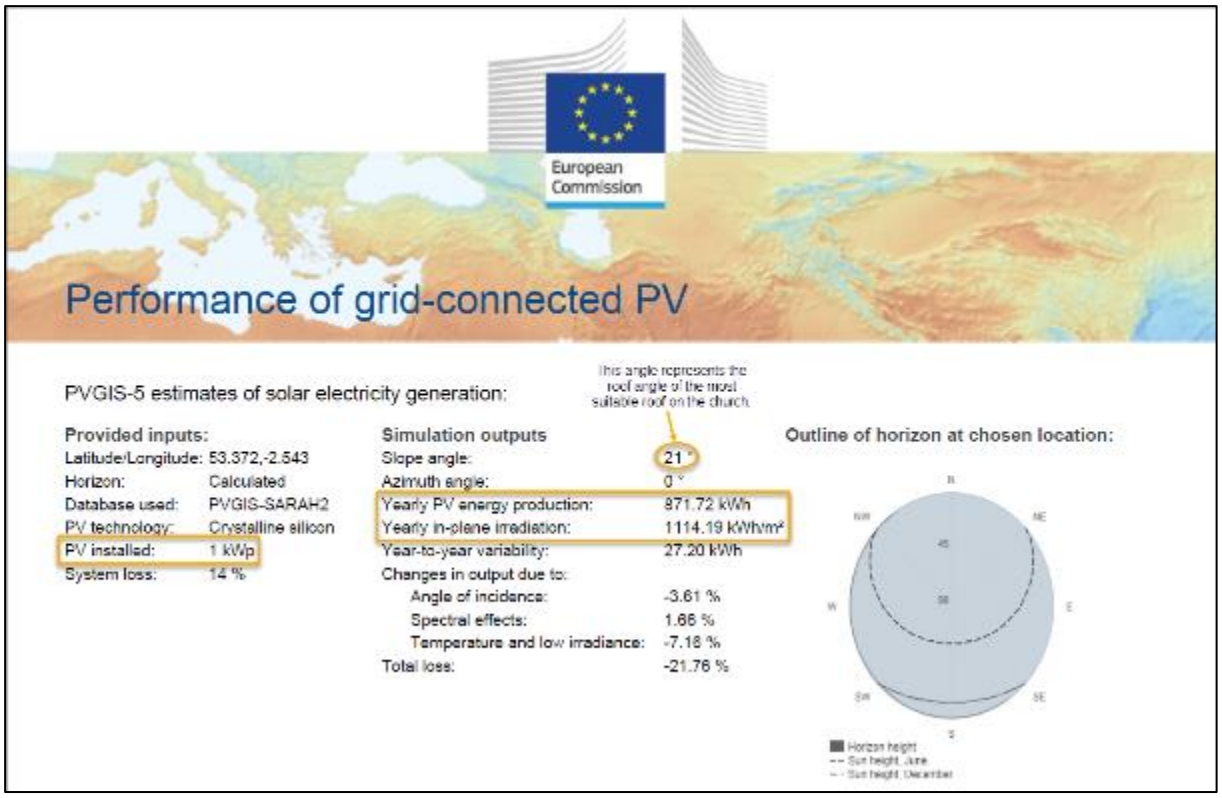


Figure 9 - An indication of the solar irradiation per m2, in the church's location.
Source: Photovoltaic Geographical Information System [8].

The 'availability of solar radiation is out of phase with the space heating demand in the UK' [10, p. 73], meaning that meeting the average December space heating demand of 995 kWh day^{-1} could be difficult to meet with limited space.

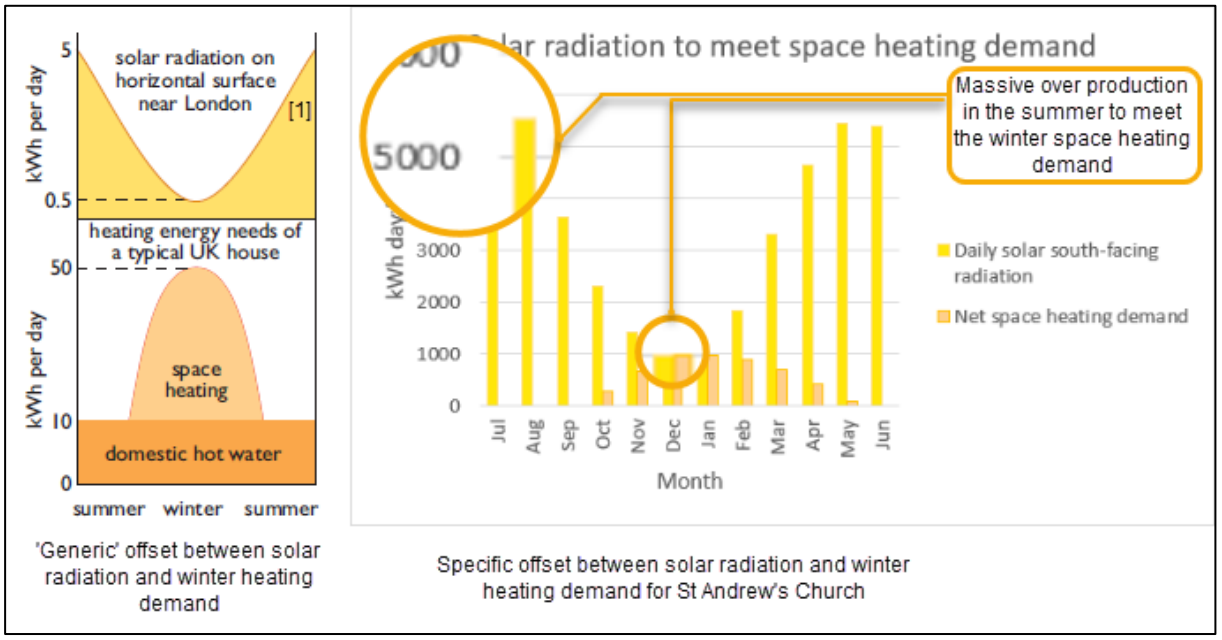


Figure 10 - Phase shift between solar radiation and net space heating demands.
Source: [1] Figure 3.16 Chapter 3 Solar thermal energy [10, p. 73]

Geothermal

Approximately a third of UK delivered energy is used for low temperature space heating [10, p. 19]. Gas boilers dominate, but heat pumps are a 'proven, scalable option for the provision of low carbon heat' [14, p. 3].

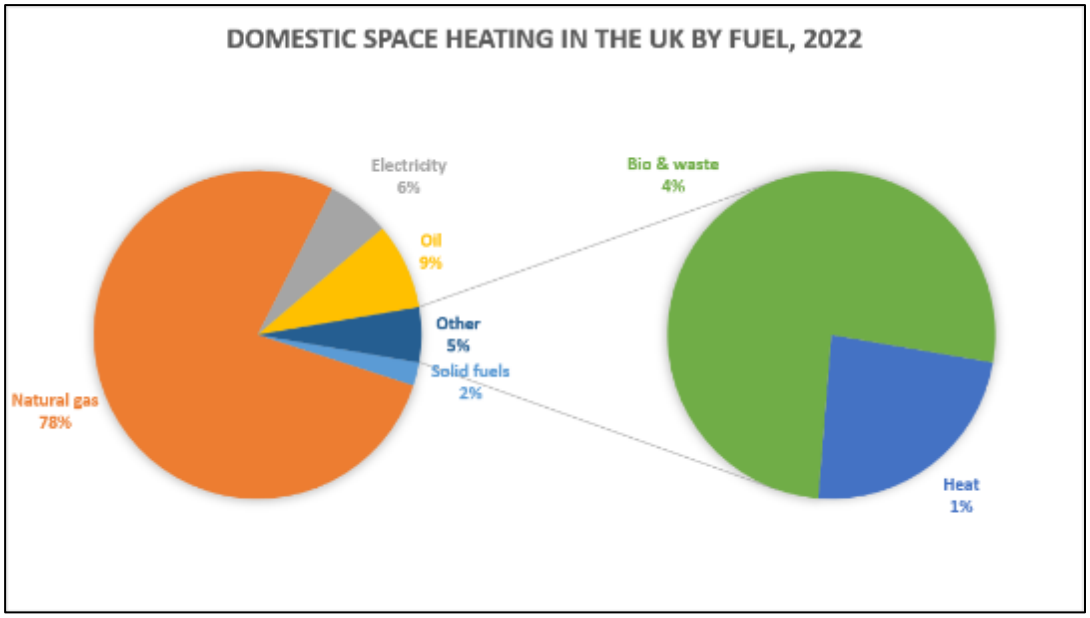


Figure 11 - Domestic space heating in the UK, split by fuel type.
Data from Energy consumption in the UK 2023 [15]

Often, they replace a gas boiler with minimal changes to the heating system. Exploiting energy from the external environment (outdoor air or coils in the ground) by using 'electrical energy to drive a compressor raising a flow of heat from a low temperature to a higher one' [10, p. 52]. 1 kWh of electrical energy can produce as much as 5 kWh of heat energy. This ratio is called the coefficient of performance (COP).

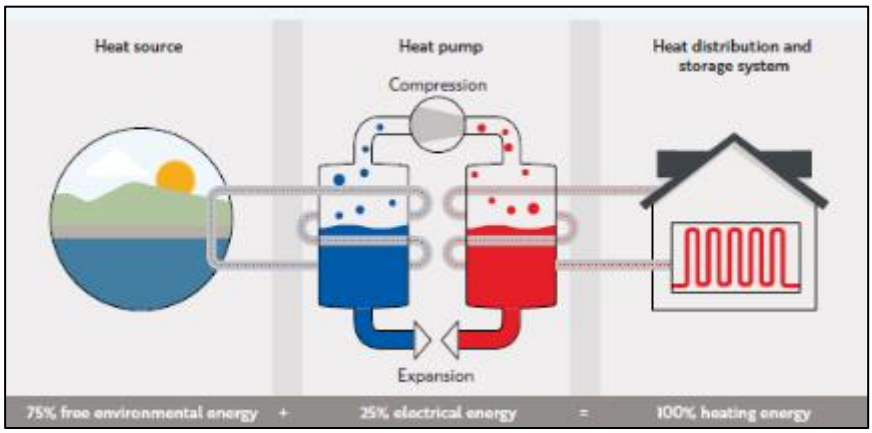
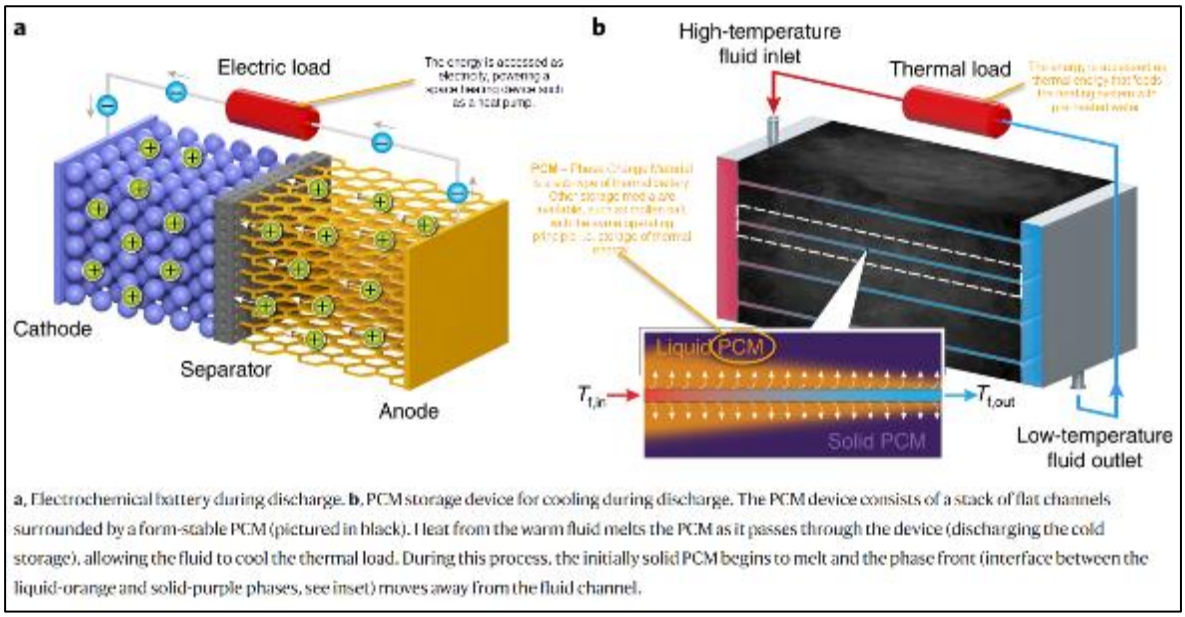


Figure 12 - Simplified heat pump operations [14, p. 4]

Ground-Source heat pumps (GSHP) are discounted as ground loops cannot be laid in the graveyard area but ASHPs are viable.

Battery

Thermal energy storage (TES) and electrical energy storage (EES) batteries could form part of net-zero strategy. TES stores energy generated, for example by a PV-array, as thermal energy and TES stores energy as electrical energy for consumption when generation drops below demand, reducing grid demand and shifting electrical load from peak times.



a, Electrochemical battery during discharge. **b**, PCM storage device for cooling during discharge. The PCM device consists of a stack of flat channels surrounded by a form-stable PCM (pictured in black). Heat from the warm fluid melts the PCM as it passes through the device (discharging the cold storage), allowing the fluid to cool the thermal load. During this process, the initially solid PCM begins to melt and the phase front (interface between the liquid-orange and solid-purple phases, see inset) moves away from the fluid channel.

Figure 13 - Thermal Energy Storage and Electrical Energy Storage battery principles.
Source: Adapted from Rate capability and Ragone plots for phase change thermal energy storage [16]

Discounted technologies

Biomass

A biomass boiler could provide the required heat, but the lack of access and storage space (see table 3) would make this impractical. The average December space heating demand is approximately 1700 kWh day^{-1}, which requires 2 m^3 of wood chip per day.

Type of fuel	kWh m^{-3}	Volume (m^3) to meet max demand	Volume (m^3) to meet max demand for 1 week
Wood chips	870[1]	2.0	14
Sawdust pellets	3100[1]	0.6	4.0

Table 3 - Storage space required for biomass fuels.
[1] Value obtained from Forest Research [17]**.**

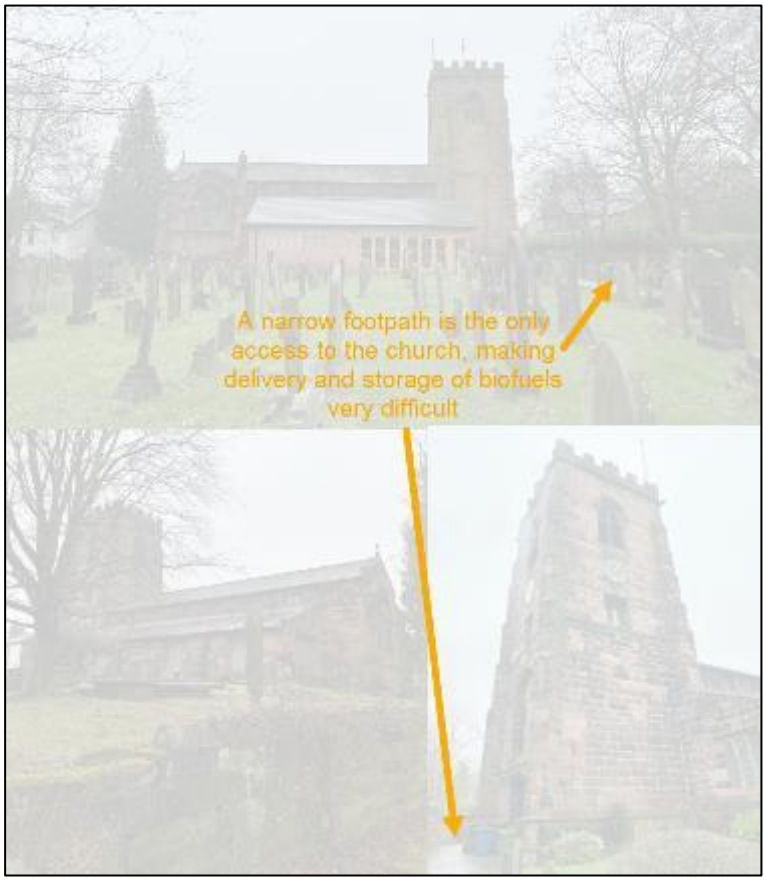


Figure 14 - No space is available in the church grounds for storing biofuels.

Wind energy

The T313 *Postcode Weather Data to go* spreadsheet [18] indicates an average wind speed of 3.9 m s^{-1}, and the Global Wind Atlas [19] 4.55 m s^{-1}, which research (see below) indicates is at the lower limit for wind power generation.

S/N	Turbine Model	Cut-in speed (m/s)	Cut-out speed (m/s)	Rated speed (m/s)	Power rating (kW)	Hub height (m)
1	PGE 20/25	3.5	25	9.0	25	24/30/36
2	Enercon	3.0	25	12.0	3000	120/135
3	GE 1.5 sle	3.5	25	14.0	1500	65/80
4	G.E 1.5 xle	3.5	20	11.5	1500	80
5	AV 927	3.0	25	13.1	3300	60-80
6	AV 928	3.0	25	11.6	2500	80
7	V 90	4.0	25	15.0	3000	80
8	SWT-3.6-107	3.0	25	13.0	3600	80

Figure 15 - A range of wind turbines with their respective cut-in and rated speeds.
Source: ***On the need for the development of low wind speed turbine generator system*** [20]

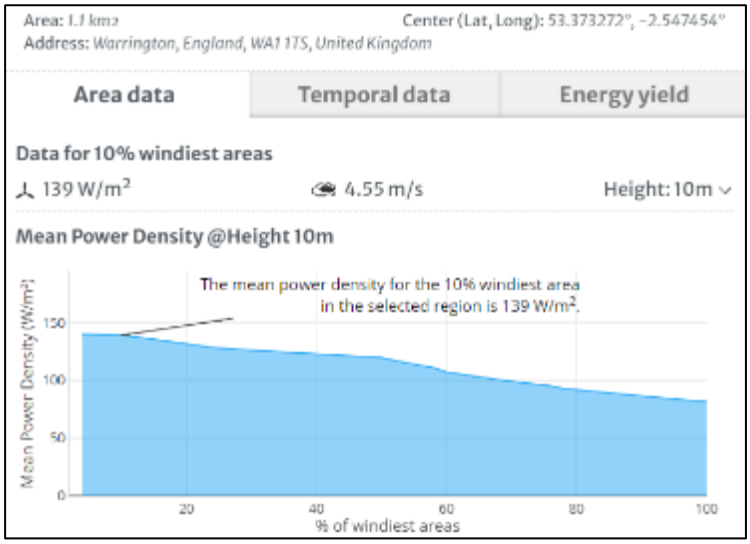


Figure 16 - Wind speed data for a 1 km² area centred on St Andrew's Church.
Source: [19].

A Rayleigh distribution formula gives an approximation of wind speed distribution based on the average wind speed, V_m , where N is the number of hours per year, V a particular wind speed.

$$N = 365 \times 24 \times \frac{\pi}{2} \times \frac{V}{(V_m)^2} \times \exp\left(\frac{-\pi}{4} \times \left(\frac{V}{V_m}\right)^2\right)$$

(3)

Scaling the generic power curve given in chapter 8 *figure 8.28* [21, p. 376] to a 1 kW output, gives a production of approximately 670 kWh yr^{-1} per installed kW.

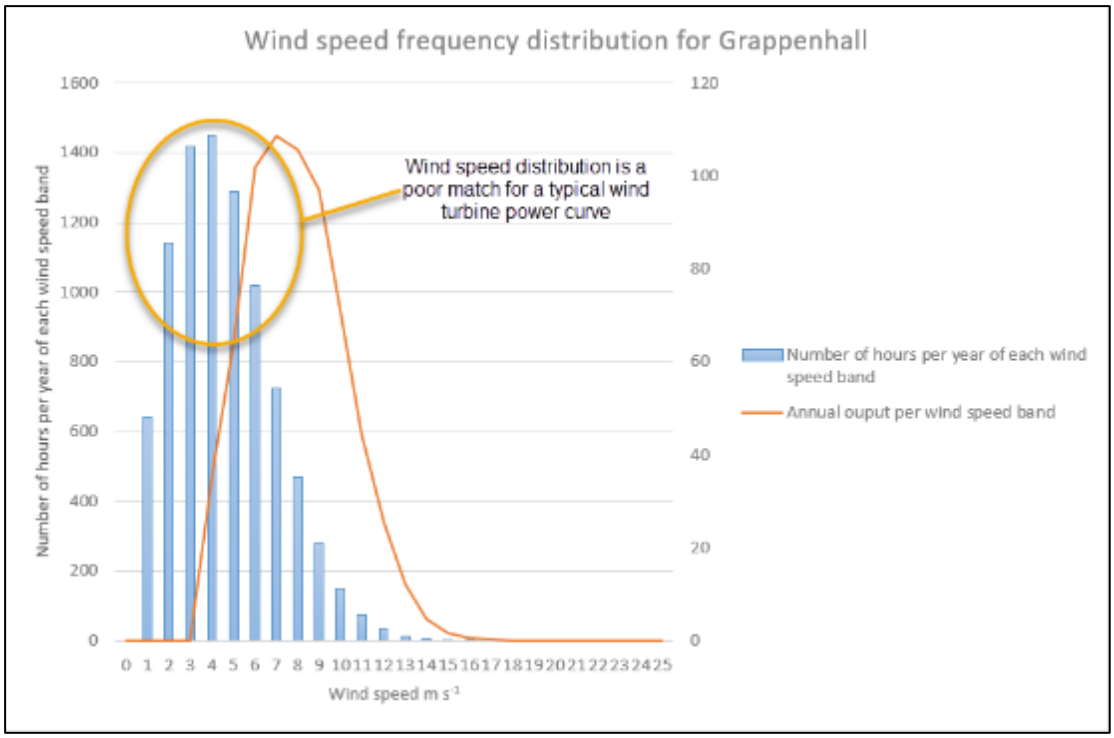


Figure 17 - Wind speed frequency distribution with a generic wind turbine power curve overlaid.

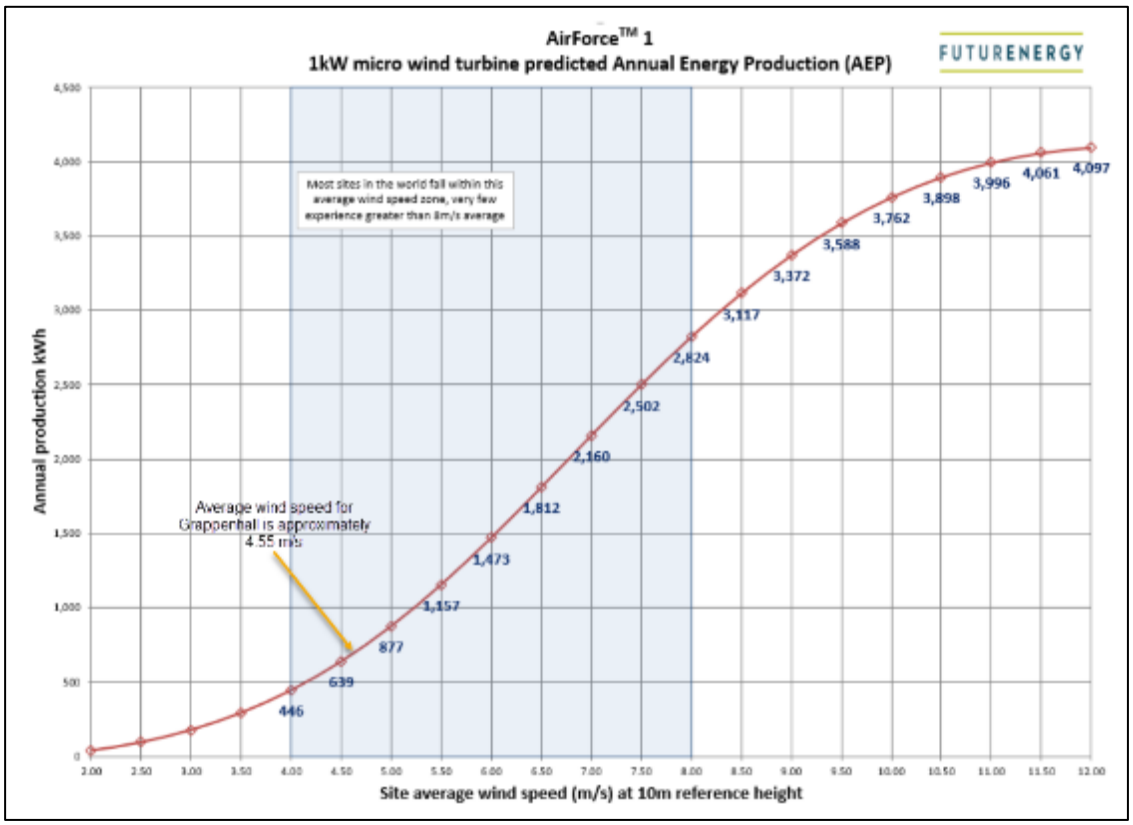


Figure 18 - Annual energy production from a 1 kW wind turbine.
Source: AirForce™ 1 datasheet [22].

It requires a 90-kW turbine ($\frac{152881\ kWh_{heat}\ yr^{-1}}{2.5}/670\ kWh \approx 91\ kW$) to supply an ASHP (with an average COP-value of 2.5) to meet net space heating demand. The Vestas V19-90 [23] is such a

turbine with a rotor diameter of 18.8 m and a height of 23.2m. The low yield is exacerbated by the space restrictions and this being a conservation area.

Figure 19 - A 90 kW wind turbine, which would be too large for siting in church grounds.

Section 3: Detailed renewable energy technology feasibility assessment

The three RE-technologies selected for further consideration are ASHP, PV, and battery.

ASHP

Dimensioning

The peak load, Q_{total}, is calculated as follows:

$$Q_{total} = \Delta T * \frac{Q_f + Q_v}{1000} kW \quad (4)$$

where ΔT is the outdoor design temperature subtracted from the desired indoor temperature, Q_f fabric heat losses and Q_v ventilation heat losses.

$$\frac{(14\ °C - (-)2.1\ °C) * 4537\ W\ K^{-1}}{1000} = 73\ kW$$

12-15 °C indoors is required to prevent interstitial condensation. Figure 20 shows that 70 kW would maintain 13 °C at design temperature. 'The peak load may only occur for a limited number of hours each year' [14, p. 37] so, five 14 kW ASHPs providing 70 kW may be a better strategy for control and plant longevity.

Design temp for postcode WA4

Heat loss and balance point temperature chart

Mean temp. in December 4.8 °C

External temperature	°C	**-2,1**	**0**	**5**	**10**	**15**	**20**
Gross space heating	kWh/day	1753	1525	980	436	-109	-653
Max power output	kW	73	64	41	18	-5	-27
Solar gains	kWh/day	10	10	10	10	10	10
Free heat gains	kWh/day	15	15	15	15	15	15
Solar and free heat gains	kWh/day	25	25	25	25	25	25

Required output from ASHP drops considerably as temperature rises. From the design temperature to the December mean temperature the output drops by 32 kW

Figure 20 - Dimensioning the ASHP power output, for an internal temperature of 14 °C.

Heat loss and balance point temperature chart

A 70 kW ASHP battery would maintain an indoor temperature of 13 °C

External temperature	°C	**-2,1**	**0**	**5**	**10**	**15**	**20**
Gross space heating	kWh/day	1644	1416	871	327	-218	-762
Max power output	kW	69	59	36	14	-9	-32
Solar gains	kWh/day	10	10	10	10	10	10
Free heat gains	kWh/day	15	15	15	15	15	15
Solar and free heat gains	kWh/day	25	25	25	25	25	25

Figure 21 - Redimensioning for 13 °C internal temperature. Same calculation as figure 17 but with 13 °C indoor temperature.

14 kW of the 69 kW 3-phase power-supply are already consumed by electric heaters and lighting, leaving 55 kW for the ASHP. Exceeding this would result in a cost of £100,000 for running a larger supply to the church. The electrical power for 70 kW heat output must be calculated. The formula for 3-phase power, *P*, is:

$$P = \frac{\sqrt{3} \times V \times I \times cos\phi}{1000}\ kW \quad (5)$$

where *V* is the line voltage, *I* the current and *cosφ* the power factor.

As an example, the Mitsubishi Ecodan R32 ASHP (PUZ-HWM140YHA) [24] could be configured as 5 x 14 kW giving 70 kW. Each unit has a maximum current of 13 A, giving $13 \times 5 = 65\ A$.

ELECTRICAL DATA	Electrical Supply	380-415v, 50Hz
	Phase	Three
	Nominal Running Current (MAX) (A)*5	4.5 [13]
	Fuse Rating - MCB Sizes (A)*6	16

Figure 22 - Electrical data for Mitsubishi Ecodan R32 ASHP [25, p. 13].

Thus:

$$P = \frac{\sqrt{3} \times 400 \times 65 \times 0.95}{1000} = 42.78165495 = 43\ kW\ (2\ s.f.)$$

(assuming the power factor is 0.95). Mitsubishi confirms this figure.

ASHP electrical consumption

Figures 22 and 23 compare the COP-values for the Mitsubishi ASHP with the theoretical values calculated using equations shown in appendix B.

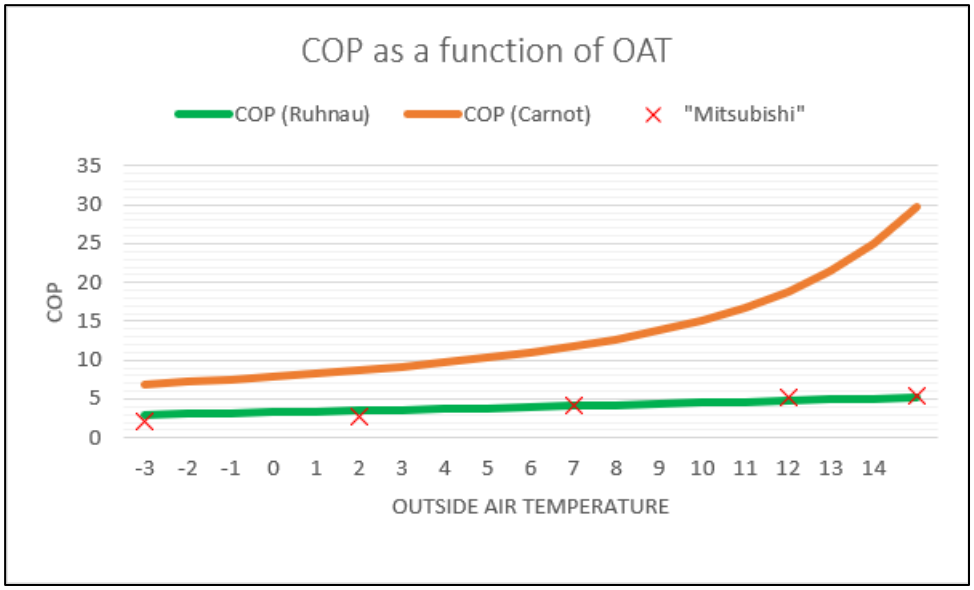


Figure 23 - Theoretical COP-values as a function of outside air temperature, based on Ruhnau et al.'s research [26] compared with manufacturer data.

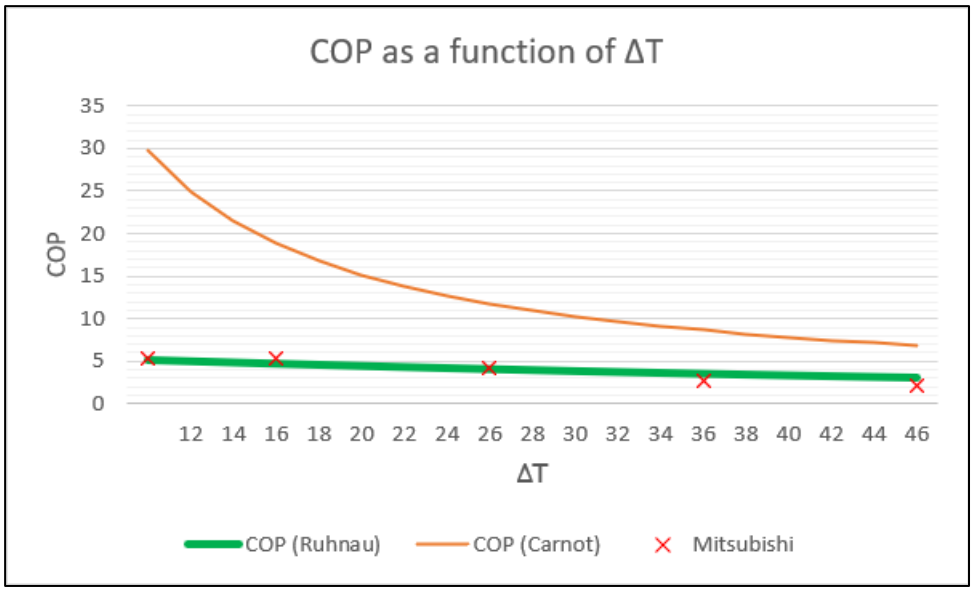


Figure 24 - Theoretical COP-values as a function of ΔT (outlet – inlet temperature), based on Ruhnau et al.'s research (Ruhnau, et al., 2019) compared with manufacturer data.

The MCS spreadsheet [27] estimates 39606 kWh yr^{-1} for the Mitsubishi ASHP. Using the calculated COP-values, the ASHP's annual electricity consumption is calculated (appendix C) to 38094 kWh yr-1. This equates to an energy saving of 189 161 kWh yr^{-1} to meet the net space heating demand of 152 881 kWh yr^{-1}, compared to the baseline energy consumption of 227 255 kWh yr^{-1}.

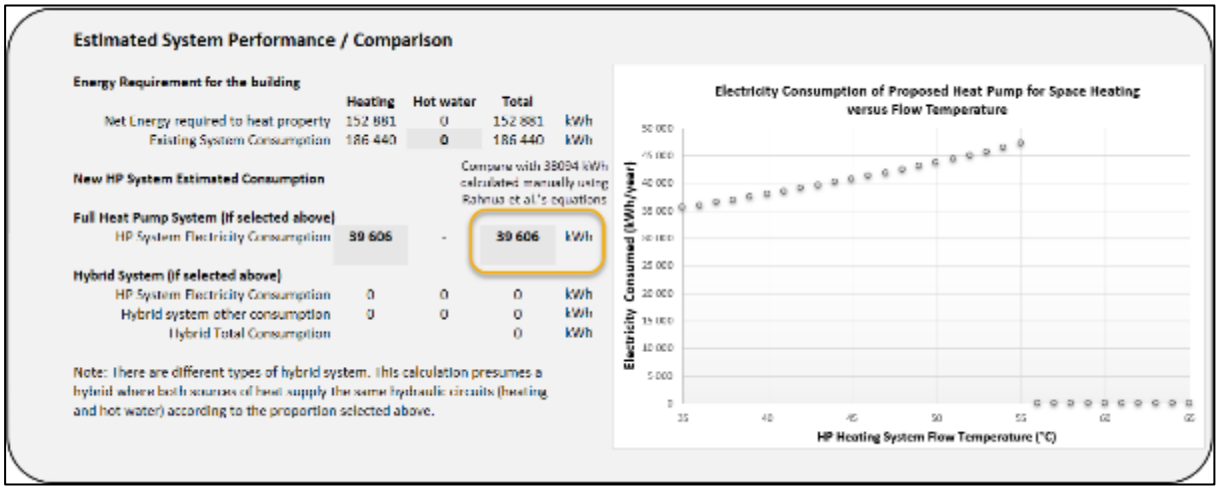
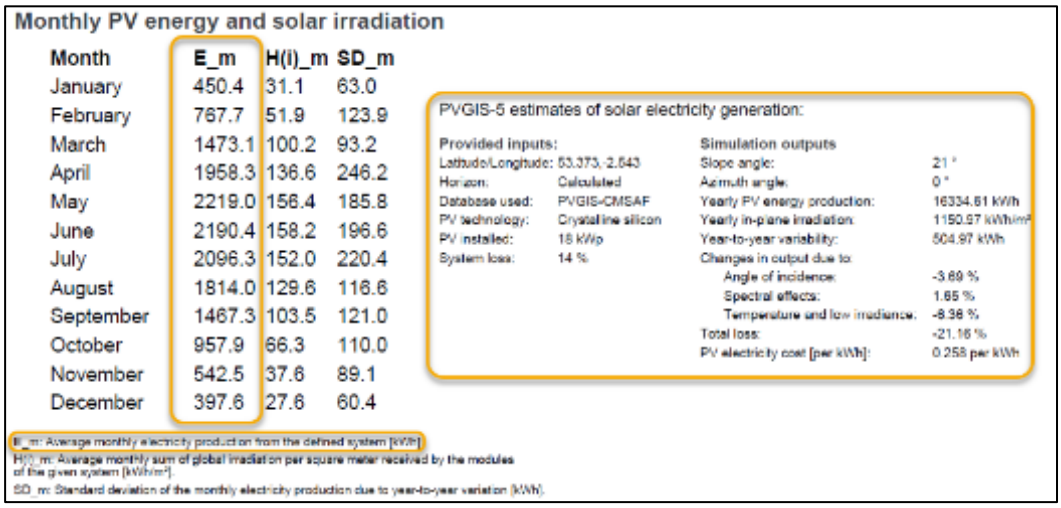


Figure 25 - Seasonal Coefficient of Performance for Mitsubishi Ecodan R32 (PUZ-HWM140YHA) ASHP, calculated using the *MCS_031_MCS_Heat_Pump_System_Performance_Estimate_Issue-3.0* spreadsheet [5].

Photovoltaic

Dimensioning

Installing a PV-array on the approximately 138 m^2 south-facing roof with a 21° slope angle (see figure 3) could provide 18 kW_p (assuming 1 kW_p 7 m^{-2}). Monthly data from the PVGIS tool [8] shows a potential production of 16334 kWh yr^{-1}.



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	450.4	31.1	63.0
February	767.7	51.9	123.9
March	1473.1	100.2	93.2
April	1958.3	136.6	246.2
May	2219.0	156.4	185.8
June	2190.4	158.2	196.6
July	2096.3	152.0	220.4
August	1814.0	129.6	116.6
September	1467.3	103.5	121.0
October	957.9	66.3	110.0
November	542.5	37.6	89.1
December	397.6	27.6	60.4

PVGIS-5 estimates of solar electricity generation:

Provided inputs:		Simulation outputs	
Latitude/Longitude:	53.373, 2.643	Slope angle:	21 °
Horizon:	Calculated	Azimuth angle:	0 °
Database used:	PVGIS-CMSAF	Yearly PV energy production:	16334.61 kWh
PV technology:	Crystalline silicon	Yearly in-plane irradiation:	1150.97 kWh/m²
PV installed:	18 kWp	Year-to-year variability:	504.97 kWh
System loss:	14 %	Changes in output due to:	
		Angle of incidence:	-3.69 %
		Spectral effects:	1.65 %
		Temperature and low irradiance:	-8.36 %
		Total loss:	-21.16 %
		PV electricity cost (per kWh):	0.258 per kWh

E_m: Average monthly electricity production from the defined system [kWh].
H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].
SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Figure 26 - Monthly PV energy and solar irradiation for Grappenhall.
Source: PVGIS [8].

Performance

Installed capacity	18	kWp
Estimated annual output	16335	kWh
kWh/kWp	907.5	kWh/kWp

Table 4 - Performance Calculations summary

To understand if the production is in phase with the demand or not, the ASHP monthly energy usage, $E_{ASHP_{Mth}}$, was calculated as follows:

$$E_{ASHP_{Mth}} = \frac{SH_{mth} \times D}{COP_{Int}}$$

(6)

Where SH_{mth} is the monthly space heating demand, D the number of days in the month and COP_{int} the interpolated COP-value. The energy consumption was subtracted from the PV-array's energy production, calculating the energy balance.

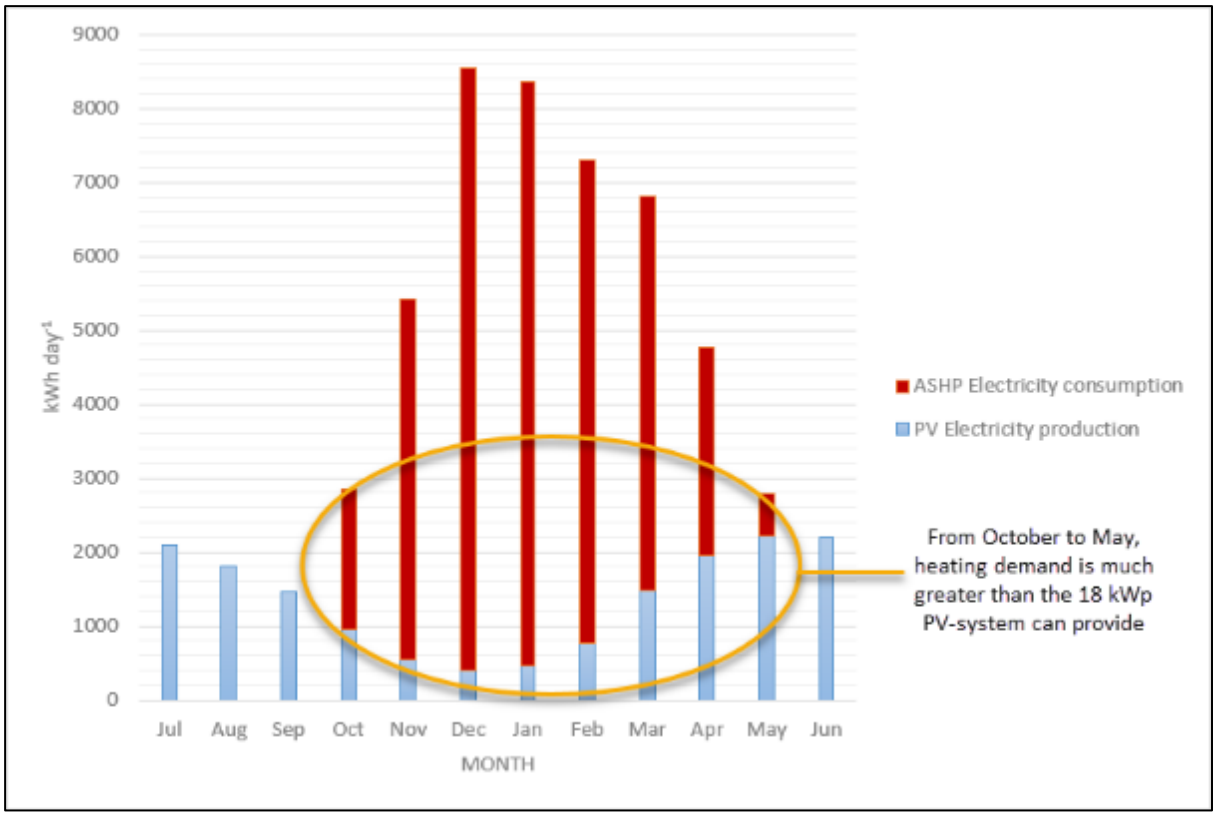


Figure 27 - The monthly PV electricity production compared to the ASHP's electricity consumption to meet net space heating demand.

		July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual kWh
Days per month (a)		31	31	30	31	30	31	31	28	31	30	31	30	-
Space heating demand (b)	kWh/ mth	0	0	0	8724	20220	30860	30166	25346	21814	12413	2715	0	152258
Estimated COP (c)		5.5	5.5	5.1	4.6	4.1	3.8	3.8	3.9	4.1	4.4	4.8	5.2	-
ASHP Electricity consumption (d=b/c)	kWh/ mth	0	0	0	1889	4880	8151	7918	6530	5348	2815	563	0	38094
ASHP Electricity consumption (d/a)	kWh/ day	0	0	0	61	163	263	255	231	173	94	18	0	-
PV Electricity production (e)	kWh/ mth	2096	1814	1467	958	543	398	450	768	1473	1958	2219	2190	16335
PV surplus after self-consumption (f=e-d)	kWh/ mth	2096	1814	1467	-931	-4337	-7753	-7468	-5762	-3874	-857	1656	2190	9223
PV surplus % (f/e x 100)	%	100	100	100	0	0	0	0	0	0	0	75	100	56
PV Surplus (average day in month)	kWh/ day	67	59	49	0	0	0	0	0	0	0	53	73	-

Table 5 - PV surplus calculations.

Battery

Battery storage provides two primary advantages:

1. Surplus energy from the PV-array can be stored.
2. The battery can be charged from the grid at off-peak times.

TES and EES batteries were mentioned in section 2. This application is space heating only which makes TES less attractive as its energy can only feed the heating system at a 1:1 ratio, where 1 kWh stored energy gives 1 kWh heat energy. Electrical energy powering an ASHP can provide a ratio of up to 1:5 making this a more energy dense solution and therefore the solution discussed here.

Dimensioning

Figure 28 looks at the daily energy flow for the ASHP and PV-array, based on the average monthly temperature's COP-value. The small PV-array is out of phase with heating demand so most production can be exported. When ASHP demand is high the PV meets only a fraction of this demand with no surplus to charge the battery. Instead, the battery has been considered for peak shaving – selling at peak times and buying at off-peak times. This is discussed in the financial section.

			jul	aug	sep	okt	nov	dec	jan	feb	mar	apr	maj	jun
PV daily surplus to battery		kWh/day	68	59	49	0	0	0	0	0	0	0	53	73
Daily Off-peak purchase from grid to battery		kWh/day	0	0	0	-30	-145	-250	-241	-204	-125	-29	0	0

Figure 28 - Heatmap for daily surplus stored in a battery or electricity purchased off-peak to store in battery.

Financial

ASHP and PV

An ASHP reduces the energy bill to approximately £9700 yr^{-1}. Adding an 18 kWp PV-array system reduces this to approximately £7900, utilising the Smart Export Guarantee, SEG. 'Small-scale low-carbon generators receive payment for any electricity they export to the grid' [28] and includes PV-installations up to 5 MW, such as this one. Consumer advice website *Which?* [29] identifies Octopus energy Flux scheme as offering the best SEG tariff, with an average of 21 p kWh [1]. This has been used for calculations.

Month	PV generation (kWh)	Electricity consumption ASHP (kWh)	Electricity imported after PV (kWh)	Electricity exported after PV (kWh)	Export credit (£)	Electricity cost before solar (£)	Electricity cost after solar (£)	Estimated savings (£)
Jan	450	7918	7468	0	0	2013	1898	114
Feb	768	6530	5762	0	0	1660	1465	195
Mar	1473	5348	3875	0	0	1359	985	374
Apr	1958	2815	857	0	0	716	218	498
May	2219	563	0	1656	348	143	0	143
Jun	2190	0	0	2190	460	0	0	0
Jul	2096	0	0	2096	440	0	0	0
Aug	1814	0	0	1814	381	0	0	0
Sep	1467	0	0	1467	308	0	0	0
Oct	958	1889	931	0	0	480	237	244
Nov	543	4880	4337	0	0	1240	1102	138
Dec	398	8151	7753	0	0	2072	1971	101
Total	**16334**	**38094**	**30983**	**9223**	**1937**	**9683**	**7876**	**1808**

Table 6 - Estimated energy bill savings with an 18 kWp PV-array.

The RE-technology described requires investment. Regrettably, the Boiler Upgrade Scheme grant of £7500 [30] is not available for ASHP installations above 45 kWth, although at the time of writing it is unclear whether the five 14 kW ASHPs discussed could be treated as individual units and qualify for the grant.

Firstly the ROR or average rate of return is shown below. With a loan of £69 500 an interest rate of 4.5 % or less is required to generate a positive ROR.

ROR - Average annual rate of return		Calculation step
Loan interest rate	4.5 %	-
Project lifetime (L)	20 yrs	
Initial investment (loan) (I)	£69 500	-
Net cash flow (NCF)	£ 2635	-
Annual average proceeds (AAP)	£132	NCF/L
Return on initial investment	0.2 %	AAP/I

Table 7 - ROR calculation for a 70 kW ASHP and 18 kWp PV-Array.

The calculation assumptions are:

Item	Cost	Comment
ASHP	£38 500	Based on price indication from *DS Refrigeration* [31] and *Saturn Sales* [32] plus an additional 10 % of price for installation.
PV-Array	£31 000	Based pro rate on quote provided by Green Squirrel Energy Ltd (appendix E).
Total cost	**£69 500**	
Life span of equipment	20	
Annual Operation & Maintenance	£150	

Table 8 - ROR calculation investment assumptions.

PV-array max capacity	18	kW_p
PV production	16335	kWh yr^{-1}
PV self-consumption	7110	kWh yr^{-1}
PV surplus	9225	kWh yr^{-1}
Smart Export Guarantee (SEG)	£0.21	kWh^{-1}
Electricity tariff	£0.25	kWh^{-1}
Total export revenue SEG	£1 937	yr^{-1}
Value of kWh saving	£1 807	yr^{-1}
Degradation of PV output	1.00	% yr^{-1}
Total initial income	**£3 744.61**	yr^{-1}

Table 9 - PV-array performance assumptions for financial calculations.

The Net Present Value, NPV, of this investment is £2000 at a discount rate of 10 %.

Year	Income (a)	NPV 5 % DR (b)	NPV 10 % DR (c)	NPV 15 % DR (d)	Expenditure (e)	NPV 5 % DR (f)	NPV 10 % DR (g)	NPV 15 % DR (h)
0	£69 500.00	£69 500.00	£69 500.00	£69 500.00	-£69 500.00	-£69 500.00	-£69 500.00	-£69 500.00
1	£3 744.61	£3 566.30	£3 404.19	£3 256.18	-£3 277.58	-£3 121.51	-£2 979.62	-£2 850.07
2	£3 707.17	£3 362.51	£3 063.77	£2 803.15	-£3 277.58	-£2 972.86	-£2 708.74	-£2 478.32
3	£3 670.09	£3 170.37	£2 757.40	£2 413.15	-£3 277.58	-£2 831.30	-£2 462.49	-£2 155.06
4	£3 633.39	£2 989.20	£2 481.66	£2 077.40	-£3 277.58	-£2 696.47	-£2 238.63	-£1 873.97
5	£3 597.06	£2 818.39	£2 233.49	£1 788.37	-£3 277.58	-£2 568.07	-£2 035.12	-£1 629.54
6	£3 561.09	£2 657.34	£2 010.14	£1 539.56	-£3 277.58	-£2 445.78	-£1 850.11	-£1 416.99
7	£3 525.48	£2 505.49	£1 809.13	£1 325.36	-£3 277.58	-£2 329.32	-£1 681.92	-£1 232.16
8	£3 490.22	£2 362.32	£1 628.21	£1 140.96	-£3 277.58	-£2 218.40	-£1 529.02	-£1 071.45
9	£3 455.32	£2 227.33	£1 465.39	£982.22	-£3 277.58	-£2 112.76	-£1 390.01	-£931.69
10	£3 420.77	£2 100.05	£1 318.85	£845.56	-£3 277.58	-£2 012.15	-£1 263.65	-£810.17
11	£3 386.56	£1 980.05	£1 186.97	£727.92	-£3 277.58	-£1 916.33	-£1 148.77	-£704.49
12	£3 352.69	£1 866.91	£1 068.27	£626.64	-£3 277.58	-£1 825.08	-£1 044.34	-£612.60
13	£3 319.17	£1 760.23	£961.44	£539.46	-£3 277.58	-£1 738.17	-£949.40	-£532.70
14	£3 285.98	£1 659.64	£865.30	£464.40	-£3 277.58	-£1 655.40	-£863.09	-£463.22
15	£3 253.12	£1 564.80	£778.77	£399.79	-£3 277.58	-£1 576.57	-£784.63	-£402.80
16	£3 220.58	£1 475.39	£700.89	£344.17	-£3 277.58	-£1 501.50	-£713.30	-£350.26
17	£3 188.38	£1 391.08	£630.80	£296.28	-£3 277.58	-£1 430.00	-£648.45	-£304.57
18	£3 156.50	£1 311.59	£567.72	£255.06	-£3 277.58	-£1 361.90	-£589.50	-£264.85
19	£3 124.93	£1 236.64	£510.95	£219.57	-£3 277.58	-£1 297.05	-£535.91	-£230.30

20	£3 093.68	£1 165.98	£459.86	£189.02	-£3 277.58	-£1 235.29	-£487.19	-£200.26
Total	£137 686.79	£112 671.60	£99 403.22	£91 734.23	-£135 051.62	-£110 345.90	-£97 403.89	-£90 015.46
	(a)-(e)	**(b)-(f)**	**(c)-(g)**	**(d)-(h)**				
Net	**£2 635.17**	**£2 325.70**	**£1 999.33**	**£1 718.77**				

Table 10 - 20-year NPV calculations for 70 kW ASHP and 18 kWp PV-array.

Like the ROR-calculation, the NPV indicates that the projected income will exceed the costs over the 20-year project lifetime, when calculated in today's money.

Battery

Optimal peak shaving (figure 29) with a battery gives a positive cashflow.

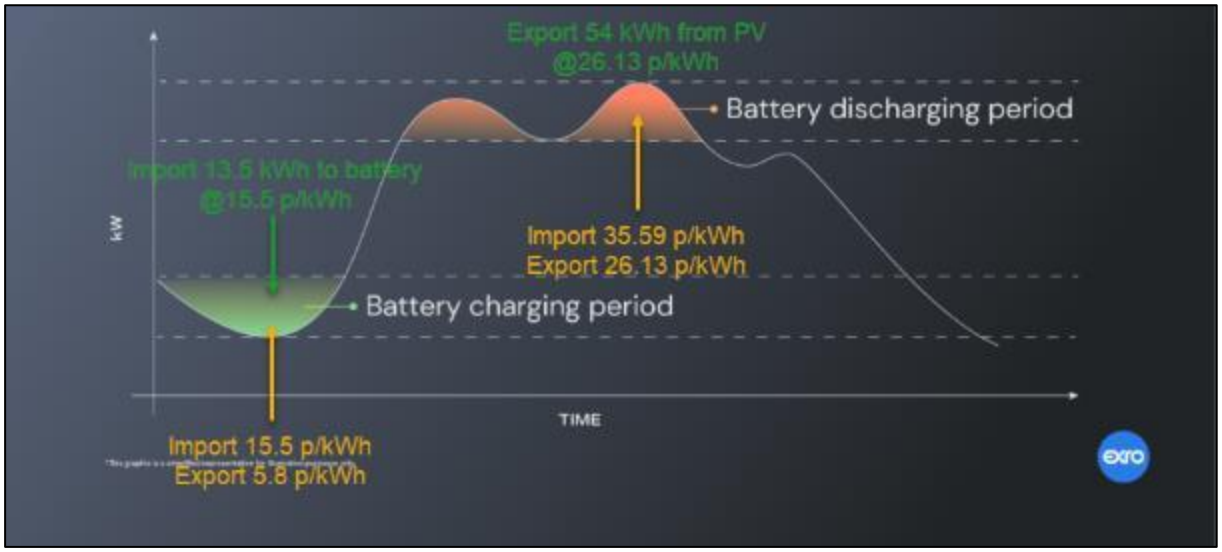


Figure 29 - The principles of peak shaving, with a PV-array and battery (Tesla Powerwall 2).
Source: Background image: https://www.exro.com/industry-insights/peak-shaving

ROR - Average annual rate of return		Calculation step
Loan interest rate	5 %	-
Project lifetime (L)	10 yrs	
Initial investment (loan) (I)	£5 800*	-
Net cash flow (NCF)	£ 20 900	-
Annual average proceeds (AAP)	£2 090	NCF/L
Return on initial investment	56 %	AAP/I

Table 11 - ROR for investing in a Tesla Power wall for peak shaving.
***Price of one Powerwall 2 from Tesla's website** [33].

Year	Income (a)	NPV 5 % DR (b)	NPV 10 % DR (c)	NPV 15 % DR (d)	Expenditure (e)	NPV 5 % DR (f)	NPV 10 % DR (g)	NPV 15 % DR (h)
0	£5 800	£5 800	£5 800	£5 800	-£5 800	-£5 800	-£5 800	-£5 800
1	£2 348	£2 236	£2 134	£2 041	-£261	-£249	-£237	-£227
2	£2 348	£2 129	£1 940	£1 775	-£261	-£237	-£216	-£197
3	£2 348	£2 028	£1 764	£1 544	-£261	-£225	-£196	-£172
4	£2 348	£1 931	£1 603	£1 342	-£261	-£215	-£178	-£149
5	£2 348	£1 839	£1 458	£1 167	-£261	-£205	-£162	-£130
6	£2 348	£1 752	£1 325	£1 015	-£261	-£195	-£147	-£113
7	£2 348	£1 668	£1 205	£883	-£261	-£185	-£134	-£98

8	£2 348	£1 589	£1 095	£767	-£261	-£177	-£122	-£85
9	£2 348	£1 513	£996	£667	-£261	-£168	-£111	-£74
10	£2 348	£1 441	£905	£580	-£261	-£160	-£101	-£65
Total	**£29 276**	**£23 928**	**£5 800**	**£17 582**	**-£8 410**	**-£7 815**	**-£7 404**	**-£7 110**
	(a)-(e)	(b)-(f)	(c)-(g)	(d)-(h)				
Net	**£20 865,93**	**£16 112,12**	**-£1 603,77**	**£10 472,13**				

Table 12 - 10-year NPV calculations for a 13.5 kW Tesla Powerwall for peak shaving.

Carbon footprint

Figure 29 shows that CO_2-emissions reduce to 6.8 tonnes yr^{-1} with the technology discussed, saving 37.2 tonnes yr^{-1}. Adding battery storage does not change CO_2-emissions.

Offsetting the rest as the Church of England recommends in their guide *A practical path to "net zero carbon" for our churches* [34] may be possible through schemes such as *Climate Stewards*. A quick calculation using their offset-calculator [35] suggests that this could cost about £200 yr^{-1} for the 30894 $kWh_{net.}$

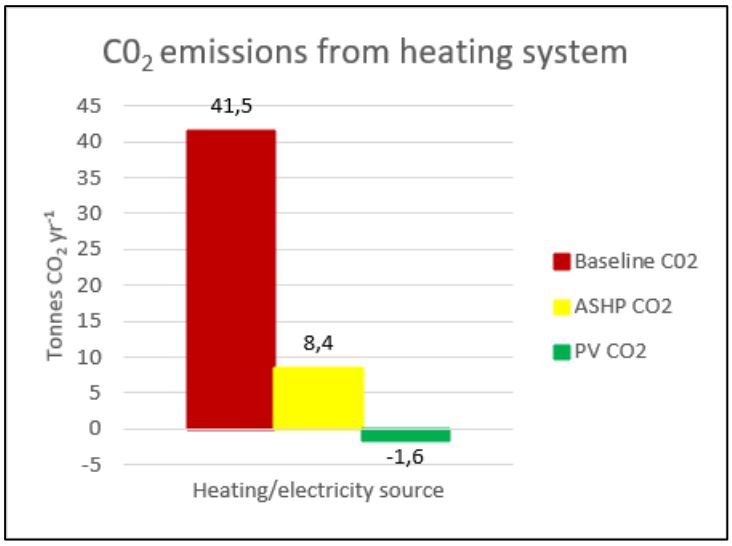


Figure 30 - Visualising the CO2 reduction from replacing a gas boiler with an ASHP and PV-array.

Section 4: Conclusions and recommendations

Conclusions

The aim of this report was to assess the feasibility of renewable energy technologies for installation in St. Andrew's Church, and help the church reach its net-zero goal by 2030. The current gas boiler and electric heaters have exceeded their technical lifetime and together consume approximately 230 000 kWh yr^{-1} releasing over 45 tonnes of CO_2. The report established a net space heating demand of 152 881 kWh yr^{-1}.

In section 2, PV, geothermal, batteries, biomass and wind power technologies were evaluated to see if they could first meet the demand but also if they were practicable. Geothermal in the form of an ASHP, PV and batteries were deemed the most suitable and further analysed, both technically and financially in section 3. Table 13 summarises section 3's performance calculations.

Technology	Production (kWh yr-1)	Consumption (kWh yr-1)	CO_2 emission (tonnes yr^{-1})
ASHP	-	3000	8.4
PV - production	16000	-	0
PV - saving	-	-7111	-1.6
Battery	0	0	0

Table 13 – Summary of the carbon emission reductions from the researched technologies

Financially, the project is viable but has a low net present value (NPV), return on initial investment and net cash flow. This should be acceptable to the PCC as the goal is net-zero driven and not profit driven. The PCC has not expressed a desired discount rate so 5, 10 and 15 % are presented. This is summarised below.

ROR - Average annual rate of return		Calculation step
Loan interest rate	4.5 %	-
Project lifetime (L)	20 yrs	-
Initial investment (loan) (I)	£69 500.00	-
Net cash flow (NCF)	£ 2635.17	-
Annual average proceeds (AAP)	£131.76	NCF/L
Return on initial investment	0.2 %	AAP/I

Table 14 - ROR for investing in a 70 kW ASHP and 18 kWp PV-array.

Income (a)	NPV 5 % DR (b)	NPV 10 % DR (c)	NPV 15 % DR (d)	Expenditure (e)	NPV 5 % DR (f)	NPV 10 % DR (g)	NPV 15 % DR (h)
£137 686.79	£112 671.60	£99 403.22	£91 734.23	-£135 051.62	-£110 345.90	-£97 403.89	-£90 015.46
Net							
(a)-(e)	**(b)-(f)**	**(c)-(g)**	**(d)-(h)**				
£2 635.17	**£2 325.70**	**£1 999.33**	**£1 718.77**				

Table 15 - NPV for investing in a 70 kW ASHP and 18 kWp PV-array.

ROR - Average annual rate of return		Calculation step
Loan interest rate	5 %	-
Project lifetime (L)	10 yrs	
Initial investment (loan) (I)	£5 800	-
Net cash flow (NCF)	£ 20 900	-
Annual average proceeds (AAP)	£2 090	NCF/L
Return on initial investment	56 %	AAP/I

Table 16 - ROR for investing in a Tesla Power wall for peak shaving.

Total	**£29 276**	**£23 928**	**£5 800**	**£17 582**	**-£8 410**	**-£7 815**	**-£7 404**	**-£7 110**
	(a)-(e)	(b)-(f)	(c)-(g)	(d)-(h)				
Net	**£20 865,93**	**£16 112,12**	**-£1 603,77**	**£10 472,13**				

Table 17 - 10-year NPV calculations for a 13.5 kW Tesla Powerwall for peak shaving.

Recommendations

5. Phase 1 - Install a 70 kW ASHP to meet the space heating requirements.
6. Phase 2 - Install an 18 kWp PV-array on the south-facing church roof.
7. Phase 3 – Offset the remaining carbon emissions through a scheme such as that mentioned in section 3 under *Carbon Footprint*.
8. Phase 4 – Investigate peak shaving by installing an EES-battery, and changing to a flexible tariff, such as Octopus Flux scheme [1] that has a high SEG-tariff.

If funding via a loan, the interest rate should be below 4.5 %.

Changing from gas to ASHP reduces the overall heating load, removes the dependency on fossil fuels but does dramatically increase electricity consumption. However this is partially offset by the relatively small PV-array and can be further offset by peak-shifting combing a suitable EES battery with a suitable tariff. PV-array combined with batteries has a limited effect in reducing CO_2-emission but can improve the projects cash-flow.

Appendix A – Estimating the church's dimensions

(All measurements in meters)						
Name	***w***	***b***	***h***	A_{floor}	***V***	
Vestry lower	6,1	4,4	1,8	26,8	48,3	
Vestry upper	6,1	4,4	4,0	26,8	107,4	
Bell tower	5,4	4,0	9,4	21,6	202,0	
Nave (without rafters inc. alter)	22,0	6,5	7,9	143,0	1129,7	
Alter	3,5	5,5	7,9	19,3	152,1	
Side aislse N (to lower edge sloping roof)	22,0	4,8	4,5	104,5	470,3	
Side aislse S (to lower edge sloping roof)	22,0	4,8	4,5	104,5	470,3	
Additional volume in nave ceiling	25,5	3,3	1,9		159,9	1/2*b* x *h*
Additional volume in side aisle N ceiling	22,0	2,4	1,9		100,3	1/2*b* x *h*
Additional volume in side aisle S ceiling	22,0	2,4	1,9		100,3	1/2*b* x *h*
			A_{tot}	446,5		
				V_{tot}	2940,4	m^3
Roof area						
Bell tower	6,6	7,0	-	46,2		
Nave/Alter (x2 both sides of pitched roof)	25,5	4,5	-	114,8		
Side aisle N	15,9	6,0	-	95,4		
Side aisle S	22,0	6,0	-	132,0		
Vestry (x2 both sides of pitched roof)	9,4	4,6	-	43,2		
			A_{tot}	589,6	m^2	

Wall area				Triangular element	A_{wall}	
Side aisle S wall E	4,8	-	4,5	9,1	30,7	
Side aisle S wall S	22,0	-	4,5		99,0	
Side aisle S wall W	4,8		4,5	4,6	26,2	
Alter wall N	3,4		8,2		27,9	
Alter wall E	6,6		8,6	12,5	69,3	
Alter wall S	3,4		8,2		27,9	
Vestry wall N	7,2		6,5	5,8	52,6	
Vestry wall E	9,9		6,5		64,4	
Side aisle N wall N	14,8		4,5		66,6	
Side aisle N wall W	4,8		4,5	4,6	26,2	
Bell tower wall N	7,0		9,4		65,8	
Bell tower wall W	6,6		9,4		62,0	
Bell tower wall S	7,0		9,4		65,8	
Nave wall N	22,0		1,7		37,4	
Nave wall S	22,0		1,7		37,4	
				$A_{wall(tot)}$	759,1	m^2
Window/door area						
Door S	1,7		2,4	4,0		
Window S	1,8		2,0	3,6		
Window S	1,8		2,0	3,6		
Window S	2,5		2,0	5,0		
Window S	2,5		2,0	5,0		
Window S (small windows x7)	1,2		0,9	1,1		
Bell tower door	1,5		2,0	3,0		
Window W	2,2		2,0	4,4		
Window W	2,5		2,0	5,0		
Bell tower window	2,5		3,9	9,8		
Windows N (small windows x7)	1,2		0,9	1,1		
Vestry window N	3,3		3,5	11,6		
Alter window E	3,4		4,7	16,0		
Window Vestry E	3,2		2,9	9,3		
Window E	2,9		2,3	6,7		
			$A_{window(tot}$	102,0		
Other windows facing out to extension have been excluded.						

Appendix B – COP-value calculations

COP – Coefficient of performance

To calculate theoretical COP-values it is first necessary to calculate theoretical outlet temperatures, *T_sink*, for the range of expected outside air temperatures, *T_ambient*. Equation (1) describes this for an ASHP combined with radiators:

$$T_sink = 40\,°C - T_ambient \quad (1)$$

This comes from a detailed study of COP values across Europe in *Time series of heat demand and heat pump efficiency for energy system modelling* [26]. Their research shows that theoretical COP-values can be calculated for different operating conditions using the following formula, where ΔT is the difference between the *T_sink* and *T_ambient*:

$$COP = 6.08 - 0.09\Delta T + 0.0005\Delta T\text{^}2 \quad (2)$$

Outside Air Temp (*T_ambient*)	T_sink (heating flow temp)	ΔT *(T_sink-T_ambient)*	COP (Carnot)	COP (Ruhnau)	Mitsubishi R32 Ecodan data sheet
-3	43	46	6.87	3.00	2.1
-2	42	44	7.16	3.09	
-1	41	42	7.48	3.18	
0	40	40	7.83	3.28	
1	39	38	8.21	3.38	
2	38	36	8.64	3.49	2.75
3	37	34	9.12	3.60	
4	36	32	9.66	3.71	
5	35	30	10.27	3.83	
6	34	28	10.96	3.95	
7	33	26	11.77	4.08	4.25
8	32	24	12.71	4.21	
9	31	22	13.82	4.34	
10	30	20	15.15	4.48	
11	29	18	16.78	4.62	
12	28	16	18.81	4.77	5.25
13	27	14	21.43	4.92	
14	26	12	24.92	5.07	
15	25	10	29.80	5.23	5.35

Table B - Calculated heating flow temperatures and COP-values.

The following Excel™ formula was used to interpolate from the table :

=GROWTH(known_y's, [known_x's], [new_x's])
=GROWTH(Known COP-values, [Known OAT], Mean temperature for month)

For comparison, COP-values calculated using Carnot's theorem - theoretical performance of a perfect heat pump without losses from friction or insulation – are shown. 'The theoretical Carnot heat engine is […] completely reversible […] supplying work and extracting heat' [10, p. 44] thus:

$$COP = \frac{Q_1}{(Q_1 - Q_2)} \quad (7)$$

Where Q_1 is the flow of heat from the 'engine' and Q_2 the flow of 'unused' heat returning to the 'engine'. Q_1 and Q_2 can be replaced with T_1, the input temperature, T_2, the return temperature, retaining the same ratio, thus:

$$COP = \frac{Q_1}{(Q_1 - Q_2)} = \frac{T_1}{(T_1 - T_2)} \quad (8)$$

Appendix C – ASHP annual energy consumption calculations

House heat loss and space heating demand		Jul	Aug	Sep	Okt	Nov	Dec	Jan	Feb	Mar	Apr	Maj	Jun
Month index m		1	2	3	4	5	6	7	8	9	10	11	12
Gross space heating loss	kWh/day	0	0	0	327	708	1024	1002	936	762	490	174	0
Free heat gains	kWh/day	15	15	15	15	15	15	15	15	15	15	15	15
Useful free heat gains	kWh/day	0	0	0	15	15	15	15	15	15	15	15	0
Total useful free heat gains	kWh/yr	**3650**											
Mean temperature	°C	16,8	16,6	14,3	11,0	7,5	4,6	4,8	5,4	7,0	9,5	12,4	15,1
Window solar transmittance (inc.frame)		0,50											
Solar gains	kWh/day	71	61	48	30	19	13	14	24	44	61	72	71
Useful solar gains	kWh/day	0	0	0	30	19	13	14	24	44	61	72	0
Total useful solar gains	kWh/yr	**8407**											
Net space heating demand	kWh/day	0	0	0	281	674	995	973	897	704	414	88	0
Annual total net space heating H_{daily}	kWh/yr	**152881**											
Days per month N		31	31	30	31	30	31	31	28,25	31	30	31	30
Estimated COP COP_{int}		5,5	5,5	5,1	4,6	4,1	3,8	3,8	3,9	4,1	4,4	4,8	5,2
ASHP Electricity consumption	kWh/mth	0	0	0	1889	4880	8151	7918	6530	5348	2815	563	0
ASHP Electricity consumption (ave day in mth)	kWh/day	0	0	0	60,93	162,7	262,9	255,4	231,2	172,5	93,849	18,152	0
Daily standing charge for Octopus Flux scheme 0,6497	£ day	0	0	0	20,14	19,49	20,14	20,14	18,35	20,141	19,491	20,141	0
Annual standing charge for Octopus Flex scheme													£158,04
Annual electricty consumption	kWh/yr												**38094**

$$\sum_{m=1}^{12} m = \frac{(H_{daily} \times N)}{COP_{int}}$$

Please note that a decimal comma instead of point is shown as the author's operating system/locale is Swedish/Sweden.

To calculation for the annual space heating demand is the sum of the daily net space heating demand, H_{daily}, multiplied by the number of days in the month, N, divided by the COP-value for the average monthly temperature, COP_{int}. COP-values were calculated at 1 °C intervals, so interpolation was used to find values between these intervals. This is expressed mathematically as:

$$\sum_{m=1}^{12} m = \frac{(H_{daily} \times N)}{COP_{int}} \quad (9)$$

Appendix D – Performance of grid-connected PV from PVGIS database.

European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

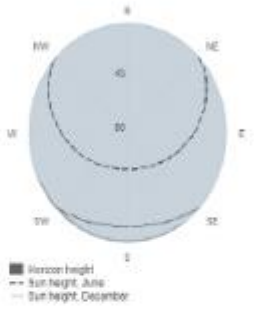
Provided inputs:

Latitude/Longitude:	
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed:	18 kWp
System loss:	14 %

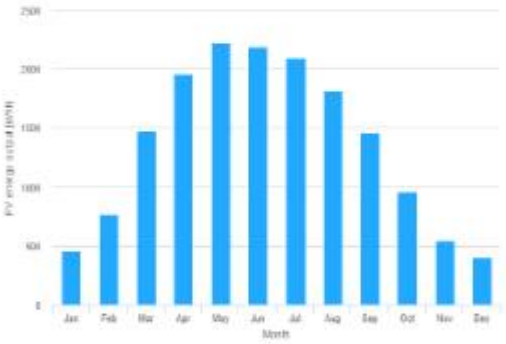
Simulation outputs

Slope angle:	21 °
Azimuth angle:	0 °
Yearly PV energy production:	16334.61 kWh
Yearly in-plane irradiation:	1150.97 kWh/m²
Year-to-year variability:	504.87 kWh
Changes in output due to:	
Angle of incidence:	-3.69 %
Spectral effects:	1.65 %
Temperature and low irradiance:	-6.36 %
Total loss:	-21.16 %
PV electricity cost [per kWh]:	0.258 per kWh

Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	450.4	31.1	63.0
February	767.7	51.9	123.9
March	1473.1	100.2	93.2
April	1956.3	136.6	246.2
May	2219.0	156.4	195.9
June	2190.4	158.2	196.6
July	2096.3	152.0	220.4
August	1814.0	129.6	116.6
September	1467.3	103.5	121.0
October	957.9	66.3	110.0
November	542.5	37.6	89.1
December	397.6	27.6	60.4

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

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Report generated on 2024/05/09

Appendix E – ROR calculations

Year	Income	Loan Repayment 4.5 %	O&M Costs	Net income
0	£0.00	£0.00	£0.00	£0.00
1	£3 744.61	-£3 127.58	-£150.00	£467.03
2	£3 707.17	-£3 127.58	-£150.00	£429.59
3	£3 670.09	-£3 127.58	-£150.00	£392.51
4	£3 633.39	-£3 127.58	-£150.00	£355.81
5	£3 597.06	-£3 127.58	-£150.00	£319.48
6	£3 561.09	-£3 127.58	-£150.00	£283.51
7	£3 525.48	-£3 127.58	-£150.00	£247.90
8	£3 490.22	-£3 127.58	-£150.00	£212.64
9	£3 455.32	-£3 127.58	-£150.00	£177.74
10	£3 420.77	-£3 127.58	-£150.00	£143.19
11	£3 386.56	-£3 127.58	-£150.00	£108.98
12	£3 352.69	-£3 127.58	-£150.00	£75.11
13	£3 319.17	-£3 127.58	-£150.00	£41.59
14	£3 285.98	-£3 127.58	-£150.00	£8.39
15	£3 253.12	-£3 127.58	-£150.00	-£24.46
16	£3 220.58	-£3 127.58	-£150.00	-£57.00
17	£3 188.38	-£3 127.58	-£150.00	-£89.20
18	£3 156.50	-£3 127.58	-£150.00	-£121.09
19	£3 124.93	-£3 127.58	-£150.00	-£152.65
20	£3 093.68	-£3 127.58	-£150.00	-£183.90
Total	**£68 186.79**	**-£62 551.62**	**-£3 000.00**	**£2 635.17**

Appendix F – Quote for PV system from Green Squirrel Energy Ltd

Recommended System Option

31.82 kW	£3,604	£54,088	£54,088
System Size	Estimated Annual Electricity Bill Savings	Total System Price	Net System Price

Your Solution

Solar Panels
Suntech
31.820 kW Total Solar Power
74 x 430 Watt Panels (STP430S-B72/Pnh+)
27,901 kWh per year

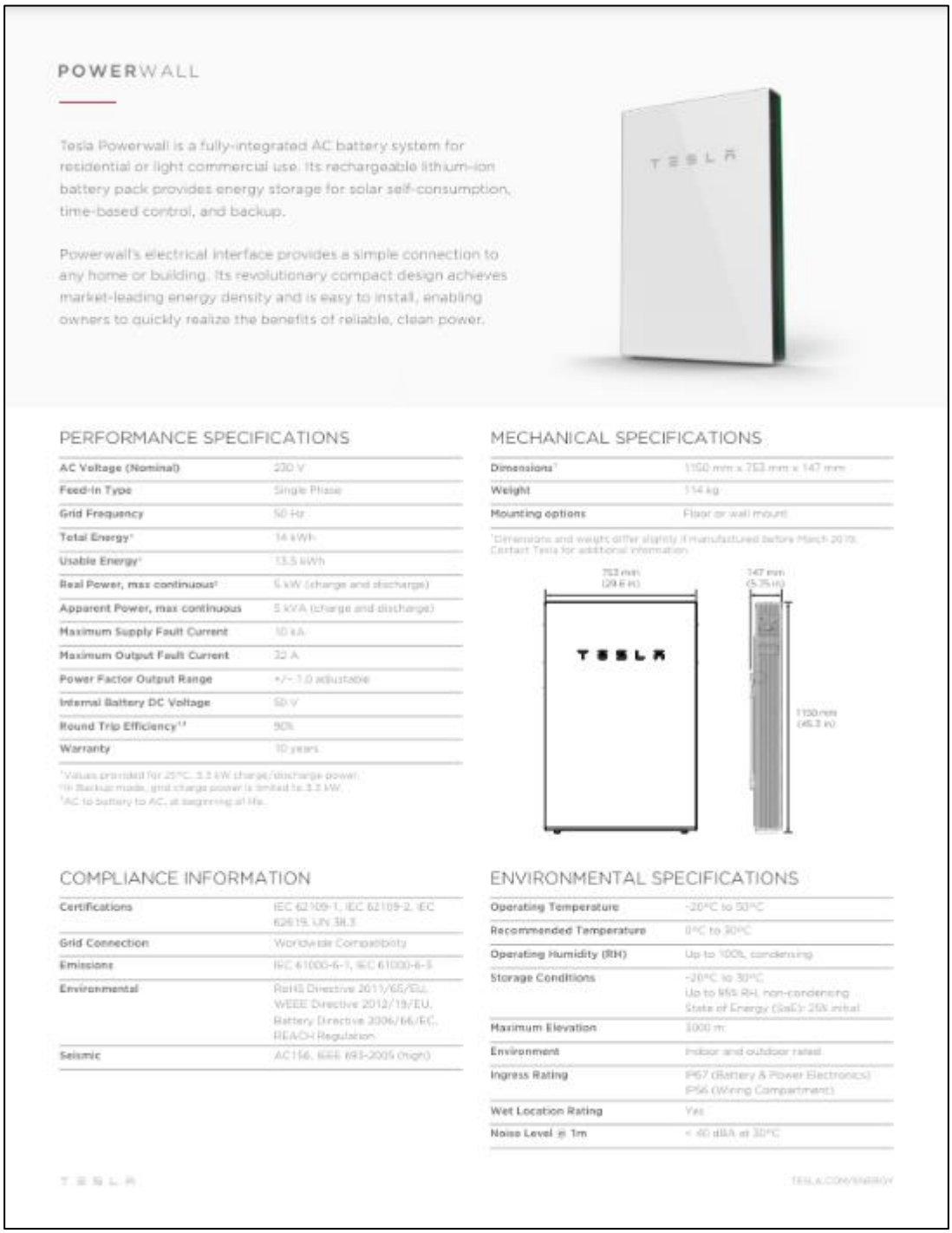
Inverter
AlphaESS
30 kW Total Inverter Rating
1 x STORION-H30-INV

Battery
AlphaESS
62.208 kWh Total Battery Storage
9 x STORION-H30-BAT-M7790-S1C

Warranties: 12 Year Panel Product Warranty, 30 Year Panel Performance Warranty, 5 Year Inverter Product Warranty

Green Squirrel energy - hello@greensquirrelenergy.co.uk - hello@greensquirrelenergy.co.uk - 01925564281 Page 2 / 12

Appendix G – Peak shaving with a Tesla Power wall 2



POWERWALL

Tesla Powerwall is a fully-integrated AC battery system for residential or light commercial use. Its rechargeable lithium-ion battery pack provides energy storage for solar self-consumption, time-based control, and backup.

Powerwall's electrical interface provides a simple connection to any home or building. Its revolutionary compact design achieves market-leading energy density and is easy to install, enabling owners to quickly realize the benefits of reliable, clean power.

PERFORMANCE SPECIFICATIONS

AC Voltage (Nominal)	230 V
Feed-in Type	Single Phase
Grid Frequency	50 Hz
Total Energy*	14 kWh
Usable Energy*	13.5 kWh
Real Power, max continuous*	5 kW (charge and discharge)
Apparent Power, max continuous	5 kVA (charge and discharge)
Maximum Supply Fault Current	10 kA
Maximum Output Fault Current	32 A
Power Factor Output Range	+/- 1.0 adjustable
Internal Battery DC Voltage	50 V
Round Trip Efficiency*†	90%
Warranty	10 years

*Values provided for 25°C, 3.3 kW charge/discharge power.
†In Backup mode, grid charge power is limited to 3.3 kW.
‡AC to battery to AC, at beginning of life.

MECHANICAL SPECIFICATIONS

Dimensions*	1150 mm x 753 mm x 147 mm
Weight	114 kg
Mounting options	Floor or wall mount

*Dimensions and weights differ slightly if manufactured before March 2019. Contact Tesla for additional information.

COMPLIANCE INFORMATION

Certifications	IEC 62109-1, IEC 62109-2, IEC 62619, UN 38.3
Grid Connection	Worldwide Compatibility
Emissions	IEC 61000-6-1, IEC 61000-6-3
Environmental	RoHS Directive 2011/65/EU, WEEE Directive 2012/19/EU, Battery Directive 2006/66/EC, REACH Regulation
Seismic	AC156, IEEE 693-2005 (high)

ENVIRONMENTAL SPECIFICATIONS

Operating Temperature	-20°C to 50°C
Recommended Temperature	0°C to 30°C
Operating Humidity (RH)	Up to 100%, condensing
Storage Conditions	-20°C to 30°C Up to 95% RH, non-condensing State of Energy (SoE): 25% initial
Maximum Elevation	3000 m
Environment	Indoor and outdoor rated
Ingress Rating	IP67 (Battery & Power Electronics) IP56 (Wiring Compartment)
Wet Location Rating	Yes
Noise Level @ 1m	< 40 dBA at 30°C

TESLA.COM/ENERGY

Full datasheet available at: https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall%202_AC_Datasheet_en_AU.pdf

Assumptions

-Battery charges at maximum 5 kW rate for 3 hours.
-Export to grid is at capacity, 18 kW for 3 hours.
-No losses have been accounted for in calculations.
-No degradation of the battery has been included in the calculation.

Octopus Energy Flux scheme			Tariff (£ kWh^{-1})	
	Time	**No of hrs**	**Import**	**Export**
Flux rate	02:00-05:00	3	-0.1525	0.058
Peak rate	16:00-19:00	3	-0.3559	0.2613
Current rate	00:00-23:59	24	-0.25	0.21
Tesla power wall				
Capacity	13.5	kWh		
DoD	100	%		
Charge capacity	5	kW		
Discharge capacity	5	kW		
PV kWp	18	kW		

Table 18 - Technical assumptions for peak shaving calculations.

Figure 31 - Octopus Energy Flux scheme tariffs for WA4 3EP.
Source: https://octopus.energy/smart/flux/

Month		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
days in mth		31	31	30	31	30	31	31	28	31	30	31	30	
Grid Demand (day)	kWh/ day	0	0	0	61	163	263	255	231	173	94	18	0	
PV surplus	kWh/ day	68	59	49	0	0	0	0	0	0	0	53	73	
Baseline														
Import		£0	£0	£0	-£15	-£41	-£66	-£64	-£58	-£43	-£23	-£5	£0	
Export		£14	£12	£10	£0	£0	£0	£0	£0	£0	£0	£11	£15	
Month		£440	£381	£308	-£472	-£1 220	-£2 038	-£1 980	-£1 633	-£1 337	-£704	£207	£460	
Import day														
Import flux		£0	£0	£0	-£2	-£2	-£2	-£2	-£2	-£2	-£2	-£2	£0	
Import peak		£0	£0	£0	-£5	-£5	-£5	-£5	-£5	-£5	-£5	-£5	£0	
Saving day		£0	£0	£0	£3	£3	£3	£3	£3	£3	£3	£3	£0	
Saving month		£0	£0	£0	£85	£82	£85	£85	£78	£85	£82	£85	£0	
Export flux		£3	£3	£3	£0	£0	£0	£0	£0	£0	£0	£3	£3	
Export peak		£14	£14	£14	£0	£0	£0	£0	£0	£0	£0	£14	£14	
Profit day		£11	£11	£11	£0	£0	£0	£0	£0	£0	£0	£11	£11	
Profit month		£340	£340	£329	£0	£0	£0	£0	£0	£0	£0	£340	£329	
Baseline														-£7 586
Flux import savings														£668
Peak export profit														£1 680
New Annual cost														-£5 239
Saving														£2 348

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