CLPM

CONSTRUCTION PROJECT CONSULTANCY

# Sustainability Review and Thermal Modelling for House near Krakow, Poland.

March 2019; Final Draft 1.5

# Sustainability Review and Thermal Modelling for House near Krakow, Poland.

## Contents



This document reports on sustainability, insulations, heating & ventilating a refurbished two storey house in Poland. It describes the results of thermal model runs estimating annual energy usage and peak heating load for the different configurations of the building. A general review of related issues, around the heating system, MVHR and how water is also included. Further work on the heating and electrical systems is also covered.

| | |
|---|---|
| Author | A Duffin, R Bohm |
| Approved | |
| Version Control | Full Draft 1.5; amends after comments, then addition of sections with block diagrams and DC Electrical etc. Final comments. |
| Date | March 2019 |

# Introduction

This report discusses sustainability of the refurbished two storey house in Poland about 50 km as the crow flies from Krakow. It presents the findings of work on the thermal performance and aims especially to reduce energy consumption and optimise the choice of heating system. The overall aims of the work are to help the client to design and build a house which has very low energy consumption and then to assist in the selection of the right heating system. Other aspects of the work include commenting on the MVHR, assisting with information on DC electrical systems and some 'future proofing' for solar PV.

The report describes the thermal model results giving estimates of annual energy usage and peak heating load for different insulations and air tightness. This allows consideration of the benefits gained by the different insulation packages, energy consumption and the sizing of the heating system in turn allowing a choice to be made of the technology.

Mechanical Ventilation with Heat Recovery is discussed because the analysis confirms that air tightness is the key to getting very low energy performance.

## *The Project*

The house is about 200 $m^2$ and over two storeys. It is located at: Lat 49°46'57.64"N, Long 20°31'34.37"E. It is partly a refurbishment of existing buildings and partly new build / extension. It has 3 bedrooms one of which has ensuite facilities. There is a large lounge, dining area and kitchen on the ground floor as well as a TV room, utility room and a pantry.

The aim is to have very well insulated walls, floor and roof as well as good air tightness. Windows are to be triple glazed.

The house is in a clear area of pasture within wooded countryside in rolling hills and at an altitude of about 480m. The aim is to install a wood stove for hot water and later on a Ground Source Heat Pump. It is planned to install solar PV in the future with a battery store likely to be included. A DC electric ring is also being planned. The site is served by electricity with water being extracted from a well.

## *Information Provided*

The site has been viewed using maps and Google Earth images to gain a general view of the location and identify key features. The aims have been discussed with the owner, Mr T Omer. The information from these sources has been incorporated into the work.

The following information has been provided:

| |
|---|
| Extract from CAD: punkt 5 A |
| Extract from CAD: punkt 6 A |
| Extract from CAD: punkt 7 |
| PDF image 'LoopCAD' of underfloor heating layout. |
| Various photographs |
| Building fabric description |
| Numerous confirmation emails. |

The following weather data has been purchased:

| |
|---|
| 18 years Krakow EPKK_HDD_15.5C |
| 8 years Liesek 11918_HDD_15.5C |
| 5 years Tarnow 12575_HDD_15.5C |
| 4 years Zakopane 12625_HDD_15.5C |

## Analysis

The main body of this report describes the results of the analysis for the building at two levels of performance: current specification by the owner and an enhanced configuration. Both cases have been analysed and each is presented individually with pie-charts comparing the enhancement in energy performance. Discussion of the heating is presented and conclusions drawn.

## Energy Related Opportunity

At this stage of planning any building there is ample opportunity to improve it and this includes insulations. U values below illustrate typical performance.

| Element | U value W/m² k | | |
|---|---|---|---|
| | **Readily achievable using current practice** | **Worst case permitted in UK building regulations** | **Estimated values used to model this house** |
| **Wall** | 0.15 | 0.25 | 0.14 (0.12 with PIR foam) |
| **Floor** | 0.11 | 0.25 | 0.11 (includes vertical insulation around foundations) |
| **Roof** | 0.11 | 0.18 | 0.14 (0.12 with PIR foam, ~0.125 with 100mm rockwool) |
| **Windows** | Better than 1.0 | 1.8 | 0.8 (spec provided) |
| | | | |
| **Air tightness** | 3 m³ / m² hr at 50 Pa | Complex but ~8 to 10 m³ / m² hr at 50 Pa | 7 in case 1 and 3 m³ / m² hr at 50 Pa in case 2 |

Note 1: A low U value is good.
Note 2: In a new building the mix of thermal performance of the whole building and its heating system are considered in concert and so only parts of the building can be at the worst case shown in the table.

The mix of insulation measures gives the overall thermal performance of the building in terms of peak heat load in winter (and therefore the size of heating plant) and annual usage (energy, bills and emissions). These then lead to a heating system specification and so the choice of heating technology can be made from an informed position.

The key choice at this stage is about whether a GSHP can be used to heat the building in the future. This then leads on to how to improve the building design; viz the thickness and type of internal insulations and improving air-tightness to accommodate this technology most effectively.

## Polish Building Energy Standards

We note that in Poland a number of proposed low-energy standards have been / are being tested. Subsidies existed from 2013 to 2018 for lenders when a building reaches either of NF40 or NF15 standards. These two standards represent demand for energy for heating and ventilation of ≤ 40 kWh/m²year or ≤ 15 kWh/m²year, the latter being extremely low and roughly equivalent to the Passiv Haus standard. For the proposed house this would mean around 8000 kWh for NF 40 or 3000 kWh /yr for NF 15.

# FINDINGS

## *Approach*

A thermal model of the building has been prepared. This includes input of the types of construction and insulations, the areas of the different elements of the building fabric and the natural ventilation rates expected for the type of construction. By taking account of typical weather conditions in this part of Poland (see Appendix 3) the model gives two key results:

1. Peak heat requirement in cold weather;
2. Annual estimated energy consumption for heating;

The first is used for choosing the rating of the heating system. Typically, three additions are made before assessing the effectiveness of the chosen the heating plant:

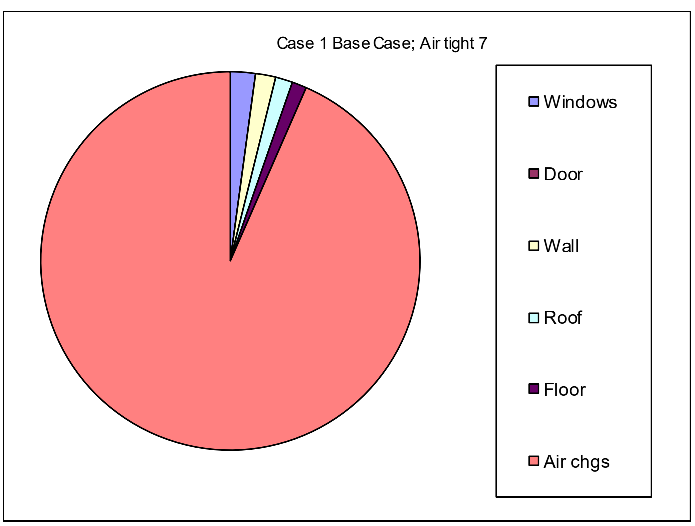
- A margin of extra power to allow heat up from cold if the building has been unheated for a few days;
- Additional power for heating hot water in parallel with the central heating;
- A factor to take account of the plant efficiency and effectiveness throughout the year, if relevant (e.g, for an air source heat pump, its performance in the coldest weather would also be taken into account as this is the worst case).

To allow choices about the insulation packages the model results are broken down by building element. The results are displayed in pie charts showing where the heat goes.

## *Initial Design*

The baseline presents the building's performance at the design level which is low energy but using fairly conventional approaches. There is a key uncertainty in the air tightness. The relevance of the baseline is as the benchmark against which to test any enhancements and also to check the heating system peak design load. In this modelled case the thermal properties of the building and heating needs with internal temperature of 18C and external temperature is taken as -12C are as follows:

- Peak heat requirement in the coldest weather; 40kW to 45kW
- Annual estimated energy consumption for heating; ~15,000 kWh




A heating system rated up to 50kW might be installed when hot water and heating-up from cold have been taken into account. However some manufacturers rate their system in a different way so care is required in selection. For reference, annual consumption is roughly UK average (which shows the building is good, given the colder winter weather in Poland). The split of heat losses is shown in the pie chart.

In the model an air tightness figure of 7 $m^3$ / $m^2$ hr at 50 Pascals has been used. This may be conservative given the design intent but in our experience without an air-test there are normally large unintended gaps in a building's fabric which allow air leakage. This view is supported by UK building regulations in which a penalty is applied if a building is not air-leakage tested so that 15 $m^3$ / $m^2$ hr at 50 Pascals is used in certifying the Energy Performance Certificate.

Draughts and other ventilation result in 'air-changes' throughout the building. Some is vital to ensure the internal air quality is maintained. However, much is unwanted especially in winter storms when warm air inside the house is replaced by cold air which has to be heated.

We note that it is intended to fit a Mechanical Ventilation with Heat Recovery unit (MVHR). In order for an MVHR to operate effectively various European building codes recommend that a maximum leakage rate value of 3 $m^3$ / $m^2$ hr at 50 Pascals is achieved (in a test the result shows the total air volume $m^3$ escaping through the total building surface area $m^2$ at a given test pressure, 50Pa. This is not the same as air changes per hour.). If this is not achieved, then natural ventilation air changes are good enough alone to maintain good air quality and the MVHR simple over-ventilates and thus wastes energy.

## Enhanced case

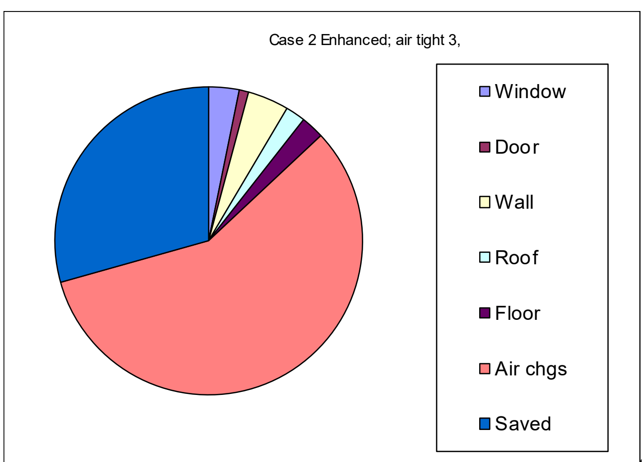
The most economically advantageous time to consider improvements to reduce heating needs and improve comfort is at the design stage. Once the building is finished adding insulation or changing the heating and ventilation, however beneficial, is much more complex. A well-insulated building will be more comfortable, save money and will reduce emissions harmful to the environment. An air-tight building will go further and if MVHR is included also maintains internal air quality with minimal energy loss.

In this modelled case the building heat loss is reduced by two enhancements:

1. Changing the internal layer of insulation to PIR foam e.g. Celotex (reduces total of conductive losses by about 10%).
2. The air leakage rate is improved to 3 $m^3$ / $m^2$ hr at 50 Pascals.

- Peak heat requirement in cold weather; up to ~20kW (See notes)
- Annual estimated energy consumption for heating; ~4,000 to 8,000kWh

It would appear that the enhanced house would be between the Polish NF40 and NF15 standards mentioned earlier (mainly depending on how they are certified for each level[1]).




A complication in low energy houses is that for most of the year very little heat is required to keep the house comfortable. This is partly because 'incidental gains' from cooking, people and electrical items in the house plus solar gain provide a lot of the heat.

Typically, a house of this type would expect to see electricity consumption of about 3000 kWh per year for non-heat uses. Almost all of this will appear as heat in the house and about 1500 kWh

…tions of heat load will be made in accordance with Polish standard PN-EN 12831 "Heating systems in buildings. Method of calculation of design thermal load " This EN is the basis of our model, but we know that different approaches may be taken and assumptions made despite the same standard being used.

will be useful in the heating season. On very clear days in winter there is also the potential for useful heat gain from the sun especially into any South and West facing windows on this plot. For this house solar gain could in a typical year account for around 1000 kWh of beneficial gain in winter.

Consequently, it is only on the few very cold days in very windy weather that much heat is required. The conundrum is how high a rating should be used for the heating system without over-sizing it?

This house, with this air tightness, is a very low energy building. It would appear that the 'average' heating system rating when air temperatures are around 0C and there is little wind is probably as low as 4kW. However, on a windy day with external temperatures at -12C it could rise to ~20kW. In a house of brick and block there would be plenty of thermal mass to store some heat for the odd cold and windy day. In a timber frame construction it is important to consider if there is enough thermal mass and whether more could be added. Choosing the rating of the heating system/s is discussed later.

At the low energy levels for heating we believe it is important to have separate systems for hot water and space heating. With low total energy input for heating the hot water demand could for a short period dominate and draw so much heat from the heating system that it could not heat the building. The conventional approach is to have separate heat inputs for space heating and hot water. Alternatively, and as appropriate for this project, the central buffer store provides a reserve of heat that prevents this short-term problem and having several sources of heat should give maximum flexibility and efficiency.

It is important to consider if all cold-bridges have been removed and relevant parts of the structure appropriately designed. Appendix 1 gives some guidance.

**Air Tightness**
Air-changes in this case are set at a target of 3 $m^3$ / $m^2$ hr at 50 Pascals which makes a significant impact on heating needs, roughly halving it from the first case. This level is still higher than the air change rate for the Passiv Haus standard. A target lower than this could perhaps be considered and would further reduce energy consumption but becomes increasingly technically complex and we would recommend three air tests be carried out:

1. Around '1st fix'
2. Again around 2nd fix
3. A further test after 2nd fix and before final 'snagging'.

Through our networks we have found a company in Krakow that can carry out a 'blower-door' air test of the type we would normally recommend. They are TERMOCENT Sp. z o.o. :

termocent.com

We have no experience of them but they are listed on a recognised industry association's web pages.

It is important to achieve the air-leakage rate of 3 $m^3$ / $m^2$ hr at 50 Pascals in order for the MVHR to operate effectively. This is seen as a reasonable target for a new-build with the objective of low energy consumption. In a timber frame construction the main areas to focus on will be:

1. Sealing the joint between concrete / masonry and timber frame and at all horizontal joints in the frame. Care will be needed in linking the blockwork elements to the timber parts.

2. Lapping the floor DPM to any wall DPC is recommended though care is needed to ensure the DPM is protected if the floor screed is not poured at this stage.
3. Ensuring the vapour control layer (which acts as an air-tightness layer) is properly fixed in place, overlapped well and not punctured especially when electrical or plumbing work is carried out.
4. Design of the air-tightness around the window frames and making it clear who is responsible for ensuring the window to wall joint is sealed.
5. Considering if enough 'slack' is included in the air tightness target to allow for movement of the timber in the next few years.
6. Preventing air leakage paths between floors through the stud walls as these are particularly difficult to seal later on.

Generally applicable detailed design and building work to achieve good air tightness is listed in Appendix 2.

Open fireplaces must not be used as the chimney creates a huge draught compared to the air tightness target. We note that there is a wood stove shown and so this must have a dedicated air intake which feeds directly into the stove. For example, the flowing stoves:

https://www.stovesonline.co.uk/direct-air-supply-stoves.html

Meeting the target can be relatively straightforward for the new build; CLPM has achieved <3 $m^3$ / $m^2$ hr at 50 Pascals on several new builds and as required for 'Passiv Haus'. However, a specific focus will be needed and it is emphasised here that air tests are recommended.

**Overheating risk**
There is relatively low thermal mass in the building. However, the windows on the south are very small, there is some roof over-hang and so it is not considered there is a great overheating risk. Most rooms have the opportunity for cross-ventilation by opening two or more windows which will help. The rural location is also helpful. The rooms that are at risk of overheating are those on the first floor.

# Wider Observations

## *Comments on heating system*

**Rated Output of a Heat Pump**
As noted in the thermal modelling results sections, the enhanced building in case 2 with air tightness of 3 $m^3/m^2$ hr at 50 Pa would have a peak heat load of up to ~20kW on the coldest, windiest days. However, only about 4kW is estimated to be required for the rest of the time during cold (zero C outside) but less windy days. Having such a high output but only using a small part of it would make the heat pump inefficient. A lower rated output of, say 10kW, could be used as a balance between operating efficiently, keeping the capital cost low and maintaining internal comfort for the majority of the time. We estimate that based on most 'normal' winters a high quality, well maintained, properly installed GSHP rated at 10kW should cope. However, in windy cold weather or in extended periods of very cold weather we would expect the house to feel cold. The model estimates that at -12C in calm weather 10kW should be enough. However, in windy weather at -12C the house will need more heat to keep it comfortable. Similarly, even at -8C in strong winds it would struggle.

In a house with high thermal mass this might not present a problem as the thermal mass provides a 'buffer' of stored heat to keep the temperature at a comfortable level during the few very cold and windy days. However, as this is a light weight building cold winds (below -5 C[2]) blowing for several hours could chill the house down and make it uncomfortable.

We suggest it may be possible to include some more thermal mass in the first floor (The ground floor has a solid floor so there is good thermal mass there, though more would be a benefit). One option we suggest considering would be if some internal walls could be blockwork instead of studwork. For example, on initial inspection and as an example to consider, the walls either side of the landing could perhaps be blockwork?

Please note, the model provides estimates for design and it cannot take account of the actual in-situ performance of the building as we cannot input the precise thermal performance factors of the whole house without extremely thorough and expensive testing. Consequently, it is also important to ensure that the build quality meets the design specification. The results are also based on the GSHP ground coils being installed in ground that has the capacity to provide the heat required for the whole winter. We are aware of cases of incorrect installation where the ground has been chilled down so much that it has frozen and can no longer provide the design heat requirement. Care is needed in design and installation of the coils!

Thus, the challenge is to choose a heating system which is efficient due to being correctly rated but still able to keep the house warm on a few cold and windy days.

The optimum solution may be a combination of:

- Ground Source Heat Pump of about ~10 kW rated output.
- Wood Stove on the ground floor for room heating and hot water ~10kW.
- Occasional use of additional heating in extreme conditions.

Alternatively, a modern automatic log-burning boiler could be considered as these are more flexible in terms of actual output vs rated maximum output.

2 It is our opinion that strong, cold north-easterly winds would definitely leave the building feeling cold.

**Heat Emitters - underfloor**

Wet underfloor heating laid in screed is the most effective system. This works very well above solid floors and under solid materials such as tiles and engineering wood (as long as these are designed to be stable above underfloor heating).

In our opinion, underfloor heating does suit the ground floor of this new build but it will be important to ensure the correct materials are used over underfloor heating as, firstly, floor coverings may be damaged by the heat and, secondly, it will affect the way the underfloor heating system works and the efficiency and effectiveness of the heating system. At the stage when floor coverings are being chosen, the manufacturer should be approached to check that they provide warranty when used over underfloor heating. So, this could be installed as a back-up for later in the life of the house.

For the first floor a laid-in-screed system between joists is also suitable with the above provisos.

**Heat Pumps**

A heat pump uses electricity and thus its running costs and emissions are due to the source / price of electricity. Their performance is stated as a Coefficient of Performance (CoP) which is essentially their effectiveness at gathering heat from the environment; the higher value the better. This also allows a conversion from electricity price to the cost of heating. For example, with electricity costing 12 p/kWh and a CoP of 3 the cost of heat is 4 p/kWh. Of course, some of the time the solar PV array would be providing 'free' electricity so this will be 'free' heating.

Carbon emissions from a heat pump powered by a solar array are extremely low, say 0.02 kg CO2e per kWh of heat supplied on a life-cycle basis.

For a professionally designed and installed system a Seasonal Performance Factor (essentially a time-averaged CoP) will be stated. This should be nearly 3 for a conventional Air Source heat pump and perhaps 4 for a Ground Source. Thus to provide an annual heat input of 6000 kWh requires about 2000 kWh of electricity for an air-source and 1500 kWh for a ground source heat pump.

Collection of heat is by ground loops (or boreholes). The condition of the ground and depth at which the loops are buried is vitally important to the effective operation of the system. We would expect in the UK's mild climate that a 1m depth is normally sufficient. However, in Poland with much colder winters we would suggest going deeper. The pipe in the loops should be laid in straight lines and at least 1m apart. The length of loops in the UK is also as an indication, for a 10kW GSHP, about 500m$^2$ (e.g. in an area 10m x 50m). For illustration the image shows double this at ~1000m$^2$. The alternative is perhaps 2 or 3 boreholes. We would suggest a greater length of ground loops should be used in Poland or boreholes due to the lower ground temperature in winter. We

suggest that a local company be contacted to quote for the supply of GSHP and ground loops / borehole equipment as they should have local knowledge about ground conditions. We suggest initial contact with:

http://www.optimapolska.com.pl
http://www.sunel.pl/

Regardless of the heating technology chosen, care should be taken to specify the right level of control, appropriate zones and monitoring of energy usage to indicate correct operation.

**ASHP dedicated to hot water**
There are also ASHP (Air Source Heat Pump) units which use the extracted air from the MVHR as a source of heat to improve performance compared to a conventional ASHP. Examples include the Ecocent from Earth Save Products and the Ariston Nuos. Two main benefits of these systems are:

1. The small and constant load for hot water is handled by a dedicated device thus can be delivered at high efficiency all year around.
2. As the device uses internal air at relatively higher temperature than external (especially in winter) the CoP is much higher, say 5, thus delivering cheap hot water.

## *Mechanical ventilation with heat recovery*

This technology provides a means of managing steamy, stale air especially in bathrooms, laundry areas and kitchen but without the heat loss associated with a simple extract fan. Many systems exist for individual room use and also at whole-house scale.

The benefit of such a device in winter is that fresh air can be exchanged for stale whilst the heat embodied in the stale warm air that is exhausted from the house is recovered and used to pre-heat the fresh air coming in. This means that there is no need to open windows and bring cold fresh air with the dual benefits of improved comfort and reduced bills.

In addition, and for this low energy house, there is a benefit in using the summer bypass mode to bring cooler air in at night. Most systems now offer this ‘summer bypass’ mode of operation.

Several manufacturers make systems for whole-house ventilation, predominantly as a result of moves toward ‘Passiv Haus’ certification of ultra-low energy homes. Example manufacturers of increasingly common MVHR units include:

- Ventaxia,
- Nuaire,
- Polyipe
- Silavent.

High-end examples with options with, for example, excellent pollen filtration and possibly comfort cooling include Earth Save Products, Zehnder, Paul and Genvex however these have a higher price. CVC Direct in the UK also supply systems and include underground pre-heat or pre-cool intakes.

A check discussion should be had with the structural engineer to ensure paths can be found for ducts through any structural members.

## *Observations on MVHR.*

**Extracts and intakes.**
Extracts should be from wet rooms and intake to others. However, one exception to this is that is vital to ensure that air is blown into a room with a combustion device to prevent suction of combustion gases back down the flue.

**Ducting;**
The layout of ducting needs to be considered. It would seem that a single MVHR unit would make sense for the whole house

Ducts should be as short and as large a cross section as possible for efficient and quiet air flow. Final ducting to/from rooms should be no smaller than 100mm diameter. For example, note that 2x63mm diameter ducts have a combined cross sectional area of only 80% of a 100mm duct (so flows less air) but 126% of the surface area of a 100mm duct. This means there will be more fan power used and more noise as the air velocity within the ducts will be higher for the same air flow than if 100mm diameter were used. Consider how much noise from the ducts and intake / extract vents will be transmitted into rooms.

There are several locations where plenum chambers and manifolds are likely to be required to split air flows. There needs to be proper consideration in the detail design of the space required for these. It needs to be clear where the ducts will pass between the ground and first floors. Where ducts rise vertically there will need to be boxing-in.

As this is a self-build with much long-term planning, it would be worth considering underground pipework for the intake. This will gain a little heat in cold winters as the ground can be at a higher temperature than the air but also gain a little 'coolth' in summer for the same reason. A few suppliers can provide the correct pipe, e.g.

AWADUKT Thermo from Rehau (can be purchased from CVC)
Ground heat exchanger for the intake (GHX) from Paul

## *Zoning and Controls*

This is a relatively small house and it is well insulated. On this basis 'zoning' in the sense of having larger parts of the house separately controlled is not really applicable. We have reviewed the overall layout and suggest the following controls:

- Room thermostat per room controlling each underfloor heating loop via manifold actuators. Ideally these should include the ability to set different temperature targets for different times of day.
- Optionally, floor sensors to detect the temperature of the floor slab (and first floor screed). These allow for the slab to be heated a little for comfort without heating the air above. This can, if used correctly, reduce the total heating need as everyone's feet are warm!
- Hot water tank sensor.
- Overall time controller with time of day and day of week settings for both heating and hot water.
- External temperature sensor for 'weather correction' (essentially turns the system off if external temperatures are above e.g. 15C).
- Lock-out controls for pumps around the thermal store to prevent accidental flow of high temperature water into the heat pump. If the wood stove has been running and the thermal store is up to say 50C, you must prevent the water going through the heat pump as it is not designed for this. So, perhaps a temperature sensor in the tank

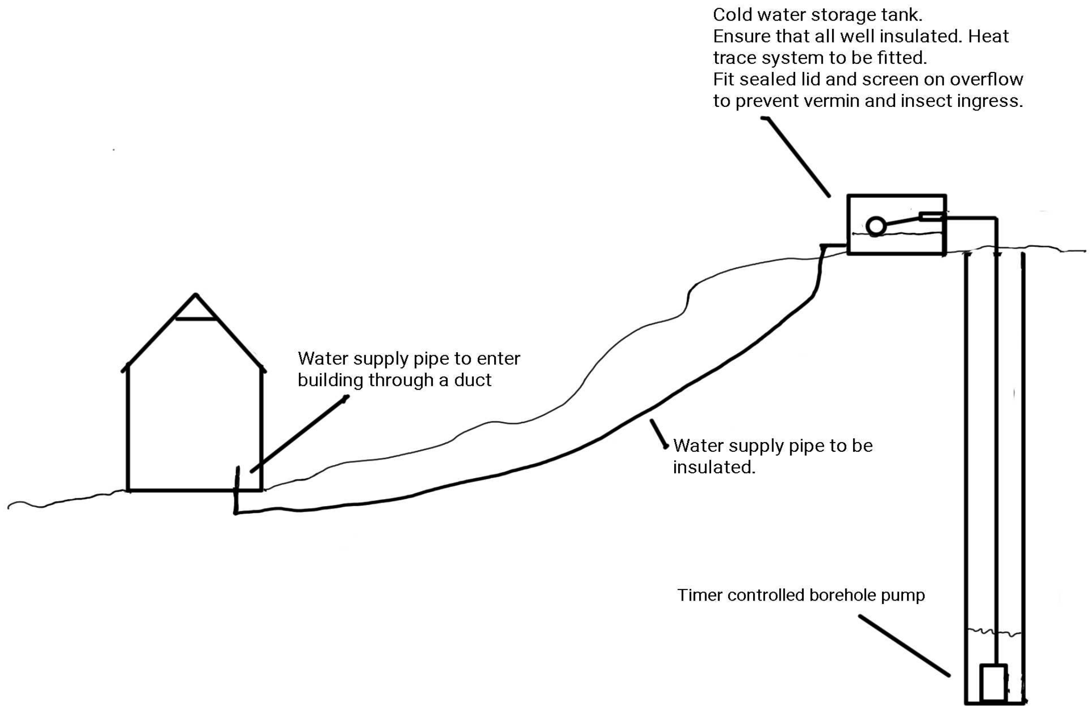
which disables the circulator pump to/from the heat pump if say T>45 (check with the heat pump supplier for a value).

## *General Observations*

The pantry is unheated space and is ventilated but sealed from the rest of the house. Consequently, this will tend to be quite cold in winter and so lose heat from the main house. We suggest it is worth considering insulating the walls to the snug and utility room almost as well as the external walls to prevent this.

## *Block Diagrams*

**Water Supply:**
The overview of the water supply as a block diagram is shown below:




The pipe would best be buried at least 600mm deep and ideally 1m to avoid freezing in winter.

The water supply to the house then enters the next block diagram to treat the water (overpage):

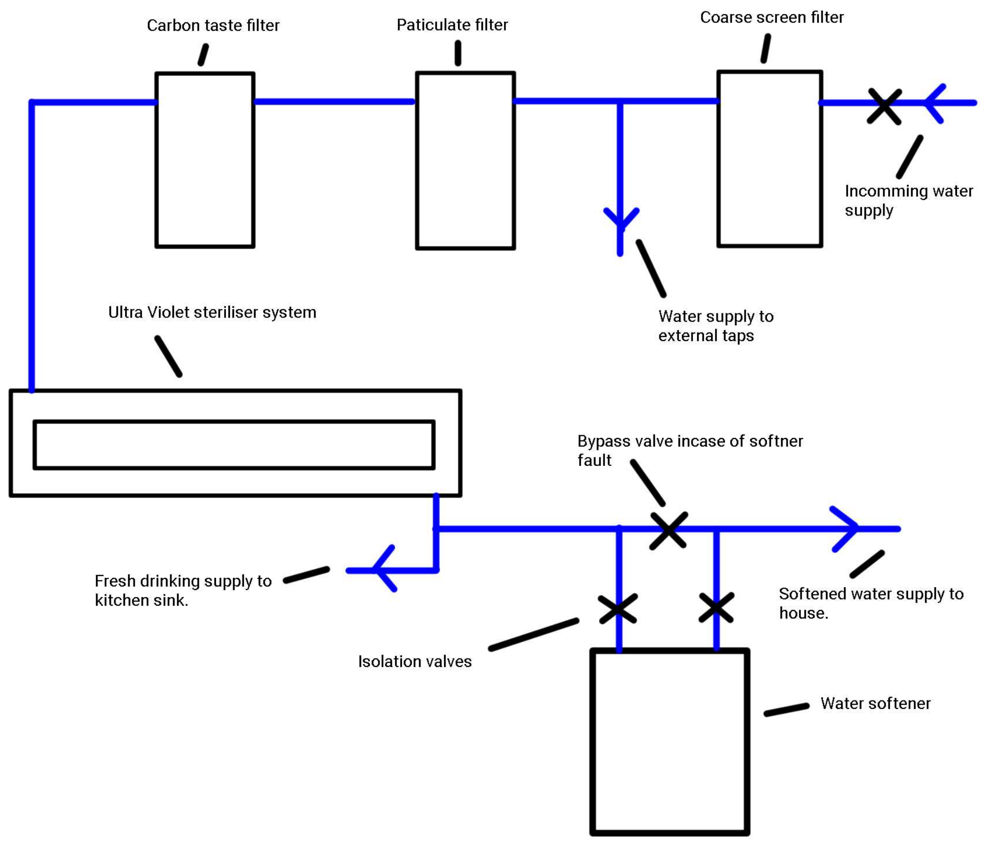
Some key points are:

- A coarse screen filter (~25 to 50μm) prevents damage to or leaky taps and valves.
- A particulate filter (1 to 5μm) removes fine suspended material including many organisms.
- Carbon filter removes odd tastes and so is optional depending on the water quality.

- The UV steriliser is important to destroy bacteria and viruses. It is especially important as other wise such organisms could breed within the pipework around the house to reach levels which are a risk to health, especially the young and old.

Combined filters are also available, e.g. a carbon filter removing down to 1um or silver impregnated ceramic filter with a claimed high degree of sterilisation.

Some coarse screen filters need back-flushing from time to time and the plumbing would need to account for this.




It is important that the UV purifier has a back up power supply or the water may not be safe following a power cut. If this is not the case, then drinking water will need to be boiled before consumption during and following a power cut.

A maintenance schedule will need to be implemented with checking/replacing filters, and replacing the UV tube when it has come to the end of its life (before it fails). We suggest keeping a small stock of spares in the house.

If fitted, we would suggest that a non electric water softener is used, e.g.

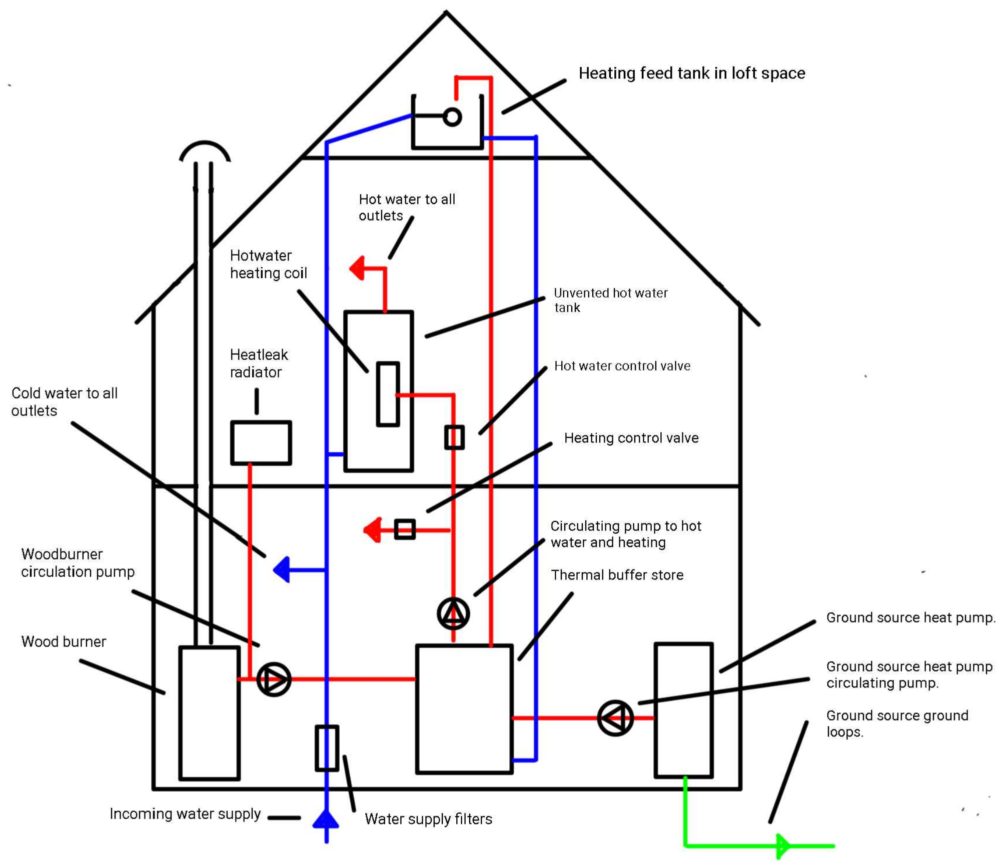
[https://www.kinetico.co.uk/products/water-softeners/essential](https://www.kinetico.co.uk/products/water-softeners/essential)

This means a reduced energy requirement and continued operation in power cuts.

Discussion with Eaton Environmental Services Ltd suggests the water is soft enough not to need a softener. Other suggestions include: ¾" fittings to match domestic equipment; include 20" iron/manganese reduction filters to reduce the manganese and iron content of the water to acceptable levels. A more complete list in appendix 4.

**Heating**

The overview heating system block diagram is shown below:




A separate heating feed tank is required as the heating system water is not clean and if the system overflowed into the main water supply all the water would be contaminated. It needs to be at the highest point in the system.

We would suggest that the pipework from the wood burner to the thermal buffer store is plumbed in such a manner that gravity circulation is possible. This would lessen the impact if there was total power failure with the wood burner running.

A gravity fed first floor radiator, potentially in the bathroom would also be a good idea. This will promote good gravity flow, ensures there is a sink for heat once the heat store is full and will allow some room heat to be gained.

If the thermal store were to be placed at a higher level than the stove a full gravity system might be possible. This has the advantage of allowing gravity circulation from the buffer store in the event of power failure. If this is done, then the heat-leak radiator should be on the return loop after the heat store.

Due to their length and narrow bore, gravity circulation will not be possible through the underfloor heating. The battery backup system should be able to run the pumps for a reasonable period of time.
We suggest a 180Ltr unvented hot water tank should be sufficient for this property. We would suggest a thermal buffer store of 500ltrs should be sufficient, but will need to be confirmed by the ground source engineer.

The unvented hot water tank will need an expansion vessel, which would normally be part of a kit of parts, but we would suggest not fitting the standard pressure reducing valve given the low and constant head of water available.

It is important that the flow and return from the wood burning stove connect into the thermal buffer store above the connections to the GHSP so that the return temperature to the GHSP can be kept within the temperature range specified by the manufacturer's instructions. We also recommend lock-out controls to prevent pumps around the thermal store accidentally feeding high temperature water into the heat pump.

We would suggest the following types of component are used in the system:

- Pex pipe is used for the underfloor heating pipe
- Stainless manifolds are used with flow top meters.
- Grundfos UPS2 15-50/60 circulating pumps.
- Honeywell V4043H zone control valves.

# DC electrical System, Batteries and Solar PV

It is understood that it is intended to install a PV array and battery store at a later date with the aspiration of being able to run off-grid. In addition, a DC electricity supply ring is intended to be installed. The solar array, battery store and DC system are discussed here as decisions about these are all interlinked. Below we have provided some guidance and indicative approaches to choosing the system and sub-systems.

**Off-Grid System: Solar PV array and Electricity Storage**

If we assume to begin that the array size and battery store should be capable of off-grid operation this gives a means of estimating the array peak power in kW and the battery kWh usable storage. Devices such as washing machines, immersion heating and readily available electrically powered plant e.g. heat pump, fridge, freezer and TV are probably best run from mains AC system. Thus, the whole system will need to include a DC – AC inverter of appropriate power. Some systems can be arranged to run in parallel with the grid but predominantly from battery store. The main challenge with off-grid systems is holding enough energy for periods of low generation from renewable sources. A DC electrical system is being considered for low-power loads and this may have advantages but requires care in design. Both are discussed.

Firstly, the total annual energy consumption and peak electrical loads are required. The Annual energy use for heating has been estimated to be 8000 kWh per year with 20kW peak load. Using a ground source heat pump with a seasonal CoP of say 3.2 therefore requires about 2500 kWh electrical input. Peak power would depend on the particular unit chosen (and surge current must be considered) For this assessment we have taken it to be around 7kW.

An estimate of other electrical loads gives a typical annual consumption of about 3300 kWh per year with a peak load of say 15kW.

Of course, an energy store connected to solar PV needs to be able to provide power at night and through winter periods of dark cloud where there is very limited electricity generation. Consequently, it is also important to know a daily energy use in winter.

In summary the house's indicative characteristics are suggested to be:

| Source | Peak kW | Annual energy kWh | Peak Winter day Energy kWh | Peak Summer day Energy kWh |
|---|---|---|---|---|
| General AC loads | 13 | 1650 | 25 | 20 |
| DC loads | 2 | 1650 | 15 | 10 |
| Heating | 7 | 2500 | 140 | Nil |
| Totals | 22 | 5800 | 180 | 30 |

Note: this assumes that the heat pump does not run at the same time as an immersion heater.

A rule of thumb in energy storage is to be able to store 10 days-worth of energy without any generation being available to supply the house or re-charge the batteries. Thus, the storage should be at least 1800 kWh of useable storage. Batteries for storage can be chosen in a number of ways but a 'deep-discharge' type would normally be recommended. Typically, the stated capacity would be 80% of total if a deep-discharge type. Care should be taken in choosing particular batteries as the manufacturer may not be clear about this. Additionally, deep-discharge can damage certain chemistries and frequent deep discharge can be expected to reduce battery life. Consequently, it may be that only 50% of the named capacity would be the advisable depth of discharge. Similarly, some battery chemistries can be damaged by frequently fully charging them and leaving them fully charged. Care is required in selecting batteries and their charging and control systems.

The resulting specification might be a peak output of 24kW on the DC side and 3600 kWh of capacity. If a voltage of 48V were to be used this would mean 75,000 Ah which is a lot of batteries! For ref. a Tesla S has ~90kWh so the store above is roughly 40 cars-worth.

**It is imperative to be aware of the safety risks associated with voltage, current and energy stored and to take the appropriate precautions. For comparison, 6 kWh is roughly the energy of a tank anti-armour round and so a sudden release of any energy from the battery store by e.g. a short-circuit will be very dangerous. As a minimum, isolation switches, fuses and circuit breakers must be fitted to the energy store and all terminals, junctions and cables suitably insulated. Insulated tools and fire and flash-proof overalls, gloves and face protection are required for working on the energy store.**

Two publicly available documents give good advice on energy storage and solar PV and we recommend these are read:

- Code of Practice for Electrical Energy Storage Systems, IET publication, 2017
- Code of Practice for Grid Connected Solar Photovoltaic System, IET publication 2015
- Code of Practice for Low and Extra Low Voltage Direct Current distribution systems in Buildings, IET publication 2015

Battery stores are not 100% efficient and typically a 'round trip efficiency' of 85% would be the best available. This may not be the case for the system finally chosen so we have taken 80% for the discussion below. For the discussion that follows we have taken:

| | |
|---|---|
| Storage required: | 1800kWh |
| Peak power required: | 22kW |
| Peak Summer day electricity | 30kWh |
| Peak Winter day electricity | 180kWh |
| Annual energy required: | 7250kWh after losses in battery store |

As an illustration of the challenges of living off-grid, a PV system might be specified as follows:

| | |
|---|---|
| Installed Peak kW capacity | 25kW |
| Area of panels | ~190 $m^2$ |
| Approx. annual generation | 25,000kWh |
| Max daily summer generation | ~150kWh (Minimum effectively nil) |
| Max daily winter generation | ~36kWh (Minimum effectively nil) |

This system would generate around 3 times the annual demand but would fail to supply the house in winter.

Typically, an off-grid electricity supply system would be adapted to avoid this problem by:

1. Heating using biomass to remove the electricity demand associated with heating.
2. Using a second renewable electricity source such as a wind turbine or small hydro power unit.

We recommend that if off-grid is still planned thorough consideration be given to a small wind turbine at this site. Perhaps start by trying a 10kW wind turbine and a 10kW PV array?

Our general recommendation is to consider using a system in parallel with the grid supply potentially including a solar PV array and a small wind turbine. The system would maximise storage of the otherwise exported energy for use at night, in calm conditions and cloudy weather and especially during power cuts. However, one day's storage could still need 180 kWh in winter. However, the primary connection to the electricity network should be retained. This could also be used to re-charge the batteries in dark winter days to be ready for the next power cut!

**Short-term Storage Option**

As an alternative to the off-grid approach, a solution which includes some energy storage, some PV and a DC ring plus a single a.c. mains circuit would allow comfort during power cuts.

The size of PV array now tends to be in the 2kW to 4kW bracket generating 2000 to 4000 kWh per year. In summer a daily maximum output might be in the order of 30kWhr in summer and 5 in winter. Thus the PV will over-supply on some summer days. An energy store can shift otherwise exported power from day to night. Around 2kWh is probably the most economic but 5 to 10 kWh provides more back-up supply in the event of a longer power cut. Example complete 'plug-and-play' devices available for purchase include:

- Moixa available in 2 kWh, 3 kWh and 4.8 kWh,
- Tesla Powerwall,
- Powervault,
- Nissan/Eaton 2nd life
- Sonnen 8.8 (an independent ref. suggests this is the most cost-effective available)

Numerous sub-system components are available to self-build a system or any size. A good supplier known to us with a wide range of parts is CCL Components based in East Kilbride.

https://www.cclcomponents.com/

**DC Ring**

Data on the potential use of a DC ring has been provided. This shows that room-by-room 'rings' would have a peak power draw of about 300W. The main exception to this is the CISCO 48 Port POE Switch which draws ~380 watts alone.

We suggest that designing the system and choosing the cables should follow these guidelines:

- The 48v suggestion for nominal battery voltage seems a reasonable balance between the issues of current draw, cable storage system equipment ratings and safety.
- The upper to lower voltage range must be considered which will depend on state of charge of batteries chosen. E.g. 45v to 60v for lead acid from deep-discharged to being charged.
- If we use ~320W per ring then that requires ~7 Amps. Client to confirm is suitable circuit breakers are available.
- Ensure max voltage drop is 3% in longest cable run (see manufacturer's specifications). Volts drop is an indication of wasted energy.
- Establish temperature rating of chosen cable when buried in a wall (see manufacturer's specifications).

So, as a worked example, using a single twin and earth cable as a 'spur' connection:

If we select a cable made by Prysmian, code 6242YH, Twin & Earth with a cross section of 2.5mm$^2$ and we take a length of 15m between battery and load we find:

| Nominal cross sectional area/ CPC | Approx. overall diameter | Approximate cable weight | Maximum conductor resistance at 20°C | Short circuit rating of conductor (1 sec) | Current rating | | | Volt drop DC or single phase AC | Volt drop three phase AC |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | DC or Single phase AC clipped direct | DC or Single phase AC enclosed in conduit in an insulated wall | Three phase AC clipped direct | | |
| mm² | mm | kg/km | Ohms/km | kA | Amps | Amps | Amps | mV/A/m | mV/A/m |
| **Three Core** | | | | | | | | | |
| 1.0 / 1.0 | 4.5 x 10.7 | 95 | 18.1 | 0.12 | 16 | 11.5 | 13.5 | 44 | 38 |
| 1.5 / 1.0 | 4.7 x 11.7 | 115 | 12.1 | 0.17 | 20 | 14.5 | 17.5 | 29 | 25 |
| 2.5 / 1.5 | 5.3 x 12.8 | 170 | 7.41 | 0.28 | 27 | 20 | 24 | 18 | 15 |

Extract from Prysmian cable spec document; PVC Flat Wiring Cables with bare CPC, New Harmonised 6241YH, 6242YH, 6243YH,

A cable of 2.5 $mm^2$ is rated at 20 Amps DC when enclosed, i.e. within a wall. This reflects the heat carrying capacity of the cable which will heat up when current passes through it.

At 7 amps and 15m length Volts drop = 7amps * 15m * 18(mV/A/m from spec. above) /1000 = 1.89 V (1.9%). This is OK.

The next smaller cable is $1.5mm^2$ and is rated at 14.5 Amps when enclosed which is OK.

However, at 7 amps and 15m length Volts drop = 7amps * 15m * 29(mV/A/m from spec. above) /1000 = 3.05 V (6.3%) which fails on voltage drop.

Suitable circuit breakers must be fitted at the battery end to protect the cables and other equipment from short circuit.

Consideration must be given to cable marking as it will be installed in the house alongside conventional ac mains cable and so could be confused with this during maintenance. This could result in accidents.

**Observations:**
The CISCO 48 Port POE Switch might be better powered from the AC mains system. Alternatively, it should be powered on a dedicated DC supply which should be kept as short as possible to reduce volts drop and energy wasted.

There may be a more optimum arrangement of the DC systems which levels the peak power requirements. Currently the range is large with the highest being ~420W and the lowest being ~20W which makes a standard cable choice much too large for the smaller circuits but marginal for the larger power draws.

**Caveats:**
These figures are preliminary and for guidance to help the client achieve the intended design. The final choice of PV array, inverter, battery store, battery charger and so on will affect these figures.
Local regulations may apply to AC and DC systems as well as the PV array and so on.
There are some EN and ISO standards which may be of assistance.
Local climatic conditions may mean that the rules of thumb are not quite right for this location.

# Appendix 1; Cold Bridges

Cold bridges have not been explicitly modelled but are implicit within the U value calculations and estimation of heat losses.

More important are the means of avoiding these by using improved thermal bridging in design details. The main points of interest for this design are:

**Roofs of single storey parts;**
It is recommended that consideration be given to warm roof construction using a layer of insulation cross-laid over the rafters.

**Roof to wall joint**
The wall insulation needs to be properly bonded to the roof structure insulation so there is no cold bridge (nor air leakage path). This detail needs to be drawn up and discussed with the roof manufacturer / tradesmen at tender stage.

**Dormer Windows and Roof Lights**
The key will be to provide a complete insulation package with no cold bridges caused by structural timbers. Appropriate air and vapour membranes will be needed.

**Porches, balconies**
These features should be looked at as being essentially free-standing and tied-in to the external skin of the house. This will avoid construction material (especially highly conductive steel) bridging the wall insulation.

**Window reveals**
Care should be taken in specifying the insulation and finishing of window reveals to reduce cold bridges.

**Insulation at base of walls**
Where the external wall penetrate below the floor, insulation is required (also perhaps internal supporting walls). The key part of insulating these elements is from the floor level down to about 200mm below ground. Below about 200mm is less important as the soil temperature is likely to be higher than 10 C at all times of year and so heat loss is reduced. This needs to be insulated with an appropriately qualified material.

As an initial guide to such details we recommend a review of accredited details on:

https://www.planningportal.co.uk/info/200135/approved_documents/74/part_l_-_conservation_of_fuel_and_power/6

# Appendix 2; Air Tightness

**Floor to wall joints**. Our experience is that particular care is required here. The location of the air tightness layer should be identified on drawings and the specifics of how this is sealed at this joint will be required.

Beam and Block Floors: Particular attention should be paid to sealing around the beam ends and where the floor meets the wall. A slurry or grout mortar poured into the beam and block joints is considered a valuable technique. For the ground floor, lapping the floor DPM to the wall DPC is recommended though care is needed to ensure the DPM is protected if the floor slab is not poured at this stage.

**Roof to wall joint**. The location of the air tightness membrane should be identified on drawings and the specifics of how this is lapped over the wall and then sealed at this joint will be required.

**Roof and wall air tightness membrane / vapour control layer**. It will be important to consider (and ideally detail) how any electrical installations and ventilation grilles are fitted near to any membranes. This is to ensure there is space for installation without the temptation to cut the membrane. It may be appropriate to install the membrane with some slack in certain areas to allow for this.

**All ceilings with timber joists/rafters**. Any plasterboard ceiling should be fixed and taped over the whole of the ceiling before any internal stud-work walls are built. This ensures that there are no air leakage paths above the stud-work. If coving is to be fitted as a final finish, the wall to ceiling joint should be sealed with plaster, mastic or foam as appropriate to the gap size and materials available.

**Window & door installation**. Cavity closures/ reveals should be sealed before installation of windows & doors. When windows are installed we recommend expanding foam sealing tape is applied to window frames and then internal as well as external foam sealant or mastic applied to prevent air ingress.

**Wall, floor and ceiling penetrations**. The number of penetrations should be kept to a minimum. Electric cables can use plastic ducts (plastic drainage pipe is sufficient) in the floor slab and then at first fix the pipes can be sealed with foam. Soil vent pipe penetrations can be sealed with proprietary grommets and mastic.

**Chimneys**. The minimum number should be retained / installed and only room-sealed stoves fitted. Proper attention should be paid to the register plate at the bottom of the chimney and the dedicated air intake to the stove.

**Walls**. Conventional wet-applied plaster is the best approach to sealing brick/blockwork/concrete walls. For new walls; ideally the undercoat should be brought down to floor screed and up between all floor and ceiling joists (including over the wall plate) to seal the whole wall. Where joist or beam ends are fixed into blockwork appropriate sealing and/or air tightness measures need to be taken e.g. joist caps, foam sealant after mortar has cured and the wet plaster noted above.

There is a trade-off here in that wet applied plaster is disliked by many builders as there is a significant drying time which can delay a project. The alternative of dry-lining is fast but not air tight. If this is to be used that we recommend a parge coat is applied (e.g. Soundcoat plaster) to the blockwork

Chasing out for cables and pipes (and ideally back-boxes) should be carried out before undercoat plaster or parge coat is applied so the channels can be sealed.  For the oak-frame walls attention to fixing to the masonry structures and around windows is key.  As the oak will 'move' with time two approaches are recommended; firstly, flexible jointing compounds and materials are used and secondly, the design and finishes should allow for re-treatment after, say, 2 years in order to compensate for movement.

For existing walls; where old lathe and plaster is removed it is recommended that a parge coat plaster (e.g. Gyproc Soundcoat) is applied to the bare brickwork.  Then internal insulation can be applied on top.  This approach is also good at reducing sound transmission.

**Air testing**.  We advise an air test around first fix to identify any major holes and seal them.  We then recommend a minimum of a second air test after second fix so any new holes can be sealed.  Depending on the results of this test a third may be sensible.

**Contractual obligations**.  It should be made clear in contracts who is responsible for the different aspects of these air tightness treatments.  E.g, expanding foam sealing tape applied to window frames and then internal as well as external foam sealant or mastic should be in the window installer's contract.

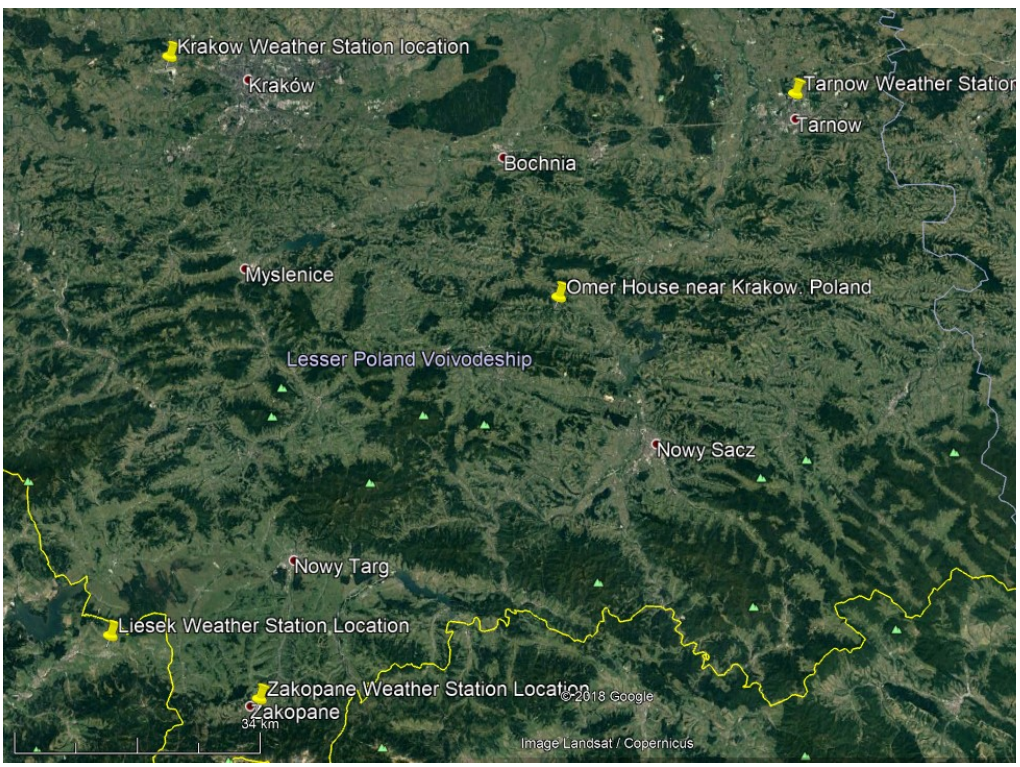
# Appendix 3; Heating data for Poland, Near Krakow

Weather & climatic data has been obtained to allow proper analysis of the heating requirements for this part of Poland. Crucially, two particular pieces of design information have been obtained; annual Heating Degree-days for the last 18 years and; worst-case heating degree days during the last 18 years. These allow analysis of the peak design heating requirement for the house and an indication of annual energy requirements.

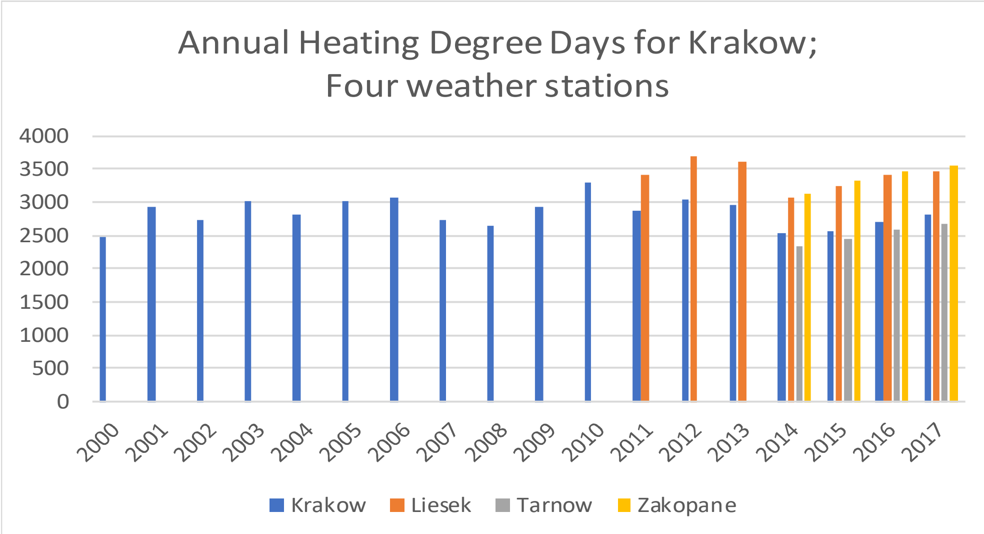
The data obtained is Celsius-based heating degree days for a base temperature of 15.5C

| **Location** | **Coordinates** | **Altitude** |
|---|---|---|
| Site of House | 49°47N 20°32E | ~480m |
| Krakow, | 19.80E,50.08N | 240m |
| Liesek, | 19.68E,49.37N | 690m |
| Tarnow, | 20.98E,50.03N | 205m |
| Zakopane, | =19.96E,49.29N | 860m |

The locations are shown on the map below.

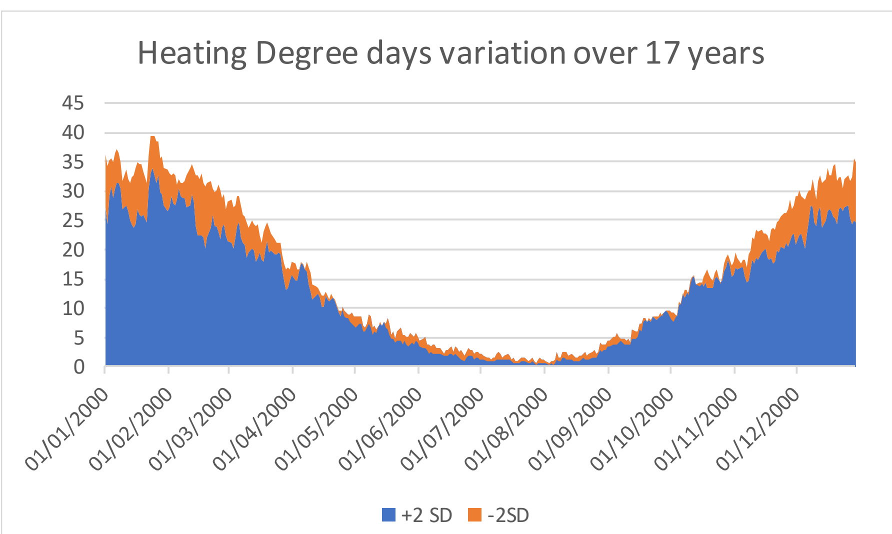



The chart over-page shows annual degree data for each location and especially how they are correlated and if there are any obvious offsets:




It can be seen that Krakow and Tarnow have similar values of annual degree days in the four years for which Tarnow data are available. It can also be seen that Liesek and Zakopane have similar values but show higher degree-days than Krakow and Tarnow (i.e. colder weather). This can be explained by the higher altitude of the Liesek and Zakopane weather stations. Noting that the site of the house is at an altitude between the four weather stations, and that Krakow has the longest consistent data set, we have taken the long term average annual degree days to be 3000 degree days for estimating the typical annual heating requirement of the house.

We have then sought out an estimate of the likely coldest weather for which the heating should keep the house comfortable. For this we have used the ~18 years of data from Krakow, noting that at the site of the house it may be a little colder due to its higher altitude. Taking all the degree-day data we have evaluated the mean daily degree days then the standard deviation for each day of the year and considered the range of degree-days between +/- 2 SDs (statistically containing ~95% of all data). Thus, the coldest degree-day range would encompass 97.5% of all the degree-days experienced at Krakow in the last 18 years. This leaves only 2.5% being colder then the mean plus 2 SDs. All this is plotted below:



The very coldest weather experienced since 2000 was during 22nd, 23rd and 24th January 2006. This has been termed the '2006_European_cold_wave'[3]. There were 33.7, 37.3 and 36.1 degree-days respectively on these days. This indicates that temperatures dropped to around -20 on these days. This represents the absolutely coldest weather in Krakow over the 18 year period.

For the site, taking account of the higher altitude, generally the coldest weather over a continuous few days appears likely to occur with external temperatures dropping to around -12 with occasional lows of -20. It is suggested that the peak heating design external temperature is taken as -12C. Using a standard internal temperature of 18C (considering the use of underfloor heating) gives a design delta-T of 30C.

[3] Ref; Wikipedia, Guardian Newspaper, et al. According to Munich Re reinsurance company, it was the deadliest cold snap between 1980 and 2011, causing 790 fatalities throughout Europe.

# Appendix 4; Water Supply Components:

This is a summary of the email exchange of components from Eaton Environmental Services Ltd.

Based on the information supplied we would recommend the following equipment to treat the water supply to a building housing about 4 – 6 people:

- UV disinfection unit capable of treating 41 lpm water, part number LB5-103, 240 volt
- Auto shut off function (to protect UV in the event of pump failure) part number MOD-SOL3
- Solenoid valve for auto shut off, ¾" 240 volt
- 4.5" x 20" filter housing including bracket and spanner x 2
- 20" polyspun 5 micron particulate filters x 4 (1 installed 3 spares)
- 20" iron/manganese reduction filters x 4 (1 installed 3 spares)

All fittings are ¾" to be compatible with domestic systems.

This is to treat the system for a year, and the auto shut off will prolong the UV lamp life for approximately another year, dependent on use.

Total cost including carriage (to the UK) = £1883.60 plus VAT

# Appendix 5; List of Key Components for The Heating System

Heating feed water tank with ball valve.

Heat leak radiator for wood stove circuit.

Hot water control valve.

Heating water control valve.

Circulating pump for hot water and heating circuits.

Circulating pump for wood stove circuit.

Ground source heat pump circulating pump (potentially within in GSHP unit).

Suggest grundfos UPS2 15-50/60 for all circulating pumps.

Pex pipe is used for the underfloor heating pipe

Stainless manifolds with flow top meters.

Honeywell V4043H zone control valves.

180 Ltr indirect unvented hot water tank.

Thermal buffer store: size to be recommended by heat pump supplier.

Day of week and time of day time controller.

Day of week and time of day thermostats; one per zone controlled.