Provision of a Solar Water Heating system for a large Dwelling

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Abstract

The aim of this project is to assess the provision of heating and hot water from solar energy for a large dwelling house. The design has incorporated the buildings heating and domestic hot water loads, the solar energy available, consideration for PV powered pumping, and the analysis of costs through savings and payback for the solar collector system.

In assessing the system the inclusion of background information on a new boiler system, a 'tank in tank' system, as this is proposed for the heating system and will be the auxiliary power for the house. Furthermore, this is one proposal derived from the method of calculation providing an effective and efficient system. Moreover, all the work done is from the plan drawings of the house as no site visit was undertaken.

In addition, through this case study it will be proved that solar water heating in a Northern climate such as the West of Scotland is practical and in this circumstance proves profitable over the lifetime of the collector proposed. Furthermore, the PV pumping arrangement will provide an insight into the outcome and considerations of introducing such a system. However, the inclusion of a PV pumping arrangement, proved to be detrimental to the overall savings but still is a value addition to a closed loop solar heating circuit.

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Introduction

The renewable energy market is in a period of high growth through the increasing demands on energy coinciding with the increase in global warming and long-term damage on the environment. It is through governments' active action and public opinion in these areas that has brought about changes and commitments. However, these actions do differ worldwide at present with Europe leading the way.

The Renewable Energy future[1]:

> World View
> A variety of studies have shown how the potential global market for renewables may develop. These have been carried out by organisations such as the International Energy Agency (IEA), the World Energy Council (WEC) and the United Nations (UN). The general opinion is that renewables will make an increasing contribution in the medium term and play a very substantial role in the long term.
>
> European View
> The European Commission's White Paper on Renewables proposes a target of doubling the renewables' contribution from meeting 6% to 12% of Europe's total primary energy requirements by 2010. The Council of Ministers has adopted a Resolution agreeing that there is need to promote a sustained and substantially increased use of renewable sources of energy throughout the European Union (EU). The Resolution also urges EU Member States to pursue national strategies for the promotion of renewables with a view to bringing about a substantial increase guided by the White Paper's indicative 12% target.
>
> UK's Current Position
> Renewable energy technologies in the UK are now establishing themselves as viable, credible contributors to energy supplies. They already meet over 2% of the UK's total electricity needs.

The cost of energy from renewables is generally higher than that produced by conventional energy sources due to high initial costs. However, as renewables become more established and the benefits of mass production take effect, the gap will reduce. Indeed, in the cases of wind power and solar heating systems as well as other technologies, this is already happening.

The market for solar panels has long been established with large research areas studied worldwide with new developments each year as more and more companies

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[1] Taken from the DTI's web-site.

have taken interest. The solar power has evolved from the novelty and inefficient systems of the early seventies to an effective option, accessible by the majority of the market place with high competition with manufacturers and suppliers. The consequences of this are shown in the price decrease where the prices for a system which once was around £2000 now costing £900. It is obvious therefore that the general increase in renewables with official backing will further improve the options available and help protect the environment, which can only prove positive.

Through the provision of a solar water heating system for a large dwelling the objective of this case study is to predict the effectiveness of such a system in the West of Scotland. Furthermore, the expanding use of using PV cells to drive a pump in a closed circuit arrangement is increasing. Therefore, further investigation into the solar heating arrangement will incorporate the possible use of a PV driven pump system.

The house itself is located at Kilcreggan, nearby to Glasgow towards Helensburgh, and is not in a built up area. The owner of the house initially instigated the project, when the permission and details of the extension had been granted. A project of works for the house is dealt with separately with planned construction already confirmed. Furthermore, it was through Carbrae Ltd, that the project evolved to the early stage of a feasibility assessment into the possible outcomes of a solar water heating system. Their aim was for the solar heating to compliment the heating system and reduce the costs of buying in gas.

The solar heating system used for the assessment was a flat plate collector in a closed loop arrangement requiring the inclusion of a PV driven DC pump, a heat exchanger, and relevant controls for the pump. The output of the system will enable the evaluation of solar heating in terms of an indication of costs and performance in the West of Scotland.

Chapter 1 – Solar Heating

Solar heating is available two main ways: Passive solar heating and Active solar heating. Passive Solar heating is the absorption of solar energy directly into the building, to reduce the energy to heat a space. This is normally integrated into the building during the design stage for the best results. However, it is possible to integrate these into extensions or even alter a wall arrangement, shown in figure 1.1 below [1]

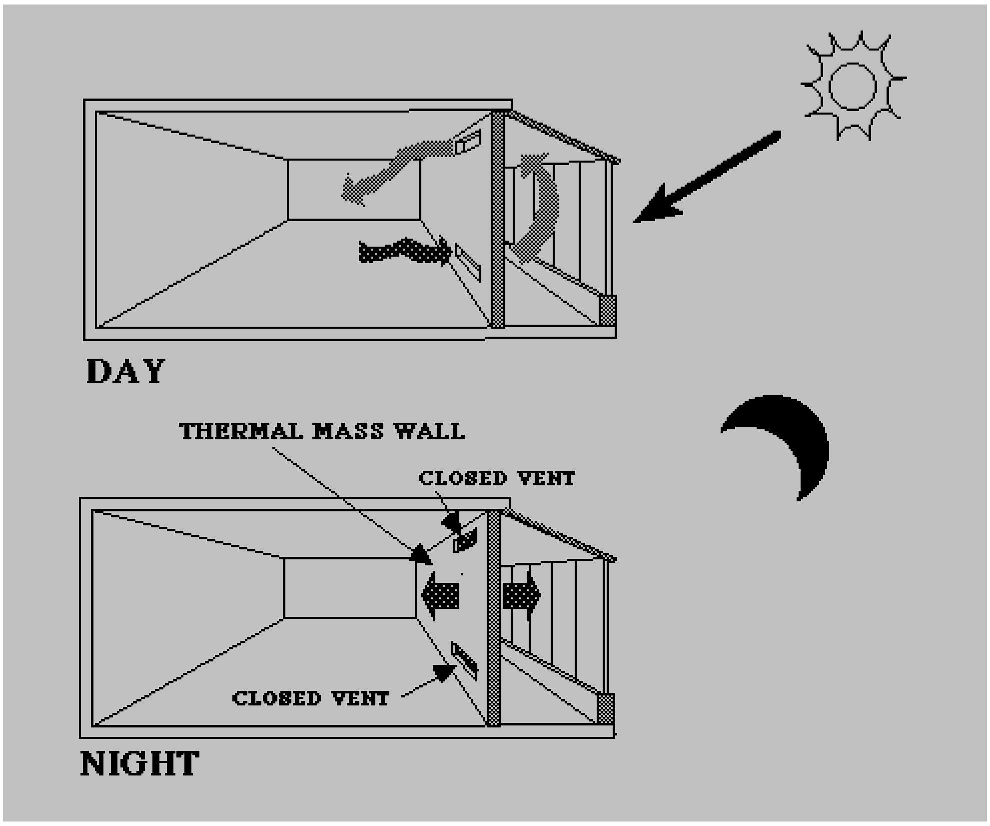

Figure 1.1: Drawing of a heat sink built on the side of building – Passive Solar heating

Active solar heating involves a solar collector, usually mounted on a roof, where it gathers the solar radiation and produces heat at low temperatures (<100°C) and more often used for water heating, shown in figure 1.2 below. In this case, active solar heating is the interest in order to supply energy for hot water heating.

Figure 1.2: Picture showing solar water heating collector – Active Solar Heating

1. 1 Active Solar Heating

1.1.1 Collector Types

There are three basic types: flat-plate, evacuated-tube, and concentrating being the most common way for heating. They are simply named after the main feature of heating water or aqueous solution.

A flat-plate collector, the most common, is an insulated weatherproof box containing a dark absorber plate under one or more transparent or translucent covers. The flat collector is particularly attractive due to its competitive price. The highly selective coating on the copper absorption plate and the very efficient, light permeable, glass cover. The highly transparent glass enables optimal absorption of the energy available, so that it can be used to make hot water, even under the low light level conditions of winter [1]

Evacuated-tube collectors are made of rows of parallel, transparent glass tube. Under the highly absorbent plate lies a heat pipe, which works similarly to a thermometer. The temperature sensitive liquid in the tube changes to a gas and expands upwards into a condenser unit. Here the gas loses temperature reverting back to a liquid and at the same time generates energy in the form of heat. This cycle then continually repeats [2]

Concentrating collectors for residential applications are parabolic shaped through the use of mirrored surfaces to concentrate the sun's energy on an absorber tube, which is called the receiver containing the heat transfer fluid. These often are packaged with a tracker system, as concentrator collectors do not possess the same ability to convert diffuse and beam irradiance, but that only of beam [1].

1.1.2 System Type

Solar water heaters can also be either active or passive. An active system uses an electric pump to circulate the fluid; a passive system has no pump, called a Thermosyphon system. The amount of hot water a solar water heater produces depends on the type and size of the system, the amount of sun available at the site, proper installation, and the tilt angle and orientation of the collectors. Solar water heaters are also characterised as open loop, direct, or closed loop, indirect. An open loop system circulates household water through the collector. A closed loop system uses a heat transfer fluid like diluted antifreeze to collect heat and a heat exchanger to transfer the heat to the household water.

1.1.2.1 Active Systems

Active systems use electric pumps, valves, and controllers to circulate water or other heat-transfer fluids through the collectors. They are usually more expensive than passive systems but generally more efficient. Active systems are usually easier to retrofit than passive systems because their storage tanks do not need to be installed above or close to the collectors. Due to the greater complexity of the system, active systems may be more prone to breakdowns than passive systems.

Open loop active systems use pumps to circulate household water through the collectors. This design is efficient and lowers operating costs but is not appropriate if the water is hard or acidic because scale and corrosion will quickly disable the system. Open loop active systems are popular in regions that do not experience subzero temperatures. Flat plate open loop systems should never be installed in climates that experience sustained periods of subzero temperatures, e.g., Iceland.

They may be installed in mild climates that experience occasional subzero temperatures, but freeze protection must be implemented. Although open flow evacuated tubes are also an open loop system, they can be used in mild subzero conditions as the vacuum between the two glass tubes prevents conductive and convective heat loss.

Re-circulation systems are a specific type of open-loop system used with flat plate collectors that do provide freeze protection. They use the system pump to circulate warm water from storage tanks through collectors and exposed piping when temperatures approach freezing. Re-circulation systems are suitable where mild subzero temperatures occur no more than once or twice a year.

If there is a power outage during a period of subzero temperatures, the pump will not function and the system will freeze. To guard against this, a freeze valve can be installed to provide additional protection in the event the pump does not operate. During subzero temperatures, the valve dribbles warm water through the collector to prevent freezing.

Activating the freeze protection frequently wastes electricity and stored heat. Some open loop systems also provide safety valves, which open as the outside temperature approaches freezing point. Water can drain from the system preventing the pressure from building up and cracking the pipes.

High quality heat pipe evacuated tube collector systems do not suffer from the disadvantages associated with flat plate open loop active systems. Water does not pass through the evacuated tubes, so the systems can be used safely in all climates.

Closed loop Active Systems pump heat transfer fluids through the collector. Heat exchangers transfer the heat from the fluid to the household water that is stored in tanks. Double-walled heat exchangers prevent contamination of household water. Some standards require double walls when the heat-transfer fluid is anything other than household water.

Closed-loop glycol systems are popular in areas subject to extended subzero temperatures because they offer good freeze protection. However, glycol antifreeze systems are more expensive to purchase and install and the glycol must be checked each year and changed every 3 to 10 years, depending on glycol quality and system temperatures [1]

The Drainback systems use water as the heat transfer fluid in the collector loop. A pump circulates the water through the collectors. The water drains by gravity to the storage tank and heat exchanger; therefore there are no valves to fail. When the pumps are turned off, the collectors are empty, which assures freeze protection and also allows the system to turn off if the water in the storage tank becomes too hot.

1.1.2.2 Passive Systems

Passive systems move household water or a heat transfer fluid through the system without pumps. Passive systems have the advantage that electricity outage and electric pump breakdown are not issues. This makes passive systems generally more reliable, easier to maintain, and possibly longer lasting than active systems. Passive systems are often less expensive than active systems.

A Thermosyphon system relies on warm water rising to circulate water through the collectors and to the tank. In this type of installation, the tank must be located above the collector. As water in the collector heats, it becomes lighter and naturally rises into the tank above. Whilst, cooler water in the tank flows downwards into the collector, causing circulation throughout the system. For small systems, the tank can be incorporated into the collector. Large tanks must be located next the collector. These systems are reliable and relatively inexpensive but require careful planning during installation because the water tanks are heavy.

Batch heaters are simple passive systems consisting of one or more storage tanks placed in an insulated box that has a glazed side facing the sun. Batch heaters are inexpensive and have few components, therefore minimal maintenance and fewer failures. A batch heater is mounted on the ground or on the roof, if the roof structure is strong enough to support it.

Some batch heaters use "selective" surfaces on the tank. These surfaces absorb sun well but inhibit radiative losses. In areas which experience subzero temperatures, batch heaters must either be protected from freezing or drained for the winter. The components that are more vulnerable to freezing are the pipes that carry water to the solar heater, although, if these pipes are well insulated, the warmth from the tank should prevent freezing. Certified systems clearly state the temperature at which damage is caused. In addition, a heat tape can be install, electrical plug-in tape to wrap around the pipes to keep them from freezing, insulate exposed pipes, or both. However, heat tape requires electricity, so the combination of freezing weather and a power outage can lead to burst pipes.

1.2 Advantages of Solar Water Heating

There are many benefits to owning a solar water heater, the primary one being the economic savings. The overall cost of solar water heating compares favourably with electric water heaters. Although the cost benefits are not so great when compared to gas heating, the environmental benefits are clear. Solar water heating also has long term benefits, such as reduced impact from future fuel shortages and gas/electricity price increases. For the environmentally minded, solar water heating is now a viable and cost effective alternative to gas or electric hot water systems.

Many home builders choose electric water heaters or gas water heaters because they are easy to install and relatively inexpensive to purchase. However, research shows that an average household with an electric or gas water heater spends about 25% of its home energy expenditure on heating water [3]. It makes economic sense to think beyond the initial purchase price and consider lifetime energy costs. It is found that solar water heaters offered the largest potential savings, with solar water heater owners saving as much as 50% to 85% annually on their utility bills over the cost of electric water heating [3]. Furthermore, solar water heater can add to an existing home raising the resale value by the entire cost of the system. However, in this instance comparisons are done with gas rather electric heating.

Active Solar Heating can be implemented several different ways to meet the requirements of the system. In this case, the collector will be required to heat an existing water tank with a gas fuelled ‘Tank in Tank’ boiler as the supplementary heating medium. For this case, it will be a flat bed collector, shown in figure 1.3 below. It is necessary to look at the layout of the system; its performance, and the cost effectiveness of the system. In order to see the actual benefits it is necessary to assess these parameters.

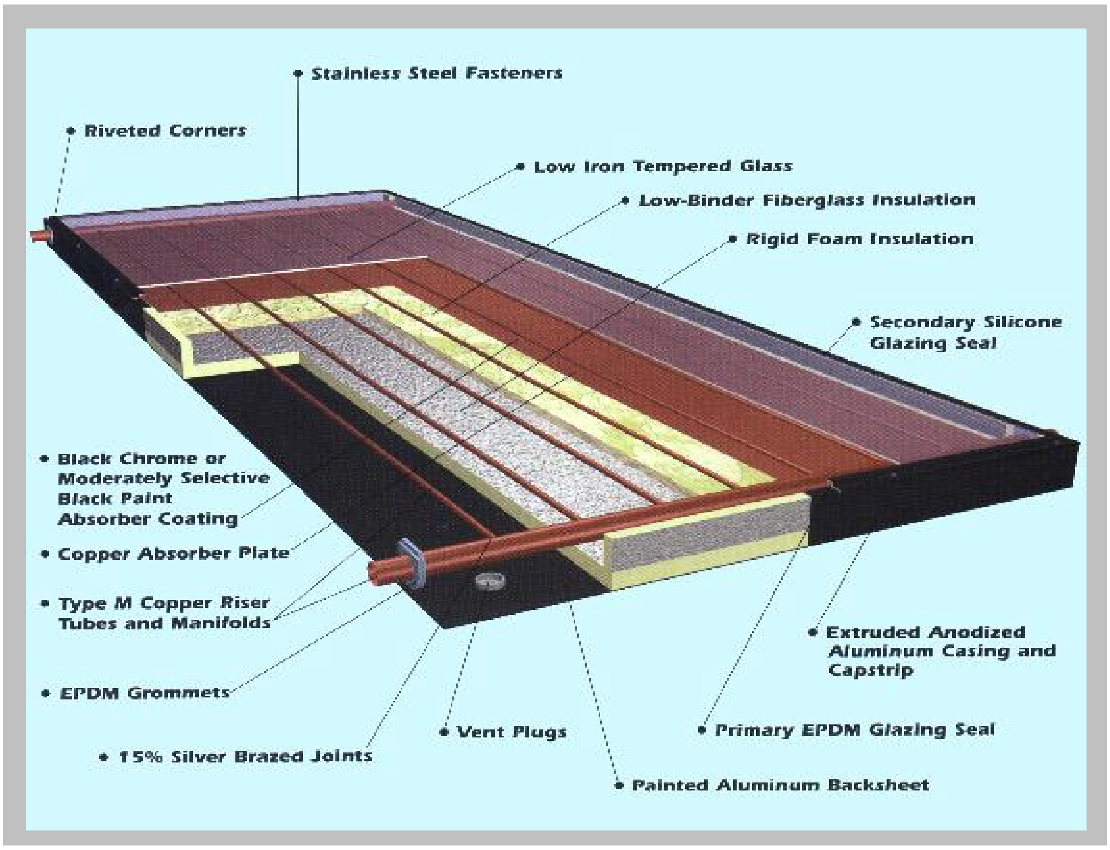

Figure 1.3: A typical Solar Flat-plate collector.

1.3 The collector

The chosen flat plate collector was chosen between two main manufacturers, although there are many distributors and a few more manufacturers. The two main manufacturers that where chosen due to the high results from the high efficiency flat plate collectors are AES and STIEBEL ELTRON. The choices of these particular collectors are doe to them being established and provide the two main differences available at present between glass and plastic covers.

1.3.1 AES

Using modern aluminium and plastic manufacturing techniques, the panel is lightweight and uses no glass so is not only easy to put on a roof but safer to fit at ground level too. The frame is normally made in multiples of square metres. The AES ‘light panel’ manufactured at Findhorn, near Inverness.

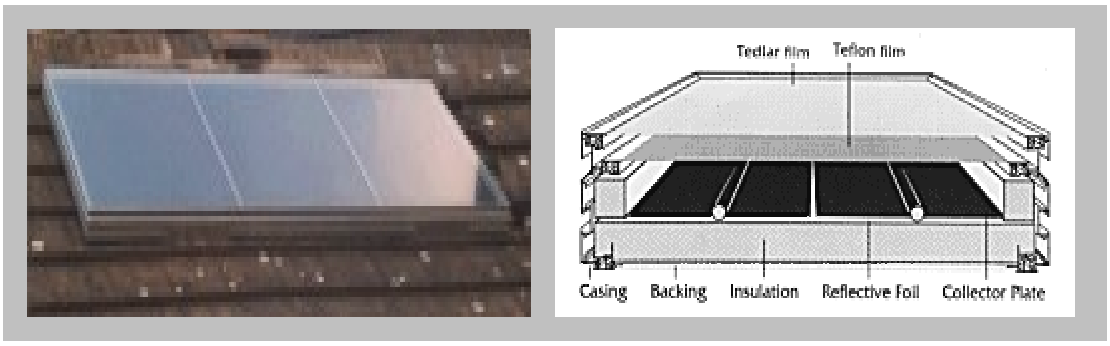

Figure 1.4: AES Flat plate collector

Net absorber area (m^2)	**2.0**	**3.0**	**4.0**
Total weight (kg)	**17**	**24**	**32**
Water capacity (l)	**2.0**	**2.9**	**3.8**
Overall dimensions (mm) w by h	**1950 by 1175**	**2875 by 1175**	**3775 by 1175**

Figure 1.5: AES Flat plate Dimensions

1.3.2 STIEBEL ELTRON

The high performance flat collector has a highly selective coating on the copper absorption plate with light permeable, glass cover. The highly transparent glass enables optimal absorption of the energy available.

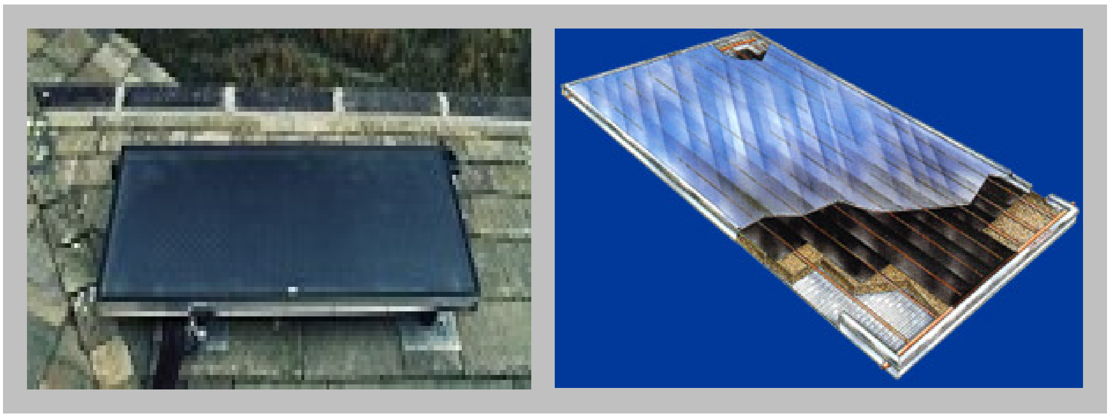

Figure 1.6: STIEBEL ELTRON Flat plate collector

Net absorber area (m^2)	**2.0**	**3.0**	**1.77**
Total weight (kg)	**55**	**80**	**42**
Water capacity (l)	**1.9**	**2.9**	**1.7**
Overall dimensions (mm) w by h	**1596 by 2040**	**2310 by 2040**	**1008 by 1978**

Figure 1.7: STIEBEL ELTRON flat plate dimensions

The choice between the two is very little in terms of performance and overall collector efficiency. The dimensions of both collectors, shown above in tables 1.6/1.7, allow for the water capacity and the weight of the systems. The main differences lay with the weight, with AES supplying 4m^2 collector less than the smallest STIEBEL ELTRON collector. This difference is due to the glazing material. The STIEBEL ELTRON collector uses a glass cover where as the AES collector uses a Tedlar and Teflon Film.

The AES panel would be the better choice in this circumstance as the total area required is likely to be above 4m^2 and so would require more than one panel. Furthermore, panels tend to be installed in pairs given more variations in the size of the panels that can be installed through the AES collectors as well as the weight and ease of installation.

1.3.3 Energy Flow of Flat Plate Collector

The materials and the properties of the collector determine how well it performs. The properties that have most bearing are: Transmission, τ, Reflectance, ρ, and Absorptance, α. Ideally, for a material the sum of these properties should be as close to one as possible, $\tau+\rho+\alpha=1$. For any absorber surface, the collector plate has to maximise the amount of solar energy collected for which it requires a high absorptance, no transmission and a very low reflectance.

It is these properties that allow for the collector to be assessed. This allows for the energy capture by the solar collector. The absorbed power, Q_P, is given by:

$$Q_P = GA\tau_c\alpha_p$$

Where,

G = total irradiance (W/m^2)
A = area of collector (m^2)
τ_c = transmission of the cover
α_p = absorptance of collector plate

However, the useful power from the collector also considers the losses from the collector. The power loss of the collector, $Q_{L,}$ is given by:

$$Q_L = UA\,(T_c - T_a)$$

Where,

U = collector U-value ($W/m^2\,K$)
T_c = temperature of collector plate (K)
T_a = ambient air temperature (K)

Therefore, the total useful energy supplied, Q_S, is given by[2]:

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[2] Hottel-Whillier equation

$$Q_S = Q_P - Q_L$$

Or,

$$Q_S = GA\tau_c\alpha_p - UA\,(T_c - T_a)$$

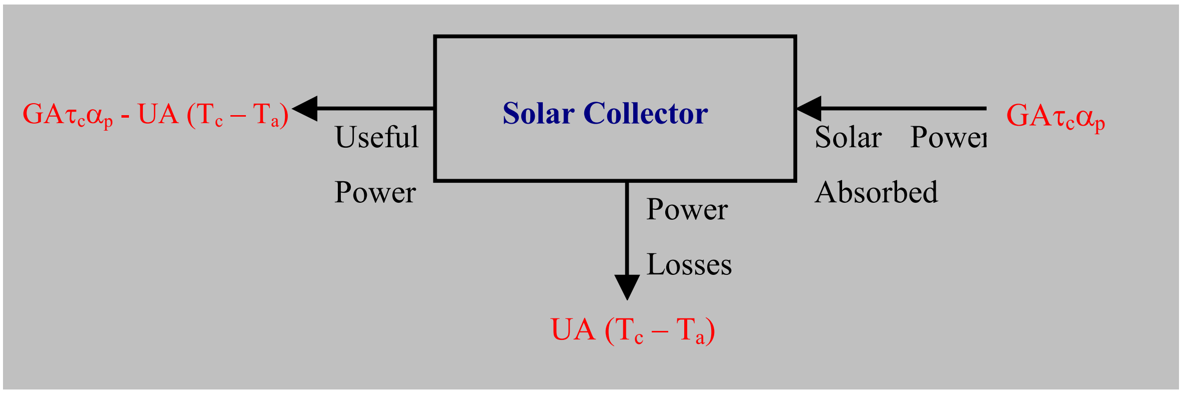

Figure 1.8: Energy flow of flat plate collector

The useful power can be calculated for any given time this way. It will enable the collector's performance for a period of time, normally over a month of a typical year. One way that uses this to calculate the useful power against the actual load required is the f-chart method, in which the solar fraction, f, is given as the useful solar divided by the total load [4]. This method will be shown when assessing the performance that will follow later.

It is also possible to have simulation techniques like the well-known TRYNSYS. Where they are computation simulations of more simplified and more regular data is used. However, the method for assessing this case study is through the design calculations with averaged data. Whilst, the design method incorporates average monthly heating data and radiation, as will be shown, these are precise enough to assess the requirements and outputs of a solar heating system in the long term.

The simulation techniques often require hourly meteorological data as well as the influence of the heating loads, like the location of the building, it's design, orientation, construction and occupancy patterns. However, for this case study the plan drawings give the building materials and location, they do not enable prediction of the casual gains and finer details that are often required by the computational simulation. Moreover, the generation of complicating the calculations unnecessarily for a more detailed assessment will not have much of an advantage on the long term performance of the system as the averaged values used are actual measured values, as well as the availability of the required data.

Instead of the simulation techniques, the design method of using an averaged predicted set of values for both the requirements and the inputs of the collector are used. However, for the heating loads a program will be used to calculate the heat losses of the building from the design and will be the basis for all calculations in the final assessment discussed in section 4.3.

Chapter 2 – ‘Tank in Tank’ Heating [5]

There are two major type of cylinder, those with coils and the twin walled tanks. The 'Tank in Tank' does not fall within either of these categories. The difference between the cylinders and those with coils is clear since in the coil arrangement the primary fluid heats the domestic hot water from the outside in whilst the other heats it from the inside out. On the other hand the twin walled cylinders have an area near the bottom, which is not heated, as the heat transfer surface is smaller unlike a ‘Tank in Tank’ arrangement.

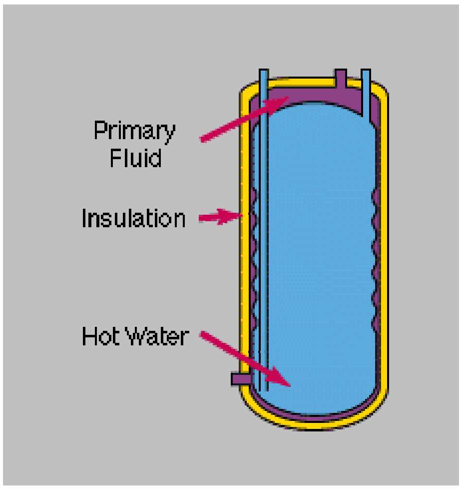

Figure 2.1: ‘Tank in Tank’ Boiler

2.1 ‘Tank in Tank’ features

The "Tank in Tank" also protects the user against flooding. In cases of the hot water tank rupturing the water will simply join the heating circuit. The only consequence of this will be a higher than normal pressure in the primary circuit. Despite all this the most important characteristics of the "Tank in Tank" are its capability for self-descaling and its long life expectancy combined with the lack of a requirement for regular maintenance.

2.1.1 Inner Tank

The heating surface of a cylinder is one of three parameters that govern the level of domestic hot water stratification. The other two are the volume of water stored and the water storage temperature. The ‘Tank in Tank’ system has an advantage as, the larger the heating surface the quicker the tank will be reheated. In addition, the more increase in the temperature of the water the more the increase the risk of lime building up on the heat exchanger but, the more the increase the temperature of the water there is, the wider become the variations in pressure. However, the wider the variations in pressure, the more cylinders of the 'Tank in Tank' design expand and contract and, the more the cylinders expand and contract, the less chance limescale has to build up. Figure 2.2 shown below, illustrates the tank inside the tank that holds the water. The corrugation on the main body allow for the expanding and contracting and are only restrained at one end.

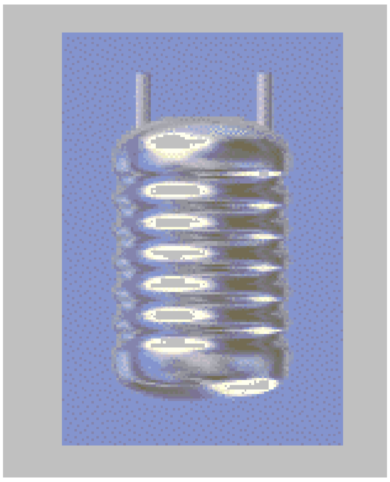

Figure 2.2: Inner tank of the 'tank in tank' system.

Stainless steel is the material used for the tanks and has the following advantages:

- It is capable of operating at high temperatures.
- Stainless steel is resistant to corrosion.
- The protective coating in an enamelled steel tank can be damaged by a knock, this does not happen with stainless steel.
- A stainless steel tank does not need a sacrificial anode.
- Stainless steel is universally recognised for its hygienic properties. It is widely used in the food industry and in the manufacture of surgical instruments.

2.1.2 Insulation

The insulation of the tanks system is by a thick layer of rigid polyurethane foam directly formed onto the body of the cylinders. This polyurethane mousse has a Lambda coefficient of 0.02 and is at least twice as effective as a similar thickness layer of rockwool as used on the majority of appliances. With the foam insulation the standing losses are reduced to a lower level than normal.

2.1.3 Tank Ranges

The ‘tank in tank’ system is available in many specifications, and come in three main ranges of interest, the GL, the HR, and the HR Duplex.

2.1.3.1 GL range

The GL Range is insulated with 50mm of the Polyurethane mousse and has the stainless steel tank. It is fully argon arc welded following the Tungsten Inert Gas technique. Before assembly the domed ends of the tank are degreased to improve their corrosion resistance. It also has the benefits described previous with the corrugated body.

A stove-enamelled jacket contains the complete assembly and is fitted with a control panel that includes the heating and domestic hot water control thermostats. Furthermore, it is wired to enable a domestic hot water programmer. Also optional is a kit to connect the cylinder with the boiler, pre-assembled and includes the pipe work and connections as well as the pump.

	GL 100	GL 130	GL 160	GL 210	GL 240
Output (kW)	23	31	39	53	68
Heating fluid flow (m^3/h)	2.1	2.6	3.5	4.2	5.5
Heating surface (m^2)	1.03	1.26	1.54	1.94	2.29
Total water capacity (l)	105	130	161	203	242
Heating fluid capacity (l)	30	31	35	39	42
Pressure drop (mbar)	17	22	37	45	51
Weight empty (kg)	71	80	93	107	121
Maximum Operating Pressure (bar)	3	3	3	3	3
Maximum operating pressure: sanitary (bar)	10	10	10	10	10
Maximum temperature (°C)	85	85	85	85	85

Table 2.1: GL range of properties

	GL 100	GL 130	GL 160	GL 210	GL 240
Peak output in 10 min at 45°C (l/10 min)	202	275	348	496	600
Peak output in 60 min at 45°C (l/60 min)	672	911	1156	1560	1988
Correction coefficients when operating at 75°C	0.8	0.8	0.8	0.8	0.8
Correction coefficients when operating at 65°C	0.6	0.6	0.6	0.6	0.6

Table 2.2: GL operating properties

Correction coefficients will allow the peak output of the system at higher operating temperatures, i.e., the output at 65°C is 0.6*672 litres for an hour.

2.1.3.2 HR Floor Standing range

The HR Range is insulated with 30mm of the Polyurethane mousse and has the stainless steel tank. Like all the ‘tank in tank’ systems the HR range it is fully argon arc welded following the Tungsten Inert Gas technique. Before assembly the domed ends of the tank are degreased and pacified to improve their corrosion resistance. It also has the benefits described previous with the corrugated body. As well as the same features of control and programmers, this system incorporates an on/off immersion heater.

	HR 110	HR 140	HR 180	HR 230	HR 271
Output (kW)	24	33	42	55	60
Heating fluid flow (m^3/h)	2.2	2.7	3.2	4	4.5
Heating surface (m^2)	1.1	1.4	1.7	2.15	2.3
Total water capacity (l)	107	140	181	227	270
Heating fluid capacity (l)	30	35	46	57	45
Pressure drop (mbar)	25	35	51	50	60
Weight empty (kg)	64	77	95	100	140
Maximum Operating Pressure (bar)	3	3	3	3	3
Maximum operating pressure: sanitary (bar)	10	10	10	10	10
Maximum temperature (°C)	85	85	85	85	85

Table 2.3: HR range of properties

	HR 110	HR 140	HR 180	HR 230	HR 271
Peak output in 10 min at 45°C (l/10 min)	236	307	408	512	680
Peak output in 60 min at 45°C (l/60 min)	727	980	1263	1640	1899
Correction coefficients when operating at 75°C	0.8	0.8	0.8	0.8	0.8
Correction coefficients when operating at 65°C	0.6	0.6	0.6	0.6	0.6

Table 2.4: HR operating properties

2.1.3.3 HR Duplex

The is an amended version of the HR range above for the purpose of high chlorine content water, de-ionised water or process applications, and high pressure applications. It has a hard jacket with powder coating is suitable to any commercial or residential configurations; it also has 50 mm water base polyurethane insulation.

	HR 271	HR 321	HR 601
Output (kW)	60	76	88
Total capacity (l)	270	318	606
Heat exchange surface (m^2)	2.3	2.65	3.58
Peak flow L/10' @ 45 ºC	680	790	1153
1st Hour recovery L @ 45ºC	1899	2342	2946
Continuous flow L @ 45ºC	1463	1862	2152
Maximum Operating Pressure (bar)	5	5	5
Maximum operating pressure: sanitary (bar)	10	10	10
Maximum temperature (°C)	85	85	85

Table 2.5: HR Duplex range of properties

Chapter 3 – Solar Pump

The purpose of a solar pump is that a PV module supplies the energy required for pumping in the small closed loop of a solar water heating system. The pump uses a DC motor instead of a mains AC motor, so utilises the energy produced from the PV module. Installing a PV panel to operate the pump will allow operation even during a power cut.

3.1 The Pump

The pump is a brass body, vane pump, with special clearances and seals for high temperature protection to 90°C.

DC Pump features are:

- A maximum pressure rise is 400 kPa
- Sliding-vane brass pump with integral strainer, 100 mesh/125 micron
- DC motor complete with mounting feet
- Pump-motor V-band coupling
- 3-ampere linear current booster
- Flow rate range of 0.3 l/min to 4.5 l/min
- Operates even at PV radiation of 200W/m^2

Figure 3.1: A DC Pump

The DC pump has no parts are subject to corrosion; all wetted parts are stainless steel, brass and carbon. The Solar Pump is a positive displacement pump, meaning no time or equipment is required to purge air from the circulation loop. It is also self-priming, with a maximum suction lift of 2 metres.

3.2 DC Motor

The DC Pump motor is larger than motors designed to operate at 110 to 240 volts AC. Unlike standard motors that use electrical coils and electric current to create the magnetic field, they use effective permanent magnets. To produce the torque required to boost the pressure of the pumped water the use of a heavy-duty, large-diameter armature with thick copper windings to reduce parasitic power consumption. Even in very weak sun the motor produces enough power to start the pump. The motor is durability and reliability as the brushes and commutators are designed so that they will not require replacement when driven by a PV module under 50 watts peak power.

3.3 PV Module Requirement

Depending on the flow and pressure requirements of the application a 10 to 50 watt PV module will power the DC Pump. A PV module with maximum peak voltage, V_{mp}, of 16-17 volts is required, which is typical of PV modules with 36 crystalline cells or 13 amorphous cells.

3.4 Other consideration

Starting and running the pump is the only concern in using a direct PV to pump connection, due to the amount of torque needed to start the pump. The motor/pump unit is supposed to start rotating when solar flux reaches 200 W/m^2. When at 200 W/m^2, a typical module should deliver just over 0.2 amperes to the linear current booster (LCB), which results in current to the motor from the LCB of about 1.1 amperes. This should be sufficient to start the pump.

A linear current booster (LCB) purpose is to maximise the power delivery of the PV module to the DC motor. At full sun the PV module drives the motor at full speed. At lower sunlight levels the LCB converts PV power into high motor current to start the motor and keep it running at low RPM. This control strategy provides a flow rate proportional to the intensity of the solar radiation.

3.4.1 Pump advantages

There are a small number of advantages that come with operating a PV driven DC pump.

- Quiet, maintenance-free operation
- Self-priming, positive displacement
- Life expectancy of more than 20 years
- Easy and inexpensive to install
- Benefits of renewable power
- Less exposure to electromagnetic fields

Chapter 4 – Characteristics, Data and Requirements

Introduction

The first stage of sizing a system for a particular location is retrieving as much information as possible. In order to assess the circumstances it is necessary to work from the detailed drawings of the house, as no site visit was possible, and the data provided by manufacturers.

In the case of the hot water needs an estimated usage for each point is described, with the exception of the bath. The use of the bath is often irregular and so heating enough water for the bath would lead to an additional 7 kW of capacity[3]. Instead the time taken for hot water to be supplied for a bath will be given. Therefore, prior to the event the water can be placed on for the required time.

4.1 Solar Data

4.1.1 Direction and Angle of collector

Naturally, the collector should receive the maximum amount of sunlight each day and throughout the year. As a general rule if you are in the Northern Hemisphere then the collector should face South and if you are in the Southern Hemisphere then the collector should face north. Furthermore, the angle at which the collector is mounted should roughly correspond to the latitude of the location, in this case, 55.52 North. Therefore, should be mounted at 55° South.

This does not have to be exact angle for mounting the collector. Instead, a roof of +/- 10^{o} of the latitude would allow for solar collector flat against the roof's surface. The added trouble of adjusting the collector to a precise angle would not be warranted, as it will not result in a great difference in efficiency. The collectors will be positioned at a 45° tilt on the south facing roof.

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[3] See Appendix I

4.1.2 Solar Radiation on Collector

It is necessary to retrieve the amount of daily radiation that will fall on the collector's surface. This is normally published as actual measured data, and for this case study, is the daily monthly average of radiation per metre area (kWh/m^2 – Day).

The values for the average daily radiation on the collector for each month in Glasgow at 45° angle are shown below in Table 4.1 [6].

Month	Daily Radiation (kWh/m^2 - Day)
January	2.77
February	5.76
March	9.07
April	14.1
May	16.2
June	16.7
July	14.3
August	12.7
September	10.4
October	7.02
November	4.00
December	2.23

Table 4.1: Average daily radiation on a collector in Glasgow at 45°, facing south.

4.2 Collector Characteristics

In order to calculate actual amounts of energy captured by the collector arrangement it is necessary to possess the following values,[4] shown below in Table 4.2. However, two further properties of the collector system are also required. Firstly is the collector heat removal efficiency factor, F_R, is the ratio of the useful energy gain to the energy gain if the collector was at the same temperature of the inlet fluid. The second is the Collector heat exchanger correction factor, ($F_R{}' / F_R$), which is an index of the penalty incurred by using a heat exchanger in the closed loop. These values are from the manufacturer's specifications, AES' High Efficiency Flat Plate Collector [7].

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[4] Previously explained in Chapter 1

Property	Value
Collector U Value	**5 W/m^2 K**
Collector Absorptance (α)	**0.95**
Transmissivity of cover (τ)	**0.85**
Collector Heat removal Efficiency Factor (F_R)	**0.9**
Collector heat exchanger correction factor (F_R' / F_R)	**0.9**
Design Temperature Difference (°C)	**50**

Table 4.2: Collector Characteristics

4.3 Heating requirements

In order to calculate what is required of the system and sizing the system, it is necessary to have the heat loss from the building and the domestic hot water needs. The heat losses will allow the sizing of radiators given the boiler size for this operation. The hot water needs will also have to be included to give a total boiler capacity.

4.3.1 Space Heating

The space heating requirements have to be theoretically calculated, as part of the building is new, so no actual consumptions are available. Furthermore, the old system will be replaced, all new parts. Therefore, the capacity of the heating system required is calculated from the sum of the fabric and ventilation losses. Using an accurate Heatloss Manager program the required heat output for each room can be totalled and give the capacity, as shown below in Table 4.3.

The Heatloss manager program from ‘Myson Heating Services’ [8] uses the building fabric’s U-values to calculate the heat losses as well as the ventilation losses from the air change rate of each room. The program will further calculate predicted losses in any system giving an accurate picture of the heat flows of the building. This program works on the basis of the heating required to heat individual rooms to a desired temperature. Thus, allowing the capacity of the system to be sized from the required radiator output. The details of the programs outcome can be seen in Appendix V.

Room	Required Heat Output (W)	Radiator Rating (kW)
Downstairs Bedroom	1416	2
Downstairs Toilet	168	1
Dining Room	1856	3
Entrance Hall	422	1
Main Hall	846	2
Sitting Room	1435	2
Kitchen	1285	2
Gym	990	2
Games Room	619	1
Utility Room	625	1
Upstairs Bedroom 1	176	2
Upstairs Bedroom 2	1376	2
Upstairs Bedroom 3	830	2
Upstairs Bedroom 4	1336	3
Upstairs Bathroom	1800	1
Upstairs Hall	486	1
Office	598	2
Upstairs Bedroom en Suite	1169	2
Upstairs Living Room	1032	2
Total	*19,698*	*34*

Table 4.3: Building heat losses and heating capacity.

4.3.2 Hot Water

In addition to the heating requirements, the domestic hot water consumptions also have to be taken into consideration. This was calculated using the recommended typical estimated usage [9], shown below in Table 4.4.

Water Points	People Using	Average Consumption per person (l)	Consumption of Hot water (l)
Main Shower	3	10	30
En suite Shower	2	10	20
Kitchen Sink	5	16	80
Two Bathroom Sinks	5	13	65
En suite Sink	2	13	36
		Total Consumption	*221 litres per day*

Table 4.4: Average hot water consumption.

The power required for the boiler to heat the required hot water is 13 kW in total.

4.3.3 Total Water Heating Requirements

Normally, the required boiler output would be the total heat loss from the building plus intermittent correction [9], 20%, as well as the domestic hot water, then an additional 15% for pipe losses. This method gives a boiler output of 42.1 kW. However, this would not take into consideration for bad weather. A boiler of 47 kW would be adequate for this instance. However, as described early, the 'Tank in Tank' system has been proposed, so the nearest to our calculated capacity will be chosen. In this case the GL210 with an output of 53kW would be the closest match although slightly over capacity.

Chapter 5 – Solar Heating System

Introduction

As already explained in a previous chapter, there are many choices existing today in terms of the collector and open or closed loop systems. The latter of these is ideal for the Scottish climate, and the necessity of an antifreeze system. Although both, closed and open loop arrangement, have the opportunity of utilising three main systems: evacuated tubes, flat plate, and tracker concentrators. For this case a flat plate collector will be used as proposed. Furthermore, the details of the pump will be discussed in the prevailing chapter along with the possible replacement of the differential controller with a linear current booster.

The layout of the solar water heating systems with a closed loop can be explained with the aid of the diagram, shown below in figure 5.1, and also through explanations of the components in the solar loop of the system. The finalised system will be achieved depending on the performance of the collectors at different areas.

5.1 System Layout and Components

5.1.1 Solar Loop Layout

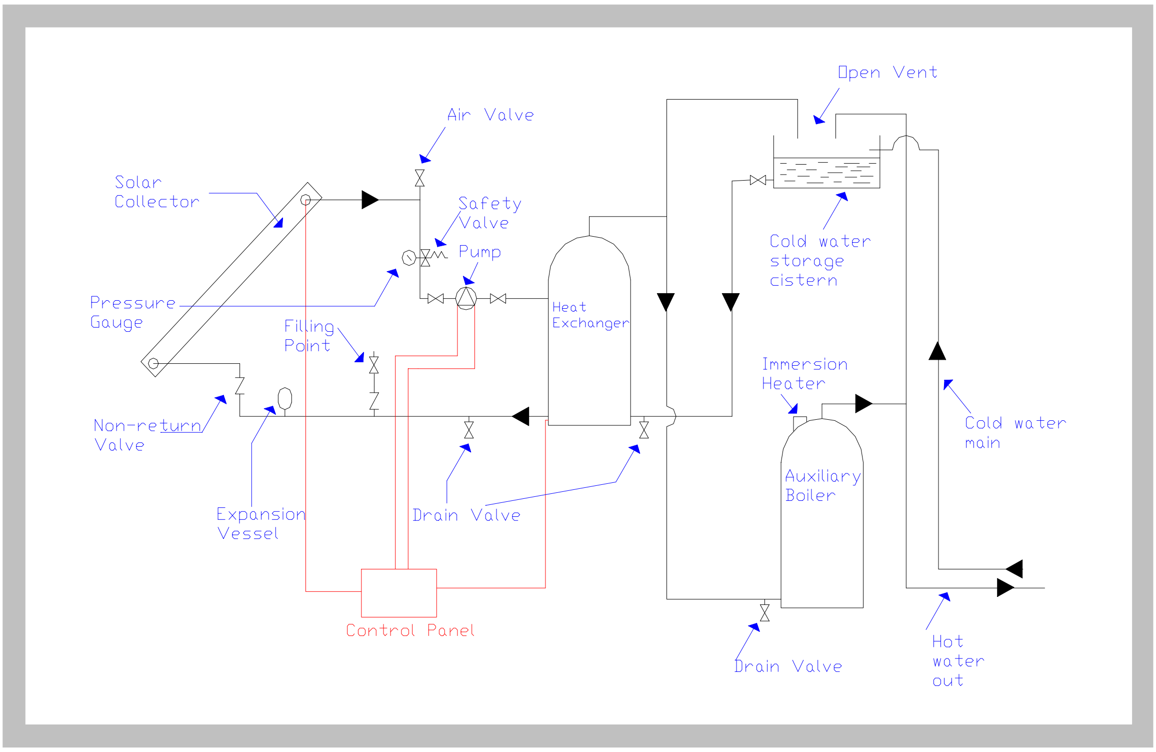

Figure 5.1: Layout of closed loop system with auxiliary boiler

The way in which the system works is in four stages:

1. The collector panels are heated by the solar energy and heat the solution of water and Glycol.
2. The pump is switched on by the differential control when the temperature at the collector outlet is +4°C more than that of the heat exchanger tank.
3. This pumps the hot solution from the collector through the heat exchanger, which heats the water.
4. When the water is drawn off through the hot taps or heating system, the cold water from the storage cistern forces the hot water from the heat exchanger to the auxiliary boiler. Reducing the heat required to raise the temperature of the conventional boiler as the water is pre-heated somewhat already. The expansion vessel takes any expansion in the antifreeze collector loop.

5.1.2 Closed Loop Components

5.1.2.1 Expansion Valve

The expansion device is sized in such a way, that even after an interruption of the power supply to the circulation pump in the collector loop just when solar irradiance is maximum, operation can be resumed automatically when power is again available.

For small closed systems which are provided with a membrane expansion device and in which the heat transfer medium can evaporate under stagnation conditions, the volume of expansion to be compensated by the expansion device should be equal to the total heat transfer medium contents of the whole collector array including the connection pipes between the collectors, plus 10% to account for the expansion of the heat transfer medium itself.

5.1.2.2 Drain Valves

The drain valves are positioned to allow for maintenance to the system. The most apparent of these is the checking of the Glycol solution and replacing in time. They are also positioned either side of the pump and heat exchanger to allow for isolation of each component, so that in-line components can be removed without draining the entire loop.

5.1.2.3 Other Valves

The air valve and pressure relief (safety) valve is precautionary where there is a build up of pressure caused by air and other blockages. Blockages are possible through excess heating of the Glycol solution. These are normally in the form of small black carbon deposits, not too similar to a small melted sweet. This valve can simply be bled when filling the system or topping up to relieve pressure. However, blockages should be removed. A further instance of this is when the heating medium in the collector evaporates in cases of stagnation, steam may reach high velocities and pressure peaks may occur. Furthermore, the pressure relief valve prevents components being put under more pressure than are specified.

The non-return valves are simply to prevent backwards flow at the filling point and at the entrance of the collector (reverse flow prevention). That is, it prevents heat from the tank rising towards the collector should the tank be warmer, i.e., at night.

5.1.2.4 Filling Point

The filling point is where the topping up or filling the system with the Glycol solution can take place. A separate filling point can be placed in the circuit at other points for ease and access, but should remain in the system as a separate point. This will allow for flushing[5] the system when required.

5.1.2.5 Cold Water Storage Cistern

The cold water storage is the feed to the heat exchanger. This must be entering at the bottom where there is less heat and stratification. Allowing for the hotter water to be drawn from the top and the cold water at the bottom, as anyway else will affect the performance, as more mixing will occur. An example of this is shown in figure 5.2 below, although the defined layers are not present in practice, as stratification does not occur so well defined.

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[5] See section on 5.2 maintenance

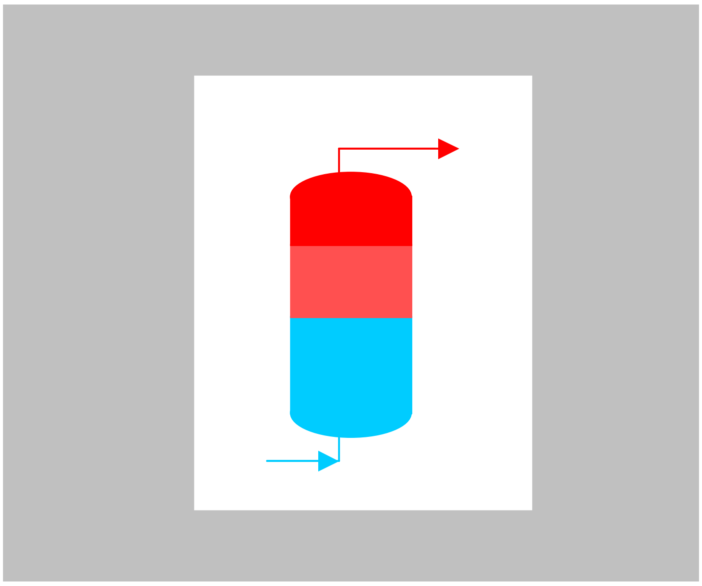

Figure 5.2: An example of stratification

5.1.2.6 Immersion Heater

The immersion heater is included in the circuit for the times where the system may not be heating the tank to a high enough temperature, most likely in winter. This is commonplace on most boilers, and the 'Tank in Tank' system has it included as normal.

5.1.2.7 Heat Exchanger

A heat exchanger is required in all closed loop systems and allows for the poisonous Glycol solution to be kept separate from the water system. The heat exchanger in this case has one coil, containing the heating medium of the Glycol solution. Passing through the cold water at the bottom of the tank from the storage cistern. The hot water rises to the top and is drawn off into the auxiliary boiler. The performance of the heat exchanger is taken into consideration when assessing the output from the system. However, the heat exchanger will not significantly reduce the collector efficiency with increasing their operating temperature.

5.1.2.8 Differential Controller

An electronic differential controller is designed specifically to regulate the solar loop’s operation. Its basic function is to monitor the collector and storage temperatures, then to automatically turn the circulation pump ON or OFF at the appropriate temperature difference, ≈±4°C.

5.2 Maintenance

Although maintenance of the solar water heating closed loop system is relatively low, there are some aspects that are required and monitored of involving the system.

5.2.1 Antifreeze Solution – Propylene Glycol [2]

Periodic maintenance of Glycol systems must address two things, the condition of the solution and the hardness of the water.

5.2.1.1 pH Levels

Glycol solutions can turn acidic after a few years of use. The pH of the propylene Glycol /water solution should be checked annually. The solution can be checked with Litmus paper or a pH meter. Too acidic solutions should be drained, purged with water and refilled with a new solution. If the system is not used for an extended period of time, the collector loop should be drained and the fluid stored or covering the collector glazing. Overheating in the loop above 110-120°C usually causes the acidic solution.

5.2.1.2 Foreign particles in solar loop

This causes high solar collector temperatures on hot, sunny days and this, over a period of time, causes a breakdown in the Glycol. It may become black, due to the carbon particles, as well as very acidic. The black particles can accumulate at a bend or crevice in the collector loop and cause blockage of flow. A blocked collector loop can cause the pump to overheat, which may destroy the seals, and Glycol then leaks from the pump. Acidic Glycol can erode the brass and copper components in the solar water heater.

5.2.1.3 Solution mix

The solution mix should be of 40% Propylene Glycol by volume with water. Reduction in this can lead to freezing in some parts of the system when the temperature is low outside. Placing a sample volume into a freezer compartment and measuring the temperature at which the sample becomes a slushy constituency may test the heat transfer fluid for this. A more accurate testing requires the use of a refractometer. The company that installed the system can often perform this service for a small fee.

5.2.2 Pressure Loss

The pressure in the system may show a slight fall after the initial period of operation. This is normal as the aerated water gives off its dissolved gases. Under normal operation the expansion vessel or make-up cistern will make up for any pressure loss due to aerated solution or gassing. However, if there is a significant drop in pressure or fluid level it may be one of the following:

- Overheating may occur during a period of hot weather if, for some reason, the pump isn't operating, and the heat transfer fluid is therefore not being circulated. Thermal energy is not being removed from the collector so the water temperature will rise, hence water volume and system pressure will increase. This could result in the release of hot water or steam from the pressure relief valve or the automatic/manual vent. When the system returns to normal operating conditions the pressure will reduce due to the loss in fluid volume.
- If water is escaping from the system the volume of water in the system decreases and hence the pressure/fluid level will drop. If there is a leak in the system it may require a drain down and repair/replace faulty component.

It is unlikely that an expansion vessel (if fitted) will develop a fault. The vessels are normally factory charged to 0.5 bars and would be double-checked prior to installation. They can be rechecked, if suspect, with a standard tyre gauge by removing the black cap on the end of the vessel. This test should only be carried out when the system is cool as there is a danger of scalding should the vessel be faulty. Any fluid escaping from the test valve indicates a leaking diaphragm and the vessel should be replaced.

5.2.3 Flushing

If there is a hard water content running through the heat exchanger, the tubes inside will eventually scale up, reducing the heat transfer surface area. Although this should not be too much of a problem the heat exchanger should be cleaned. If it is not taking apart, it is possible to flush through and corrected by a light acidic solution, i.e., vinegar or Tri-Sodium Phosphate. This should be circulated until the any deposits are gone.

5.2.4 Other Considerations

Apart from the two main areas of checks, there are observations that can be made that will allow alert any circumstances affecting the performance.

5.2.4.1 External observations

Observations of the system as seen from outside.

It may not be necessary to use a ladder for this but from a good vantage point with or without binoculars.

- The glazing seals are weather tight
- All the insulation is firmly attached
- That there is no evidence of serious corrosion or persistent condensation
- All covers, fixing screws, etc., are in place and the panel is secure
- The panel sensor is secure in the pocket provided

5.2.4.2 Internal Observations

Observation of the internally working system can be less obvious be just as important.

- All air has been expelled from the system (none observed in flow-meter window or audible in pump)
- All insulation is firmly in place
- There is no damage to pipe work
- There is no evidence of leaks
- The system is at the correct pressure
- Electrical controls and operational indicators are working correctly, referring to the user manual
- The sensors are securely fitted into the pockets provided in the cylinder
- All components are securely fixed and that all covers, fixing screws, etc., are present
- The pressure relief valve releases fluid when briefly twisted

5.3 Legal Requirements

The following is a list of relevant legal aspects to consider; although these are not obstructive they have to be considered. In this case due to the location and permission for an extension already granted, there is no cause for concerns.

5.3.1 Insurance

Most domestic solar water heating systems are automatically included in general household policies apart from frost damage. However it is recommend that insurers are best informed in writing in any case.

5.3.2 Planning

Most systems fitted to existing buildings do not need to involve planning controls. The exceptions are in conservation areas, national parks and listed buildings. In these cases the first step is to talk with the relevant local planning officer. Typically if roof aerials, satellite dishes or skylights are permitted then so too can solar collectors. Sometimes the planning officers are simply unaware of the new designs and possible locations for solar collectors.

Planners normally will consider the following:

- Appearance and visual impact
- Impact character of area
- Visibility from road
- Area in relation to roof
- New buildings normally include the solar systems as part of the whole planning application for the development.
- Town & Country planning (GPDO) 1995 Schedule 2, Part 1, Class B, C or E
- Town & Country planning (GDO) 1992 Schedule 2, Part 1

Policy Guidance

There is increasing official promotion of renewable energy sources in the UK and European Union

DOE PPG12 Feb 1992

DOE PPG22 Feb 1993 and annexes OCT 1994

EU Council regulations 2618/80 and 218/84, Resolution 86/C316/01,
Recommendation 88/349/EEC
UN Framework Convention on climate change 1992

Relevant standards
BS 5918: 1989, Domestic hot water systems
HSC ACOP Legionellosis Control 1991.
CIBSE memoranda ‘Minimising the risk of Legionaries’ Disease 1991)

Enforceable legislation
G3 Building Reg. 1995, soon to be updated
Local water byelaws,
The water supply regulation 1989 & 1991 amendment,
Health Safety at wok Act 1974,
Control of substances - Hazardous to Health Regulations 1994,

Chapter 6 – Solar Pump

It is apparent that the DC electricity is used for the pump and is going to be produced by a PV cell. Even though this task is relatively simple, it is still necessary to calculate the amount of energy produced by the PV cell matches the pump. The DC pump can run between 10 and 50 watts as described earlier. However, this will have to be met by the output of the cell. Therefore, we can calculate the PV output from the daily radiation data. Furthermore, if too much is produced by the PV cell, a buffering arrangement involving a battery may be necessary. At the same time this will address the use of a Linear Current Booster.

6.1 PV Cell

Using the recommended PV cell of size 50W, 12V. It is feasible to calculate the energy flow from the cell. This will come of no consequence if the use of a Linear Current Booster is used. However, if a battery is used to buffer the collected output although this is not a usual method of including a DC pump simply due to the high cost of a battery.

Required energy for eight hours running at the normal 30W, excluding start up.

$Q = 8 * 30 = 240$ W

Energy produced by PV cell for hours for an average input of 2.7 kWh/m^2day.

$Q = 2700/8 = 675$ W

Checking the current in the System.

A_s = Load *1.2 / EHS

Where, 1.2 accounts for the losses and EHS is the Equivalent hours of sunshine kWh/m^2/day.

$A_s = 30*1.2 / 2.7 = 13.3$ Amps

This will be the approximate running current of the pump.

There is no case for to including a battery along with the PV cell. The main reason is that the output for the average running will be enough and the inclusion of the LCB will enable the pump to start and regulate the flow. The addition of a voltage regulator will prevent burning out the pump on sunny days.

An example of the LCB role is where the voltage on the motor drops due to lack of solar power, the current from the solar panels increases by almost the exact same percentage as the drop in voltage from the panel maximum power point voltage. This is Linear Current Boosting playing its part. This can be illustrated, where the pump is running in partial sun at 8 V from the panel that has a Maximum peak of 16 V, (motor at 1/2 panel voltage) the current will be 2 X the panel current. If the panel is producing 1 amp at reduced sunlight, the motor current will be 2 amps providing quality torque to keep pumping, even in the reduced sunlight.

6.1.1 Cell Characteristics

The cell proposed is the widely used BP PV cell, BP245. The characteristics of the cell can be seen below in table 6.1.

Current	**3.33A**
Peak Power	**16.5**
Watts	**50W**
Length	**1110 mm**
Width	**502 mm**
Depth	**50 mm**
Weight	**7.2 kg**

Table 6.1: PV cell characteristics

Chapter 7 – System Performance

The performance of the system will be assessed from the energy available from the collector and the total requirement. Furthermore, the performance of the pump will be assessed by the total energy produced from the PV cells and the energy required by the pump.

In addition to this, the 'tank in tank' system will not be assessed for any money saved for two reasons: it is part of a separate system, and there is no additional costs from the heating system itself as the boiler to the radiators would be fitted regardless. Consequently, it is the value of adding a solar water heating system and the option of a PV driven DC pump that it will be judged on. The advantages that the 'tank in tank' system will be instead discussed, as will any joint benefits.

7.1 Collector Performance

7.1.1 f-chart method [4]

The performance of the system will be analysed through the annual saving in energy and the money it will save. Analysis of the collector performance has been done using the f-chart method, devised by Solar Energy Laboratory and is a widely used method. The f-chart method is the solar fraction of useful energy against the total load. The calculations of using the f-chart method and the worksheets used to calculate the solar fraction can be seen in the appendices. Figures 7.1 to 7.3 below show the performance of the solar collector in terms of the solar fraction and the loads. Table 7.1 below, shows the actual useful output of the collector for a typical year. The Degree Day figures were taken as the ten-year average for the West of Scotland. The calculation also takes the generalisation that available radiation is constant for each day. However, for solar water heating assessments this arrangement is acceptable.

The solar fraction, f, can be given by:

$$f = \frac{\text{Useful Solar Energy}}{\text{Total Load}}$$

Or,

$$f = 1.040Y - 0.065X - 0.159Y^2 + 0.00187X^2 - 0.0095Y^3$$

for $0<Y<3$ and $0<X<18$

Where X and Y are dimensionless group, and are, ratio of the total energy absorbed on the collector surface to the total heating load, and ratio of a reference collector loss to the total heating load respectively.

$$X = F_R U_L (F_R'/F_R)(T_{REF} - T_a)\Delta T(A/L)$$

$$Y = F_R(\tau\alpha)_n(F_R'/F_R)[(\tau\alpha)/(\tau\alpha)_n]H_T(A/L)$$

Month	[kWh/month]			
	$12m^2$	$16m^2$	$24m^2$	$32m^2$
January	**133.8E+6**	**133.8E+6**	**133.8E+6**	**669.1E+6**
February	**512.5E+6**	**678.4E+6**	**678.4E+6**	**574.0E+6**
March	**1.3E+9**	**1.7E+9**	**1.7E+9**	**2.1E+9**
April	**2.3E+9**	**3.0E+9**	**3.0E+9**	**3.8E+9**
May	**2.7E+9**	**3.4E+9**	**3.4E+9**	**4.2E+9**
June	**2.5E+9**	**3.1E+9**	**3.1E+9**	**3.6E+9**
July	**2.0E+9**	**2.4E+9**	**2.4E+9**	**2.7E+9**
August	**1.8E+9**	**2.2E+9**	**2.2E+9**	**2.5E+9**
September	**1.5E+9**	**1.9E+9**	**1.9E+9**	**2.3E+9**
October	**887.8E+6**	**1.2E+9**	**1.2E+9**	**1.3E+9**
November	**174.5E+6**	**234.8E+6**	**234.8E+6**	**105.5E+6**
December	**137.2E+6**	**137.2E+6**	**137.2E+6**	**960.6E+6**

Table 7.1: Collector useful Output

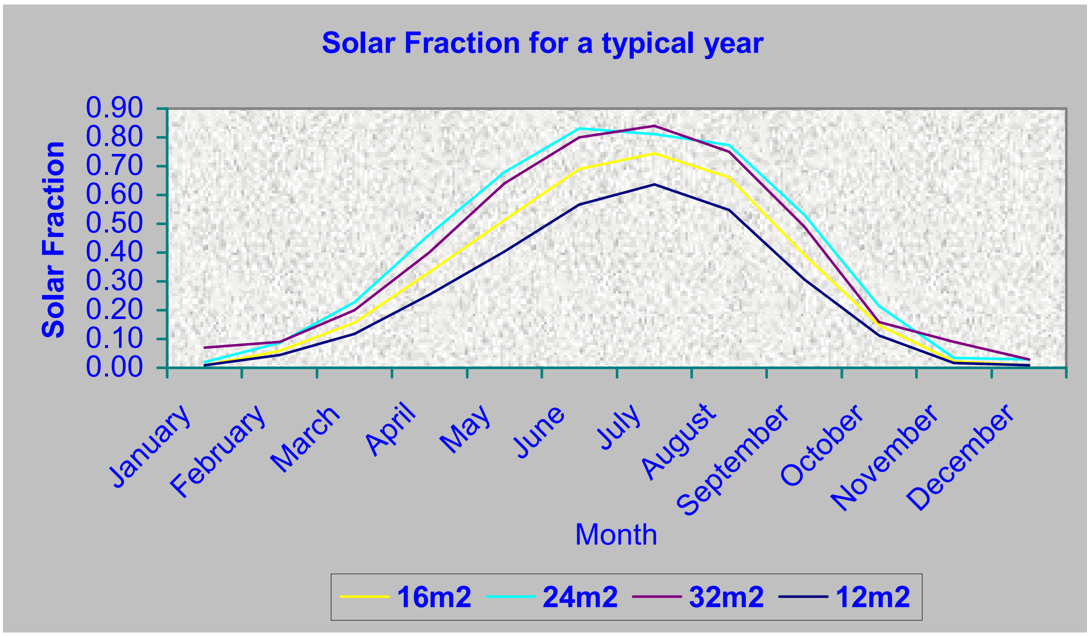

Figure 7.1: Solar Fraction for a typical year

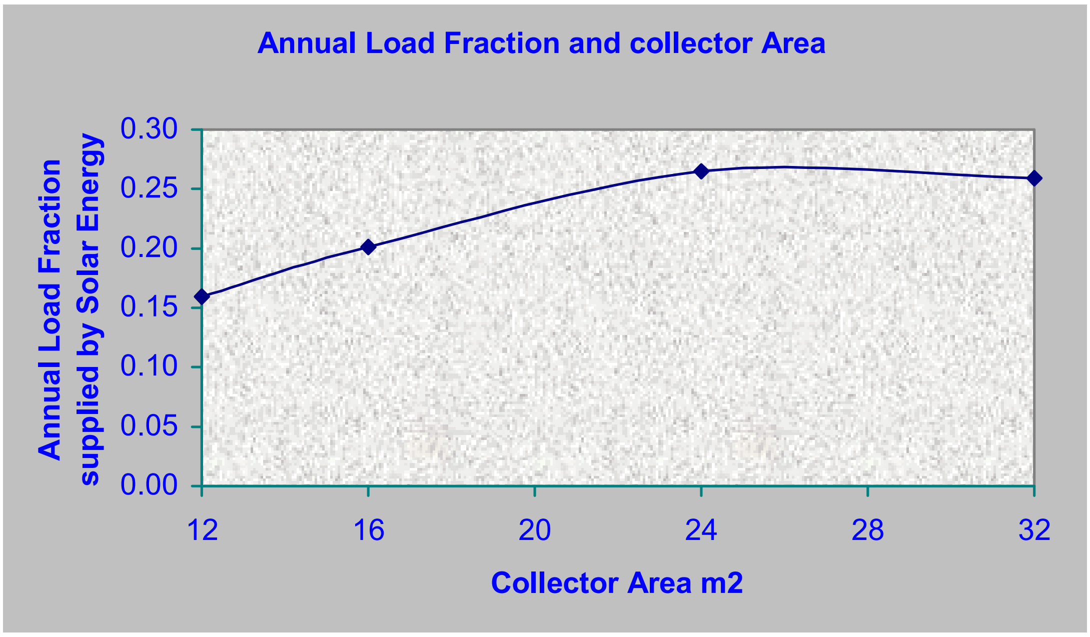

Figure 7.2: Annual load fraction for collector area

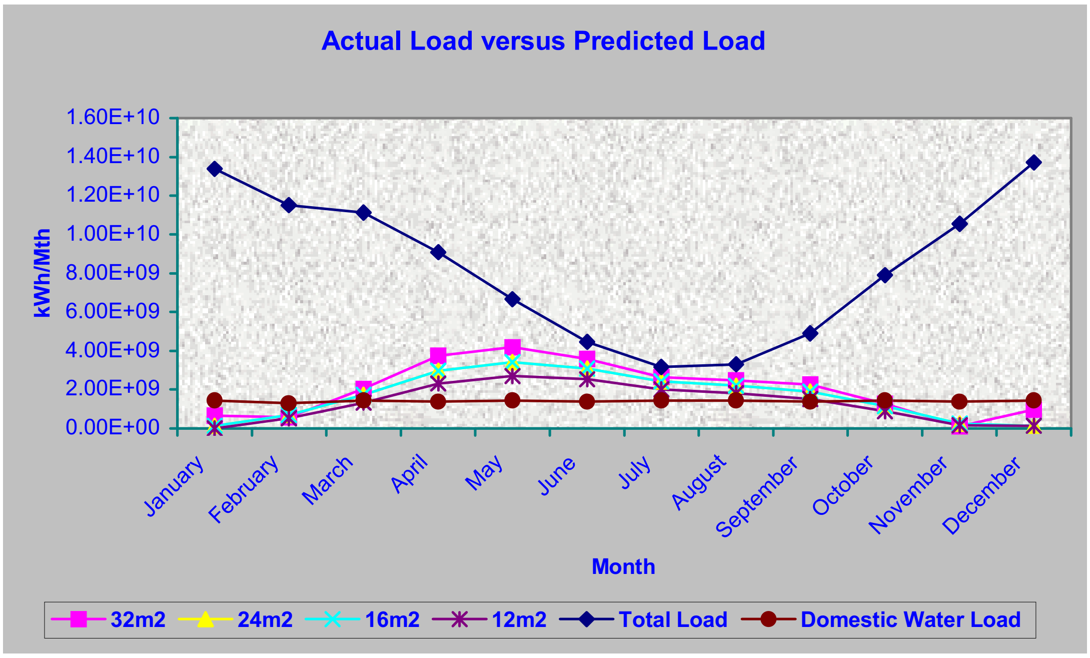

Figure7.3: Actual loads and predicted loads of collectors

As would be expected the peak solar fraction occurs in mid-summer, where less heating is required. However, the plot of the heating system for this period would be still calculated but generally the Scottish heating season is only 38 weeks of the year. Thus, we can expect the heating to be turned off for this period and only domestic hot water would be required. Therefore, it will be necessary to check that the solar collector will not exceed its maximum temperature at the peak of summer if not enough hot water is drawn off. Furthermore, it can be seen that the efficiency of the collector size deteriorates slightly. This is due to the capacity of the larger arrangements not being met for the long winter months. Consequently, the collector size chosen will accommodate for this as well as the saving and payback.

7.1.2 Further consideration

Check that maximum temperature does not exceed limits

Method

The maximum stagnation temperature

When stagnation occurs the output is equal to zero.

Where,

$$\text{Output} = \text{Input} - \text{Losses}$$

And,

$$\text{Input} = GA\tau\alpha$$

$$\text{Losses} = UA(T_c - T_a)$$

Therefore,

$$\text{Input} = \text{Losses}$$

$$GA\tau\alpha = UA(T_c - T_a)$$

The collector temperature T_c can be calculated for any corresponding data.

$$T_c = \frac{GA\tau\alpha}{UA} + T_a$$

$$T_c = \frac{G\tau\alpha}{U} + T_a$$

Where,

U = collector U-value

T_a= ambient air temperature

Calculation

For the first hour,

$$T_c = \frac{G\tau\alpha}{U} + T_a$$

$$T_c = \frac{193.28 * 0.85 * 0.95}{5} + 8 = 39.22°C$$

And repeating for the additional seven hourly readings.

Hour	Collector Temperature (°C)
2	47.78
3	50.78
4	52.78
5	54.78
6	54.78
7	53.78
8	51.78

Table 7.2: Collector temperature during peak radiation levels

After the eight hours the collector temperature starts to drop. Furthermore, the maximum temperature of 54.78°C is not above the limit of the collector, which is 210°C.

The overall, efficiency of collector system is given by:

$$\eta_C = \frac{\text{Output}}{\text{Input}} = \frac{\text{Useful Output}}{\text{Input Required}}$$

The input is given as the required input for the system, showing what percentage of energy it is contributing to the whole system.

For example $12m^2$,

$$\eta_C = \frac{15.9E+9}{99.8E+9} = .16 = 0.16\%$$

This also corresponds to the solar fraction as the useful energy against the input required (total load).

	$12m^2$	$16\ m^2$	$24\ m^2$	$32\ m^2$
Efficiency	**16%**	**20%**	**27%**	**26%**

7.2 Financial benefits

The benefits of the system will be calculated from the savings made from using the solar energy instead of the gas providing the energy. The cost of the system will be assessed to give a payback period, where the system will start making a profit for the owners.

7.2.1 Savings

The savings from installing the system will be calculated from the displaced gas to produce the same amount of energy.

Savings = energy displaced * cost of the gas = total energy * f * cost

$12m^2$ Savings = 32,698 * 0.159 * 1.006 = £523

$16m^2$ = 32,698 * 0.201 *1.006 = £661.2

$24m^2$ = 32,698 * 0.265 * 1.006 =£871.8

$32m^2$ = 32,698 * 0.259* 1.006 = £859.5

PV Cell

The savings from the PV is simply the electricity required to run the pump, throughout the year. Estimating the pump time of 8 hours per day will give:

Savings = total energy used * cost of electricity = 30*8*365 * 7.82p/kWh

Savings = £68.5

This figure is high due to the pump not on continuous use when supplied by an AC supply as the differential controller operates the pump. Therefore, taking the winter sunshine of 2 hours in total and 4 hours for summer period. Therefore, the savings can be given as:

Savings = 30*2*98 * 7.81 + 30*4*266

Savings = £29.52

7.2.2 System Costs

Solar collector system

Collectors of $4m^2$ @ £1200 + £ 900 per $4m^2$ thereafter

	$12m^2$	$16\ m^2$	$24\ m^2$	$32\ m^2$
Total Costs	**£ 3000**	**£ 3900**	**£ 5700**	**£ 7500**

PV Cell

PV Cell	£ 198
LCB & Voltage Regulator	£ 95
Total Cost	£ 293

7.2.3 Payback

The payback = Total Cost / Annual savings

Solar system

	$12m^2$	$16\ m^2$	$24\ m^2$	$32\ m^2$
Payback	**5.7 years**	**5.8 years**	**6.5 years**	**8.72 years**

With PV Pump

	$12m^2$	$16\ m^2$	$24\ m^2$	$32\ m^2$
Payback	**5.9 years**	**6.1 years**	**6.65 years**	**8.77 years**

It is noticeable that the payback is slightly more with the addition of the PV powered pump. This is because the payback period for the pump is 10years. However, all the systems will pay for themselves in their lifetime with the typical flat plate collector lasting 20 years. Furthermore, selecting the final size of the collector system it seems that the solar fraction as well as efficiency have ruled out the largest collector area calculated. Moreover, it has left a narrow choice between the next two sizes as both have almost received the same results.

Life Time savings (20 years)

Life time saving = (20 - payback) * (32698*f)

$16m^2$, Life time savings = 92,862.32 kWh

$24m^2$, Life time savings = 119,184 kWh

Therefore, after looking at the long-term performance it would be a better choice to opt for the $24m^2$ collector and receive a lifetime gain of 22% over the $16m^2$.
The final arrangement for the solar circuit can be seen in figure 7.4.

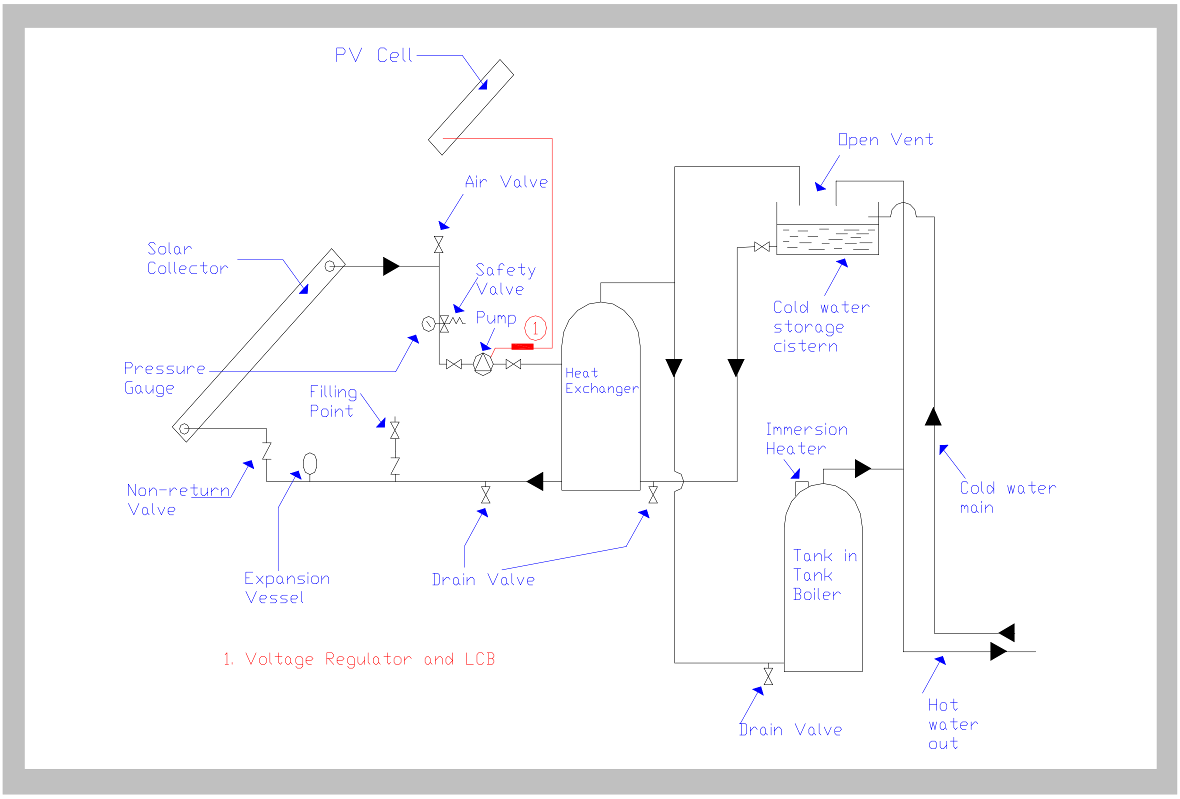

Figure 7.4: Finalised solar circuit layout

Conclusion

Renewable energy generation has evolved and matured since the early prototypes and are starting to significantly contribute to the UK's energy supply. However, there is substantial potential in this country but that has yet to be recognised. This has shown through general observation with other countries, i.e., Denmark and Sweden [10]. Where they have developed this technology with great success by benefiting in the long-term budget and health of the country. It would appear that the government has to continue its support, which it cannot do to due to commitments anyway, and show clearly the way to go. It is increasingly recognised that renewable energy sources can have a number of positive benefits including the environment, the economy and competitiveness.

The environmental benefits are well known with relatively low environmental impacts, and in their operation they produce little to no emission of the polluting gases in particular CO_2 and other greenhouse gases. The economic benefits are often long term, greater than five year, but a recent study showed that any renewables added to a house immediately gain the value of the construction to property price [3]. The benefit for developing countries also, as it allows for supply to occur locally and prevent buying in.

The competitiveness of a market place drives down the price of system but also with renewables bring security as well as diversity of the supply through a reduction on imports. In addition to this the competitiveness also opens opportunity for job prospects as well as exporting to countries that are even further behind in renewables. Consequently, there are barriers that need to be overcome before the true benefits reach their potential. These include the social, technical, economic and legislative hurdles. As with the lack of experience in complying with planning regulations and gaining public acceptance strongly influences the initial market success. Furthermore, the need to improve the technical and financial performances in such area as conversion efficiency, reliability and their integration to the grid, to name a few, can only but help their promotion and position in the future.

The government is directly influencing the other factors mentioned, economic and legislative barriers, as they have control over the subsidies and the external costs involved, which to affect the prices obtainable through renewable energy. Finally, the legislative barrier is caused by lack of information and high transaction costs.

Contrary to this, renewable energy technology is expected to gain market place to the extent that by ten years time 10% of the UK's energy use will be from renewables with a current position of around 6% and 2% in 1990[11]. This may slow once this target has been achieved through our government active nuclear program that guarantees demand until their end life is near and also lack in past advances beyond need.

This project has shown that renewable technology can be utilised through general household needs. However, it also shows the feasibility of such options and how they are restrictive in some circumstances but mainly through cost rather than attitude. This assessment of a solar heating arrangement has many advantages that are relevant to accessing solar water heating and renewable technology.

In this particular case, the payback of the system is one quarter of its expected life, 20 years. This system will provide profit, exclusive of any value on the house. This system will have a return of three times the initial investment for a 20-year life. Therefore, the system will not only deliver savings but also profit for the owners. Moreover, this shows that a solar water heating system for the West Central Scotland is very viable due to its effectiveness and profitability.

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Appendix I – Calculations & Workings

Energy required for a hot water bath of 120litres.

Chapter 4 – Introduction

$$Q = \frac{mC_p\Delta T}{3600}(kW)$$

$$Q = \frac{120*4.2*50}{3600}$$

$$Q = 7kW$$

Energy required for the average hot water consumption.

Chapter 4 – 4.3.2 Hot Water

$$Q = \frac{mC_p\Delta T}{3600}(kW)$$

$$Q = \frac{221*4.2*50}{3600}$$

$$Q = 12.89kW$$

The total capacity required of the boiler.

Chapter 4 – 4.3.3 Total Water Heating Requirements

Total Heat loss from the building	19,698 W
Intermittent Correction (20% heat losses)	3,940 W
Domestic Hot water	13,000 W
Pipe Losses (15% of total)	5,495 W
Required Boiler Output	*42,133 W**

**Exclusive of any severe heating requirements needed, i.e., unexpected bad weather.*

Alternatively,

Capacity of the boiler = total heating capacity + total domestic heating load

= 34 kW + 13 kW

= *47 kW**

**Inclusive of any severe heating requirements.*

f-chart method of collector’s performance

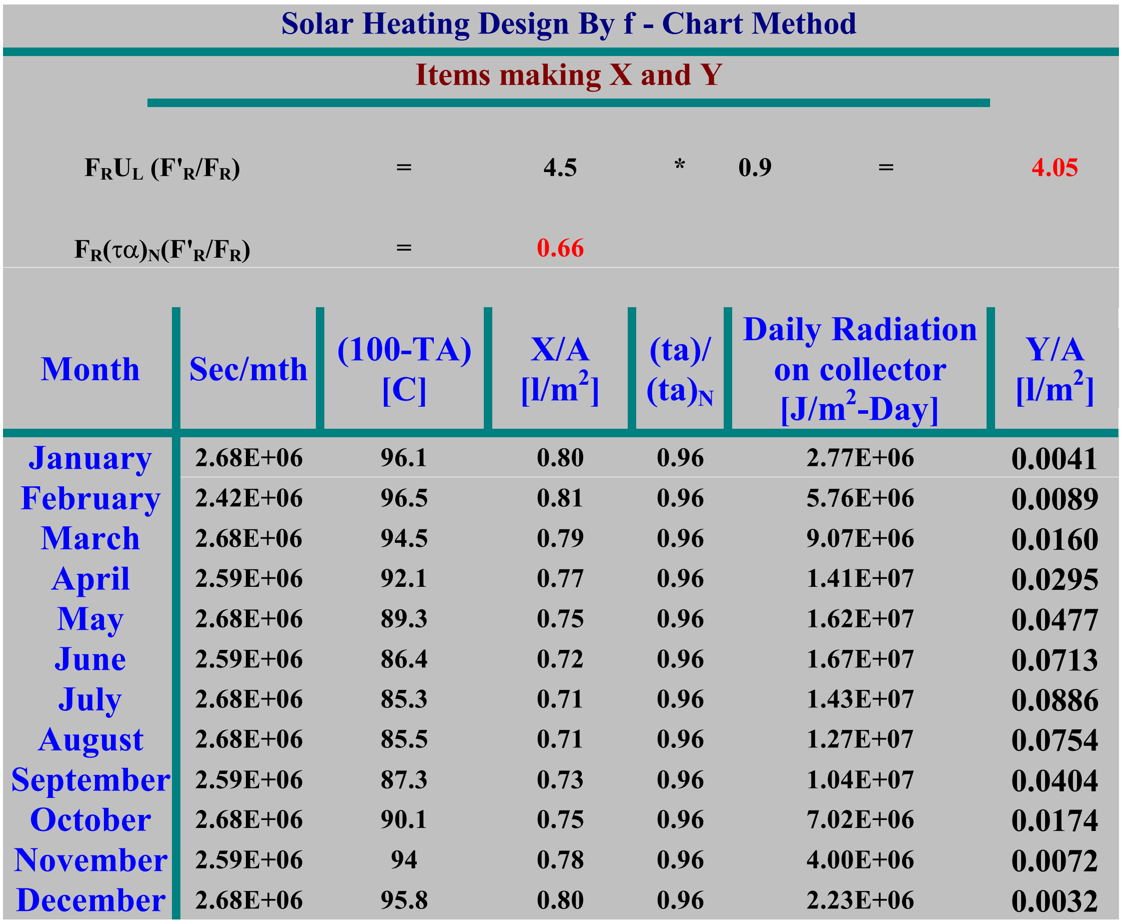
Chapter 7 – 7.1 Collector Performance

Solar Heating Design By f - Chart Method

Heating Loads

Water Usage =	Amount used per day	x	Specific Heat Capacity	x	Change in T (Tw - Tm)	=	J/Day
UA =	Design Space Heating Load [W] Design Temperature Difference [°C}	=			19,698 50	=	393.96 W °C
Water Usage =	Amount used per day	x	Specific Heat Capacity	x	Change in T (Tw - Tm)	=	J/Day
Water Usage =	221 [litres/day]	x	4190	x	50 [J/litre]	=	46.3 E+06 [J/Day]

Month	Domestic Water Load [J/Month]	Days per Month
January	1.30E+09	31
February	1.17E+09	28
March	1.30E+09	31
April	1.26E+09	30
May	1.30E+09	31
June	1.26E+09	30
July	1.30E+09	31
August	1.30E+09	31
September	1.26E+09	30
October	1.30E+09	31
November	1.26E+09	30
December	1.30E+09	31
Total	*15.3E+09*	*365*



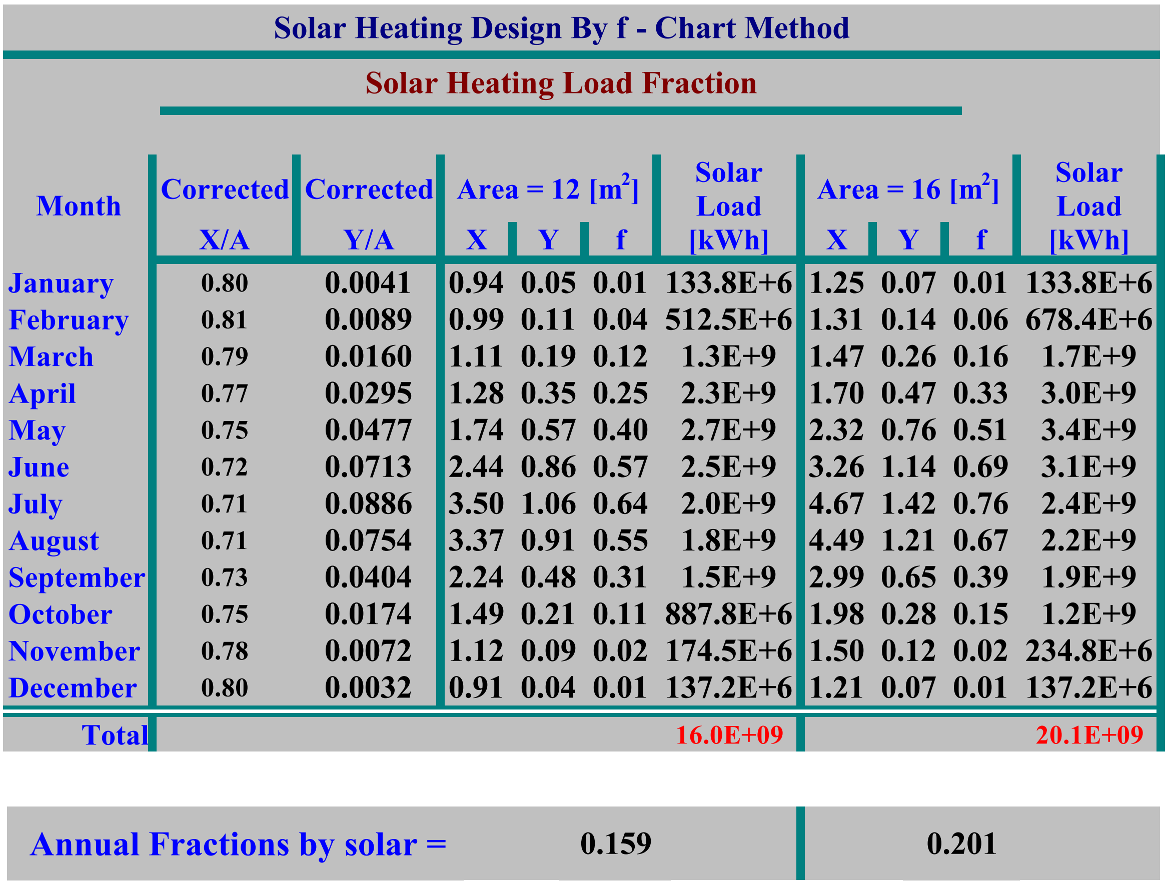
Solar Heating Design By f - Chart Method

Items making X and Y

$F_R U_L\ (F'_R/F_R)$ = 4.5 * 0.9 = 4.05

$F_R(\tau\alpha)_N(F'_R/F_R)$ = 0.66

Month	Sec/mth	(100-TA) [C]	X/A [l/m^2]	(ta)/(ta)$_N$	Daily Radiation on collector [J/m^2-Day]	Y/A [l/m^2]
January	2.68E+06	96.1	0.80	0.96	2.77E+06	0.0041
February	2.42E+06	96.5	0.81	0.96	5.76E+06	0.0089
March	2.68E+06	94.5	0.79	0.96	9.07E+06	0.0160
April	2.59E+06	92.1	0.77	0.96	1.41E+07	0.0295
May	2.68E+06	89.3	0.75	0.96	1.62E+07	0.0477
June	2.59E+06	86.4	0.72	0.96	1.67E+07	0.0713
July	2.68E+06	85.3	0.71	0.96	1.43E+07	0.0886
August	2.68E+06	85.5	0.71	0.96	1.27E+07	0.0754
September	2.59E+06	87.3	0.73	0.96	1.04E+07	0.0404
October	2.68E+06	90.1	0.75	0.96	7.02E+06	0.0174
November	2.59E+06	94	0.78	0.96	4.00E+06	0.0072
December	2.68E+06	95.8	0.80	0.96	2.23E+06	0.0032



Solar Heating Design By f - Chart Method

Solar Heating Load Fraction

Month	Corrected X/A	Corrected Y/A	Area = 12 [m^2] X	Area = 12 [m^2] Y	Area = 12 [m^2] f	Solar Load [kWh]	Area = 16 [m^2] X	Area = 16 [m^2] Y	Area = 16 [m^2] f	Solar Load [kWh]
January	0.80	0.0041	0.94	0.05	0.01	133.8E+6	1.25	0.07	0.01	133.8E+6
February	0.81	0.0089	0.99	0.11	0.04	512.5E+6	1.31	0.14	0.06	678.4E+6
March	0.79	0.0160	1.11	0.19	0.12	1.3E+9	1.47	0.26	0.16	1.7E+9
April	0.77	0.0295	1.28	0.35	0.25	2.3E+9	1.70	0.47	0.33	3.0E+9
May	0.75	0.0477	1.74	0.57	0.40	2.7E+9	2.32	0.76	0.51	3.4E+9
June	0.72	0.0713	2.44	0.86	0.57	2.5E+9	3.26	1.14	0.69	3.1E+9
July	0.71	0.0886	3.50	1.06	0.64	2.0E+9	4.67	1.42	0.76	2.4E+9
August	0.71	0.0754	3.37	0.91	0.55	1.8E+9	4.49	1.21	0.67	2.2E+9
September	0.73	0.0404	2.24	0.48	0.31	1.5E+9	2.99	0.65	0.39	1.9E+9
October	0.75	0.0174	1.49	0.21	0.11	887.8E+6	1.98	0.28	0.15	1.2E+9
November	0.78	0.0072	1.12	0.09	0.02	174.5E+6	1.50	0.12	0.02	234.8E+6
December	0.80	0.0032	0.91	0.04	0.01	137.2E+6	1.21	0.07	0.01	137.2E+6
Total						16.0E+09				20.1E+09

Annual Fractions by solar =	0.159	0.201

Appendix II – Degree Day Information

Ten-year average monthly degree day values

		Heating			Cooling		
Month	Region	18.5C	15.5C	10.0C	15.5C	5.0C	-20.0C
Jan	13EEO: W Scotland	444	351	182	0	31	750
Feb	13EEO: W Scotland	385	300	146	0	41	705
Mar	13EEO: W Scotland	378	285	121	0	69	815
Apr	13EEO: W Scotland	315	226	82	1	107	840
May	13EEO: W Scotland	239	154	42	11	190	958
Jun	13EEO: W Scotland	166	90	14	20	247	995
Jul	13EEO: W Scotland	116	51	5	41	316	1091
Aug	13EEO: W Scotland	120	55	7	43	314	1088
Sep	13EEO: W Scotland	181	103	20	15	230	977
Oct	13EEO: W Scotland	282	190	59	1	150	911
Nov	13EEO: W Scotland	359	269	114	0	79	796
Dec	13EEO: W Scotland	454	361	192	0	34	740

Appendix III – Glossary

Absorber Plate – the surface in a flat-plate collector upon which incident solar radiation is absorbed.

Absorptance – the ratio of the radiation absorbed by a surface to that incident on the surface.

Active Solar Heating System – a solar heating system which uses equipment to collect, store and distribute solar heat.

Annual Load Fraction – fraction of the annual heating needs supplied by solar energy.

Auxiliary Energy – energy supplied for heating by some mean other than solar.

Beam Radiation – solar radiation which is not scattered by dust, water droplets or clouds.

Building Overall Energy Loss Coefficient Area Product – the factor which when multiplied by the monthly degree days yields the monthly space heating load.

Collector Efficiency – the ratio of the useful energy gain for a time period to the solar energy incident on the surface during the same time period.

Collector Heat Exchanger Correction Factor, F_R'/F_R – an index ranging in value from 0 to 1 indicating the penalty in useful energy collection resulting from using heat exchanger between the collector and the storage tank in liquid solar tank heat systems.

Collector Heat Removal Efficiency Factor, F_R – the ratio of the actual useful energy gain of a flat plate solar collector to the energy gain if the entire collector plate were at the temperature of the inlet fluid.

Collector Overall Energy Loss Coefficient, U_L – a parameter characterising the energy losses of the collector to the surroundings.

Degree Days (Monthly) – the sum of the differences between 18.5°C and the mean daily temperature for each day of the month.

Design Heating Load – maximum probable space heating needs of a building.

Design Temperature Difference – the maximum probable difference between the indoor and the ambient temperatures.

Diffuse Radiation – solar radiation which is scattered by air molecules, dust, water droplets and clouds before reaching the ground and not capable of being focused.

Dimensionless Variable – a quantity which does not have a dimensional units and is therefore has the same value in any system.

Domestic Hot Water – hot water used for conventional purposes such as washing and bathing.

f-chart – a correlation, presented graphically and analytically, which expresses the monthly load fraction supplied by solar energy in terms of two dimensionless variables which include measured collector parameters and monthly average meteorological conditions.

Flat Plate Collector – the basic heat collection device used in solar heating systems; consisting of a black plate, insulated on the bottom and edges, and covered by one or more transparent covers.

Incidence angle – the angle between the perpendicular to a surface and the direction of the solar radiation.

Liquid based Solar Heating – solar heating system in which liquid, either water or antifreeze solution, is heated in the solar collector.

Load – space or domestic water heating needs which is to be supplied by solar or conventional energy.

Mean Daily Temperature – average of the minimum and maximum daily temperatures used to determine the number of degree days.

Reflectance – the ratio of radiation reflected from the surface to the total radiation incident on the surface.

Selective Surface – a surface which has a high absorptance for solar radiation, but a low emittance for thermal long wave radiation.

Solar Savings – the life cycle cost of conventional heating minus the life cycle cost of solar heating.

Transmittance – the ratio of the radiation passing through a material to the radiation incident on the upper surface of that material.

Useful Energy Gain – the energy collected by a solar collector which is not lost to the surroundings and can ultimately be used for space or water heating.

Appendix IV – Myson Heatloss Program

Building Overview

Room	No	Output Share (%)	Req. Output (W)	Variance (%)
Downstairs Bedroom	1	100	1866.78	-100
Downstairs Toilet	1	100	208.66	-100
Dining Room	1	100	2446.18	-100
Entrance Hall	1	100	556.13	-100
Main Hall	1	100	1115.82	-100
Sitting Room	1	100	1891.16	-100
Kitchen	1	100	1694.05	-100
Gym	1	100	1232.37	-100
Games Room	1	100	770.44	-100
Utility Room	1	100	777.83	-100
Upstairs Bedroom 1	1	100	1813.85	-100
Upstairs Bedroom 2	1	100	1094.26	-100
Upstairs Bedroom 3	1	100	1761.05	-100
Upstairs Bedroom 4	1	100	2372.98	-100
Upstairs Bathroom	1	100	653.48	-100
Upstairs Hall	1	100	744.84	-100
Office	1	100	1455.21	-100
Upstairs Bedroom en Suite	1	100	1387.83	-100
Upstairs Living Room	1	100	1622.04	-100

Building Summary

HEATLOSS	
Total Heatloss from Building	19698 W
Domestic Hot Water	13000 W
Intermittent Correction (20%)	3940 W
Total	36638 W
Pipe Losses at 15%	5495 W
Required Boiler Output	42133 W

BUILDING DETAILS	
External Temperature	-1°C
Mean Water Temperature	76°C
Domestic Hot Water	13000 W
Correction Factor	20 %
Intermittent Factor	20 %
Pipe Losses	15 %

Downstairs Bedroom

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Area 1	4.2	4	2.4	459.11
Area 2	1.1	1.15	2.4	34.57

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bedrm1/dining	Wood/rockwool/…	5.3	2.4	0.35	18	13.36
Bedrm1/hall	Wood/rockwool/…	1.15	2.4	0.35	18	2.9
Bedrm1/out	Block/Cavity	4	2.4	1.7	-1	263.67
Window	WIN UPVC	1.7	1.5	1.6	-1	89.76
Bedrm1/out	Block/Cavity	3.95	2.4	1.7	-1	354.55

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Down bedrm	TJ+TB/12.5mm…	4	3.95	1.62	18	76.79

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Down bedrm	Floorboards	4	3.95	0.32	-1	121.34

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	2	43.36	34.86	493.68
Walls	4	32.01	44.81	634.48
Windows	1	2.55	6.34	89.76
Ceilings	1	15.8	5.42	76.79
Floors	1	15.8	8.57	121.34

Downstairs Toilet

Internal Temperature 18.00°C
Air Changes 2 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Toilet	1	2.45	2.4	77.1

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Toilet/bedrm	Innerleaf	1	2.4	0.35	18	0
Toilet/bedrm	Innerleaf	2.45	2.4	0.35	18	0
Toilet/hall	Innerleaf	2.45	2.4	0.35	18	0
Toilet/out	WinStandard	1	2.4	1.7	-1	46.03

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Toilet Ceiling	TJ+TB/12.5mm…	1	2.45	1.62	18	0

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Down toilet	Floorboards	1	2.45	0.32	-1	14.9

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	5.88	45.98	77.1
Walls	4	15.59	27.45	46.03
Windows	1	0.97	17.68	29.64
Ceilings	1	2.45	0	0
Floors	1	2.45	8.88	14.9

Entrance Hall

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Entrance Hall	2.15	2.5	2.4	146.89

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Entr hall out	WinStandard	2.15	2.4	1.7	-1	192.98
Entr hall din	Innerleaf	2.5	2.4	0.35	18	6.3
Entr hall sit	Innerleaf	2.5	2.4	0.35	18	6.3
Entr hall in	Innerleaf	2.15	2.4	0.35	18	5.42

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Toilet Ceiling	TJ+TB/12.5mm…	2.15	2.5	1.62	18	26.12

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Down toilet	Winfloor	2.15	2.5	0.32	-1	37.84

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	12.9	34.82	146.89
Walls	4	22.32	50.02	211
Ceilings	1	5.38	6.19	26.12
Floors	1	5.38	8.97	37.84

Dining Room

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Dining Room	4.5	5.6	2.4	688.67

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Diningrm in	Innerleaf	5.6	2.4	0.35	18	502.66
Diningrm in	Innerleaf	4.5	2.4	0.35	18	249.65
Combined Window	WIN UPVC	2.75	1.5	1.6	-1	145.2
Diningrm out	Winstandard	5.6	2.4	1.7	-1	14.11
Diningrm out	WinStandard	4.5	2.4	1.7	-1	11.34

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Diningroom c..	Floorboards	4.5	5.6	0.12	-1	66.53

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Dining room f..	Win floor	4.5	5.6	0.32	-1	177.41

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	60.48	37.11	688.67
Walls	4	44.35	41.91	777.75
Windows	1	4.13	7.83	145.2
Ceilings	1	25.2	3.59	66.53
Floors	1	25.2	9.56	177.41

Main Hall

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Main Hall	2.15	7.25	2.4	425.98

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Main hall out	WinStandard	2.15	2.4	1.7	-1	192.98
Hall/din/bdrm	Innerleaf	7.25	2.4	0.35	18	18.27
Hall/sit/kit	Innerleaf	7.25	2.4	0.35	18	18.27
Main/entr in	Innerleaf	2.15	2.4	0.35	18	5.42

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	TJ+TB/12.5mm…	2.15	7.25	1.62	18	75.76

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	Winfloor	2.15	7.25	0.32	-1	109.74

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	37.41	50.33	425.98
Walls	4	45.12	27.76	234.94
Ceilings	1	15.59	8.95	75.76
Floors	1	15.59	12.96	109.74

Sitting Room

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Siting Room	4.5	5.5	2.4	676.37

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Sit/hall	WinStandard	5.5	2.4	0.35	21	0
Sit wall out	WIN Standard	4.5	2.4	1.7	-1	274.89
Window	WIN UPVC	2.3	1.5	1.6	-1	121.44
Sit/gym	WIN Standard	5.5	2.4	1.7	18	67.32
Sit/kit	Innerleaf	4.5	2.4	0.35	18	0

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	TJ+TB/12.5mm…	4.5	5.5	1.62	18	120.29

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	Winfloor	4.5	5.5	0.32	-1	174.24

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	59.4	47.15	676.37
Walls	4	44.55	23.85	342.21
Windows	1	3.45	8.47	121.44
Ceilings	1	24.75	8.38	120.29
Floors	1	24.75	12.15	174.24

Kitchen

Internal Temperature 21.00°C
Air Changes 2 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Kitchen	4.5	3.85	2.4	631.28

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Kit/sit	Innerleaf	4.5	2.4	0.35	21	0
Kitchen wall 3	WIN Standard	4.5	2.4	1.7	-1	345.02
Window	WIN UPVC	1.05	1.5	1.6	-1	55.44
Kit/games	WIN Standard	3.85	2.4	1.4	18	47.12
Kit/hall	Innerleaf	3.85	2.4	0.35	21	0

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	TJ+TB/12.5mm…	4.5	3.85	1.62	18	84.2

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	Winfloor	4.5	3.85	0.32	-1	121.97

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	41.58	79.13	631.28
Walls	4	38.51	30.52	392.14
Windows	1	1.57	4.31	55.44
Ceilings	1	17.32	6.55	84.2
Floors	1	17.32	9.49	121.97

Gym

Internal Temperature 18.00°C
Air Changes 2 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Gym	3.6	5.5	2.4	623.08

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Gym/sit	Win Standard	5.5	2.4	1.7	21	0
Gym out	Cavity/brick	3.6	2.4	0.35	-1	38
Window 1	WIN UPVC	1.95	1.5	1.6	-1	88.92
Gym out	Win Standard	5.5	2.4	0.35	-1	78.8
Window 2	WIN UPVC	0.9	1.5	1.6	-1	41.04
Gym/games	Innerleaf	5.5	2.4	0.35	18	0

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Roof	Singlestoreyroof	3.6	5.5	0.12	21	0

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	Winfloor	3.6	5.5	0.32	-1	120.38

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	47.52	62.92	623.08
Walls	4	43.97	11.8	116.81
Windows	2	4.28	13.12	129.96
Ceilings	1	19.8	0	0
Floors	1	19.8	12.16	120.38

Games Room

Internal Temperature 18.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Games Room	3.6	4.47	2.4	380.22

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Games/kit	Innerleaf	4.47	2.4	0.35	21	0
Games/gym	Innerleaf	3.6	2.4	0.35	18	0
Games/utility	Innerleaf	3.6	2.4	0.35	18	0
Games out	Win Standard	4.47	2.4	0.35	-1	51.97

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	TJ+TB/12.5mm…	3.6	4.47	1.62	18	0

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	Winfloor	3.6	4.47	0.32	-1	97.95

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	38.66	61.42	380.22
Walls	4	35.83	8.39	51.97
Windows	1	2.93	14.36	88.92
Ceilings	1	16.11	0	0
Floors	1	16.11	15.82	97.95

Utility

Internal Temperature 18.00°C
Air Changes 2 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Utility	3.25	4.05	2.4	431.47

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Utility/kit	Innerleaf	4.05	2.4	0.35	21	0
Games/utility	Innerleaf	3.25	2.4	0.35	18	0
Utility/store	Innerleaf	3.25	2.4	0.35	18	0
Utility out	Win Standard	4.05	2.4	0.35	-1	51.02

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	TJ+TB/12.5mm…	3.25	4.05	1.62	18	0

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	Winfloor	3.25	4.05	0.32	-1	80.03

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	32.91	69.06	431.47
Walls	4	32.99	8.17	51.02
Windows	1	2.05	9.96	62.24
Ceilings	1	13.16	0	0
Floors	1	13.16	12.81	80.03

Bedroom 1

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Bedroom 1	3.9	5.6	2.4	596.85

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bdrm1/bdrm2	Innerleaf	5.6	2.4	0.35	18	14.11
Bdrm1/off	Innerleaf	3.9	2.4	0.35	18	9.83
Bdrm1/living	Win Standard	5.6	2.4	1.7	21	0
Bdrm1 out	Win Standard	3.9	2.4	1.7	-1	285.55

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	3.9	5.6	0.63	-1	302.7

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	3.9	5.6	1.62	18	106.14

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	52.42	43.38	596.85
Walls	4	43.88	22.49	309.49
Windows	1	1.72	4.41	60.72
Ceilings	1	21.84	22	302.7
Floors	1	21.84	7.71	106.14

Bedroom 2

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Bedroom 2	3.45	3.5	2.4	329.99

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bdrm2/bdrm3	Innerleaf	3.5	2.4	0.35	18	8.82
Bdrm2/hall	Innerleaf	3.45	2.4	0.35	18	8.69
Bdrm1/bdrm1	Innerleaf	3.5	2.4	0.35	18	8.82
Bdrm2 out	Win Standard	3.45	2.4	1.7	-1	253.57

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	3.45	3.5	0.63	-1	167.36

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	3.45	3.5	1.62	21	0

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	28.98	39.76	329.99
Walls	4	31.86	33.72	279.91
Windows	1	1.5	6.36	52.8
Ceilings	1	12.07	20.16	167.36
Floors	1	12.07	0	0

Bedroom 3

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Bedroom 3	3.8	3.5	2.4	363.46

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bdrm3/bdrm2	Innerleaf	3.5	2.4	0.35	18	8.82
Bdrm3/bath	Innerleaf	3.8	2.4	0.35	18	9.58
Bdrm3 out	Win Standard	3.8	2.4	1.7	-1	341.09
Bdrm3 out	Win Standard	3.5	2.4	1.7	-1	246.84

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	3.9	5.6	0.63	-1	302.7

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	3.9	5.6	1.62	21	0

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	31.92	27.21	363.46
Walls	4	33.24	45.39	606.32
Windows	1	1.8	4.74	63.36
Ceilings	1	21.84	22.66	302.7
Floors	1	21.84	0	0

Bathroom

Internal Temperature 22.00°C
Air Changes 2 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Bathroom	2.6	1.9	2.4	188.18

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bathrm/bdrm3	Innerleaf	2.6	2.4	0.35	18	8.74
Bathrm/bdrm4	Innerleaf	2.6	2.4	0.35	18	8.74
Bathrm/hall	Innerleaf	1.9	2.4	0.35	21	1.6
Window	WIN UPVC	3.8	2.4	1.7	-1	52.44
Bathrm/ out	Win Standard	3.5	2.4	1.7	-1	122.58

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	2.6	1.9	0.63	-1	71.58

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	2.6	1.9	1.62	18	32.01

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	11.86	38.73	188.18
Walls	4	20.17	29.15	141.65
Windows	1	1.42	10.79	52.44
Ceilings	1	4.94	14.73	71.44
Floors	1	4.94	6.59	32.01

Bedroom 4

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Bedroom 4	5.5	3.75	2.4	563.64

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bdrm3/bath	Innerleaf	5.5	2.4	0.35	18	13.86
Bdrm3/hall	Innerleaf	3.75	2.4	0.35	18	9.45
Bdrm4 out	Win Standard	3.75	2.4	1.7	-1	280.5
Bdrm4 out	Win Standard	5.5	2.4	1.7	-1	52.8
Window	WIN UPVC	1	1.5	1.6	-1	493.68

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	5.5	3.75	0.63	-1	284.86

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	5.5	3.75	1.62	18	100.24

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	49.5	31.31	563.64
Walls	4	42.9	44.3	797.49
Windows	1	1.5	2.93	52.8
Ceilings	1	20.63	15.88	285.86
Floors	1	20.63	5.57	100.24

Upstairs Hall

Internal Temperature 18.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Area 1	4.15	1.35	2.4	132.23
Area 2	2.15	4.65	2.4	235.96

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Hall/bath	Innerleaf	1.35	2.4	0.35	18	0
Hall/bdrm23	Innerleaf	4.15	2.4	0.35	18	0
Hall/bdrm1/off	Innerleaf	6	2.4	0.35	18	0
Hall/bdrm4	Innerleaf	4.65	2.4	0.35	18	0
Hall out	Win Standard	2.15	2.4	1.7	-1	108.53

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	4.15	1.35	0.63	-1	67.06

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	4.15	1.35	1.62	18	0

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	37.44	61.52	368.19
Walls	4	42.12	18.13	108.53
Windows	1	1.8	9.14	24.72
Ceilings	1	5.6	11.21	67.06
Floors	1	5.6	0	0

Office

Internal Temperature 18.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Office	4.6	3.7	2.4	267.8

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Office/hall	Innerleaf	3.7	2.4	0.35	18	0
Office/bdrm1	Innerleaf	4.6	2.4	0.35	18	0
Bdrm5/office	Win Standard	3.7	2.4	1.7	-1	286.82
Office out	Win Standard	4.6	2.4	1.7	-1	299.66

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	3.9	5.6	0.63	-1	261.42

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	3.9	5.6	1.62	21	0

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	40.85	22.9	267.8
Walls	4	38.08	50.16	586.49
Windows	1	1.76	4.58	53.58
Ceilings	1	21.84	22.36	261.42
Floors	1	21.84	0	0

Bedroom 5 en suite

Internal Temperature 22.00°C
Air Changes 2 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Bedroom 5 ensuite	3.6	4.35	2.4	596.55

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Bedrm5 en….	Innerleaf	3.6	2.4	0.35	18	70.99
Bedrm5/office	Win Standard	4.35	2.4	1.7	18	57.48
Bedrm5 out	Win Standard	3.6	2.4	0.35	-1	55.2
Bedrm 5 out	Win Standard	4.35	2.4	0.35	-1	84.04
Window	WIN UPVC	1	1.5	1.6	-1	12.1

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	Exitingceiling/loft	3.6	4.35	0.63	-1	54.03

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	3.6	4.35	1.62	18	101.48

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	37.58	57.81	596.55
Walls	4	36.66	21.77	224.61
Windows	1	1.5	5.35	55.2
Ceilings	1	15.66	5.24	54.03
Floors	1	15.66	9.83	101.48

Living Room

Internal Temperature 21.00°C
Air Changes 1.5 per hour

AREAS				
Description	Length (m)	Width (m)	Height (m)	Heatloss (W)
Living Room	3.6	4.3	2.4	423.04

WALLS						
Description	Construction	Length (m)	Height (m)	U Value	Temp. (°C)	Heatloss (W)
Living/bdrm1	Win Standard	4.3	2.4	1.7	-1	385.97
Living out	Win Standard	3.6	2.4	0.35	-1	43.43
Window	WIN UPVC	2	1.5	1.6	-1	105.6
Living out	Win Standard	4.35	2.4	0.35	-1	80.39
Living/bdrm5	Innerleaf	3.6	2.4	0.35	18	9.07

CEILINGS/ROOFS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
Ceiling	lvgrmroof	3.6	4.35	0.31	-1	106.8

FLOORS						
Description	Construction	Length (m)	Width (m)	U Value	Temp. (°C)	Heatloss (W)
floor	TJ+TB/12.5mm…	3.6	4.35	1.62	18	76.11

HEATLOSS				
	Number	Size	Heatloss (%)	Heatloss (W)
Areas	1	37.15	34.38	423.04
Walls	4	35.04	42.17	518.86
Windows	1	3	8.58	105.6
Ceilings	1	15.66	8.68	106.8
Floors	1	15.66	6.19	76.11