EM401 Individual Project

Final Report

"Sustainable Retrofit of Mamores Lodge, Kinlochleven"

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Declaration

I hereby declare that this work has not been submitted for any other degree/course at this University or any other institution and that, except where reference is made to the work of other authors, the material presented is original and entirely the result of my own work at the University of Strathclyde under the supervision of Dr Paul Tuohy.

Abstract

The main aims of this project were to design a redevelopment of the derelict Mamores lodge in Kinlochleven, a small village in the Scottish Highlands, to sustainability standards. Initially, the fundamental construction principles for low energy buildings as well as measurement and assessment of environmental and social impact of a construction were examined. The existing lodge was modelled to show the inefficiencies compared to Passive House standards and a new construction was proposed to be built on the same site due to the difficulties associated with retrofitting the existing building. A fabric retrofit was carried out, proposing construction components to be used for the floor, walls and roof and the U Value of each section quantified. The energy demands of the new construction were determined using Passive House Planning Package to show Passive House standards are met and build a full electrical profile for the building including domestic electricity, auxiliary electricity, domestic hot water demand and space heating demand supplied. Both heating demands being modelled to be met by a heat pump. An energy supply system was proposed to supply this load containing 70 1kW PV Panels and 1 3kW wind turbine in combination with grid purchases. The output and characteristics of this system were analysed to ensure loads were met and analyse the performance of the system in different climate conditions. A discussion of the effect which the limitations and assumptions made was carried out as well as further work suggested to be completed as part of a more detailed study. The construction sustainability has been at the forefront of design and the final proposal of building and supply system meets low energy standards of Passive House and should have a positive impact on the local community.

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1. Introduction

1.1. Project Aims and Objectives

This project, “Sustainable Retrofit of Mamores Lodge, Kinlochleven” has been conducted as part of the EM401 Individual Project Class. The objectives of the project were outlined as reviewing and understanding the fundamentals of sustainable buildings and applying these to provide a scoping study focused on bringing the currently derelict Mamores Lodge, in the village of Kinlochleven in the Scottish Highlands, back into operation while meeting sustainability standards. The study should include fabric retrofit of the building; proposing the physical construction components and practices to be used to meet low energy building standards of Passive House, and proposal of a renewable energy system to supply the energy demands of the lodge in a sustainable manner.

This report will outline the work carried out during the project; a summary of the information gathered at research stages and discussion of how these were applied to Mamores Lodge in order to provide a full proposal of fabric retrofit and an energy supply system, providing justifications for choices made and results of calculations and simulations. Limitations and assumptions which have been made throughout the project have been acknowledged and explained as well as further work to be carried suggested.

1.2. Sustainability

Sustainability is a term with varying definitions. The World commission of Environment and Development define the term as:

“Meeting the needs of the present without compromising the ability of the future generations to meet their own needs” [1]

The United Nations has 17 “Sustainable Development Goals” to be met by 2030. These goals span many sectors, with the goals being targeted as relevant in this project as:

- “Ensure access to affordable, reliable, sustainable and modern energy for all”
- “Make human settlements inclusive, safe, resilient and sustainable.”
- “Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.” [2]

Sustainability is separated into three pillars; environmental, economic and social. Environmental Integrity should be ensured through utilisation of renewable energy sources therefore reducing the use of fossil fuels and damage to the environment. Social Equity should be aimed for via development of processes which maintain healthy communities for current and future members. Economic Vitality should be protected to support a level of economic production indefinitely. For a building to be considered sustainable, it must have a positive impact on all of these pillars.

1.3. Energy in Buildings

Buildings are responsible for 40% of the energy consumed and 36% of the CO2 emissions in the EU. A large portion of this energy is utilised for the cooling/heating of buildings, therefore improvement in thermal efficiency of buildings is a key policy in order to reduce energy consumption and consequently CO2 emissions. Improving efficiency of buildings also generates social, economic and environmental benefits leading to production of more sustainable communities. The EU has produced 2 directives concerned with the promotion of energy performance in buildings; The 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive. [3]

Heat balance in buildings is a representation of all sources and sinks of energy present within the building envelope. The building envelope is defined as the volume which is to be a set temperature (normally 20℃). These sources (gains) and sinks (losses) can be defined as:

1. Transmission Losses L_T –losses through the exterior of the building envelope such as walls, floor and roof to the exterior.
2. Ventilation Losses L_V –losses through ventilation system which is required to maintain air quality.
3. Solar Gains G_S –gains through solar energy through windows or other transparent elements.
4. Internal Gains G_I –gain from heat outputs inside the building envelope from sources such as people and appliances.
5. Heating Demand H –the amount of energy required to maintain the desired temperature and ensure the energy balance in equation 1 is maintained.

The solar gains and internal gains are not 100% effective for heating, therefore the utilisation factor (F_u) which determines the proportion of these gains which is used for heating should be taken into account. Normal values for F_u range from 0.5-0.9 depending on energy demand and type of construction.

$$L_T + L_V = F_U(G_S + G_I) + H \quad (1)$$

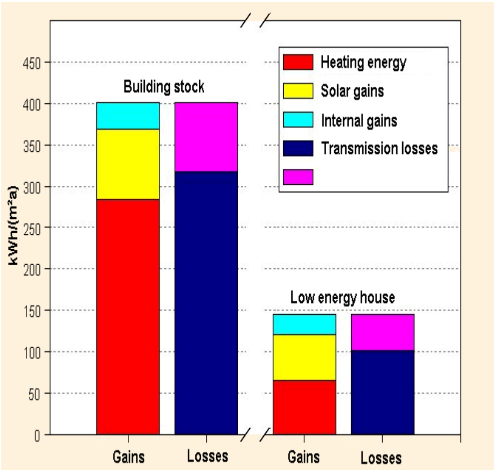


Figure 1- Comparison of low energy building and standard building

By looking at equation 1, it can be concluded that the two ways to reduce the heating demand (H) in a building are to decrease the losses in the building or in increase the useful gains. Figure 1 shows the extent to which the heating energy can be decrease in a building by carrying out these changes.

2. Background and Research

A focussed literature review of credible resources was carried out to ensure fundamental principles of sustainable buildings were understood. The main details to be established from this review were:

- Standards and measurement of sustainability in buildings.
- Construction principles and practices used in sustainable buildings.

2.1. Standards and Measurement of Sustainability

2.1.3. Passive House Institute

In 1990, the Passive House Institute (PHI) was founded by Dr Wolfgang Fiest in Darmstadt, Germany. The institute carry out dedicated research into low energy buildings and provide a voluntary standard which a building can be compared to in order to achieve official Passive House accreditation. The institute also provide the Passive House Planning Package (PHPP) which is a planning tool to carry out energy balance calculations for buildings, providing output values to be compared to table 1 and 2. The institute also provide an online resource "Passipedia" which contains an array of articles relevant to principles and construction of a Passive House. [4] For a new construction the criteria of the Passive House Standard can be seen in table 1.

Table 1- Passivhaus Standard

Primary Energy Demand	$\leq 60kWhr/m^2yr$
Space Heating Demand	$\leq 15kWhr/m^2yr$
Space Cooling Demand	$\leq 15kWhr/m^2yr$
Airtightness	$\leq 0.6\ air\ changes\ per\ hour$

For a retrofit project the requirements are outlined in The Passive House EnerPhit Standard as in table 2 with reduced criteria due to constraints when a building has already been constructed.

Table 2- EnerPhit Standard

Primary Energy Demand	$\leq 120kWhr/m^2yr$
Space Heating Demand	$\leq 25kWhr/m^2yr$
Space Cooling Demand	$\leq 25Whr/m^2yr$
Airtightness	$\leq 1.0\ air\ changes\ per\ hour$

The standard has a maximum value of primary energy demand to be met which is a measure of the energy required at source, therefore taking into account losses in the transmission system and conversion systems.

The space heating and space cooling demand is a measure of the heating/cooling energy required per unit of treated floor area per year.

Airtightness is a measure of air gaps in the building envelope as explained in section 2.2.3.

2.1.4. BREEAM

BREEAM is a UK sustainability promotion and assessment system. It provides a "score" based on many factors to measure the sustainability of a building.

BREEAM provides 4 in depth standards relating to the assessment of the environmental performance of buildings being developed at the following stages:

- Communities - for the master planning of large communities of buildings
- New Construction- for new build non-domestic buildings
- In Use- for existing non-domestic buildings in use
- Refurbishment and Fit out- Homes and Commercial building

With a new standard for infrastructure being developed currently for civil and public realm projects. For this project, the refurbishment and fit standard should be examined. The assessment is split up into 4 frameworks with which part being assessed being dependant on the specific project. These 4 parts are; Fabric and Structure, Core Services, Local Services and Interior Design. The BREEAM assessment is measured against the following criteria in table 3 which will produce a single BREEAM certified rating:

Table 3- BREEAM Criteria

1	Management
2	Energy
3	Water
4	Waste
5	Pollution
6	Health and Wellbeing
7	Transport
8	Materials
9	Land use and Energy
10	Innovation

The final BREEAM rating is determined using a score which is calculated using a combination of:

- The scope of the assessment- which of the 4 framework parts are being assessment
- The benchmarks in table 4
- Minimum standards in key areas such as energy and water
- Weighted credits provided for each area in table

Table 4- BREEAM Ratings benchmarks

BREEAM Rating	% score	Band
Outstanding	≥85	Top 1%
Excellent	≥70	Top 10%
Very Good	≥55	Top 25%
Good	≥45	Top 50%
Pass	≥30	Top 75%
Unclassified	≤ 30	Non-compliant

"A discussion document comparing internal environment assessment methods for buildings" by Thomas Saunders is a paper produced to evaluate different international sustainable scoring mechanisms. [5]

It summarises main international assessment methods across the world as:

- BREEAM -origin in the UK
- LEED – origin in United States
- Green Star – origin in Australia
- CASBEE – origin in Japan

The report highlights the difference between each assessment method at all stages and performs an analysis to produce the comparison image in figure 2 showing equivalency between different scores/ratings. Since this paper, BREEAM has introduced a new rating of "outstanding" as in table 4 which would place above "excellent".

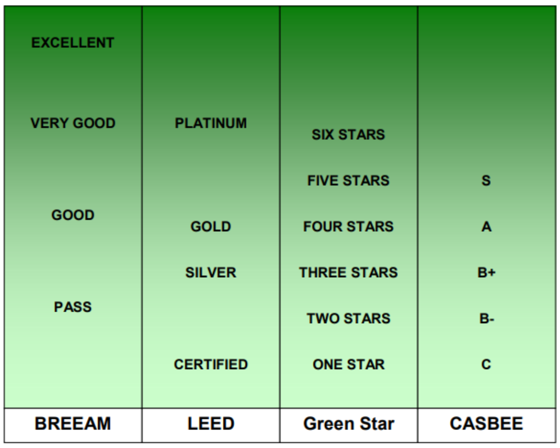


Figure 2 - BREEAM compared to international standards

As can be seen BREEAM has the highest standards of sustainability when compared to other international methods. The report provides a framework to compare buildings which have been assessed using different international standards.

2.1.5. Social Impact

While Passive House and BREEAM provide standards and assessment for mainly the environmental impact of a construction. Social impacts must also be considered as in section 1.2. "The Social Side of Sustainability" is a paper by Joanna Brain which looks specifically at social sustainability; what social issues are involved in this concept and how targets can be met. [6] It is stated how planners making decisions regarding economics and environment can have a consequential effect on social sustainability in that region. An example being given regarding a mining operation being shut down in New Zealand and having a detrimental effect on employment but also sense of community and lifestyle in that region. This example is analogous to the village of Kinlochleven as discussed in section 3.1 which experienced social difficulty following the close of the Aluminium smelter. Table 5 outlines what are pinpointed as the key influences of social wellbeing and adjacent the factors which affect these.

Table 5- Influences on social wellbeing

Influences of Social Wellbeing	Factors which affect Social Wellbeing
Health	Equity
Personal Relationships	Understanding
Safety	Diversity
Standard of Living	Inclusion
Material Affluence	Quality of Life
Equality	Opportunity
Freedom	Individual Empowerment

Public and private projects should consider all of these factors and influences when planning a project and the report by Joanna Brian outlines how consideration of these will provide the body or private company with benefits such as boost in reputation and improved finances due to economic improvements in the region. The impact of this project on these factors along with environmental effect should be evaluated as part of the measurement of sustainability and success of the proposal.

2.2. Principles

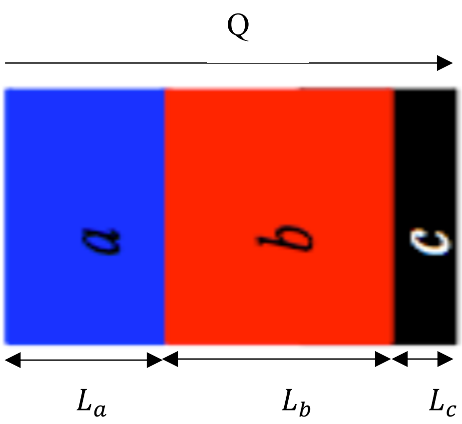
The Passive House Institute provides literature and information through the online resource "Passipedia" on the construction methods and principles utilised to meet the Passive House standard, with the aim being to reduce the losses while increasing the gains in the building to reduce the heating demand as explained in section 1.3 [7]

2.2.1. Thermal Insulation

The building envelope should restrict heat losses to the outside in order to maintain comfortable conditions inside and reduce transmission losses in the building. Therefore, thermally efficient materials must be used to limit the heat losses. A materials thermal performance is quantified by its "U Value", for a Passive House the advised U value for the wall, floor and roof areas is less than 0.15$\frac{W}{m^2K}$. This value can be calculated using equation 2, where k is the thermal conductivity of the material and l is the thickness.

$$U = \frac{1}{l/k} \tag{2}$$

When composite components are arranged as in figure 3 the U value of the component can be calculated using equation 3.



$$U = \frac{1}{\frac{l_a}{k_a} + \frac{l_b}{k_b} + \frac{l_c}{k_c}}$$

$$U = \frac{1}{\sum \frac{l}{k}} \tag{3}$$

Figure 3- Composite component

The advised U values of the windows and glazing should be less than 0.8 $\frac{W}{m^2K}$. The windows should be installed in an airtight manner with minimal thermal bridges as in section 2.2.2. Triple glazing windows filled with a noble gas should be used to achieve this level of thermal efficiency.

2.2.2. Thermal Bridging

A thermal bridge or a cold bridge is a part of a construction which has a higher heat transfer than the surrounding materials. This occurs when there is an element with a higher thermal conductivity than its surrounding material. A common example of this is when there is a break in insulation or insulation is penetrated by a material such as timber with a practical example of this for a house shown in figure 4. This can result in heat losses from the building and therefore it is important to eliminate thermal bridging where possible in a Passive house.

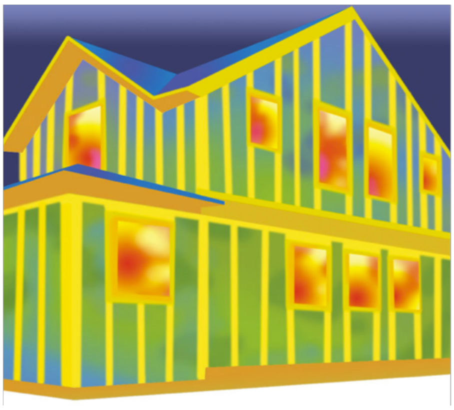


Figure 4- Thermal bridging in buildings

2.2.3. Airtightness

A Passive House construction requires air tightness. This essentially means that there is a draught free envelope within the building to increase energy efficiency and retain comfort. There should be no gaps in the building for air to leak in or out and this airtight envelope should include windows, doors and roof. Common areas for leakage occur at junctions between walls, junctions between walls and floors, between window frames and walls, access doors and other wall penetrations, therefore these areas should be treated with specific care.

The unit airflow leakage at 50Pa is called n_{50} measured in Vol/hr. The standard for Passive House states that n_{50} value should be ≤ 0.6 as in table 1 this means that in one hour a maximum of 60% of the complete building air volume can leave due to leaks this value is reduced to ≤ 1 as in table 2 for EnerPHit standard. This value takes into account the ventilation system and assumes one window of area $56m^2$ being open continuously.

2.2.4. Ventilation

The purpose of ventilation is to replace "used air" with fresh air which will increase the air quality in the building and therefore comfort of occupants. The air exchange desired is 0.33 air changes per hour. This could be achieved in practice with no ventilation system however an occupant would have open windows for 5-10 minutes every hour for 24 hours a day. This is of course impracticable therefore a system must be installed to meet this target.

In an efficiency-controlled ventilation system, the air is being removed from the kitchen, toilet and bathroom and supplied to the living area. The required energy efficiency can only be met if a heat recovery system is used which means that the hot humid air being withdrawn is used to heat the supply air using a heat exchanger in counter flow operation as in figure 5 with efficiencies of 75-95% able to be achieved in modern ventilation systems.

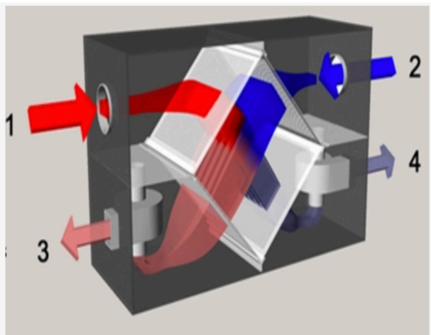


Figure 5- Ventilation system in counter flow operation

2.2.5. Solar Gain

A sustainable building should utilise the suns energy to provide a portion of the light and heat required. In the northern hemisphere, the sun will rise in the east and set in the west, this means that the long façade of the building should have a southern orientation and this side of the building should have maximum glazing to increase heat gain from the sun and glazing on the north side should be kept to a minimum. The building should be long and thin in order to allow the sun to shine deep into the building providing natural lighting.

The sun has a steeper path in the summer and is closer to the earth than in winter as shown in figure 6. In winter the large amounts of glazing on the south side will aid in heating the building, however during summer risk of overheating is possible. This issue is solved by using an overhang on the south side of the building shown by the label “control” in figure 6. Blocking the path of the sun into the building when it is high in the sky and reducing the likelihood of overheating.

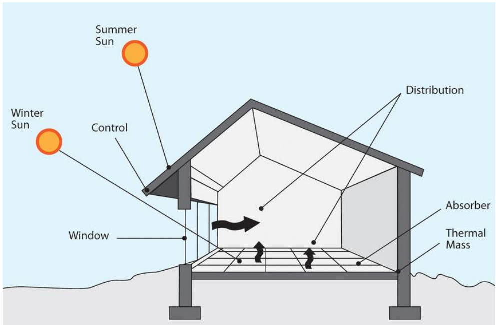


Figure 6- Passive House overhang [8]

3. Existing Construction

3.1. Kinlochleven

Kinlochleven is a village located in the Scottish Highlands shown in figure 7. The population of the previously small village grew when the North British Aluminium Company built an Aluminium smelter powered by a hydro-electric plant in 1907. With the associated employment opportunities, the village grew to over 1000 inhabitants. The aluminium smelters close in June 2000 had a significant detrimental effect on the economy of the village. [9] In response, the Kinlochleven Community Trust, was established to address regeneration of the area. [10] The village has since experienced funding to regenerate the area including development of a climbing centre however there are still more opportunities to continue to improve the sustainability of the village and unlock the potential of tourism and visitors to the area. [11]

Figure 7- Kinlochleven Aerial View [12]

3.2. Mamores Lodge

Mamores Lodge is a former hotel on the slope of Am-Bodach overlooking Kinlochleven as seen in figure 8. The lodge was originally built for a shipping company owner Captain Frank Bibby in the late 1800's. The lodge then operated as a hotel boasting 12 bedrooms as well as additional rooms for hospitality. The lodge briefly operated as self-catering rooms before closing in 2000 and has remained derelict since this time.

Figure 8- Mamores Lodge [13]

This project aims to unlock the potential of the building by proposing the lodge be brought back into operation as accommodation or as a hub for outdoor sports. Designing the building to advanced sustainability standards will allow the building to act as an icon in the region for education and awareness of sustainable buildings while having a positive impact on the socio-economics of the surrounding region.

3.3. Site Visit

A site visit was carried out to gain more information about the construction and condition of the building. The site visit was carried out on 20/11/18 with a meeting with the Kinlochleven Community Trust being carried out and Olivia Gemmill from Jahama estates being present for the site survey. The pictures in figure 9 show images of the interior and exterior of the building which has been boarded up to ensure the building is watertight. The interior of the building can be seen to be derelict and in poor condition. The relevant information regarding materials and dimensions of the existing building envelope were obtained.

Figure 9- Images from site visit on 20/11/18

3.4. 3D Model

A scale 3D Model of the lodge was created in Solidworks using the floor plans provided by Jahama Estates as seen in appendix A along with information from site visit as in section 3.3. An isometric view of this model can be seen in figure 10 with the 4 sides of the building shown in figure 11.

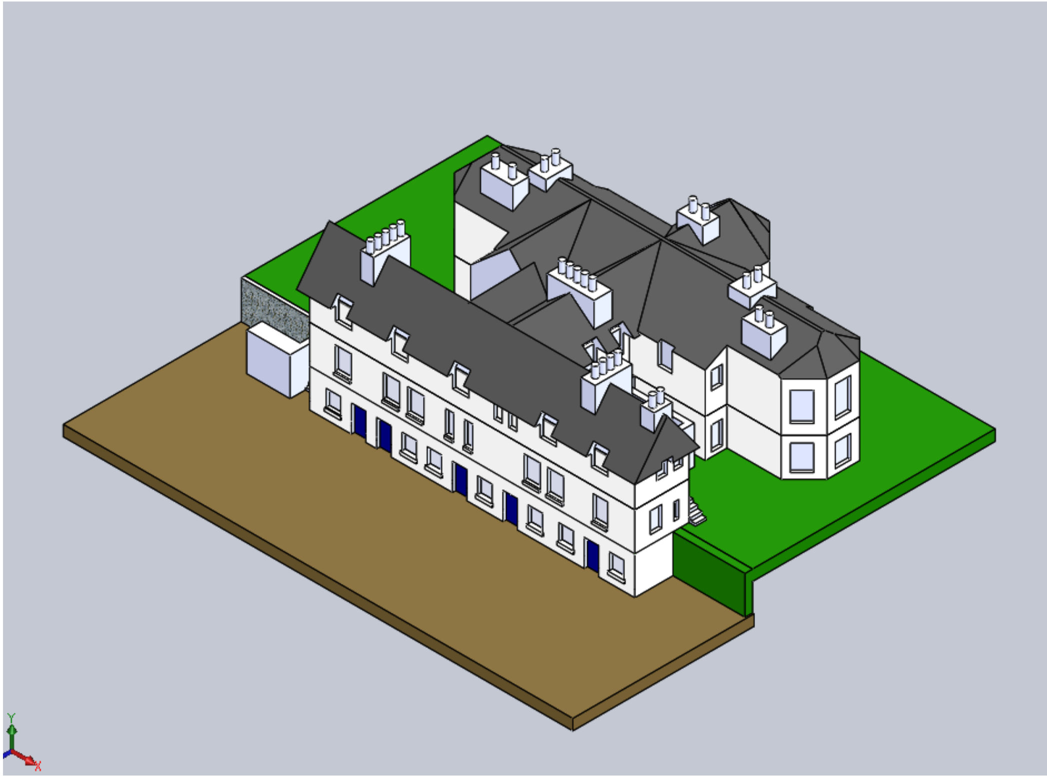


Figure 10- 3D Model of Mamores Lodge

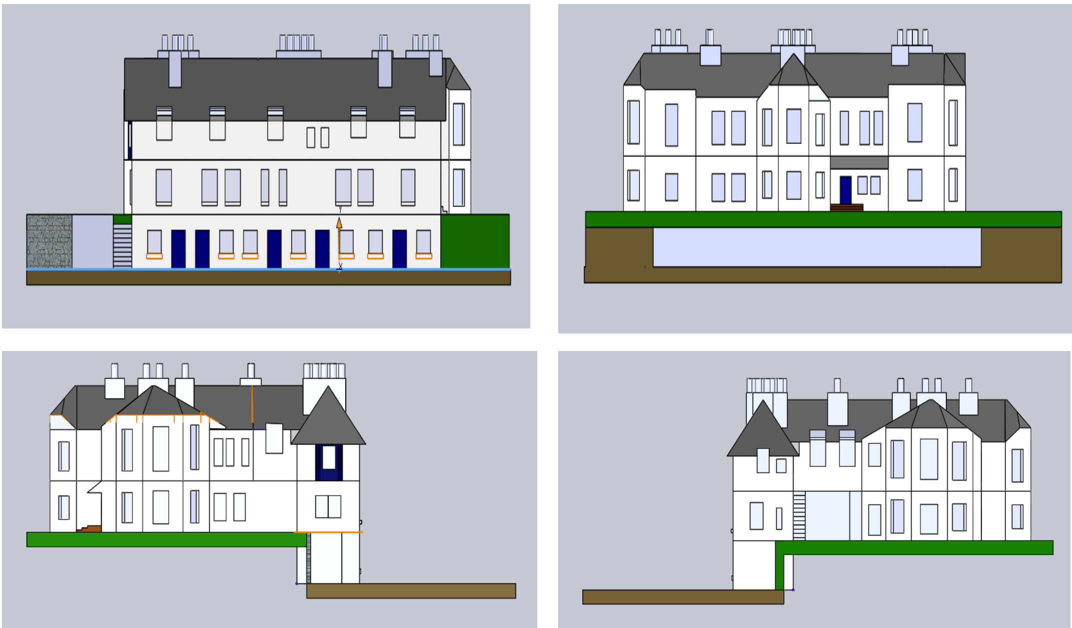


Figure 11- 4 Sides of Mamores Lodge

3.5. Energy Model

3.5.1. Pre-processing

The energy demands of Mamores Lodge were to be modelled as it currently exists in order to examine the thermal efficiency and compare to Passive House standards. The Passive House Planning Package (PHPP); an energy balance software package provided by the Passive House institute, should be used to carry out modelling.

The Aviemore climate was selected as it was the closest available weather station data to the lodge. The height of the weather station at Aviemore is 200m above sea level and the height of the lodge is 213m above sea level, therefore this climate gives a reasonable data set to use for the energy balance calculation.

The wall was measured as 420mm of solid stone taken to have a thermal conductivity of 2 *W/mK.* [14] The floor was confirmed to be a suspended timber floor upon inspection from the site visit and the report "Scotland: Assessing U Values of existing housing" details U values of buildings built pre-1919 and states that the U values of flooring to be used is 0.6 W/m^2K. [15] The roof was determined during the sight visit to be chipboard and plaster ceiling. [16] The U Values of building assembly components can be seen in table 6 calculated using equation 3.

Table 6- U values of existing construction

Construction	Thermal Conductivity (W/mK)	Thickness (mm)	U Value (W/m^2K)
Wall	2	420	2.632
Roof/Ceiling	0.13	50	1.678
	0.7	50	
Floor Slab	-	-	0.6

Associated dimensions of walls, floor and roof were entered along with orientation of each. Windows were determined to be single glazing with a timber frame upon inspection at site visit and were added with their orientation to the PHPP data.

The ground material was rock from inspection and the dimensions of the floor slab and perimeter length were also entered.

3.5.2. Results

The results of the energy balance calculation were obtained from the PHPP software using the input data in section 3.5.1. The comparison with EnerPHit Passive House standard for retrofit projects can be seen in figure 12.

					Criteria	Alternative criteria	Fullfilled?[2]
	Treated floor area	m²	1350.0				
Space heating	Heating demand	kWh/(m²a)	278	≤	25	-	no
	Heating load	W/m²	73	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	0	≤	10		yes
	Frequency excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	0.2	≤	1.0		yes

Figure 12- PHPP comparison to Passive House Standards

It can be concluded that the building does not meet Passive House EnerPhit standard. The heating demand was calculated to be $279kWh/m^2a$, significantly larger than the required value of $25kWh/m^2a$ required to meet the Passive House EnerPHit standard.

The primary energy demand of the building was not measurable as the building is derelict. The full electrical demands of the building therefore could not be quantified. This value could have been modelled using default values, however was determined not to be necessary as the building does not meet Passive House standard for space heating and is being redeveloped. The primary energy demand of the new construction should be established and compared to the standard.

Due to the climate, the cooling demands for the lodge are negligible as shown in figure 12, with the exterior temperature never high enough to require a cooling system to be installed. A graphical representation of the energy balance using can be seen in figure 13 from PHPP.

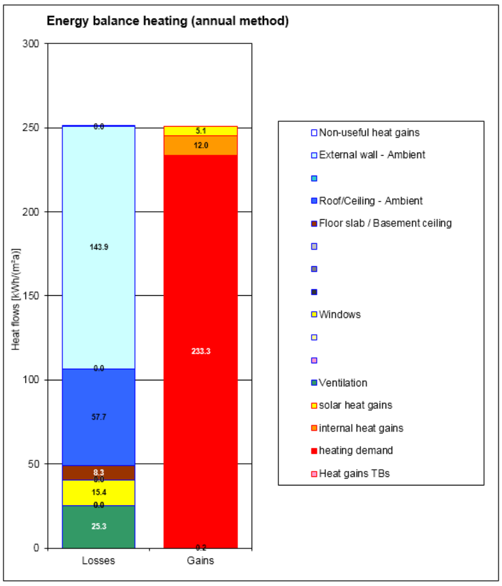


Figure 13- Energy Balance Graph for Mamores Lodge

The graph shows the breakdown of the gains and the losses in the building. A large proportion of the losses are due to heat transfer through the walls (143.9kWh/m^2a) and the roof (57.7 kWh/m^2a). Additionally, the solar gains (5.1 kWh/m^2a) in the building are minimal.

4. Justification of New construction

The possibility of the lodge being rebuilt rather than retrofitted was explored. There were several reasons for this with the main factors being the large transmission losses in the building, the complex geometry of the building making the thermal bridge losses difficult to minimise, the minimal solar gain available and the poor condition of the interior of the building.

The heating demand for the lodge as it currently exists was determined to be 279kWh/m^2a as in section 3.5.2 and this was compared to the Passive House EnerPHit standard criteria of 25kWh/m^2a. This value can clearly be seen to be significantly larger and the reasons for this were outlined as large losses through the roof and walls and would also be impacted by thermal bridge losses. The losses in the roof and walls could be reduced through large increases in amount and quality of insulation, however, with common thermal bridges occurring at junctions in the building between elements such as walls, doors and windows and the current geometry of the building being extremely complex and non-uniform, these losses will be extremely hard to minimise to a reasonable value. Figure 14 shows the large number of key areas where thermal would have to be considered. The solar gain of the existing construction was also determined to be minimal in section 3.5.2, and this would be difficult to change with the position and orientation of windows pre-determined. Design of a new construction would allow a simple geometry to be used minimising thermal bridging, adequate levels of insulation to be installed and solar gain to be maximised through strategic design of window placement and orientation.

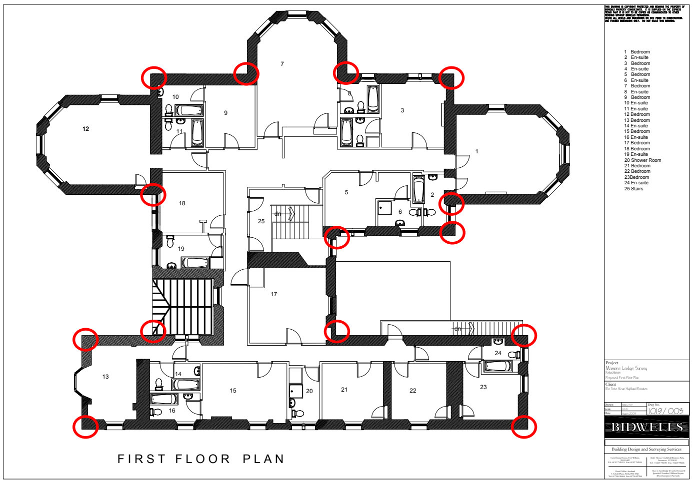


Figure 14- Location of thermal bridges in existing construction

The poor condition of the inside of the building as seen in figure 15 was also another issue when considering a retrofit of the lodge. The interior of the lodge can be seen to completely derelict and the sky light was exposed upon site visit causing dampness to build up inside the building.

Figure 15- Interior of building

Due to these factors; the extremely large losses combined with complex geometry of the building and the poor condition of the interior it was concluded that the lodge should be rebuilt to on the same site rather than carrying out a retrofit of the existing lodge. The community trust, who a relationship has been built up with throughout the project, should be contacted to gain information about the public opinion of the lodge being rebuilt. The existing building should be demolished, with any useful materials which can be salvaged to be used for the new construction and the existing foundations for the lodge to be used for the new construction.

5. Fabric Retrofit of New Construction

5.1. Geometry and Shape of Building

A simple geometrical shape should be used for the floor plan of the building, the best way to achieve this was using a rectangle, with the shape being narrow and long in order to also maximise solar gain in the building as explained in section 2.2.5. Through analysis of the area available, the floor plan of the new construction and dimensions to be used can be seen in figure 16.

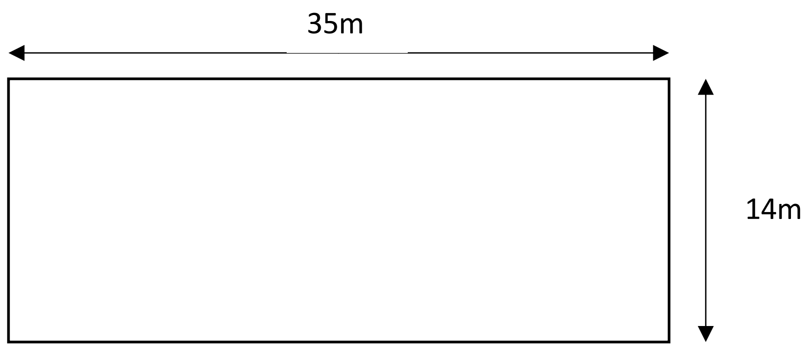


Figure 16- Floor plan of new construction

The building was decided to be 2 storeys high, with the height of each floor 3.5m. The full building envelope comprising of 4 walls, floor and ceiling can be seen in figure 17. This limits the number of junctions where potential thermal bridges could arise between walls, floors and ceiling panel to 8 which have been highlighted in figure 17. This simple geometrical construction will also result in a significantly lower wall area to treated floor area ratio for greater efficiency as seen in table 7.

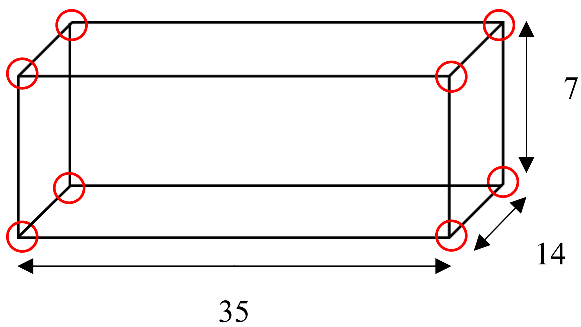


Figure 17- Building envelope of proposed construction

Table 7 - Wall to treated floor area ratio comparison

	Treated Floor Area (m^2)	Wall Area (m^2)	$\frac{\text{Treated Floor Area}}{\text{Wall Area}}$
Existing	490	945	1.89
Proposed	490	686	1.4

The areas of the 3 respective elements of the building envelope can be calculated as in table 8.

Table 8 - Areas of building envelope components

Walls	$2x(35x7)m^2 + 2x(7x14)m^2 = 686m^2$
Floor	$14x35 = 490m^2$
Roof	$14x35 = 490m^2$

Due to the location of the lodge, significant rain and snow would be expected throughout the year therefore it was concluded a sloped roof should be constructed as in figure 18, however the attic space above the top floor ceiling is not to be part of the thermal envelope. An overhang on the south side of the building should be used in order to minimise the likelihood of overheating in summer as outlined in section 2.2.5.

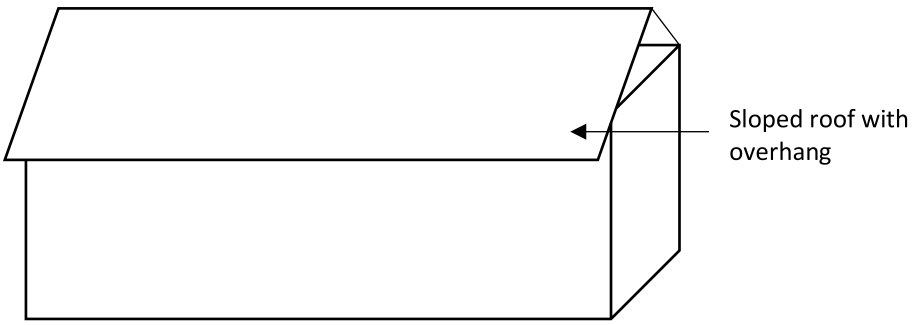


Figure 18- Building with sloped roof and overhang on south side

The building should aim to promote sustainability in the area where possible with electric vehicle chargers and e-bike chargers to be installed to encourage use of these vehicles in the local area.

5.2. Construction Method

The construction should be built to meet sustainability standards. This means that protection of the environment should be at the forefront of the design, with energy demands being minimised and the remaining demand to be supplied through renewable sources where possible but also that the construction project should have a positive impact on the local community as in section 2.1.

Bringing the lodge into operation will bring business to the village of Kinlochleven and will have associated job opportunities. The construction of the lodge should also aim to utilise local resources and materials.

Scottish timber is an underutilised and abundant material in the Scottish Highlands, and this is used by an architect led design and build firm MAKAR, based in Inverness in the Scottish Highlands, to build ecological healthy buildings. MAKAR complete off-site manufacturing of timber frames to build homes which are energy efficient. An example of a MAKAR construction can be seen in figure 19. [17]

Figure 19- MAKAR construction in Glenelg

This method of using Scottish Timber, sourced and manufactured in the Scottish Highlands should act as a model for this project, with MAKAR being used for the project or a similar model being carried out in Kinlochleven itself. This method will have a number of a benefits to the project, bringing investment and job opportunities to the local area, and local materials being used will reduce the carbon footprint of the project as a whole with reduced transport required for key materials.

5.3. Component Details

Components should be selected for all parts of the building envelope which are proven to meet Passive house standards and minimise thermal bridges. Wall components should be selected which utilise wooden panel method, in order to follow the timber frame method outlined in section 5.2. IBO Book is a catalogue produced by the Austrian Institute for Healthy Ecological Buildings which states its aim as providing "Details for Passive Houses- A catalogue for ecologically rated constructions". This catalogue gives details of proven construction unit details for walls, floor, ceilings and roof slabs which are known to meet Passive House thermal performance standards. It also provides details on connections between different components to ensure airtightness and minimise thermal bridging.

5.3.1. Floor

Passive House standard states that the U Value of floor components should be smaller than 0.15 $\frac{mK}{W}$. The IBO Book determines that for rocky ground, which is present at Mamores Lodge, insulation should be beneath floor slab for maximum performance. The construction of the floor slab component with insulation beneath floor slab can be seen in figure 20 and section details in table 9. [18]

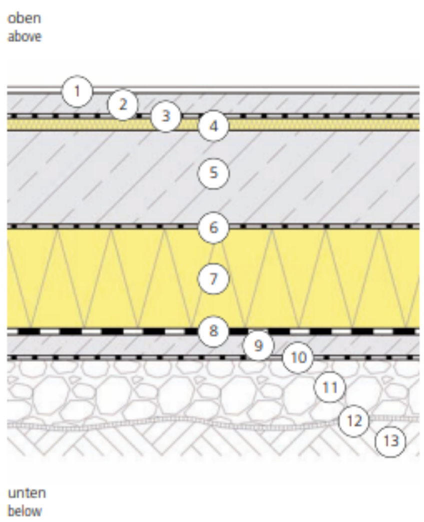


Figure 20- Floor component

Table 9- Materials in wall component

	Material	Thickness
1	Flooring	-
2	Cement screed	5
3	Building Paper	-
4	Wood fibreboard	3
5	Reinforced concrete	20
6	PE Separating layer	-
7	Foamed Glass	24
8	2 Layer polymer bitumen	1
9	Lean mortar/clean layer	5
10	Building Paper	-
11	Setting layer	15
12	PP Filter Fleece	-
13	Subsoil	-
		73cm

This construction uses foamed glass panels used as insulating material. The stated U Value of this floor slab in IBO Book is 0.15$\frac{mK}{W}$ which meets Passive house standard. Thermal conductivities of all materials were taken from PHPP manual and components with minimal thickness were assumed to have no insulating properties. Scottish timber should be used for all wood components with thermal conductivity to be used as $0.12\frac{W}{mK}$. The practical U value of this construction can be calculated using equation 3 and this value should be used for energy modelling. [16] [19]

$$cement\ screed, k_2 = 1.4\frac{W}{mK}$$

$$wood\ fibreboard\ (Timber), k_4 = 0.12\frac{W}{mK}$$

$$reinforced\ concrete, k_5 = 2.1\frac{W}{mK}$$

$$foamed\ glass\ panels, k_7 = 0.045\frac{W}{mK}$$

$$mortar\ \approx cement\ screed, k_9 = 1.4\frac{W}{mK}$$

$$setting\ layer, k_{11} = ?\frac{W}{mK}$$

$$U = \frac{1}{\sum \frac{l}{k}}$$

$$U = \frac{1}{\frac{0.05}{1.4} + \frac{0.03}{0.12} + \frac{0.2}{2.1} + \frac{0.24}{0.045} + \frac{0.05}{1.4}}$$

$$\boldsymbol{U = 1.74\frac{mK}{W}}$$

5.3.2. Wall

Passive House standard states that the U Value of wall components should be smaller than $0.15\ \frac{mK}{W}$. A component utilising wooden panels was selected from the IBO Book due to the use of Scottish timber as a sustainable material for the construction as in section 5.2. The cross section as well as details of each section can be seen in figure 21 and table 10. [20]

Table 10- Materials in wall component

	Material	Thickness
1	Wood shuttering	2.5
2	Upright wood lathes	5
3	MDF Board	1.6
4	Mineral wool	30
5	Polyethylene	-
6	Stacked wood wall	12
		51.1cm

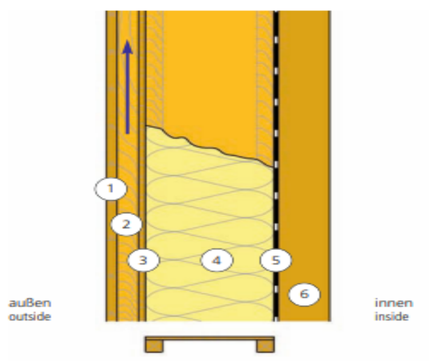


Figure 21- Wall component

This construction uses wood panels as the exterior layer of the building with upright wood lathes to provide rear ventilation and mineral wool as insulating material. The component is determined to have a U Value of $0.15\frac{mK}{W}$ in the IBO Book which is within the criteria of Passive House standard for a new construction and provides the opportunities to use locally sourced Scottish timber. The IBO Book also determines the component is suitable for prefabrication which is the preferred method of construction due to the benefits associated. The practical U value of this construction can be calculated using equation 3 and this value should be used for energy modelling. [16]

$$wood\ shuttering\ (Timber), k_1 = 0.12 \frac{W}{mK}$$

$$wood\ lathes\ (timber), k_2 = 0.12 \frac{W}{mK}$$

$$MDF, k_3 = 0.12 \frac{W}{mK}$$

$$mineral\ wool, k_4 = 0.045 \frac{W}{mK}$$

$$stacked\ wood\ wall\ (Timber)\ , k_6 = 0.13 \frac{W}{mK}$$

$$U = \frac{1}{\sum \frac{l}{k}}$$

$$U = \frac{1}{\frac{0.025}{0.12} + \frac{0.05}{0.12} + \frac{0.016}{0.12} + \frac{0.3}{0.045} + \frac{0.12}{0.13}}$$

$$\boldsymbol{U = 0.12 \frac{mK}{W}}$$

5.3.3. Roof/Ceiling

Passive House standard states that the U Value of roof components should be smaller than 0.1 $\frac{mK}{W}$. As a sloped roof is to be built above this ceiling, a plaster ceiling could be used, the IBO Book recommended component cross section and section details can be seen in figure 22 and table 11. [21]

Table 11- Materials in floor component

	Material	Thickness (cm)
1	Flooring layer	-
2	Chipboard	3
3	Mineral wool	8
4	Reinforced concrete	20
5	EPS, Dowelled and bonded	30
6	Silicate Plaster	
		61cm

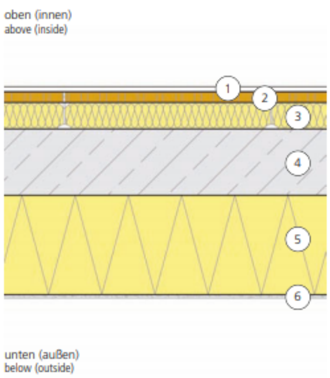


Figure 22-Roof Component

The stated U Value of this component is $0.1\frac{mK}{W}$ which is within Passive House standards. The practical U value of this construction can be calculated using equation 3 and this value should be used for energy modelling. [16]

$$chipboard, k_1 = 0.1\frac{W}{mK}$$

$$mineral\ wool, k_2 = 0.045\frac{W}{mK}$$

$$reinforced\ concrete, k_3 = 2.1\frac{W}{mK}$$

$$EPS, k_5 = 0.04\frac{W}{mK}$$

$$U = \frac{1}{\sum \frac{l}{k}}$$

$$U = \frac{1}{\frac{0.03}{0.1} + \frac{0.08}{0.045} + \frac{0.2}{2.1} + \frac{0.3}{0.04}}$$

$$\boldsymbol{U = 0.10\frac{mK}{W}}$$

5.3.4. Connections

Specific practices should be used in areas of connecting components. Figure 23 shows how a stacked wood wall should be connected to a floor slab with lower side insulation in order to minimise thermal bridging. The thermal bridging coefficient of this component is given as $0.013W/mK$. [21]

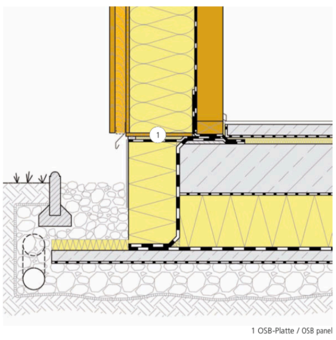


Figure 23- Wall to floor connection

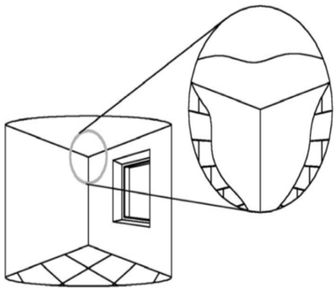
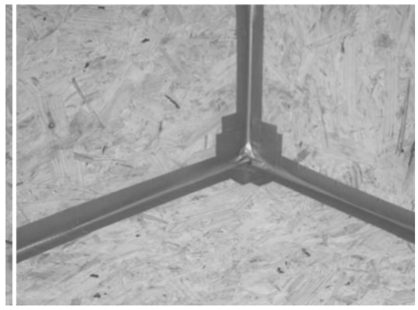
5.3.5. Windows/Glazing

Windows should be used with a low U Value to minimise the transmission losses. The U Value of windows should be $0.8\frac{W}{m^2k}$.This will be achieved using tripe glazing windows installed in an airtight manner. [23]

5.3.6. Junctions between Components

The connection of more than two components leads to 3D connection points, e.g. corners. The components must meet at the same point and the IBO book gives solutions to ensure the connection remains airtight as seen in table 12.

Table 12- Junction details to avoid thermal bridging [24]

3D Sealing connections	3D Plaster Connections	3D Taped panel connections
		

Additional construction methods will be implemented with junctions' areas such as door and window frames to ensure the building envelope maintains airtight.

5.3.7. Penetrations

Penetrations in the building envelope should be avoided however some unavoidable penetrations include cables, sewage and ventilation. Sanitary installations in toilets and kitchens etc normally involve a number of penetrations. An effective method to limit the effect of these is pouring non-shrinking expanding mortar or anhydrite slag into the penetrations. Another solution for lightweight constructions in the use of stable open diffusion and airtight soffit layer to cover the opening. [25]

5.3.8. Ventilation Systems

As in section 2.2, a heat recovery ventilation system should be installed in a building using exhaust air from the building to heat the supply air in order to meet Passive House requirements for airtightness and improve air quality within the building.

5.4. 3D Model

Using the geometry designed in section 5.1 and wooden façade as in section 5.2, an indicative 3D model of the lodge was created as in figure 24 showing 3 views of the model.

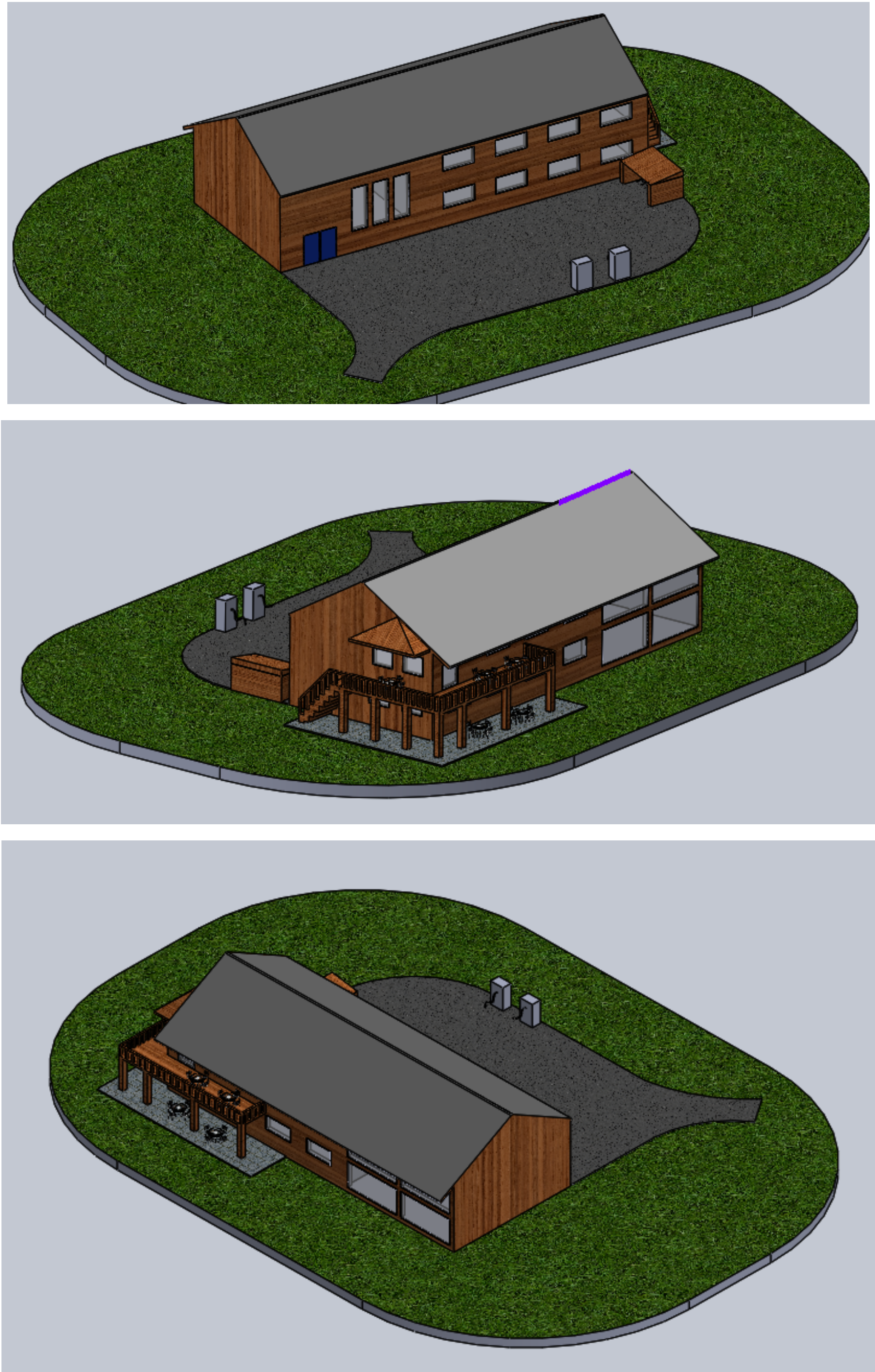


Figure 24- 3D Model of lodge

The wooden façade of the building can be seen around all 4 sides using large panels of Scottish Timber as the outer layer. The design was created to maximise solar gain as in section 2.2.5 with large amounts of glazing used on the south side of the building and minimal amounts used on the north side which is the side at the car park area. Electric vehicle chargers were shown installed in the car park area as well as a bike shed with e bike chargers. A balcony area overlooking the village of Kinlochleven as well as down the valley adjacent to the lodge was designed with the intention being to have a café with outdoor seating areas at the lodge. A large reception area was designed where the 4 large windows are located on the south side of the lodge, this area would act as a hub for sports and activities in the area and the other part of the building where the small windows are located would act as bedrooms for guests. The number of guests in the lodge was estimated to be an average value throughout year was estimated of 30 occupants. This model will allow the size and orientation of windows and walls to be measured for purposes of energy model using Passive House Planning Package.

6. Energy Model

The new lodge should be modelled using PHPP, as was carried out in section 3.4 to the existing construction. The details of the new lodge including size and construction of the building envelope components as well as orientation and size of triple glazing windows were entered from the 3D Model in section 5.4 along with installation of a ventilation system. The electrical demands and hot water demand of the building were determined to be that of 30 occupants for the purpose of energy modelling and the lodge was assumed to be in operation 365 days a year, despite the likelihood of increased demands in winter. The full energy demand of the lodge can be split up into four categories; space heating, domestic hot water, domestic electricity and auxiliary electricity.

The heating demand for both space heating and domestic hot water should be supplied by a heat pump, which converts electrical energy to useful heating energy. The season performance factor (SPF) is a characteristic of a heat pump which represents the efficiency as in equation 4.

$$SPF = \frac{Heat\ energy\ output}{Electical\ energy\ input} \quad (4)$$

6.1.1. Space Heating Demand

The space heating demand of the building is calculated in PHPP using the energy balance equation in equation 1. The ventilation losses are calculated using the specified U Values of building envelope components, the solar gain is calculated using orientation and size of windows in the building and internal gains are calculated using specific values for components and appliance in combination with the number of occupants in the building.

The monthly method to calculate heating demand applies an energy balance to each month in the year to produce an individual heating demand for each month. The results can be seen in table 13 for both specific values and actual values based on the treated floor area from the 3D model of 798m^2.

Table 13- Space Heating monthly loads

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Spec Heating Demand (kWh/m^2)	4.1	1.8	0.4	0	0	0	0	0	0	0.3	2.7	4.5	13.9
Space Heating Demand (kWh)	3271	1436	319	0	0	0	0	0	0	239	2155	3591	1101

The yearly specific heating demand 13.9 kWh/m^2a meets the Passive House standard for specific heating demand of smaller than 15 kWh/m^2a. The full electricity demand should be modelled along with the supply system to provide a thorough proposal for the lodge as well as compare the primary energy demand to the criteria in the Passive House standard.

An air source heat pump should be used to supply the space heating demand, with PHPP calculating the SPF of the heat pump based on the distribution losses and characteristics of the heat pump to be 1.73 for space heating. Using equation 4 for this SPF, the electrical demand for each month can be seen in table 14.

Table 14- Space Heating Electrical Demand

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Spec Electrical Demand (kWh/m^2)	2.37	1.04	0.81	0	0	0	0	0	0	0.17	1.56	2.60	8.04
Space Electrical Demand (kWh)	1891	830	184	0	0	0	0	0	0	138	1245	2076	6416

6.1.2. Domestic Hot Water Demand

The domestic hot water heating demand is calculated in PHPP using a default demand of 25 litres of hot water per person per day. The final demand is then determined using the defined occupancy of 30 people including guests and staff with losses in the distribution system also taken into account. This load is assumed to remain unchanged throughout the year, therefore the demand in each month will be the same. The specific and actual heating demand for hot water results from PHPP can be seen in table 15.

Table 15-Domestic Hot Water Heating Demand

	Spec Heating Demand (kWh/m^2)	Space Heating Demand (kWh)
Annual	25.3	20182
Monthly	2.11	1682

An air source heat pump should be used to supply this heating demand, with PHPP calculating the SPF of the heat pump based on the distribution losses and characteristics of the heat pump to be 1.87. Using equation 4 for this SPF value, the annual and monthly electrical demand can be seen in table 16.

Table 16- Domestic Hot Water Electrical Demand

	Spec Electricity Demand (kWh/m^2)	Spec Electricity Demand (kWh)
Annual	13.5	10773
Monthly	1.125	898

6.1.3. Domestic Electricity Demand

The domestic electricity demand should be taken into account as part of the energy demands. The energy used by essential systems such as lighting, clothes washing, and cooking are calculated using standard values combined with the occupancy of 30 people and will have the same value in every month of the year. The lodge should also have two 3kW electric vehicle charging ports and 5 e-bike charging stations to provide convenient services for people visiting the lodge or guests, while encouraging and promoting sustainability in the local area.

A 3kW car charger takes 6-12 hours for a full charge. The energy demands of the 2 chargers was assumed, for the purpose of energy modelling, to be 100 9-hour chargers throughout the year. This corresponds to a load of $2700 kWh/a$. [26] The 5 e-bike chargers were assumed to be 500W and take around 4 hours to charge a bike. Each charger to assumed to be used for one full charge 100 times. This corresponds to a load of $1000 kWh/a$ [27]These elements would likely be used more in summer than winter however will be assumed to be used equally in each month of the year for the purpose of energy modelling.

This gave a total domestic electricity demand as in table 17 showing yearly and monthly values.

Table 17- Domestic Electricity Demand

	Spec Electrical Demand (kWh/m^2)	Electrical Demand (kWh)
Annual	17.3	13805
Monthly	1.44	1149

6.1.4. Auxiliary Electricity Demand

Auxiliary electricity is defined as the electricity required to run the mechanical systems in a building. These values are standard values for components such as ventilation. This demand, though may in reality be higher in winter due to some of this demand is for systems such as frost prevention, should be assumed to be the same for all months. The values determined from PHPP can be seen in table 18.

Table 18- Auxiliary Electricity Demand

	Spec Electrical Demand (kWh/m^2)	Electrical Demand (kWh)
Annual	2.6	2075
Monthly	0.22	172.9

6.1.5. Monthly Summary

The total electrical demand can be summarized as in table 19, showing the sum of the values for the 4 categories of load in each month. Figure 25 shows the portion that each load represents in each month. With the space heating load shown to cause the total demand in the winter months to be larger.

Table 19- Total monthly electrical load

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Total Electrical Demand (kWh/m^2)	5.15	3.82	3.59	2.78	2.78	2.78	2.78	2.78	2.78	2.95	4.34	5.38	41.93
Total Electrical Demand (kWh)	4111	3050	2866	2220	2220	2220	2220	2220	2220	2355	3465	4295	33460

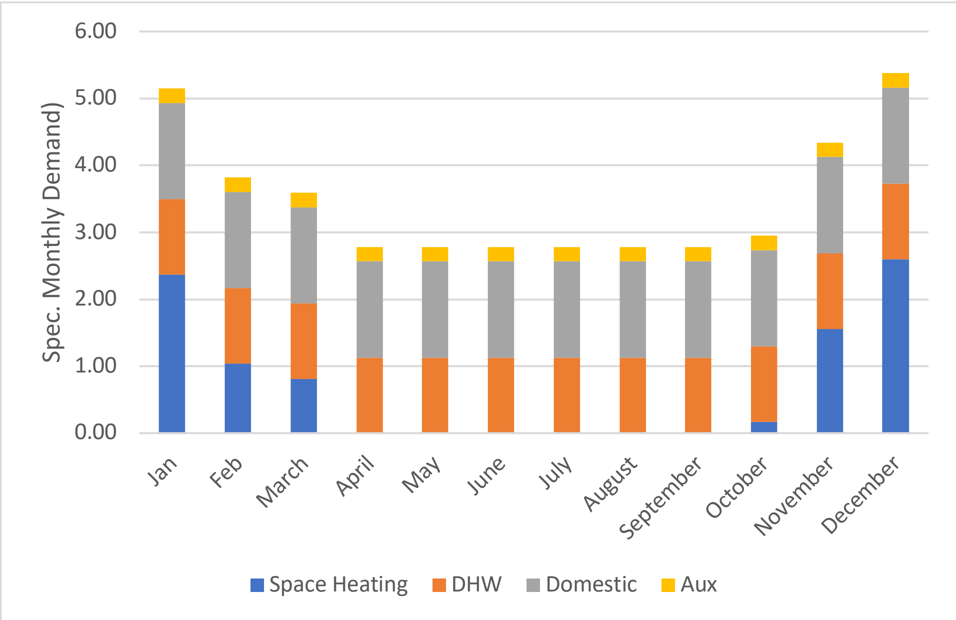


Figure 25- Monthly Load profile contributions

7. Supply System

HOMER energy software should be used to model the supply system of the lodge. This software allows design and optimization of microgrid systems to meet a specified input load providing detailed breakdown of the operation and characteristics of the system. The climate set was set to Kinlochleven in HOMER, downloading solar and wind speed data using this location.

7.1. Domestic and Auxiliary Electricity

The domestic electricity and auxiliary electricity will be assumed to follow a residential load profile over a time period of one day as shown in figure 26. The profile shows the peaks of demand at 7am, 1pm and 7pm, with low points between 11pm and 4am. These peaks are due to large loads being used such as cooking. Applying this daily profile in HOMER will allow a value of power required in kW for a full year in 60-minute intervals. The value of the domestic and auxiliary electric demands should be assumed to be the same in every month as in section 6.1.3 and 6.1.4. and the total can be calculated by summing the values in table 17 and 18. This provides a total annual load of 15880kWh and therefore an average daily load of 43.5kWh.

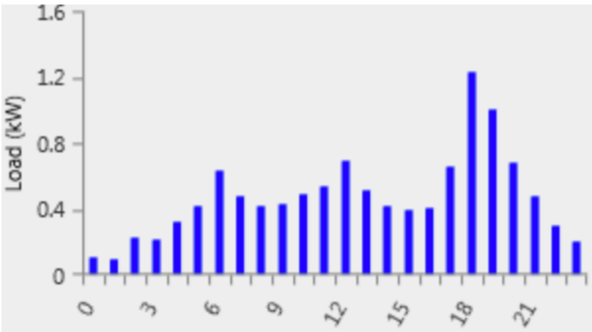


Figure 26- Residential Load Profile [28]

HOMER uses this average daily load of 43.5kWh along with the daily residential load profile to build a full load profile at 60-minute intervals throughout the year using a baseline default load which is scaled based on the average daily load. Random variability is also added to model real life fluctuations in demand between days. The full profile for domestic and auxiliary electricity demand can be seen in figure 27, with a zoomed in portion shown in figure 28 for a 7-day period in June where the residential daily load profile can be clearly seen to follow the daily profile in figure 26 with expected random fluctuations. A summary of the load details generated can be seen in table 20.

Table 20- Electric load summary

Average load (kWh/day)	43.5
Average (kW))	1.81
Peak (kW)	8.08
Load Factor	0.22

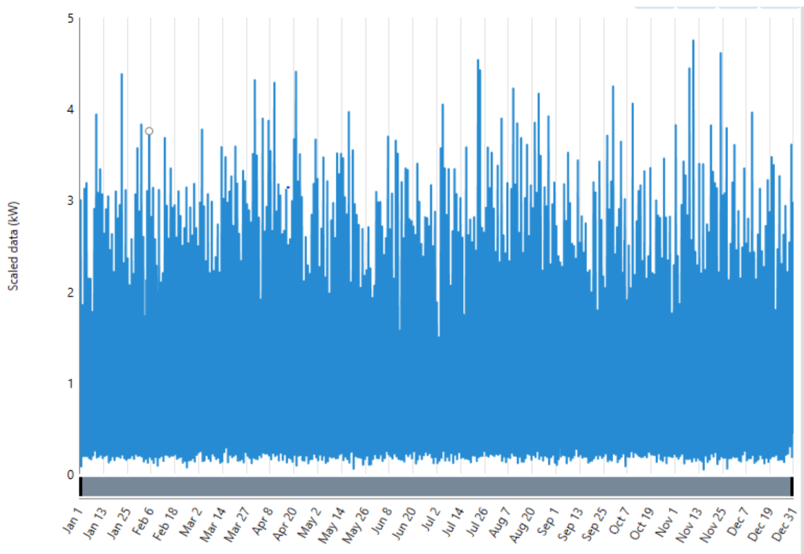


Figure 27- Load profile for domestic and auxiliary electricity [29]

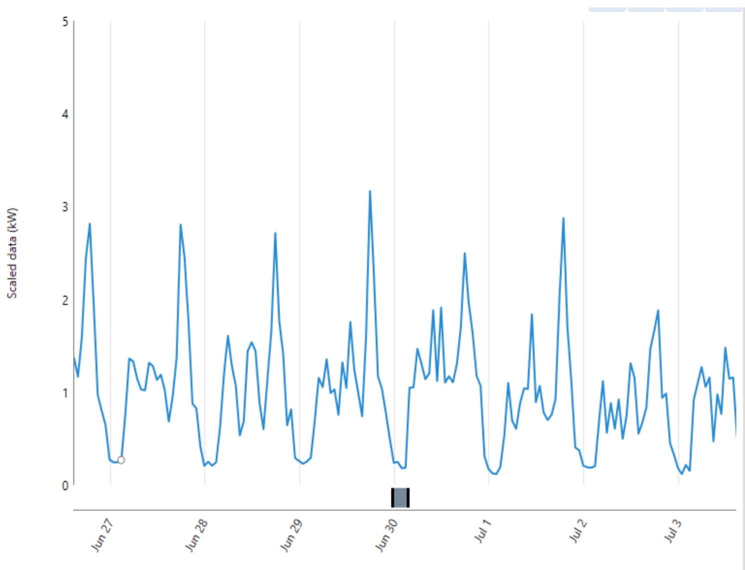


Figure 28- Zoomed in period of figure 27 [29]

7.2. Space heating and Domestic Hot Water

A deferable load is an electrical load which requires an amount of energy within a time period however the exact timing that the load is supplied is not important. [30] The space heating and domestic hot water demand should be assumed to be deferrable for the supply system as they can be supplied at any time providing there is a storage tank which is not empty to provide hot water when it is required. In reality, two separate storage tanks for space heating and hot water would be used however HOMER only offers a single deferrable load to be added therefore a single storage tank must be used for both hot water and space heating demand. The storage tank used for modelling was 1000L. The total electrical demand for the hot water and space heating was calculated using values in table 14 and table 16 to provide results in table 21.

Table 21- Electrical Demand for space heating and DHW

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Electrical Demand (kWh/m^2)	3.50	2.17	1.94	1.13	1.13	1.13	1.13	1.13	1.13	1.30	2.69	3.73	22.05
Electrical Demand (kWh)	2789	1728	1544	898	898	898	898	898	898	1033	2143	2973	17596

The deferrable load is assumed to be constant within each day in the month, therefore the average daily load can be calculated using the yearly value scaled to an individual day. The average daily deferrable load is therefore 48.2kWh and the average daily load in each month can be seen in figure 29 from HOMER software.

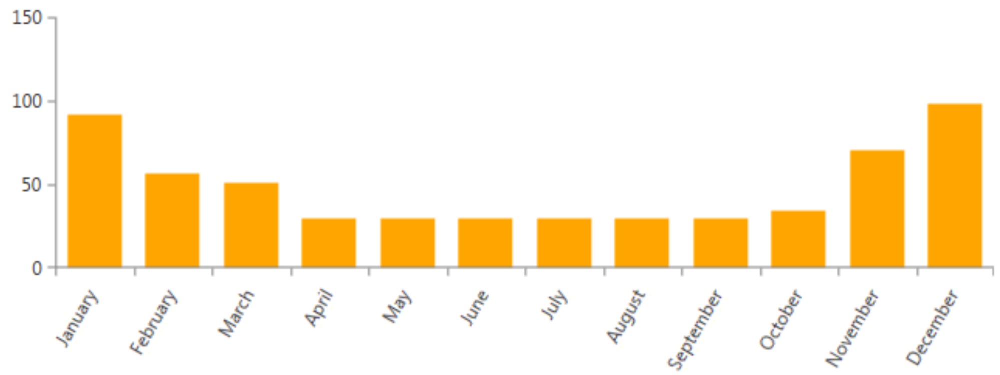


Figure 29- Average Daily Deferrable load per month [29]

The peak load is the rated electrical consumption of the heat pump from PHPP which was 10kW, with the minimum load ratio being 0 as the heat pump is able to switch off.

The capacity of the storage tank should be calculated using equation 5. The water should be heated to 55$°C$ for both hot water and space heating and the supply air should be assumed to be entering the tank at 10$°C$.

$$E = mC\Delta T \tag{5}$$

$$E = (0.997x1000)x4.186x(55 - 10)$$

$$E = 187804.89kJ = 52.17kWh$$

This represents the heat energy required to heat 1000L of water to 55 degrees from 10 degrees. As the electricity is supplied via a heat pump the electricity required for this amount of heat can be calculated using equation 4. The seasonal performance factor should be taken as the average value between the value for hot water and space heating as a single storage tank is being modelled. The average seasonal performance factor would be 1.795. The electrical storage capacity was therefore calculated to be 29.06 kWh.

These details were added to HOMER to model the deferrable load of the domestic hot water and space heating demand with a summary of the load details in table 22.

Table 22 Deferrable load details in HOMER

Scaled Annual Average *(kWh/day)*	48.20
Storage Capacity (*kWh*)	29.06
Peak Load (*kW*)	10
Minimum load ratio (%)	0

7.3. Renewable Systems Input

The energy model should now be simulated to propose a supply system which can meet the demand. With the aim being to use as high a percentage of renewable sources as feasible. The electric load from domestic and auxiliary electricity in section 7.1. was entered along with the deferrable load for the hot water and space heating demand as in section 7.2.

Practical limitations should be considered with the maximum amount of PV panels covering the full roof of the building. The area of this from the 3D Model in section 5.4 was approximately $560m^2$. A 1kW PV panel has an approximate area of $8m^2$. [31] Therefore, the maximum number of 1kW PV Panels which could be installed is 70. A 1kW PV system was added to HOMER with a solution to be simulated for all numbers of panels up to 70 in intervals of 10. The default price on HOMER of PV panels was $3000 per kW and solar data for Kinlochleven was downloaded from the internet to be used for simulations. A converter should be added to convert the direct current output from the PV panel to alternating current and should be sized to the peak load of the solar panel for each iteration, for example using a 30kW converter for a 30kW solar panel system.

Utilisation of wind energy through a wind turbine should be examined. A 3kW wind turbine with height from the ground of 17m was added to the HOMER simulation. The number of these was limited to 1 given the rural setting and likely negative opinion by local community to a wind turbine larger than this. The option of placing this wind turbine on the roof of the building could also be explored. The default price of a 3kW wind turbine on HOMER was $18000 and wind data from the area was downloaded from the internet to be used for simulations.

The grid was added to provide a backup energy system whenever renewable sources cannot cover the demand. When excess energy is produced it can also be sold back to the gird, with default values in HOMER being a price to buy energy of 0.1$/kWh and sell back price of 0.05$/kWh.

A schematic of the system can be seen in figure 30.

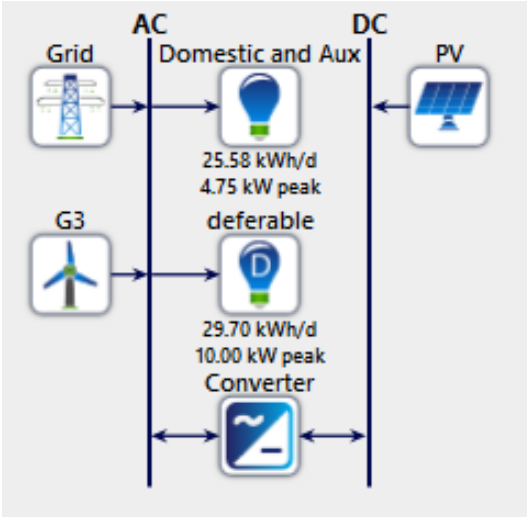


Figure 30- Schematic of Renewable Supply System [32]

7.4. Results

The model was simulated, with results being gained for 16 different systems. The number of PV panels being scaled from 0 to 70 in intervals of 10 with each number of PV's being simulated with and without a wind turbine in the system. The solution which uses the largest portion of energy from renewable sources to supply the demand should be selected. This was measured using equation 6, where the energy which must be purchased from the grid ($E_{grid\ purchases}$) is divided by the energy consumption of the load ($E_{consumption}$) which is the energy consumed in the building not including grid sales. This differs from the definition of renewable fraction produced in the HOMER energy software which includes grid sales in the energy consumption value, therefore providing higher values of renewable fraction not wholly representative of the proportion of energy consumed by the load which originates from renewable sources.

$$Renewable\ fraction = 1 - \frac{E_{grid\ purchases}}{E_{consumption}} \quad (6)$$

Other factors to be considered were operating costs. Operating costs quantify the costs per year that the system will have incur due to grid purchases counterbalanced by grid sales and also taking into account standard cost and frequencies for maintenance of components and excess is electricity which is unused.

Full detailed results for each iteration of the simulation can be seen in appendix B. The solution with maximum renewable fraction calculated using equation 6 was the system with 70 1kW PV panels and an associated 70kW converter combined with 1 3kW wind turbine. A summary of the results for this system can be seen in table 23.

Table 23- Supply system characteristics summary

Production	
Production from PV ($kWh/year$)	56928
Production from Wind ($kWh/year$)	6812
Grid Purchases ($kWh/year$)	11518
Consumption	
Domestic and Auxiliary Load	15878
Deferrable Load	17579
Grid Sales ($kWh/year$)	38955
Renewable Fraction (%)	65.57
Financial	
Capital Costs ($000)	249000
Operating Costs ($\$/year$)	643.53

In the proposed system, electricity is produced from photovoltaic panels, a wind turbine and also grid purchases. The daily average monthly production can be seen in figure 31 with the contribution of each source shown. Using results from table 23, photovoltaic panels produce 75.6% of the electricity produced and the wind turbine produces 9.05%. Grid purchases therefore make up the remainder to cover the full load of the two loads of the system representing 15.3%. The production can be seen to peak in summer due to the PV panel output and that the grid purchases in the summer months are minimal. The production can be seen to be lower in winter with the output of the wind turbine being a larger portion of the production while grid purchases are required to meet the demands of the loads. The daily average load input to HOMER for the domestic and auxiliary load as in section 7.1 was 43.5kWh, representing 15878Wh per year which matches the value consumed in table 23. The deferrable load daily average input to HOMER as in section 7.2 was 48.2kWh, representing 17580kWh per year which matches the value in table 23. Looking at the yearly values, the loads are being met however more in-depth analysis should be carried out to inspect the daily operation of the system.

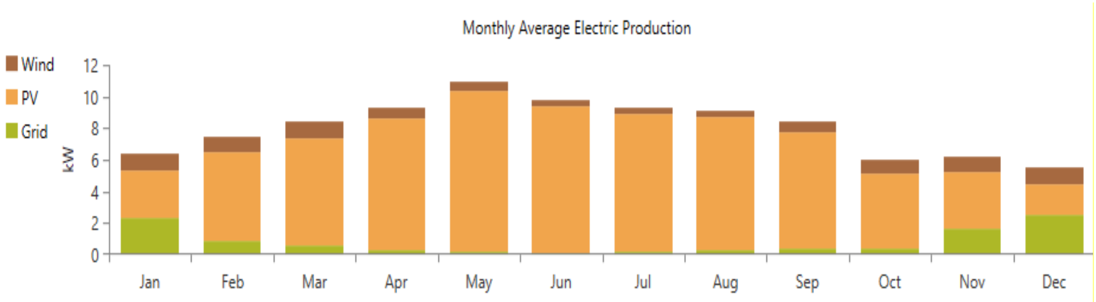


Figure 31-Electrical Production

The operation of the system should be analsyed both in winter and summer for all extreme conditions of wind speed in m/s and solar power incident in kW/m^2. The two extreme conditions for the PV Panels would come when the conditions were sunny to provide maximum output and cloudy to produce minimum, similarly the max output from the wind turbine would come in high speed windy conditions and minimum coming in low wind speed calm conditions. The dates selected to match each criteria are shown in table 24. Daily averages and max values were taken from the hourly data on HOMER. The variation in solar energy can be seen to be higher between sunny and cloudy days than the variation in wind speed between calm and windy days.

Table 24- Extreme weather conditions summary

Summer					
		Solar		Wind	
		Average	Max	Average	Max
Sunny and Windy	July 19th	0.1875	0.9581	7.73	14.6
Sunny and Calm	July 9th	0.348	1.08	4.337	9.22
Cloudy and Windy	June 25th	0.030	0.119	8.14	11.3
Cloudy and Calm	June 26th	0.057	0.181	4.005	8.01

Winter					
Sunny and Windy	Jan 26th	0.1778	0.99	8.02	16.9
Sunny and Calm	Nov 24th	0.169	1.01	5.95	11.4
Cloudy and Windy	Dec 24th	0.006	0.03	6.81	16.8
Cloudy and Calm	Jan 5th	0.007	0.09	5.56	10.4

7.4.1. Summer operation

The effect of the different conditions in each of the 4 summer days shown in table 24 should be analysed using the data from HOMER. Determining what effect the changes in wind speed and solar energy have on the system.

The operation of the system should be analysed for conditions in summer when the PV output is high for both high and low wind speeds. From HOMER data, the day representing high solar power and high wind turbine output was 19th July with plots for the operation of the system in figure 32, 34 and 36. In figure 32, the output of the PV Panel can be seen to be significantly larger than the wind turbine output and has a peak in the daylight hours, while the wind turbine output is spread across the day. The day selected to represent high PV output and low wind turbine output was July 9th, with plots for the characteristics of the operation in figure 33,35 and 37. The wind turbine output in figure 33 is smaller than in figure 31, however both high and low wind turbine outputs are small in comparison to the PV output.

The AC primary load, representing the domestic and auxiliary electricity, is shown to be met in figure 34 and 35 following the expected residential profile. The operation of the storage tank is clearly shown; the storage tank level will increase towards full capacity when the deferred load is applied, with the storage tank level for both of these conditions remaining full for a large portion of the day. The grid sales and grid purchases can be seen in figure 36 and 37, it can be seen that a small amount of grid purchases are required to meet the load between 7pm and 11pm due to the decreased output of the PV panel. The grid sales for these conditions are large and follow the same profile as the PV Panel power output on that day. It can be concluded the wind turbine output has a negligible effect on the operation of the system when the PV output is high.

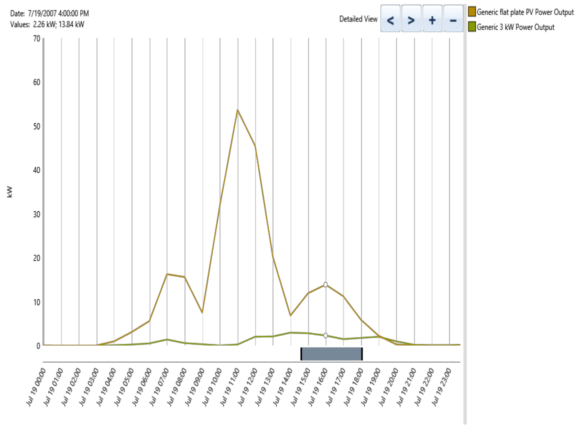


Figure 32- PV and wind output for sunny and windy summer day

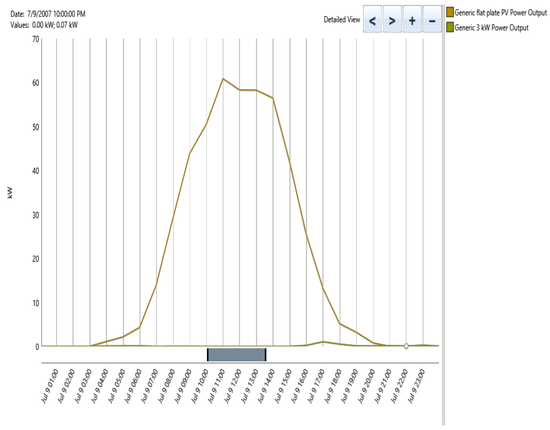


Figure 33- PV and wind output for sunny and calm summer day

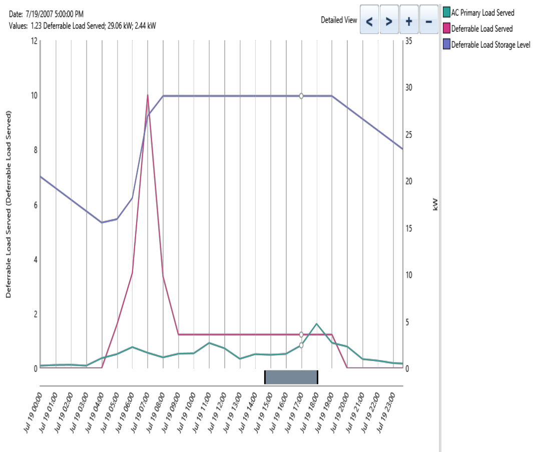


Figure 34- AC primary load, deferrable load and storage tank level for sunny and windy summer day

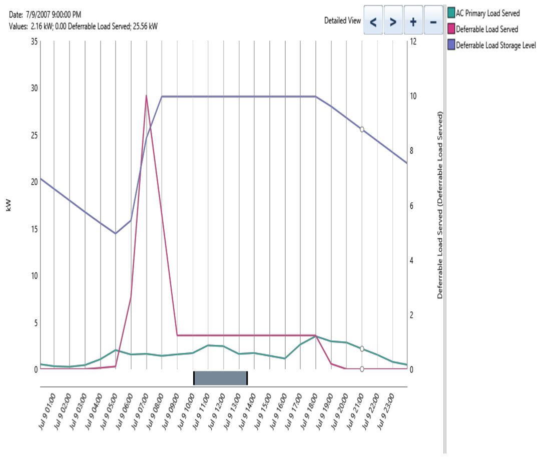


Figure 35- AC primary load, deferrable load and storage tank level for sunny and calm summer day

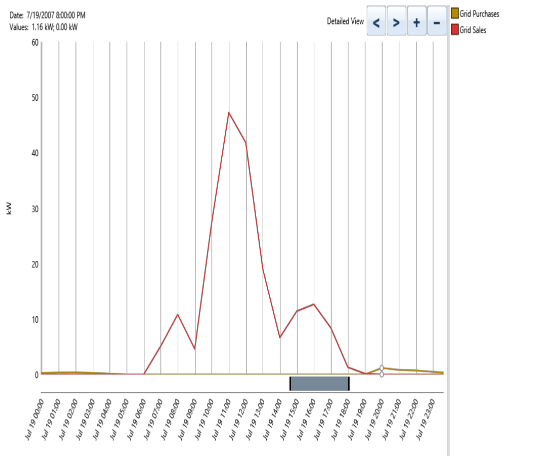


Figure 36- Grid sales and grid purchases for sunny and windy summer day

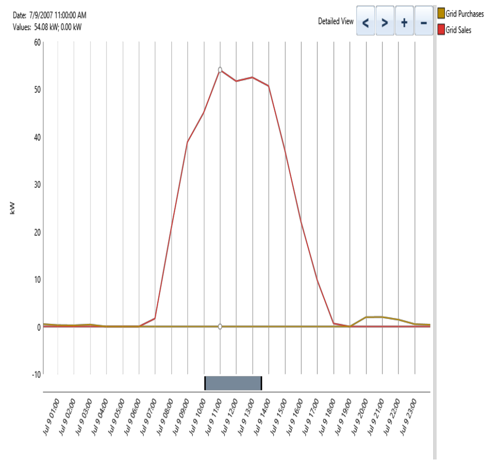


Figure 37- Grid sales and grid purchases for sunny and calm summer day

A day in summer with low PV output should be considered for both high wind speed and low wind speed. A cloudy day, therefore low PV output, with high wind speeds was selected as June 25th with the system operation shown in figures 38,40 and 42. In figure 38, the wind turbine output can be seen to still be smaller than the PV output however will be a significantly larger portion of the energy produced than when the PV output was high for the previous conditions. A day with small amounts of output from both PV and wind systems should also be analysed in summer, with a day selected as June 26th from HOMER data. The operation of this day can be seen in figure 39,41 and 43 with the small output of both systems can be seen in figure 39. The effect of the wind turbine output on the operation of the system in this condition can be seen to be minimal with systems with high and low wind turbine output operating very similarly.

In both systems, the AC primary load is met, and the deferred load is effectively used as the storage tank level remains at a high level throughout the day, however the storage tank level can be seen to be at lower than full capacity for a longer time than on the sunny days analysed previously. Grid purchases are required to meet the load later in the day, with an additional amount of grid purchases required throughout the day for days with low wind speeds as in figure 43. There are no grid sales on either of these days of operation, highlighting that the grid sales arise from high PV output as in figure 36 and 37.

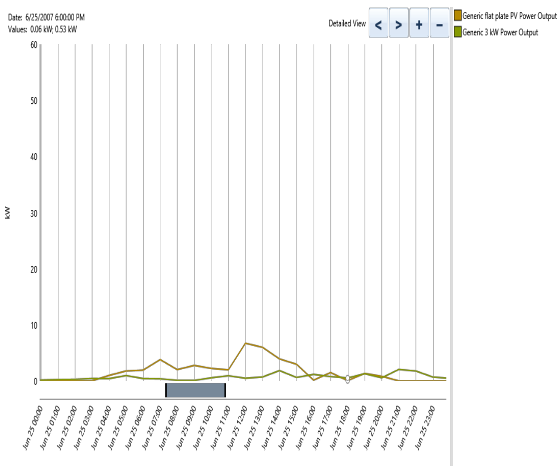


Figure 38 PV and wind output for cloudy and windy summer day

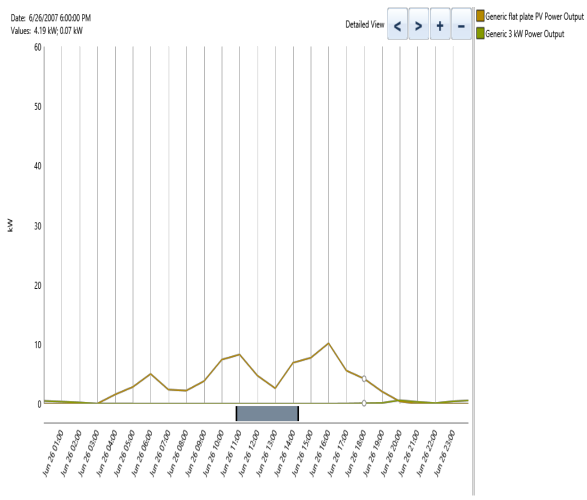


Figure 39- PV and wind output for cloudy and calm summer day

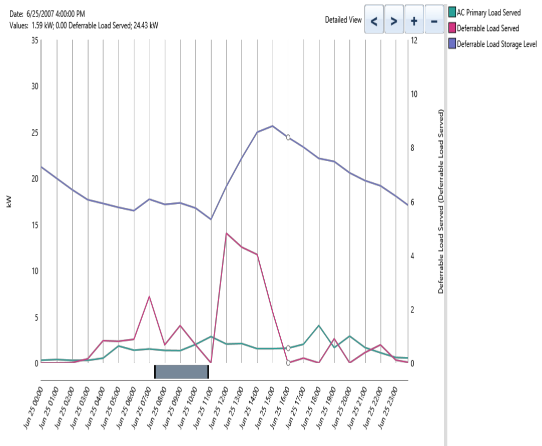


Figure 40- AC primary load, deferrable load and storage tank level for cloudy and windy summer day

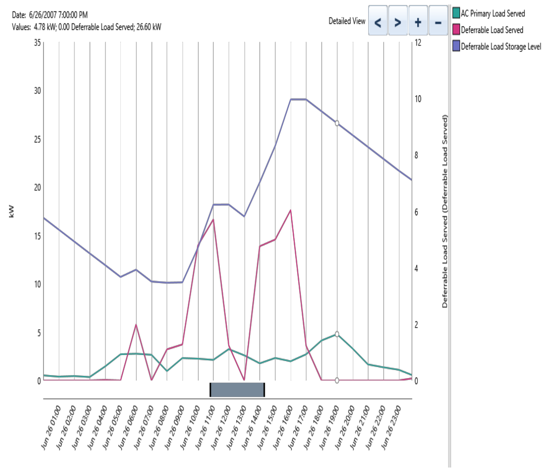


Figure 41- AC primary load, deferrable load and storage tank level for cloudy and calm summer day

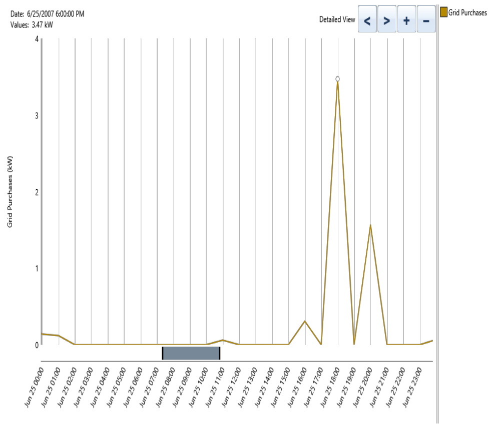


Figure 42- Grid purchases for sunny and calm summer day

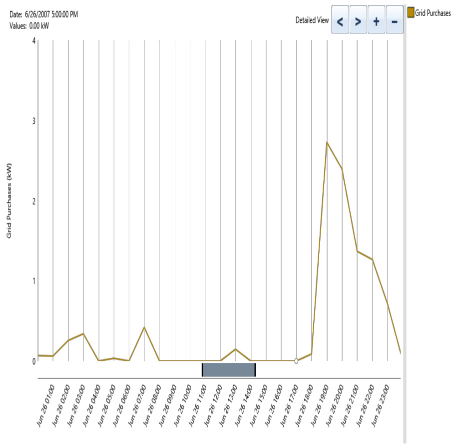


Figure 43- Grid purchases for cloudy and calm summer day

The operation of the system in summer is confirmed to be correct as the AC primary load is met for all condtiions, and the storage tank level remains greater than 0, meaning that the hot water and space heating demands are able to met. The plots for each system exhibit how the PV output has a large impact on the system during summer, being the main contributor to produce grid sales. As the PV output is concentrated between 6am to 8pm, grid purchases are required for all conditions in the evening once the PV output has decreased, and for days of low PV output small amounts of additional grid purchases are required throughout the day to meet the full demand.

7.4.2. Winter Operation

The system should be analysed in winter, where the AC primary load remains the same however the deferrable load is increased due to larger space heating demand. The operation should be inspected using HOMER data for the same four conditions as summer.

As in summer, from HOMER data a day with solar power in winter should be anslysed for both high and low wind speeds. A day with high PV output and high wind speed represnting high wind turbine outout was January 26th, the operation of the system on this day can be seen in figure 44,46 and 48. A day should also be analysed with high PV output and low wind turbine output. This was selected as November 24th from HOMER data with operation of the system seen in figure 45, 47 and 49. Both systems can be seen to act in the same manner due to the wind turbine output being signifacently smaller than the PV output.

The grid sales are large and follow the same profile as the PV output on the given day, however large grid purchases of maximum value 10kW are required to supply the deferrable load between midnight and 9am. The renewable energy sources are not producing enough energy in this time to prevent the storage tank becoming empty, thereore further energy must be purchased to supply the tank while continueing to meet the AC primary load. The storage tank reaches full capacity once again at 1pm due to the increase in PV output and once the PV output decreases again at 3pm the storage tank level begins to fall. It can be seen that the increase in demand in winter causes a larger amount of grid purchaes to be made at times of low PV output to meet the demand, however a large surplus of energy is still being produced during daylight hours resulting in high levels of grid sales being maintained.

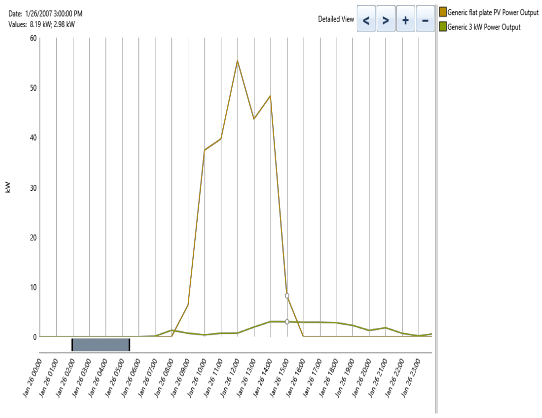


Figure 44- PV and wind output for sunny and windy winter day

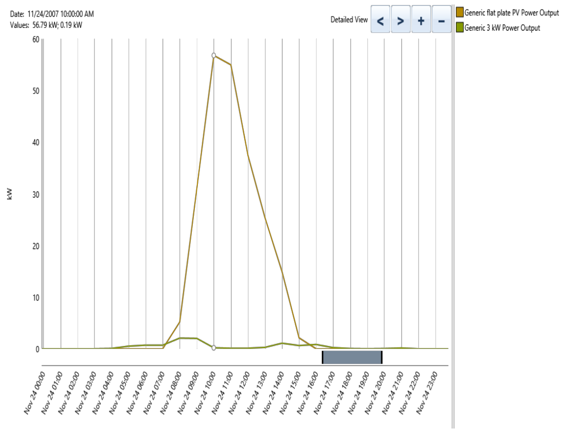


Figure 45- PV and wind output for sunny and calm winter day

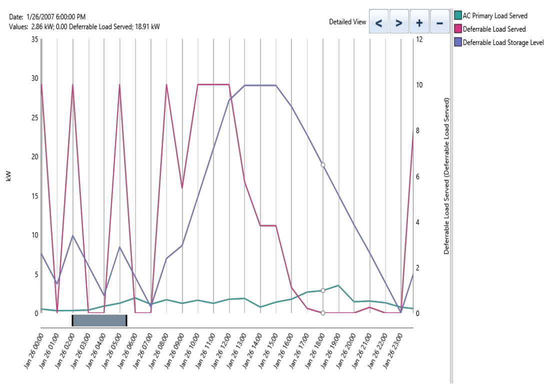


Figure 46- AC primary load, deferrable load and storage tank level for sunny and windy winter day

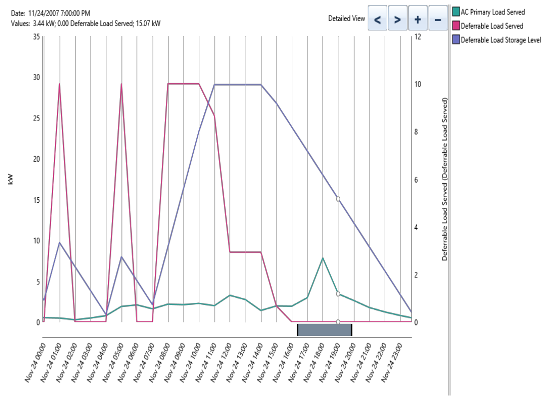


Figure 47- AC primary load, deferrable load and storage tank level for sunny and calm winter day

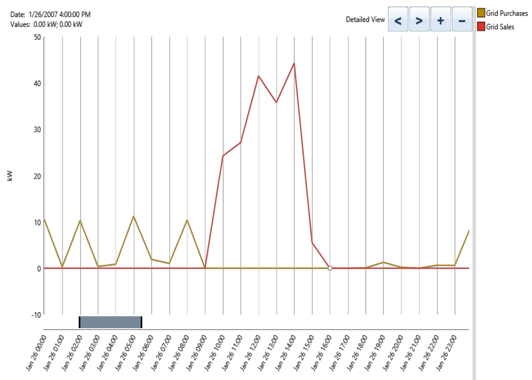


Figure 48- Grid purchases and grid sales for sunny and windy summer day

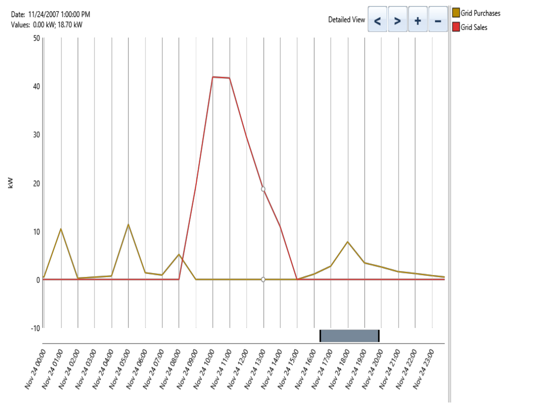


Figure 49- Grid purchases and grid sales for sunny and calm winter day

Winter operation should be anslysed when the PV output is low for both high and low wind speeds. From HOMER data, a winter day when the PV output is low but wind turbine output is high was December 24^{th}. The operation of this system can be seen in figure 50, 52 and 54. The wind turbine output can be seen to larger than the PV output at peak in figure 50. A condition should be analysed in winter when there are low winds and also low solar, representing the least favourable condition for the system for renewable output. January 5^{th} was selected using HOMER data to represent this and system characteristics on this day can be seen in figure 51, 53 and 55.

The maximum deferrable load of 10kW is required frequently for both systems. This deferrable load is purchased from the grid due to lack of availability of renewable sources and can be seen to effectiveluy prevent the storage level becoming 0. There are no grid sales due to small output of the PV and the storage tank never reaches full capacity due to the limited amount of renewable energy available. This system has high reliance on grid pruchses throughout the day to meet both the deferrable load demandsl, by maintaining the storage tank level above 0, and also the AC primary load.

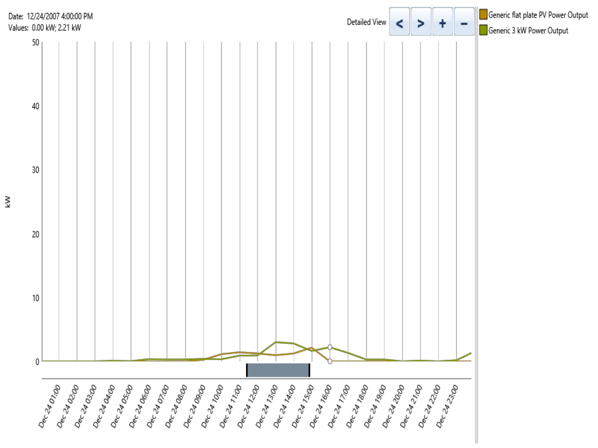


Figure 50-PV and wind output for cloudy and windy winter day

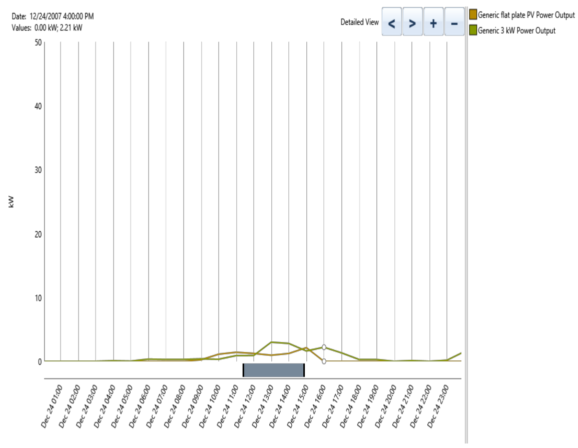


Figure 51-PV and wind output for cloudy and calm winter day

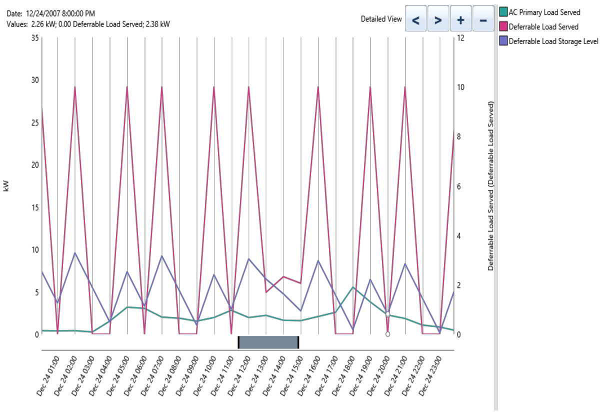


Figure 52- AC primary load, deferrable load and storage tank level for sunny and calm winter day

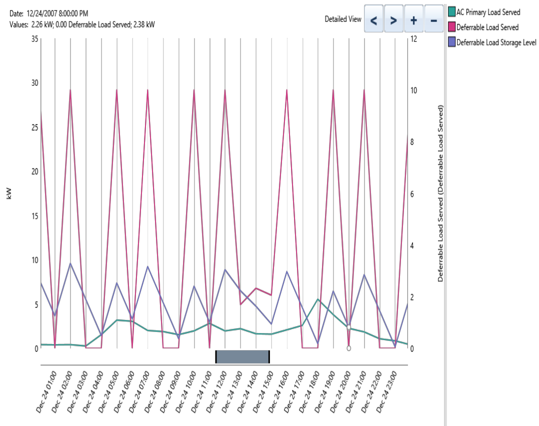


Figure 53- AC primary load, deferrable load and storage tank level for cloudy and calm winter day

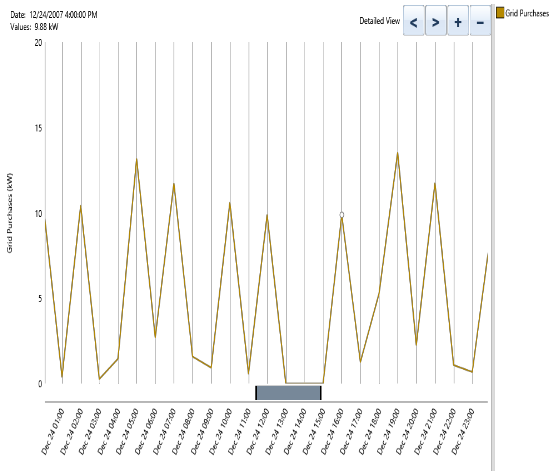


Figure 54- Grid purchases and grid sales for sunny and calm winter day

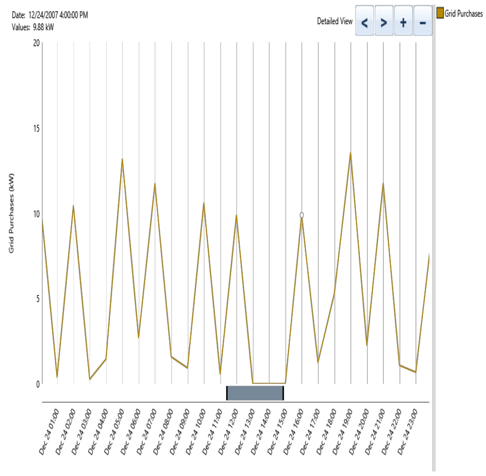


Figure 55- Grid purchases and grid sales for cloudy and calm winter day

The system can be seen to operate correctly in winter as the AC primary load is met for all conditions and the storage level prevented from becoming zero. However, a large amount of grid purchases are required to do this in comparison to summer operation. The grid sales can be seen to once again be dependent on the PV output, being high and following the same profile as the PV output on sunny days and being 0 on cloudy days.

The operation of the system can be seen for all conditions in summer and winter to be largely dependent on the PV output, with the wind turbine output having negligible effects. However, when analysing a system with the same number of PV panels and no wind turbine from the full HOMER data in Appendix B, the renewable fraction can be seen to fall from 65.57% to 53.41%, showing that despite the overall operation of the system not being largely affected by the inclusion of the 3kW wind turbine, the wind turbine plays a significant part in ensuring the loads in the system for electricity and heating are met from renewable sources.

8. Discussion

This paper is a scoping study for the regeneration of Mamores lodge, covering the main areas of the fabric retrofit of the building along with energy supply system. Assumptions and simplifications in the project have been made due to limitations in time and resources available. These should be acknowledged and further work to be considered as part of a more detailed study suggested.

The sustainability of the project should be analysed. The energy demands of the building for space heating have been minimised through use of construction components with low U values in line with recommended values in Passive House, meaning that the energy required to supply the building will be smaller, and therefore a positive effect on the environment through reduced C02 emissions and other damaging effects that energy production causes. Renewable energy sources have been used to supply this heating demand as well as domestic and auxiliary electricity and hot water demand, which produce energy in a clean manner furthermore benefitting the environment. The production of electricity from renewable sources was added to the PHPP data which provided a primary energy value of $53kWh/m^2a$, which when compared to the Passive House standard criteria of less than $60kWh/m^2a$, it can be stated that the building meets Passive House accreditation as the space heating criteria is also met as in section 6.1.1. The social impact of the construction would be positive for the local community, with job opportunities at construction stage as well once the lodge is in operation, combined with an increase in tourism that the lodge should aim to bring to the local area should benefit the local economy. The use of local Scottish timber will of mean that forest areas in the Scottish Highlands will be damaged however this is a plentiful commodity therefore with the associated benefits of using this material, it was decided as the best option. Other materials required should be sourced locally where possible to ensure that the carbon footprint of the project remains as low as possible with large scale transportation of materials having a negative effect on the environment. Proposal to install electrical vehicle chargers and e bike chargers has been taken into account for the modelling of the new lodge which should promote and encourage green transportation in the area.

The fabric retrofit of the building included proposed construction components to be used for the building envelope comprising of the walls, floor and roof. The U Value of these components were confirmed using the thermal conductivities of the materials and thickness, this allowed the transmission losses in the building to be modelled using PHPP. In addition, the parts of the construction requiring special care were pinpointed such as penetrations and junctions between walls and roof. Further work could be carried out on these particular sections, with specific construction details to minimise losses and thermal bridges at windows and doors being highlighted. More detailed analysis of the ventilation system could be carried out as part of a further study once a full interior plan of the building has been created. The areas which the used air would be removed from such as toilets should be determined along with the locations where the supply air should enter the home. The construction method was explained to use MAKAR construction as a model in the Scottish Highlands, who carry out off site timber frame homes, this could be furthered by enquiring with MAKAR whether this project would be of interest or carrying out a study to determine whether there would be capacity to use a similar model in the village of Kinlochleven.

The electrical demands of the lodge were modelled based on the 4 categories of loads which were space heating, domestic hot water, domestic electricity and auxiliary electricity. These loads were based on an occupancy of 30 people including staff and guests and assumed operation of the lodge all year round with the values in each individual month to be the same. This provided values to be used to model the supply system, however a more detailed study should model various loads including a difference in occupancy figure's which will change the values of domestic electricity and domestic hot water demands. With the location of the lodge in Scottish Highlands, it is likely that the lodge will only operate at full capacity for the summer months, the electrical load could be extended to take this into account, modelling the reduced demand in winter. Other factors to be considered to establish a more reliable demand would be to model the demand over multiple climate years and to build a specific daily load profile for the operation of the lodge rather than using the standard daily residential load profile in figure 28.

The space heating and domestic hot water heating demand was designed to be met with air source heat pump systems. The seasonal performance factor, calculated using equation 4, of an air source heat pump can be said to be lower than that of a water source heat pump as shown in table 25 with values taken from PHPP. The area around Mamores Lodge should be examined to determine whether a stream or water source is present allowing a water source heat pump to be used, therefore improving the efficiency of the conversion system and reducing the electrical energy required for the same heating demand.

Table 25- Heat pump Seasonal Performance factor

	Space Heating SPF	Domestic Hot Water SPF
Air source	1.73	1.86
Water Source	3.25	2.99

The Kinlochleven hydroelectric plant is located close to the village of Kinlochleven and provides electricity for the aluminium smelter in Fort William. The possibility of receiving a direct supply from this plant could be explored further, with the cost of this to be compared to the local renewable system proposed using PV Panels and wind turbine.

In reality, the hot water and space heating system would have separate storage tanks. As HOMER software only allowed one deferrable load to be added, these loads were combined with an average seasonal performance factor between the two values used. This means that the system simulated was not able to distinguish between heating demand for hot water or space heating. Further analysis on these systems should consider using exhaust air which is at higher temperature than outside air as input back into the storage tank therefore reducing the energy required for heating.

The system proposed contains 70 1kW PV Panels and 1 3kW wind turbine in combination with grid purchases to cover the demands. This system operates correctly to meet the full demand as shown in section 7.4. Using a system with lower production from the PV panels could be explored to reduce capital cost. Reducing the number of PV panels moderately, will reduce the capital cost of the renewable energy system while not having a significant impact on the renewable fraction as seen in figure 56. The renewable fraction can be seen to follow a $-x^2$ relationship, with high correlation shown by an r squared value 0.9485, meaning as the number of PV panels increases the rate at which the renewable fraction increases will slow. This is due to the fact that a large portion of the extra renewables created is simply sold onto the grid and does not get directly used for energy consumption in the building. The possibility of using a more financially efficient system with a lower number of PV's while still meeting full energy demands of the lodge should be explored at a further stage as part of a full cost analysis.

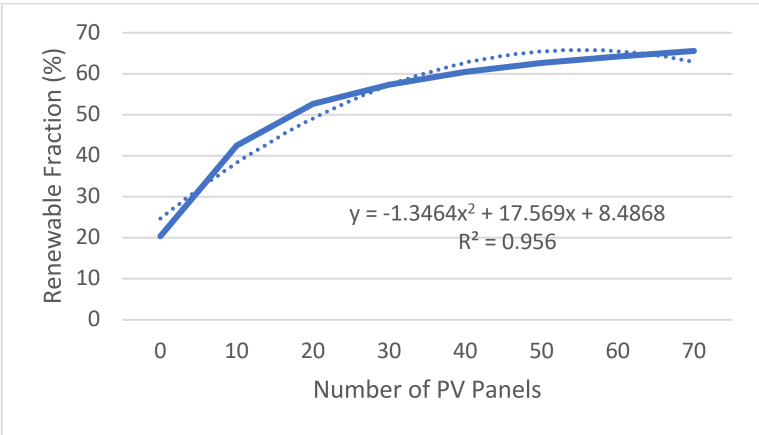


Figure 56- Renewable fraction/Number of PV Panels

Throughout the course of the project, communication has been carried out with the estates company, Jahama, with the floor plans of the existing building being gathered. Communication have also been carried out with the Kinlochleven Community Trust throughout the project and the local opinion on the redevelopment of the lodge was gathered through a survey with an indicative example of what the lodge will look like shown alongside the survey as in figure 57. The responses can be seen in Appendix C. It can be concluded that the responses are mainly negative towards the idea of the aesthetics of the lodge changing, with the local community a focus in this project, this should be taken into account and solutions suggested to allow the lodge to maintain the aesthetics of the current building.

Figure 57- Indicative image as part of survey

The first option considered would be to use a white rendered finish to the building. This would not change any of the energy modelling carried out on the building while would mean the building would appear more similar to the current building from a distance. This solution will require minimal changes from the design in this project, with the colour of the outer layer being made white as in figure 58 where the PV Panels have been added to the roof, however the appearance of the lodge when close will still be very different from the current building.

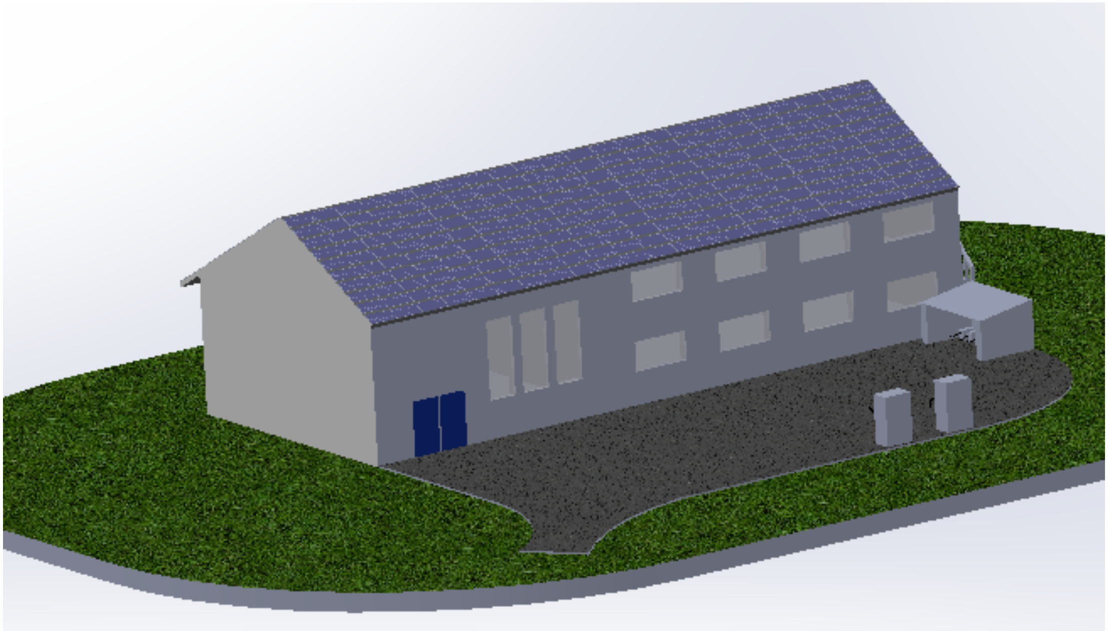


Figure 58- Lodge with white facade

Another option would be to use the original façade of the building as a “rainscreen” while the interior would be completely demolished and replaced with the building components designed in this project. This would mean that the building would appear the same as currently while energy modelling carried out would still be valid. This method will have associated issues such as issues with the structural integrity of the existing construction and methods used to completely demolish the interior of the building without impacting the exterior.

These options should be considered in conjunction with the Kinlochleven Community Trust to determine a suitable solution from a construction point of view but also one that the local community will be in support of.

9. Conclusion

In conclusion, the fundamentals of sustainable buildings have been outlined with standards and measurement systems of Passive House and BREEAM providing assessment of environmental impact while social impact should also be considered. The key construction principles of thermal insulation, airtightness, thermal bridging, ventilation and solar gain have been pinpointed and summarised. The existing building has been modelled to show the energy inefficiency in comparison to Passive House Standard and a recommendation has been made to demolish the existing building and construct a new building on the new site due to difficulties in improving the efficiency of the existing building. A fabric retrofit of the new construction has been proposed providing example wall, floor and roof components to meet recommendations by Passive House while utilising Scottish timber panels in the model of MAKAR. The electrical load of the building was modelled using an occupancy of 30 people and additional elements of electrical vehicle chargers and e-bike chargers included in this load. The heating load for space heating and domestic hot water was to be met using an air source heat pump with the electrical energy this system will require modelled. The renewable energy system to meet this full electrical demand was modelled with the space heating and domestic hot water demand taken as a deferrable load. The system proposed, to produce a maximum amount of energy consumption from renewable sources, contained 70 1kW PV Panels, and a 3kW wind turbine combined with grid purchases to meet the demand. The operation of this system under different weather conditions influencing the output of the renewable systems was analysed to confirm the loads are effectively met and determine the effect that the changes in weather will have on important characteristics such as grid purchases and grid sales. Assumptions and limitations involved in the project have been acknowledged and further work suggested to improve the detail of the study.

This project has shown how the site at Mamores Lodge can be effectively brought back into operation, constructing a building and supply system which meets relevant sustainability standards, having a minimised negative impact on the environment while providing impactful benefits to the local community and region.

10. Bibliography

[1] United Nations, “Report of the World Commission on Environment and Development: Our Common Future",” 1987.

[2] United Nations, “The Sustainable Development Goals 2018,” 2018.

[3] European Commission, “Buildings,” 2018.

[4] “The Passive House Institute,” 2019. [Online]. Available: https://passivehouse.com. [Accessed October 2018].

[5] T.Saunders, “A discussion document comparing international assessment methods for buildings,” 2008.

[6] J. Brian, “The Social Side of Sustainability,” Not determined.

[7] Passive House Institute, “Passipedia- The Passive House Resource,” 2019. [Online]. Available: https://www.passipedia.org. [Accessed February 2019].

[8] L. ALter, “Everything I ever knew or said about green sustainable design was probably wrong,” 2015.

[9] Liberty Capital, “GFG Alliance companies complete £330m Scottish acquisition and unveil major new investment plans for the highlands,” 2016.

[10] “Kinlochleven Community Trust,” 2019. [Online]. Available: https://www.kinlochleven.co.uk. [Accessed October 2018].

[11] The Scotsman, “Electric village entering the ice age,” 2003.

[12] Visit Fort William, “Kinlochleven,” 2019. [Online]. Available: https://visitfortwilliam.co.uk/visit-glencoe-and-kinlochleven/visit-kinlochleven-on-the-west-highland-way. [Accessed November 2018].

[13] J. E. O. Gemmill, 2018.

[14] “R Value for natural stone,” 2019. [Online]. Available: https://www.naturalstoneinstitute.org/stoneprofessionals/technical-bulletins/rvalue/. [Accessed March 2019].

[15] Energy Efficiency Best Practice in Housing, “Scotland: Assessing U-Values of existing housing,” 2004.

[16] Passive House Institute, “Passive House Planning Package- The Energy Balance Design tool for efficient buildings and retofits,” 2015, pp. 60-61.

[17] MAKAR, “Timber Innovation,” 2019. [Online]. Available: http://makar.co.uk/what-we-do/timber-innovation. [Accessed March 2019].

[18] Austrian Institute for Healthy Ecological Buildings, “IBO BOOK - Details for Passive Houses- A catalogue for ecologically rated constructions,” 2009, p. 46.

[19] B. Anderson, “Conventions for U-value calculations,” BRE Scotland, 2006, p. 5.

[20] Austrian Institute for Healthy Ecological Buildings, “IBO BOOK - Details for Passive Houses- A catalogue for ecologically rated constructions,” p. 76.

[21] Austrian Institute for Healthy Ecological Buildings, “IBO BOOK - Details for Passive Houses- A catalogue for ecologically rated constructions,” 2009, p. 108.

[22] A. I. f. H. E. Buildings, “IBO BOOK - Details for Passive Houses- A catalogue for ecologically rated constructions,” 2009, p. 180.

[23] The Passive House Institute, “Passipedia- Windows,” 2019. [Online]. Available: https://passipedia.org/planning/thermal_protection/windows.

[24] Austrain Institute for Healthy Ecological Buildings, “IBO BOOK - Details for Passive Houses- A catalogue for ecologically rated constructions,” 2009, p. 28.

[25] Austrian Institute of Healthy Ecological Buildings, “IBO BOOK - Details for Passive Houses- A catalogue for ecologically rated constructions,” 2009, p. 29.

[26] ea car club, “How long will it take to charge the car?,” 2019. [Online]. Available: https://ecarclub.co.uk/help-article/long-will-take-charge-car/. [Accessed March 2019].

[27] e-bikeshop, “Electric bike charging times,” 2017. [Online]. Available: https://www.e-bikeshop.co.uk/blog/post/electric-bike-charging-times-bosch-yamaha-shimano-ebikes/. [Accessed March 2019].

[28] HOMER, “Residential Load Profile,” 2019.

[29] HOMER Energy, 2019.

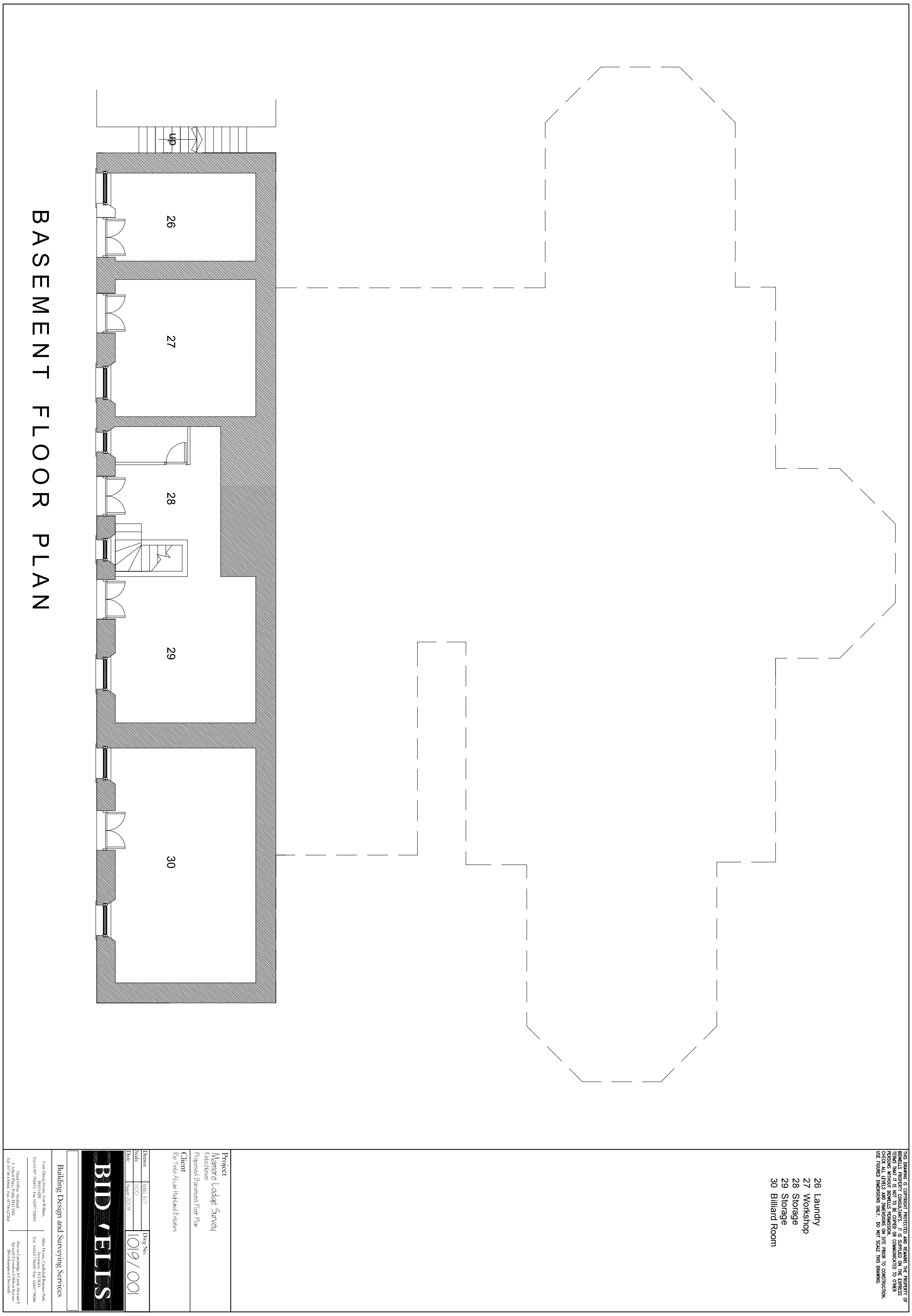
[30] HOMER Energy, “Deferrable Load,” 2019. [Online]. Available: https://www.homerenergy.com/products/pro/docs/3.10/deferrable_load.html.

[31] The eco experts, “1kW Solar Panel System,” [Online]. Available: https://www.theecoexperts.co.uk/solar-panels/1kw-pv-systems.

[32] HOMER Energy, “Schematic,” 2009.

[8]

Appendix A



BASEMENT FLOOR PLAN
up
26
27
28
29
30
26 Laundry
27 Workshop
28 Storage
29 Storage
30 Billiard Room
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Project
Mamore Lodge Survey
Kinlochleven
Proposed Basement Floor Plan
Client
Rio Tinto Alcan Highland Estates
Drawn MMG, ECT
Scale 1:100
Date August 2009
Dwg No. 1019/001
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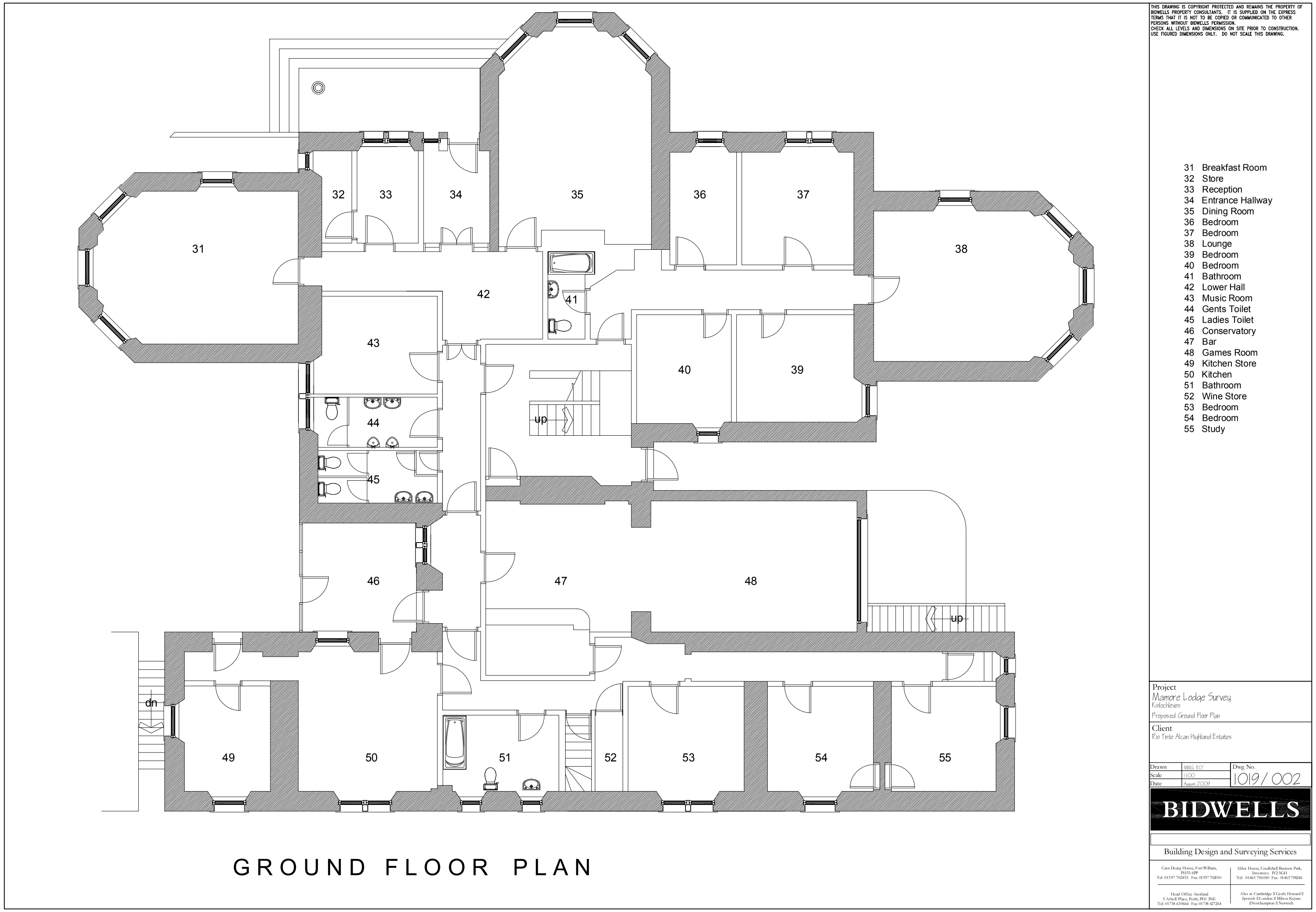
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GROUND FLOOR PLAN
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CHECK ALL LEVELS AND DIMENSIONS ON SITE PRIOR TO CONSTRUCTION. USE FIGURED DIMENSIONS ONLY. DO NOT SCALE THIS DRAWING.
31 Breakfast Room
32 Store
33 Reception
34 Entrance Hallway
35 Dining Room
36 Bedroom
37 Bedroom
38 Lounge
39 Bedroom
40 Bedroom
41 Bathroom
42 Lower Hall
43 Music Room
44 Gents Toilet
45 Ladies Toilet
46 Conservatory
47 Bar
48 Games Room
49 Kitchen Store
50 Kitchen
51 Bathroom
52 Wine Store
53 Bedroom
54 Bedroom
55 Study
Project
Mamore Lodge Survey
Kinlochleven
Proposed Ground Floor Plan
Client
Rio Tinto Alcan Highland Estates
Drawn MMG, ECT
Scale 1:100
Date August 2009
Dwg No.
1019/ 002
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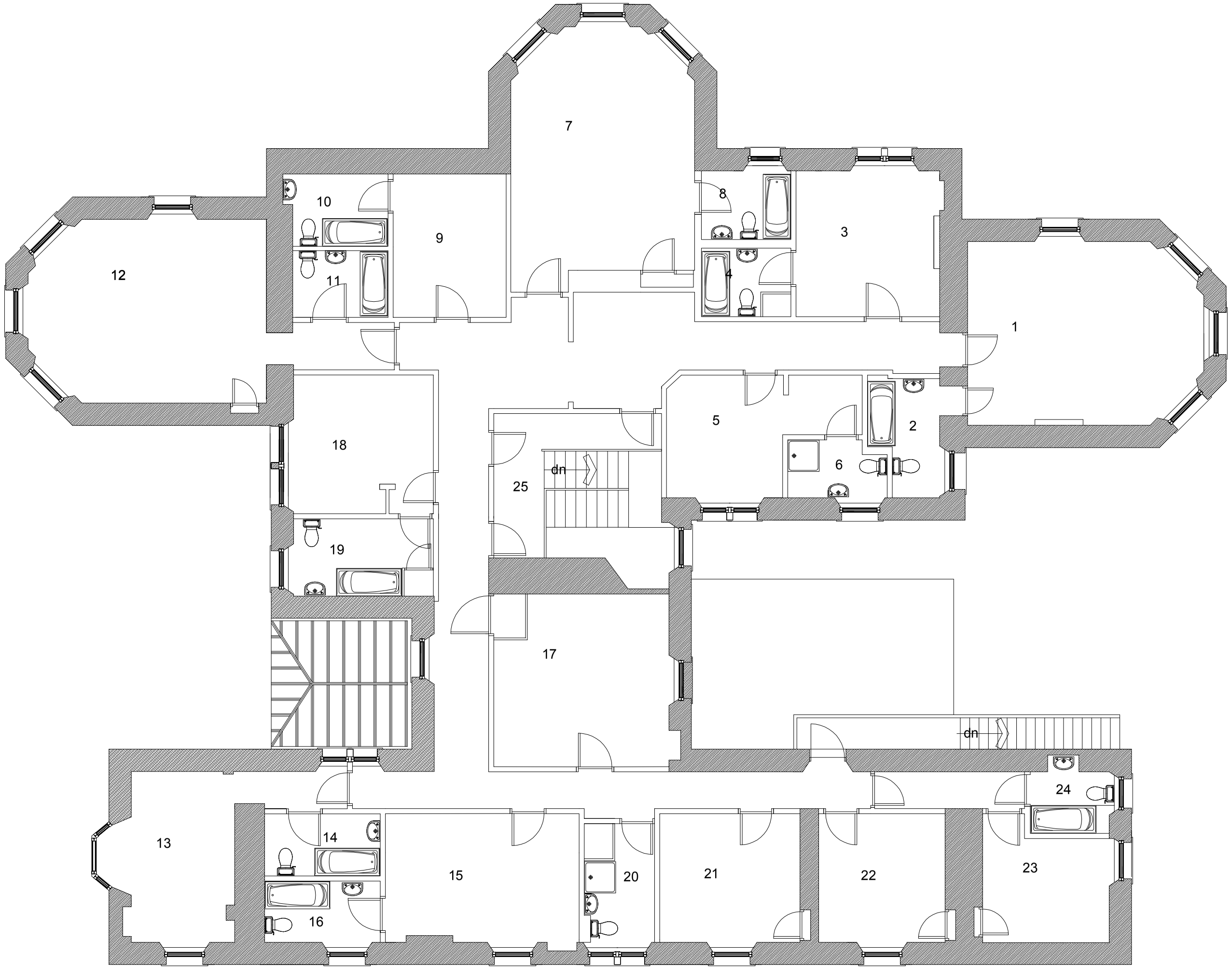

FIRST FLOOR PLAN

1 Bedroom
2 En-suite
3 Bedroom
4 En-suite
5 Bedroom
6 En-suite
7 Bedroom
8 En-suite
9 Bedroom
10 En-suite
11 En-suite
12 Bedroom
13 Bedroom
14 En-suite
15 Bedroom
16 En-suite
17 Bedroom
18 Bedroom
19 En-suite
20 Shower Room
21 Bedroom
22 Bedroom
23Bedroom
24 En-suite
25 Stairs

Project
Mamore Lodge Survey
Kinlochleven
Proposed First Floor Plan

Client
Rio Tinto Alcan Highland Estates

Drawn	MMG, ECT	Dwg No.
Scale	1:100	1019/ 003
Date	August 2009	

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Appendix B

	PV?	Wind?	Converter (kW)	Production from PV (kWh)	Production from Wind (kWh)	Grid purchases (kWh)	Grid Sales (kWh)	Renewable Fraction (%)	Capital Cost (£)	Operating Cost (£)
1	0	0	0	0	0	33458	0	0	0	3345.75
2	10	0	10	8133	0	25777	51.1	22.9	33000	2755.03
3	20	0	20	16265	0	21266	3259	36.44	66000	2323.55
4	30	0	30	24398	0	19180	8907	42.66	99000	2012.45
5	40	0	40	32530	0	17886	15335	46.54	132000	1741.61
6	50	0	50	40663	0	16908	22087	49.45	165000	1486.05
7	60	0	60	48795	0	16190	29089	51.61	198000	1244.07
8	70	0	70	56928	0	15587	36213	53.41	231000	1008.00
9	0	1	0	0	6812	26646	0	20.4	18000	2844.64
10	10	1	10	8133	6812	19250	338	42.45	51000	2268.00
11	20	1	20	16265	6812	15833	4638	52.68	84000	1891.25
12	30	1	30	24398	6812	14265	10796	57.37	117000	1606.49
13	40	1	40	32530	6812	13242	17508	60.41	150000	1348.53
14	50	1	50	40663	6812	12518	24509	62.58	183000	1106.00
15	60	1	60	48795	6812	11964	31678	64.24	216000	872.09
16	70	1	70	56928	6812	11518	38955	65.57	249000	643.53

Appendix C

MAMORE LODGE CONVERSION – OPINIONS

- Why change an iconic building into something so no (sic) descript as this. Would suggest keeping the front of the building intact.

- Wouldn't like any change to the outside of the building – it's always been a part of Kinlochleven.

- The lodge is an iconic building within the village. I wouldn't like to see any changes to the outside of the building but would be open to changes inside.

- I would like the building to 'be kept' and renovated.

- I could see that type of building fitting into where the old lodges where, but Mamore Lodge is an iconic building and should be renovated keeping the existing white fascia.

- The building proposed looks lovely but it is a shame to lose the current white one. It is part of the scenery – why not keep the old one and put the new one at the back instead of the annexe falling into pieces.

- I would like to see the original stonework maintained, suggest an eco-friendly wooden frame structure behind it. This would not alter the look of the building, but would offer a more stable building for future use.