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Investigation of Summer Overheating of the Passive House Design in the Scottish Climate

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MSc Renewable Energy Systems and the Environment

Copyright Declaration

Acknowledgements

I would to thank Paul Tuohy for his support and advice as my supervisor for this project, his knowledge of Passive House standard and his experience with building simulation proved to be an invaluable resource throughout this project.

Special thanks must of course go to my family, without whom I would have been unable to study for this degree. My gratitude for their support and encouragement for this past year cannot be put into words.

Abstract

The Passive House Standard was developed in 1991 in Germany and has since become an accepted standard for energy efficient buildings in a number of countries in Europe. The standard is now beginning to be implemented in the United Kingdom though only 8 examples have been currently certified and only one of these within Scotland, located on the West coast in the town of Dunoon.

This project investigates the performance of the Passive House standard in the Scottish climate during the summer months of June, July and August. The research focused upon the incidences of overheating during this time period and its effects on the thermal comfort levels of the buildings occupants.

Using monitored data from the Dunoon Passive House to provide a performance guide, a building simulation model was created with ESP-r. This model was then used with climate data from three select sites throughout Scotland, and results compared to the predicted overheating from the Passive House Planning Package (PHPP) provided by the Passive House Institute.

The ESP-r model predicted a greater incidence of overheating than PHPP, though overall results did not broach the accepted maximum of a 10% occurrence of temperatures over 25°C. This however could only be obtained through occupant intervention through the opening of windows to regulate the internal temperature, despite the use of a mechanical ventilation system. The results also highlighted the differing levels of personal thermal comfort and that a building that meets the PHPP standard, may result in greater levels of personal thermal discomfort if an individual's upper limit of comfort was at a temperature lower than that of 25°C.

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1. Introduction

The Passive House design standard was first introduced in 1991 (1) in Germany and has since spread and been utilised in a number of European countries and also in North America, thanks no doubt to the Passivhaus Institut encouraging the standard through a thorough certification process. This design standard is now slowly being introduced into building designs in the UK, though at this moment in time there are only 8 certified Passive House designed buildings with only one of these being in Scotland (2). Within the EU the standard was encouraged through the CEPHEUS project (3) which involved the construction and scientific evaluation of some 220 homes built to Passive House standard in five countries; Austria, France, Germany, Switzerland and Sweden. This project proved the concept of the standard by in-use measurement of these buildings performance through the winter of 2000 – 01 and proved to be a spur of the commercial development in Austria, Germany and Switzerland of the technologies associated with the Passive House standard.

This standard is new to Scotland, and as such the real world performance of such a building in our climate is still a relative unknown. As the design calls for maximum use of available heat gains, windows are designed with a view to making the most of solar gains to assist in maintaining the ambient air temperature within the building and assuring the comfort levels of the occupants. The Passive House Planning Package (PHPP) (4) takes into account regional climate data to predict the buildings performance with regards to maintaining this internal temperature. This assists the designer in ensuring that overheating of the building during the summer months, where there are longer periods of solar gains, does not occur. The data used by the package only gives a single average temperature and overall sunshine hours for each month, leading to a very general impression of how the building will respond in a given climate.

The Scottish climate, whilst not renowned for its sunny nature, does have spikes of high solar gain during the summer period, the effects of which could adversely affect the performance of the building causing periods of overheating and negatively affecting the occupants comfort levels. As such it would be of benefit to study the response of such a building design at a more detailed resolution than is possible using the PHPP method of monthly calculations, using dynamic simulation with more detailed sets of climate data.

1.1 Aims

The aim of this project is to investigate the performance of the Passive House design within the climate of Scotland during the summer period, with specific focus upon the possibility of overheating within the building during this period. Building simulation software tool ESP-r will be used to build a model of an existing Passive House that was built in Dunoon, Scotland, and implement this model with differing climate data for the four main regions of Scotland. Monitored data from the Dunoon Passive House will be used to ensure that the model is in reasonable agreement with the actual performance of the building.

1.2 Objectives

The primary objective will be to provide insight and recommendations for future Passive House designers in Scotland as to what aspects of the building design would have to be considered to ensure that the possibility of summer overheating was minimised without affecting the overall performance of the design. A secondary objective will be the creation of an accurate dynamic simulation model of the Dunoon house for ESP-r, providing a resource for future research work.

2. Literature Review

In order to assist in the approach to the literature review two excel matrices were used. The first broke down the review into differing topics of interest, each item of literature viewed could then be marked against these topics, showing at a glance what areas of interest had been covered and what topics needed further research. The second matrix was a more detailed breakdown of each journal or book that had been read, a brief overview of the topics covered and a listing of the pros and cons of each title. This served as a reference guide during the project and allowed for straightforward referencing as the thesis was written.

Topics of interest to the project were;

- Passive House design
- Summer overheating
- Building simulation
- Climate data
- Thermal comfort levels
- Mechanical ventilation systems
- Natural ventilation
- Thermal insulation in building construction
- Glazing and Passive House
- Residential occupancy studies

3. Project Background

The following chapter covers the relevant background information for this project. To provide an overview the following topics are discussed;

- The Passive House design concept
- The Passive House at Dunoon
- Summer overheating
- ELTEK Monitoring package
- Passive House Planning Package (PHPP)
- ESP-r building simulation software

3.1 Passive House Design Concept

The Passive House design concept is based upon reducing the energy requirements for both heating and cooling a building, whilst also providing excellent indoor comfort levels. This is achieved by using high levels of insulation in the fabric of the building, by specifying exceptionally high levels of airtightness, which combined with mechanical ventilation and heat recovery system is able to maintain a constant, comfortable interior air temperature (5).

The first Passive House was built in 1991 in Darmstadt Kranichstein, Germany (1), and was the culmination of research and development by Professors Bo Adamson of Sweden and Wolfgang Feist of Germany. The Passive House Institute (also Passivhaus Institut) was then created to promote the design standard, provide consultation facilities for architects, certification of designs as well as testing and monitoring buildings.

As part of the research for this project, a Passive House Certification course was undertaken. Lasting two weeks the course provided the detailed knowledge of the design standard with taught lectures, practical work and worked examples and enabling a familiarity with the subject.

The following gives an overview of the Passive House design standard as relevant to this project, providing detail of the principles an architect would need to follow when designing a building to Passive House standard.

3.1.1 Passive House Design Standard

To expand upon the principles that Passive House design is based upon, the Passive House Institute specifies the following over-arching standards (6) that a building must meet in order to be certified;

Energy Performance Targets	
Specific heating demand	≤ 15 kWh/m² per year
Specific cooling demand	≤ 15 kWh/m² per year
Specific heating load	≤ 10 W/m² per year
Summer overheating	< 10% hours > 25 °C
Specific primary energy demand	≤ 120 kWh/m² per year

Table 1: Energy Performance Targets (source: Passive House Institute)

In order to assist the designer in making these targets the following table shows the energy requirements for specific components of the building.

Design Component	Limiting Value
Walls, roofs, floors (U values)	≤ 0.15 W/m²K
Glazing unit	≤ 0.8 W/m²K
Installed glazing	≤ 0.85 W/m²K

Doors	≤ 0.8 W/m^2K
Infiltration (air-changes per hour)	≤0.6 @ n50
Thermal bridging (linear Ψ value)	≤0.01 W/mK
MVHR coefficient (ŊHR)	≥ 0.75
Ventilation electric limit	0.45 Wh/m^3

Table 2: Design Component Values (source: Passive House Institute)

3.1.2 Design Details

For the designer to meet the targets given in tables 1 and 2 specific attentions must be given to the following design details;

- **Airtight Construction:** The building must be kept as airtight as possible, with much care and attention given during the construction period to ensure that the airproof membrane is not pierced. By keeping the building as airtight as possible heat losses by airflow through the fabric of the building are minimised. The MVHR's heat exchanger then ensures that up to 75% of this heat is retained in the building as mechanical ventilation occurs, reducing the energy requirement for space heating.

- **Glazing Units:** The high thermal performance specified for glazing units reduces heat losses through the window unit and also contributes towards the thermal comfort level within the building. As part of the specification for BS ISO 7730, one element of thermal comfort is addressed by the difference between the radiant temperature of a surface and the ambient air temperature. If this difference is greater than 4 degrees Kelvin then the occupant may have a lower comfort level due to a feeling of coldness coming from the window surface. By proper specification of window units for a building design, this form of thermal discomfort can be minimised.

- **Thermal Bridging:** This must be minimised by careful design of features that meet or intersect with the fabric of the building exterior. Proper attention must be paid to insulation materials used in the design of these intersections to ensure that thermal bridges are kept to a minimum. Particular points of intersection are the installation details of windows and exterior door frames, roof joists, building foundations and where the supply and extract vents of the MVHR pierce the building exterior.

- **Exterior Walls and Roof Construction:** Attention must be paid to the materials specified for wall and roof constructions. In order to attain the designated U values for the constructions whilst still maintain structural integrity and avoiding thermal bridges. The high thermal performance of these constructions allow the building to maximise the use of retained heat, minimising heat losses through the building fabric and reducing energy use for space heating.

3.2 Dunoon Passive House

Figure 1: Dunoon (source: Google Maps)

Dunoon is a small town located on the West coast of Scotland, roughly 35 miles west of Glasgow. The house itself was part of a number of homes built by Fyne Homes, completed in 2010. The development consisted of ten semi-detached homes consisting of a mixture of single dwellings and flats. The homes were all built to the Code 4 standard, with the exception of the Passive House.

The site itself is situated right on the coastline, with the homes having an east-west orientation (figure 2 – see Appendix A for larger image). The Passive House is a 2 bedroom dwelling over two floors, with separate living room and kitchen and a small W.C. on the ground floor with the two bedrooms and main bathroom on the first floor. The full floor plans for the home can be found in Appendix A.

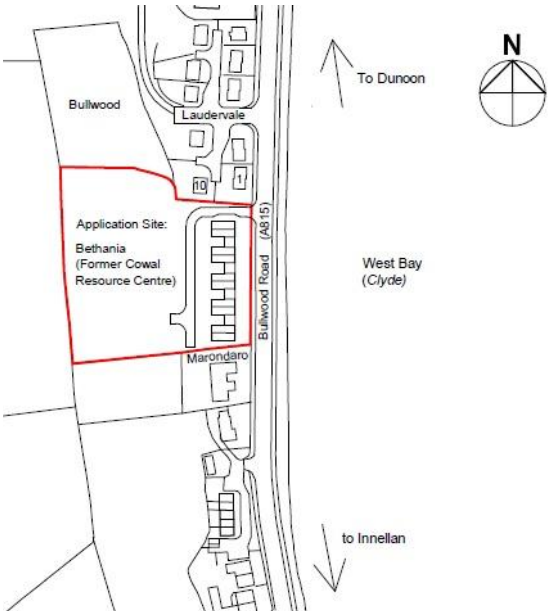


Figure 2: Dunoon Site (source: Fyne Homes)

In an agreement with the University of Strathclyde the owners of the Passive House allowed for monitoring of the energy use of the building for a period of one year. The details of this monitoring are outlined in Chapter 2.4.

The site posed difficulties for the architects when it came to designing the building towards the Passive House standard. Being part of an overall development the design of the passive house would have to be in keeping with the other homes in the development, thus limiting the architects when designing towards passive house standard.

In order to maximise solar gains, the recommendation is to situate the majority of glazing to the south and north faces of a building, while also minimising the use of glazing on east and west facades. In the case of the Dunoon site the buildings were oriented on an east-west axis, with the windows located in the east and west gable ends to be in keeping with the rest of the development. There was also an issue with shading as there is an approximately 25m high cliff located 20m to the west of the site, which effectively blocks the evening sun from reaching the kitchen windows, minimising the available solar gains.

Despite these issues the building was able to complete the Passive House certification process. Due in part to the issues with glazing the specific space heating demand of the building is 20 kWh/(m^2a), not achieving the specified 15 kWh/(m^2a) which would normally result in the building not achieving certification. However the building does meet the pressurisation test with a figure of 0.4 air changes per hour plus the specific primary energy demand is only 93 kWh/(m^2a), comparing well with the set standard of 120 kWh/(m^2a). Certification was finally certified for meeting the heat load requirement of the standard.

3.3 Summer Overheating and Thermal Comfort

The term “thermal comfort” is used to describe a psychological state of mind, most often pertaining to whether a person feels too hot or too cold. It is defined under BS ISO 7730-2005 as “that condition of mind which expresses satisfaction with the thermal environment.”

Thermal comfort is not limited wholly to the air temperature of a room, and is indeed built up from a number of factors;

- Personal factors such as clothing and activity levels, occupancy numbers
- General factors – air temperature (or dry bulb temperature), mean radiant temperature and relative humidity
- Localised factors – air velocity and floor surface temperatures

Both BS ISO 7730-2005 (7) and BS EN 15251-2007 (8)refer to the comfort levels of occupants of buildings. To massively simplify both standards, BS ISO 7730 applies more towards comfort levels for buildings with some form of conditioning whilst BS EN 15251 takes into account the design of buildings without mechanical ventilation.

As the model of the Passive House will take into account natural ventilation from the opening and closing of windows, it would be prudent to take into account the range of temperatures given for thermal comfort from BS EN 15251.

Figure 3 is taken from BS EN 15251 and shows the varying acceptable thermal comfort levels for a building with natural ventilation dependent on the exterior temperature. There are two main levels given; maximum (red) and minimum (blue) with a range of three levels of comfort for each:

I. Minimum extreme
II. Acceptable median
III. Maximum extreme

These temperature ranges will be taken into account when analysing the results from dynamic simulation. The central guiding temperature for analysis though will be that of 25°C. This is purely down to the fact that the PHPP package uses this temperature when calculating summer overheating in a design (2.1.1 Table 1)

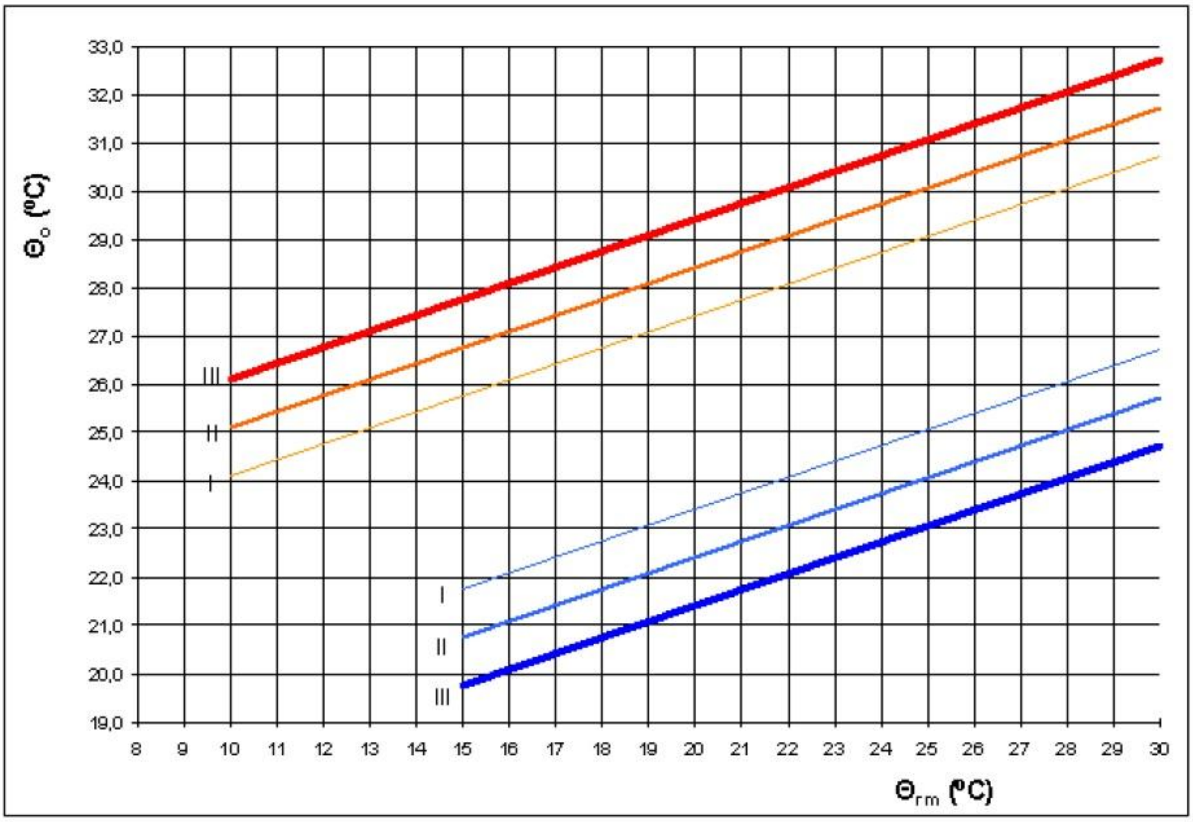


Figure 3: Indoor Temperature Ranges (BS EN 15251)

As previously described, the Passive House design maximises the potential of solar gain in maintaining the temperature of a building during the heating season. However windows that are designed for maximum solar gain during the winter months when daily sunshine hours are low may not perform well during the summer months when the building may experience the maximum amount of sunshine hours. Solar shading can be introduced to minimise direct solar gains during the summer months when the sun is much higher on the horizon than during winter, however there would still be the potential for wide discrepancies in solar gains between the winter and summer periods.

3.4 Monitoring of the Dunoon Passive House

As has previously been discussed the owners of the Passive House agreed to the monitoring of the energy performance of the building. The initiative was taken between the University of Strathclyde and Fyne Homes with a view to using the data to investigate and assess the impact of new design methods and materials on energy utilisation and occupant satisfaction. Part of the data logged will be used in this project to assess the building simulation model built in ESP-r.

Telemetry monitoring was used to remotely collect data logged by the monitoring devices. These devices transmit the data logged by radio to a main receiver unit which can then be remotely accessed by a PC to record the data allowing the user complete access without requiring the buildings occupant being involved.

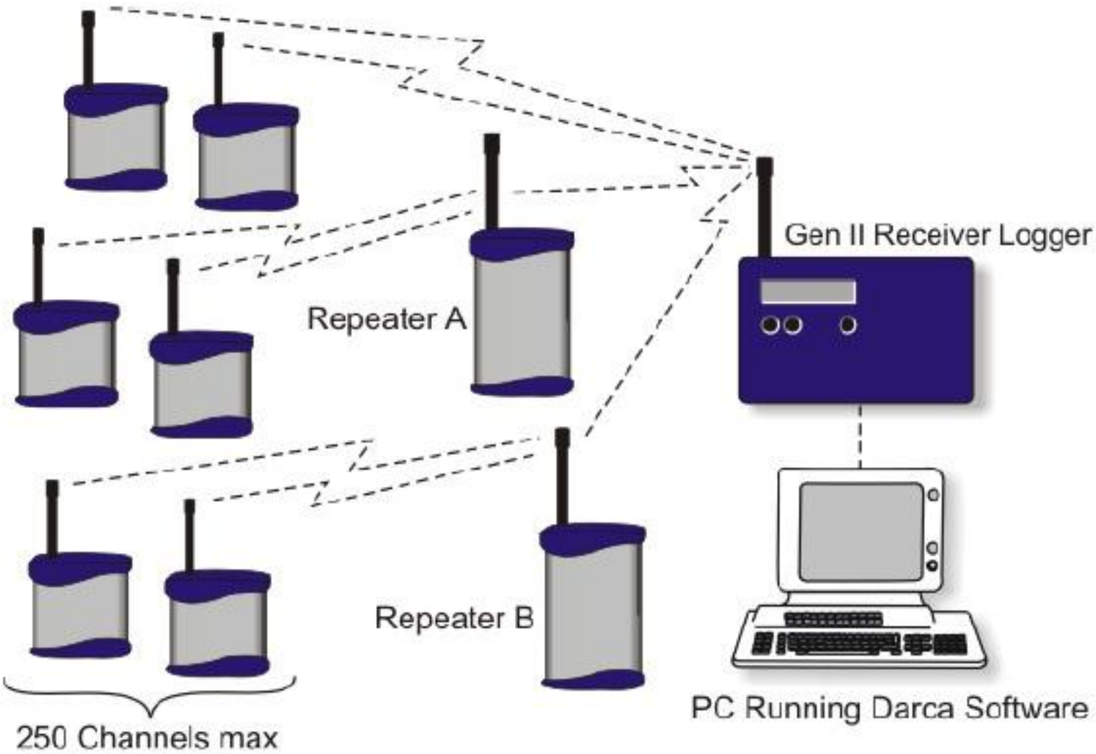


Figure 4: Monitoring Configuration (source: http://www.eltekdataloggers.co.uk)

Data was monitored from a number of sources for the above initiative; internal temperatures of several rooms as well as humidity and CO2 levels, electrical measurement of the main electric meter, mechanical ventilation and heat recovery system, heat pump and various temperatures of the solar domestic hot water system. For the purposes of this project it was only necessary to utilise the information recorded for the internal room temperatures, details of which are listed in the following table.

Location	**Measuring**	**Component ID**
Lounge	Relative Humidity, Temperature and CO2	GD 47 (http://www.eltekdataloggers.co.uk/pdf/GD47_product_preview.pdf)
Kitchen	Temperature	GC 05 (http://www.eltekdataloggers.co.uk/transmitter.shtml)
Coldest Room	Temperature	GC 05 (http://www.eltekdataloggers.co.uk/transmitter.shtml)
Bathroom	Temperature	GC 05 (http://www.eltekdataloggers.co.uk/transmitter.shtml)

Table 3: Monitoring Equipment (source: Gavin Murphy)

The monitoring equipment used was sourced from Eltek Dataloggers including the software used to view the data recorded. The image below provides an example of the data recorded, including all data recorded as well as the room temperatures.

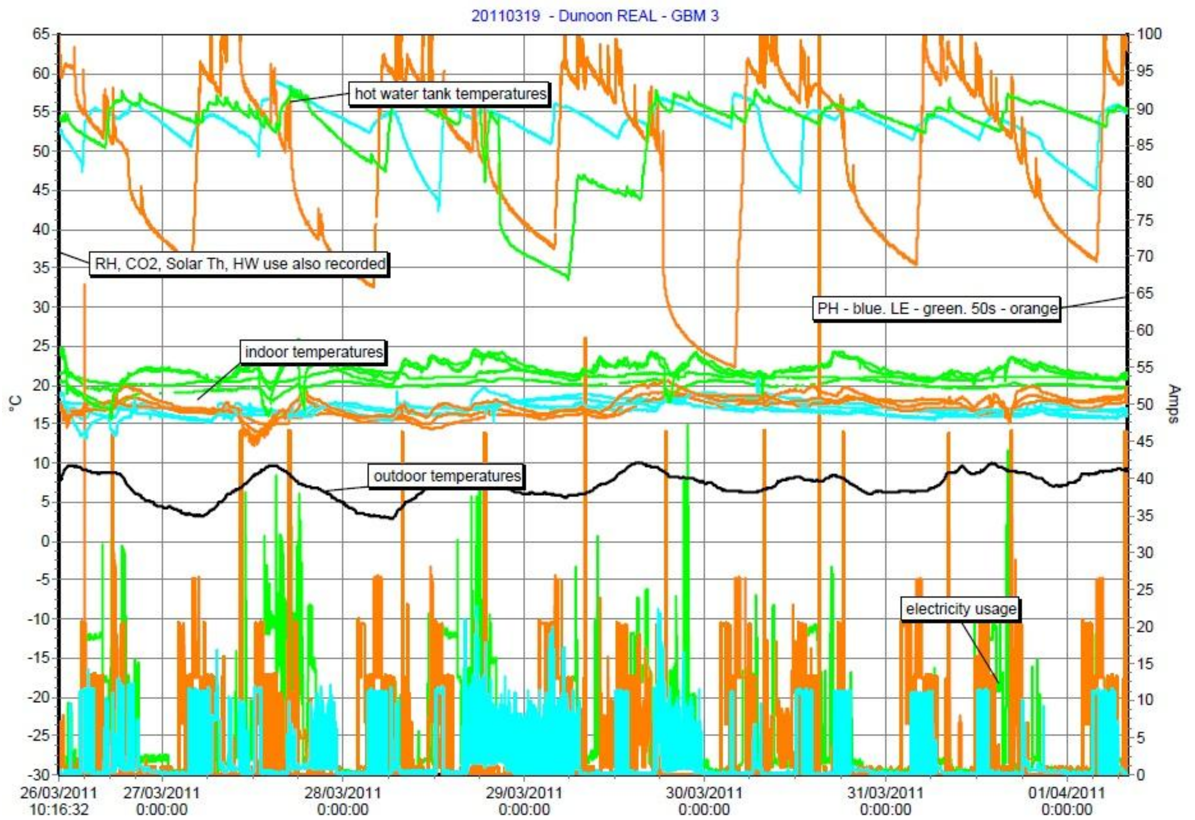


Figure 5: Example of Dunoon Monitored Data (source: Gavin Murphy)

3.5 Passive House Planning Package (PHPP)

The Passive House Planning Package (PHPP) (4) was developed by the Passive House Institute as a method of planning that a proposed building design would be compliant with the Passive House design standard. Essentially an Excel spread sheet, PHPP breaks down the building design into several areas;

- Building floor areas
- Building materials, their U-values and composition
- Floor slab
- Window constructions and their U-values
- Shading
- Ventilation
- Annual heat demand, the monthly variations and heating loads
- Summer over-heating
- Electrical usage

There are further requirements for solar domestic hot water systems, boiler system and the primary energy value, these however are not pertinent to this project. The planning package also takes into account exterior shading, be it in the form of trees or local topography.

It must be kept in mind that PHPP is not a temporal building simulation software system. The package uses monthly averages for its climate data when calculating the building performance and as such the calculations used within the package will give a very close approximation of how a building design may perform but not predict the buildings performance at the extremes of a local climate. Indeed, the PHPP package specifies that there would be a need for more detailed simulation where gains are concentrated in space and time.

In order to qualify for certification the Dunoon Passive House had PHPP report created. This was made available for use in this project and the data contained within was used to form the basis of the ESP-r model as well as being used for creating reports used with different climate data sets.

3.6 ESP-r Building Simulation Program

ESP-r (9) is an open source building simulation program developed for the simulation of thermal, visual and acoustic performance of buildings and the energy use associated with environmental control systems. The program is very flexible and allows the user to accurately simulate a buildings performance within a given set of climate data. For this project ESP-r was used to build a model of the Dunoon Passive House.

ESP-r is a research tool, not a commercial product and as such undergoes constant upgrading, tweaking and expansion of its abilities from the wide number of users dotted throughout the academic world. Therefor it is of prime importance that a stable version of the software is used and that for the course of a simulation project no other version of ESP-r is obtained.

4 Methodology

The following chapter describes the work undertaken in building the model for ESP-r, any underlying assumptions that were made and the reasoning behind decisions that were taken. There is also a discussion of the use of climate data, the work undertaken to narrow down what sites throughout Scotland to use in the simulations and details of the chosen sites.

4.1 Overview of Approach

In approaching this project knowledge gained from the literature review and from attending the Passive House Designer Course needed to be channelled into a process to build an effective building simulations model. Initially a matrix of variables needed for the simulations to be run using this model would need to be defined, this would enable the needs of the model to be determined before undertaking the actual build. Once these variables were determined and a simulation matrix produced this then raised further questions of data necessary for the building of the model.

In order to determine the occupational use of the Dunoon Passive House a questionnaire was developed for the home owners to complete, providing data that could be implemented in the model. Then the question of what locations around Scotland would need to be considered in order to cover the range of climates throughout Scotland in the summer months. The MET Office was the best source of data to determine these potential sites. This would then lead to the acquisition of climate data that was compatible with ESP-r and was as close an approximation of the desired simulation sites.

Finally in order to balance the ESP-r simulations it was necessary to complete PHPP reports for each of the selected locations around Scotland in order to determine how closely results from these PHPP reports would match the results obtained from the ESP-r simulations.

4.2 Matrix of Variables

To assist in planning the ESP-r model and determining what simulations would need to be run it was necessary to identify and define what variables could occur and which would have a definite effect upon the model simulations. From completing the Passive House Designer Course it was relatively straightforward to determine these variables. The primary questions to pose were;

- What can affect the internal temperature of the building?
- Which of these variables would have a minimal or negligible effect upon the simulations and could therefore be omitted from the simulation work?

Factors that could then influence the internal temperature of the building were;

- Operation of the MVHR
- Casual gains from occupancy
- Ventilation control in the form of opening/closing windows
- Casual gains from lighting
- Casual gains from appliances, specifically cooking
- Direct solar gains from site specific climate data
- Building orientation – as the current building is orientated East/West or by rotating 90° so that the living room end faces South

As the project was conducted during the summer months of June, July and August the first item to be looked at was the potential heat gains from lighting. In terms of sourcing the times of sunrise and sunset for Dunoon the closest matching figures available were for Glasgow whose latitude corresponds with Dunoon. For the above months the table below provides the times of sunrise, sunset and daylight hours for the 1st, 15th and last day of the month.

With sunrise so early in the mornings it would be reasonable to assume that no artificial lighting would be needed in the home. During the evening it would be feasible for lighting to be required after 9pm during June and into July whilst in August it would be required after 8pm.

Date	**Sunrise**	**Sunset**	**Daylight Hours**
June 1st	03:40am	20:50 pm	17hrs 10min
June 15th	03:31am	21:04pm	17hrs 33min
June 30th	03:35am	21:05pm	17hrs 30min
July 1st	03:36am	21:05pm	17hrs 29min
July 15th	03:52am	20:53pm	17hrs 1min
July 31st	04:19am	20:26pm	16hrs 17min
August 1st	04:22am	20:03pm	15hrs 41min
August 15th	04:49am	19:53pm	15hrs 4min
August 31st	05:20am	19:13pm	13hrs 53min

Table 4: Sunrise, Sunset and Daylight Hours for Dunoon (source: MET Office)

However the lighting used in the house would be low-wattage fluorescent bulbs which generate very little heat in comparison to incandescent bulbs. As lighting would only be used for short periods in the late evening, it would be reasonable to assume that the overall effect of this casual gain would be minimal towards the potential of overheating and as such the need to use this as a variable in simulation work could be omitted.

The other variable with a potential to be omitted would be casual gains from cooking. Occupancy data procured from a questionnaire of the home owners (Chapter 3.3) does show that the building is occupied over lunch and dinner periods. As these time periods coincide with periods of daylight and hence potential solar gains, it would be reasonable to include heat gains from cooking appliances within the simulation of the Dunoon house. If there is negligible influence upon overheating on the model of Dunoon from these gains then it would be viable to omit them from simulations of the other sites throughout Scotland.

The other variables listed above all have direct influence upon heating gains in the building and as such must be included in building simulations. This results in the following simulation matrix.

Building Orientation	MVHR Operation	Occupancy Levels	Window Operation
East/West North/South	On Off	2.5 occupants 0	Open Closed

Table 5: Matrix of Variables

4.3 Questionnaire and Results

To assist in the research of Passive House a brief questionnaire was developed for the occupants of the house at Dunoon, the full response to which can be found in Appendix B. The aim of the questionnaire was to gain insight to the occupancy pattern of the home during summer months, the pattern of having windows opened by the occupants and the motivations for doing so, how the MVHR was operated during the summer period and also an overarching view of the occupant's feelings on potential overheating during this timeframe. The questions asked were:

1. During the summer months what setting do you keep the Mechanical Ventilation (MVHR) during summer?
2. During summer months do you feel the need to open windows more often to regulate room temperature than in other seasons.
3. How would you describe the general use of windows throughout the summer? i.e. need to leave some open overnight, effects of weather on whether you open them etc.
4. In an average summer week, what are the usual hours of occupation of the building?
5. Would you be willing to keep a log for a period of seven days of when windows are opened and closed in the building? Below are tables for each day with the windows of the home listed. The times are the most important information but if you are able to provide the motivation (i.e. too warm, air stuffy) for opening the windows it would be worthwhile as would be whether the windows are opened fully or just a small gap.

While the evidence gathered via the questionnaire was anecdotal in form, it nonetheless gave some valuable insight into the performance of the building during the summer months. A key piece of anecdotal evidence was in response to the question pertaining to the general use of windows in the summer;

> "The windows are generally open if the weather is sunny as this causes the front and upstairs of the house to heat up. They are normally closed at night with (last year I did have them open but the midges were too bad!). If the weather is cloudy but warm I also open them even during rain if it is warm enough. If it gets very warm I would also open the Velux on the top floor as this quickly releases any heat. Generally between April and October the windows can be opened."

This indicates that the occupants do experience overheating of the building during sunny periods and that occupant intervention has to take place to provide extra ventilation on top of that provided by the MVHR. The use of the Velux windows in the upstairs hall was also of interest in terms of their ability to quickly vent heat from the building and would provide another possible variable for simulation. What was also useful to discover was that the MVHR is maintained at the automatic setting regardless of the time of the year and that the summer bypass mode was not utilised by the occupant.

The occupancy details would be used in generating profiles on the ESP-r model for the occupancy casual gains. The trend for the week was for occupancy in the morning until 9 or 10am, the building would then be vacant until 5 or 6pm.

The window log provided information for creating schedules for the opening of windows in the ESP-r model. From the logged data and also from the anecdotal evidence it would appear that the living room and bedroom above experience the most overheating as it is only these rooms that have consistent opening of windows and whilst no opening of the Velux windows were logged, the anecdotal evidence leads to their occasional use.

Figure 6 below shows the internal temperatures for the living room from 16/08 to 23/08. According to the response to the questionnaire the window of the living room was opened on 17th from 8:30am to 3pm, on the 19th from 8:30am to 4pm and on the 21st from 12:45pm to 5pm. The graph clearly shows the drop in temperatures caused by these openings, particularly on the 19th where the temperature drops from 22°C to 17°C. The window was closed when the temperature reached 22°C and then closed at 17°C where the temperature was below the occupants comfort threshold. The temperature can then be seen to rise back to 22°C to then dip again, where it can be inferred that the MVHR was able to maintain the thermal comfort level of the occupant.

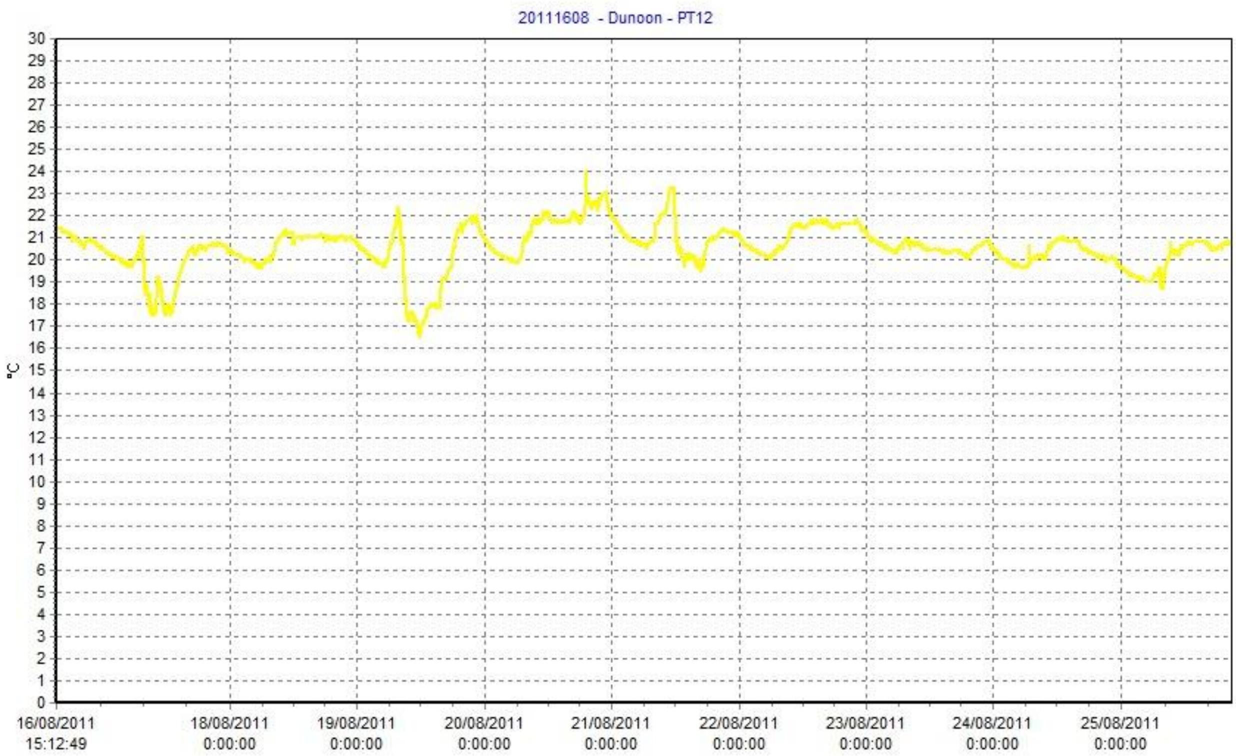


Figure 6: Living Room Temperature

The 19th of August is an example of the need for the occupants to intervene through opening a window in order to prevent the room from overheating.

4.4 Selection of Scottish Sites – Climate Data

In order to properly assess the viability of the Dunoon Passive House model in different regions of Scotland it is necessary to ascertain what sites to source climate data for. To do this regional climate data was used from the MET office (10), following their breakdown of Scotland into different regions.

The MET office split Scotland into three distinct regions; Eastern, Western and Northern (including the northern isles). Within these regions the MET office provide annual average figures based on data recorded over long timescales (these vary by location but cover at least 50 years), as well as the maximum and minimum extremes. For the purposes of this project and to assist in determining the climate data needed for the ESP-r model, primarily the datasets for number of sunshine hours were most useful though the annual temperature ranges were also of use. The number of sunshine hours would correlate to the potential solar gains for the ESP-r model, while ambient air temperatures would also have an effect upon the internal temperatures of the building model.

For each region the MET office provides two examples locations for each climate type – a location that represents the maximum recorded data and a corresponding site that represents the minimum.

4.4.1 Western Scotland

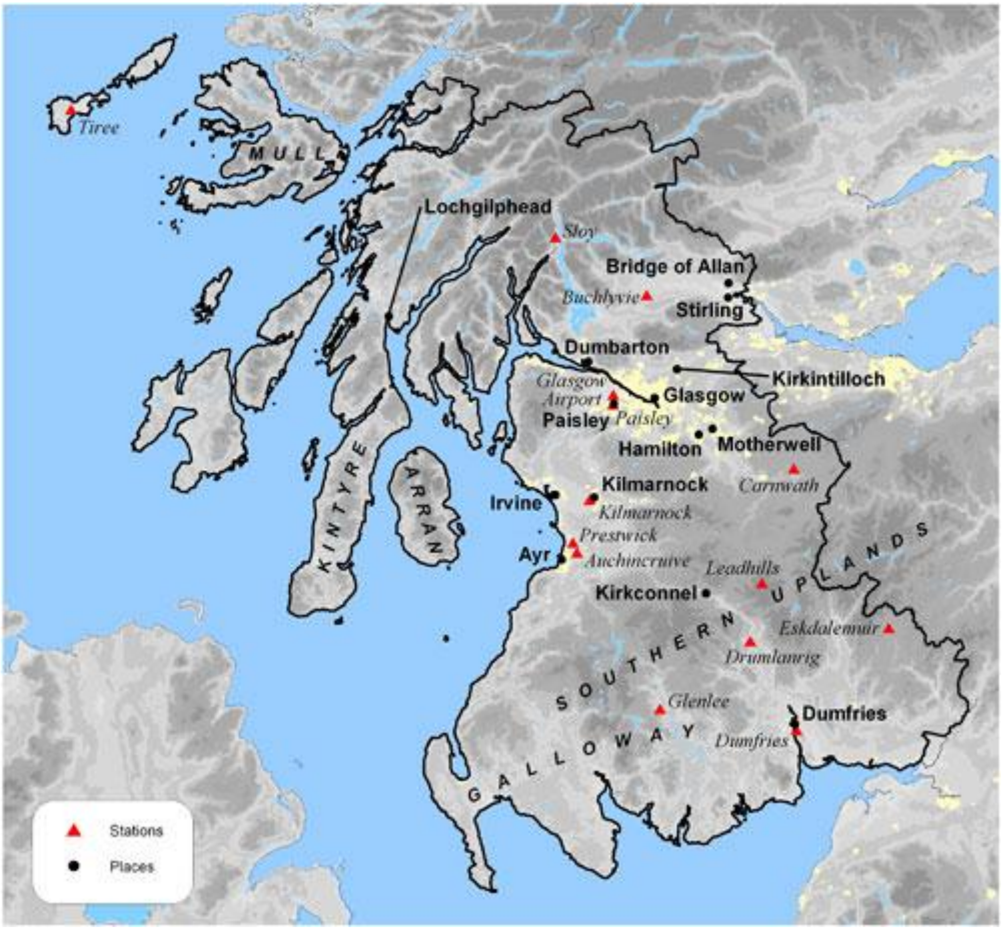


Figure 7: Western Scotland (source: MET Office)

According to the MET Office (11) the temperature of the west coast of Scotland is milder than that of the east, due in part to the warming effect of the Gulf Stream and also the prevailing maritime winds coming from the west. The warmest months in the region are July and August with a daily maximum ranging from 14.6 °C to 18.5 °C from data recorded from 1971-1990. The variation for mean daily maximum and minimum temperatures were provided for locations at Paisley and Tiree. Sunshine hours for Tiree and Eskdalemuir are given below in figures 7 and 8. Temperature graphs can be found in Appendix C.

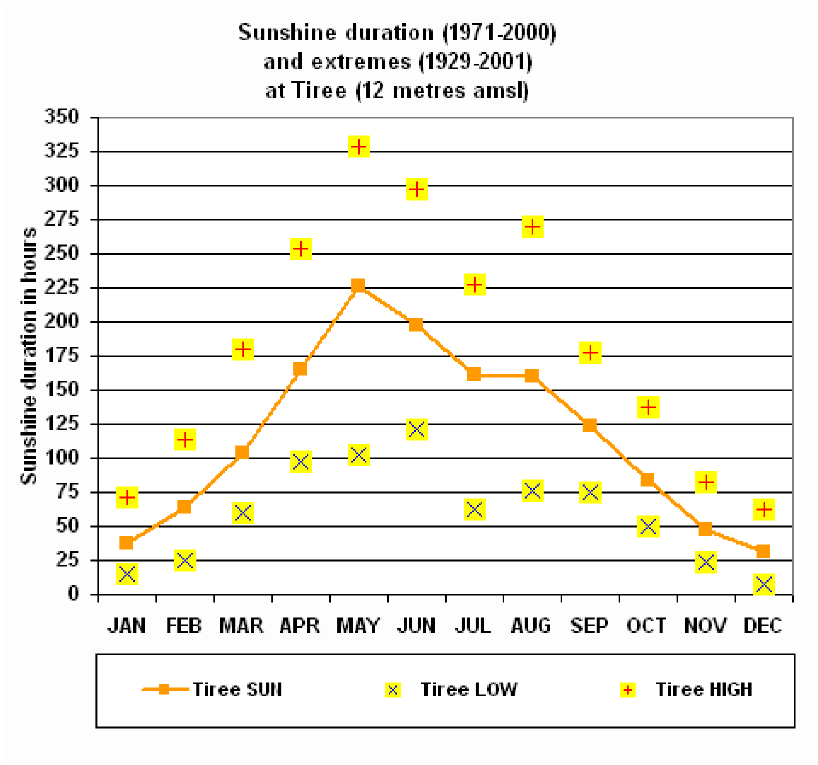


Figure 8: Sunshine hours for Tiree (source: MET Office)

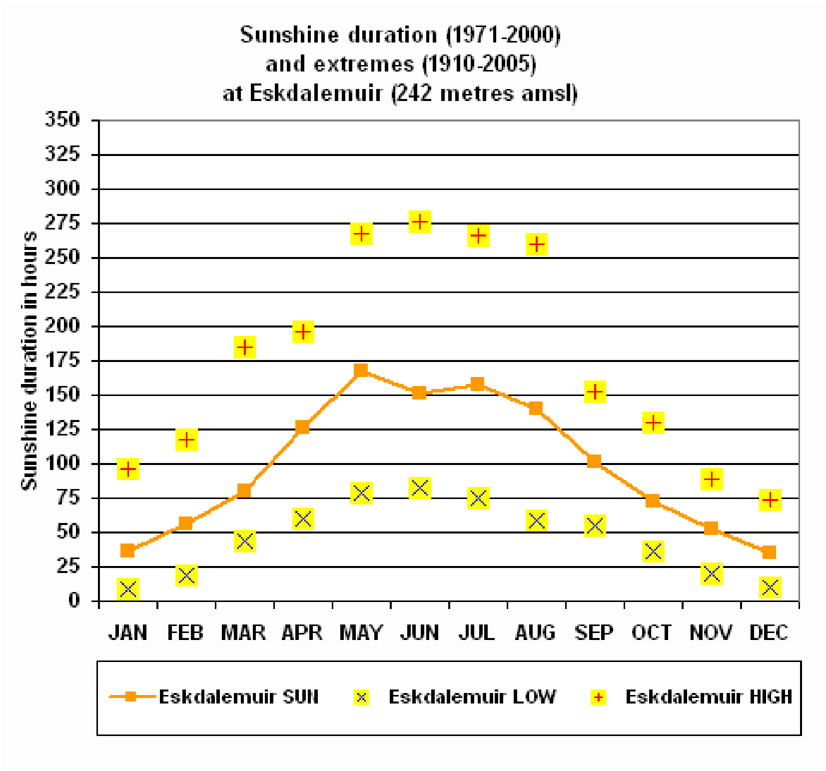


Figure 9: Sunshine hours for Eskdalemuir (source: MET Office)

4.4.2 Northern Scotland

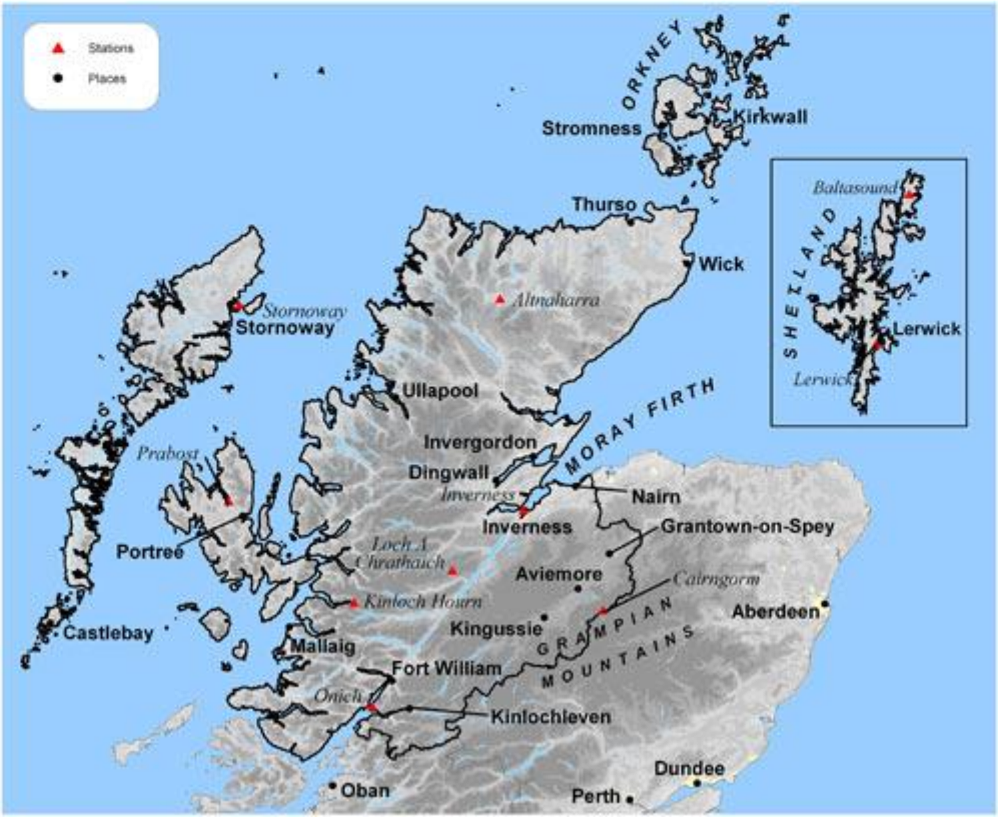


Figure 10: Northern Scotland (source: MET Office)

For Northern Scotland (12)the mean daily maximum temperatures are 19°C at low levels for the months of July and August for areas around the Moray Firth. Elsewhere the mean daily maximum is somewhat lower at 16°C for higher levels and the western isles. There can be extreme temperatures up to and exceeding 28°C, particularly in sheltered areas of the Western Isles though this is contrasted by Shetland where only a maximum of 25°C has been recorded.

The sunniest areas of the region are the around the Moray Firth and the southern Outer Hebrides. Here the annual average is up to 1300 hours, though the majority of the coasts experience 1200. The sunniest month is May rather than the more usual June due to more settled anti-cyclonic weather in late spring. The annual sunshine hours for Inverness and Lerwick are given in figures 10 and 11. Temperature graphs can be found in Appendix C.

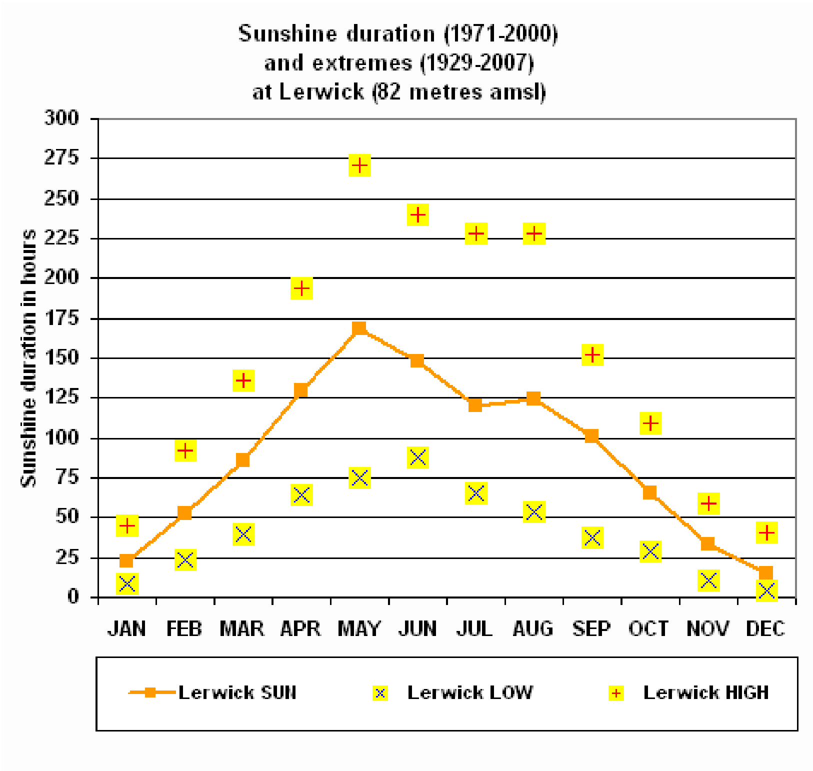


Figure 11: Sunshine hours for Lerwick (source: MET Office)

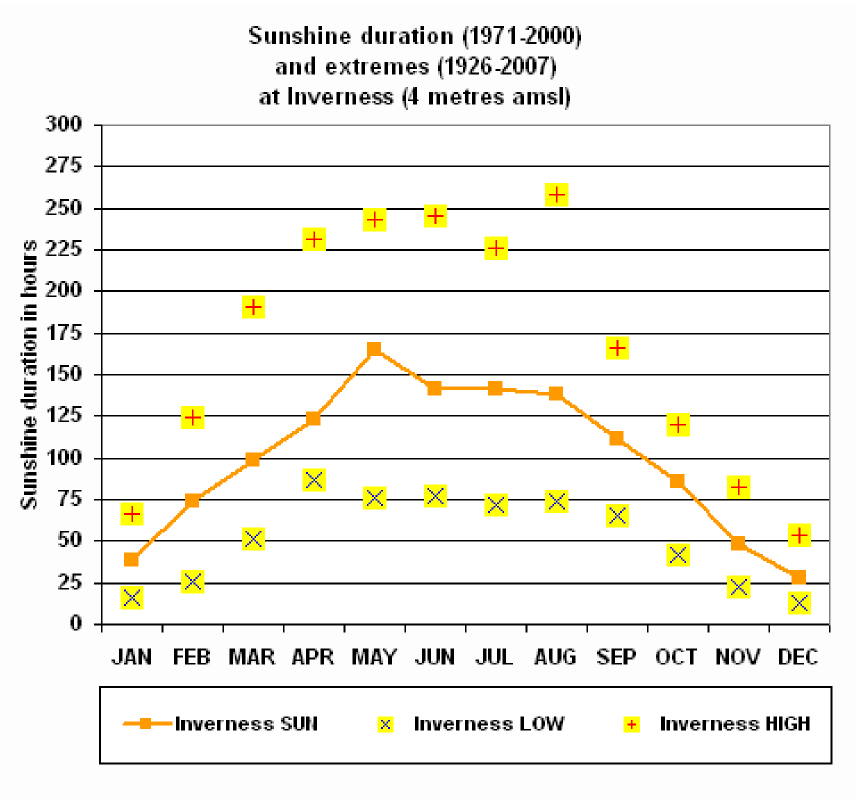


Figure 12: Sunshine hours for Inverness (source: MET Office)

4.4.3 Eastern Scotland

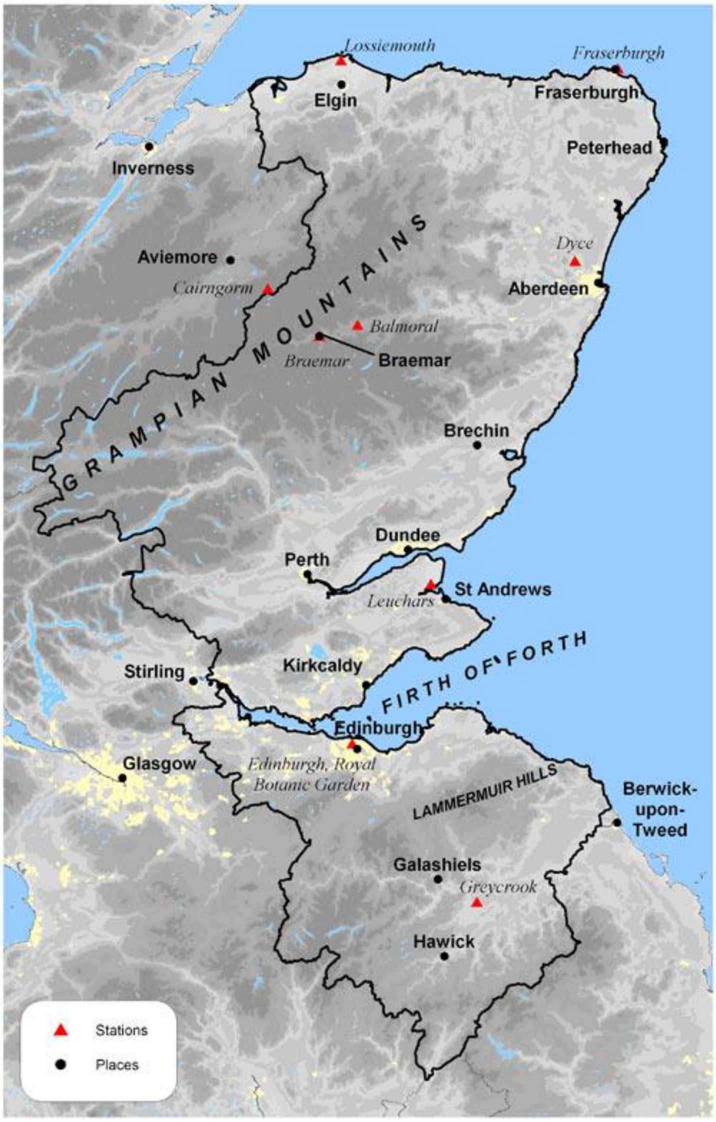


Figure 13: Eastern Scotland (source: MET Office)

The mean annual temperature for Eastern Scotland (13) can vary from 6°C over the Grampian region to 9°C for the Firth of Forth. This variation can be proscribed to a mixture of proximity to the coast, local topography and to a lesser extent urban development around Edinburgh. The warmest month is July with mean daily maximum temperatures approaching 20°C for low level inland areas though there are lower temperatures of less than 16°C for the coastal areas of the Grampian region.

Eastern Scotland is the sunniest region of the country with an annual average of 1500 hours per year along the coast of Fife. East Lothian experiences around 1400 hours while the

Grampians have the lowest number of sunshine hours at less than 1100 hours. Sunshine hours for Dyce and Braemar are given in figures 13 and 14. Temperature graphs can be found in Appendix C.

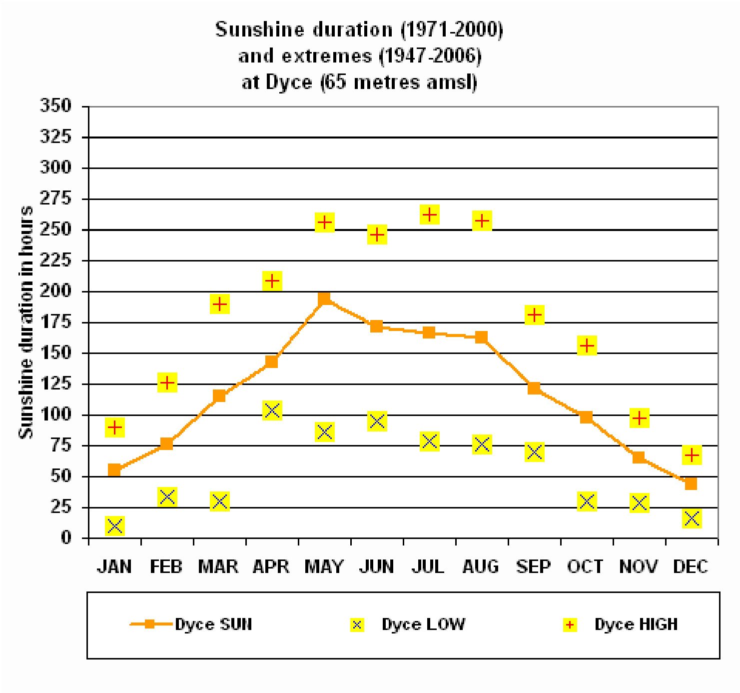


Figure 14: Sunshine hours for Dyce (source: MET Office)

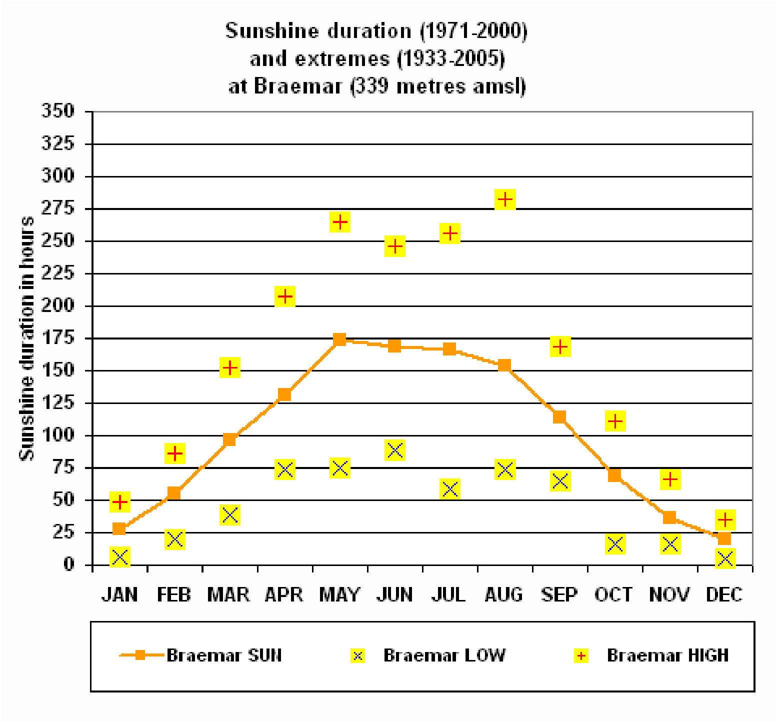


Figure 15: Sunshine hours for Braemar (source: MET Office)

4.4.4 Site Selection and Sourcing Relevant Climate Data

Taking the locations given by the MET Office as representations of the annual average of sunshine hours as a starting point, the next stage was to locate climate data suitable for use with ESP-r that was the nearest match to these potential sites. The sites selected from the information gained from the MET Office were;

- Tiree
- Eskdalemuir
- Lerwick
- Inverness
- Dyce
- Braemar
- Dunoon

Dunoon was of course included as a desired location for suitable data as this is the location of the Passive House that the ESP-r model was built to represent. The other sites gave a range of climatic conditions and geographic locations that would provide a representation of the variation of Scotland's climate throughout the summer months. As part of the literature review sources of climate data suitable for use with ESP-r was undertaken.

ESP-r is compatible with the EPW file format (14), the International Weather for Energy Calculations or IWEC format developed by ASHRAE. This data format provides hourly data for dry bulb temperature, wind speed and direction and solar radiation that would be necessary to run the required building simulations for this project. The source used for locating climate data for this project was the US Department of Energy's Energy Efficiency and Renewable Energy web site (15) - they provide climate data in the EPW format for several locations in the United Kingdom.

ESP-r itself comes installed with a variety of climate datasets, including some of those available through the Department of energy. From these locations the following datasets were able to be located;

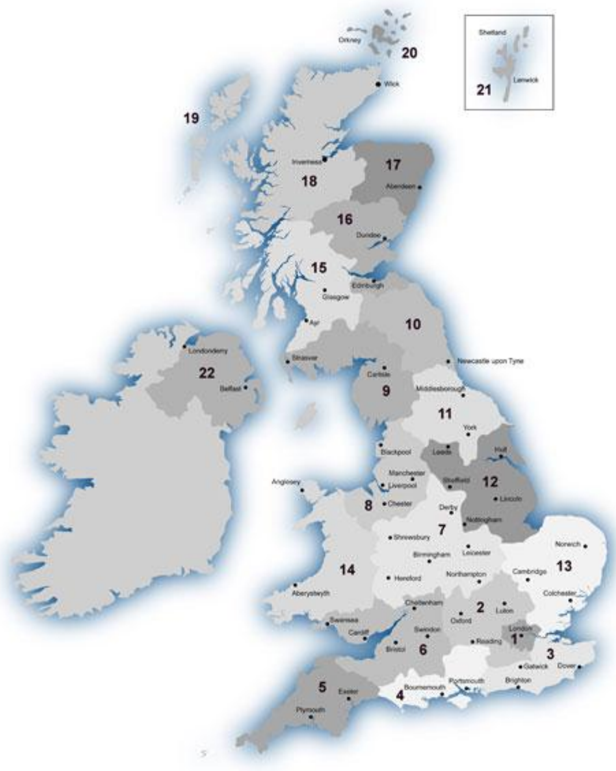
- Aberdeen/Dyce
- Glasgow
- Leuchars
- Oban

The data for Aberdeen/Dyce matches with the location determined from the MET weather information, Glasgow is a close match to Dunoon in terms of latitude and would also correspond to Eskdalemuir. Leuchars is within the vicinity of Braemar whilst the Oban data is within the vicinity of Tiree. The locations derived from MET Office data are listed in the table below with the corresponding ESP-r climate data sets.

Desired Locations	**ESP-r Climate Data**
Dyce	Aberdeen/Dyce
Tiree	Oban
Braemar	Leuchars
Dunoon/Eskdalemuir	Glasgow

Table 6: Desired Locations and Matching ESP-r Climate Data

What is missing is viable climate data for the North of Scotland, particularly the Western Isles and the Outer Hebrides. The MET Office do provide recorded weather data (16) in hourly increments for individual climate types and it was possible to source separate recorded data for ambient temperature, wind speed, direction and solar radiation. However it was not possible to combine these datasets into a format readable by ESP-r and so it was not possible to source a dataset to represent the North of Scotland.



Sourcing climate data for use with PHPP was much more straightforward. The Passive House Institutes website provides data from BRE (17) in a format compatible with PHPP for a number of regions of Scotland. The country is broken down into smaller regions than that of the MET Office. The locations and corresponding regions are listed in the table below.

Figure 16: BRE Climate Data Map (source: BRE)

Desired Location	**PHPP Climate Data**
Dyce	Region 17
Tiree	Region 15
Braemar	Region 16
Dunoon/Eskdalemuir	Region 15

Table 7: Desired Location and PHPP Climate Data

4.5 ESP-r Model of Dunoon Passive House

The following section details the work required to build the ESP-r model of the Dunoon house broken down into these sections;

- The physical model – geometry, materials and constructions, boundaries and connections.
- Airflow network – the MVHR airflow network, internal airflow network between rooms and exterior windows.
- Internal gains – occupancy and other gains.
- Simulations and comparison to monitored data from Dunoon house.

The existing PHPP report for the Dunoon house was used to obtain values for the thermal properties of the building materials and glazing as well as the operating parameters of the MVHR to be able to simulate it as an airflow network.

4.5.1 Physical Model

4.5.1.1 Approach and Assumptions

The first stage in developing the ESP-r model was building the geometry of the house itself. There were a number of options to consider; a simplified box, a more representative version with zones for each room and finally a more architecturally representative model with zones for each room.

The determining factors in choosing what approach to take when building the geometry was the information available from the builders, Fyne Homes. What was available were floor plans of the building (Appendix A) as well as a simple cross section. Construction details were absent, especially those concerned with the minimisation of thermal bridges where the buildings structure met the foundations. However the construction details for the materials used in the buildings walls, floor slab, roof and first floor were available from the

PHPP report for the house. The lack of other construction details meant that it would not be possible to construct and architecturally accurate model of the building.

Next to be considered was a simple box design, representing the structure in abstract terms but still with enough level of detail to produce useable results. A closer look at the data obtained from the monitoring of the existing building in Dunoon began to make that approach more complicated than it would first appear. The datasets recorded for the four individual rooms monitored for temperature meant that these rooms would have to be consigned individual zones. Trying to represent this with only a single zone, or to attempt the simulations with zones dedicated to just those rooms would result in uncertainty as to the viability of the model.

Instead the more straightforward approach was to build a representative model, with zones designated for each room, hall and stairwell and yet not complicate the model with a further level of architectural detail. Further to this, the lack of information available on the construction details used to minimise thermal bridges within the tolerances of the Passive House standard meant that it could be possible to neglect the possibility of thermal bridges within the model itself. As the stated goal of Passive House is to minimise thermal bridging completely it appeared rational to assume no thermal bridging within the model, and the impact of its inclusion in the model would be negligible to the overall results desired from the model design.

4.5.1.2 Materials and Constructions

The nature of the Passive House standard calls for building constructions with high thermal insulation. Walls, roofs and floors need to have a U value ≤ 0.15 W/m²K. In order to implement these constructions within ESP-r it was necessary to develop the materials database for the model so that each individual component material needed for wall, floor and roof constructions had the same U values as specified in the PHPP report for the Dunoon House. These materials could then be used to create specific constructions with a similar U value property to that described in the PHPP report.

Assembly No.	Building Assembly Description
1	Ambient wall

Heat Transfer Resistance [m²K/W]	
interior R_{si} :	0.13
exterior R_{se} :	0.13

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	Plasterboard	0.210					13
2.	PU insulation TW55	0.021					50
3.	OSB	0.130					9
4.	Mineral wool/I-studs	0.032	softwood	0.130			50
5.	Mineral wool/I-studs	0.032			softwood	0.130	200
6.	Mineral wool/I-studs	0.032	softwood	0.130			50
7.	OSB	0.130					9
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
				8.3%		1.6%	38.1 cm

U-Value: **0.086** W/(m²K)

Figure 17: Exterior Wall Construction: PHPP

The above figure shows the layer makeup of the exterior wall construction as detailed in PHPP, providing both U values for each material and the thickness of each layer. Within ESP-r the standard database did have representations of each of these materials, though there were slight differences in U-values. These could be modified providing materials closely matching those described in PHPP. The figure below shows the layer makeup of the ESP-r construction for the exterior wall.

```
No insolation analysis requested.
Current MLC ../dbs/passive_house.constrdb
Accessing MLC db: ../dbs/passive_house.constrdb


Details of opaque construction: extern_wall and overall thickness  0.381

Layer|Matr|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
    |db  |(mm)  |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext   79   9.0    0.130   650.  1700. 0.90 0.70  1200.  0.07 OSB : OSB wood based on the SBEM database
  2  293   50.0   0.032    12.  1000. 0.90 0.70    30.  1.56 Min wool quilt 50mm tb : Studwork
  3  292  200.0   0.032    12.  1000. 0.90 0.70    30.  6.25 Min wool quilt 250 mm tb : Quilt (Min wool q
  4  293   50.0   0.032    12.  1000. 0.90 0.70    30.  1.56 Min wool quilt 50mm tb : Studwork
  5   79    9.0   0.130   650.  1700. 0.90 0.70  1200.  0.07 OSB : OSB wood based on the SBEM database
  6  205   50.0   0.021    30.   837. 0.90 0.50    90.  2.38 Polyurethane foam bd : Polyurethane foam boa
Int  110   13.0   0.210   900.  1000. 0.91 0.26    11.  0.06 Plasterboard (wallboard) : Internal finish (
ISO 6946 U values (horiz/upward/downward heat flow)=  0.082  0.083  0.082 (partition)  0.082
```

Figure 18: Exterior Wall Construction: ESP-r

What is interesting to note is that in ESP-r, whilst the U-values for each material and thickness of each layer is the same as in PHPP, the overall U value performance of the construction is 0.082 W/m²K in ESP-r compared with PHPP's 0.086 W/m²K. These differences in performance are negligible in terms of the overall performance of the Esp-r model, however it is worth noting that there are differences in the calculation methods used by both packages when determining overall performance of a layered material construction.

The next construction is that of the roof. The below figures show the PHPP construction details, followed by the ESP-r representation.

Assembly No. 2 — Building Assembly Description: Roof

Heat Transfer Resistance [m²K/W] — interior R_{si} : 0.10; exterior R_{se} : 0.04

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	Plasterboard	0.210					13
2.	PU insulation TW55	0.021					50
3.	OSB	0.130					9
4.	Mineral wool/I-studs	0.032	softwood	0.130			50
5.	Mineral wool/I-studs	0.032			softwood	0.130	200
6.	Mineral wool/I-studs	0.032	softwood	0.130			50
7.	Sarking boards	0.130					22
8.							

Percentage of Sec. 2: 8.3% — Percentage of Sec. 3: 1.6% — Total: 39.4 cm

U-Value: 0.087 W/(m²K)

Figure 19: Roof Construction: PHPP

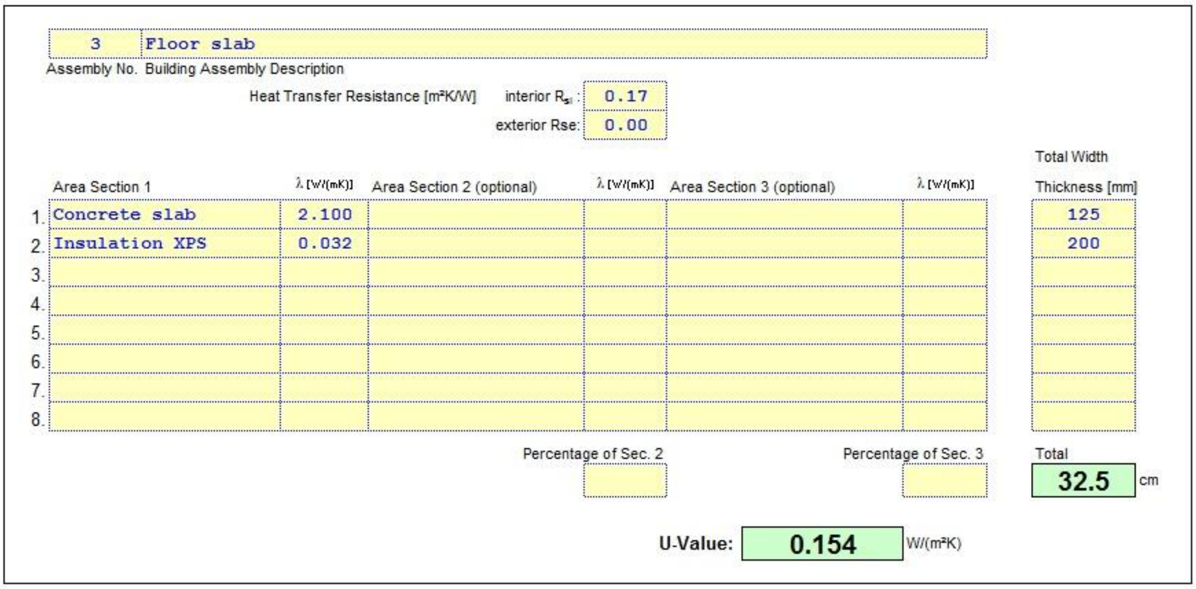
```
Details of opaque construction: roof and overall thickness  0.394

Layer|Matr|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm)  |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext    79   22.0    0.130   650.  1700. 0.90 0.70  1200.  0.17 OSB : OSB wood based on the SBEM database
   2  293   50.0    0.032    12.  1000. 0.90 0.70    30.  1.56 Min wool quilt 50mm tb : Studwork
   3  292  200.0    0.032    12.  1000. 0.90 0.70    30.  6.25 Min wool quilt 250 mm tb : Quilt (Min wool q
   4  293   50.0    0.032    12.  1000. 0.90 0.70    30.  1.56 Min wool quilt 50mm tb : Studwork
   5   79    9.0    0.130   650.  1700. 0.90 0.70  1200.  0.07 OSB : OSB wood based on the SBEM database
   6  205   50.0    0.021    30.   837. 0.90 0.50    90.  2.38 Polyurethane foam bd : Polyurethane foam boa
Int   110   13.0    0.210   900.  1000. 0.91 0.26    11.  0.06 Plasterboard (wallboard) : Internal finish (
ISO 6946 U values (horiz/upward/downward heat flow)=  0.082  0.082  0.082 (partition)  0.081
```

Figure 20: Roof Construction: ESP-r

Again there are differences in U value; ESP-r at 0.082 W/m²K compares to PHPP's 0.087 W/m²K.

Below are the constructions for the floor slab.



3	Floor slab	
Assembly No.	Building Assembly Description	

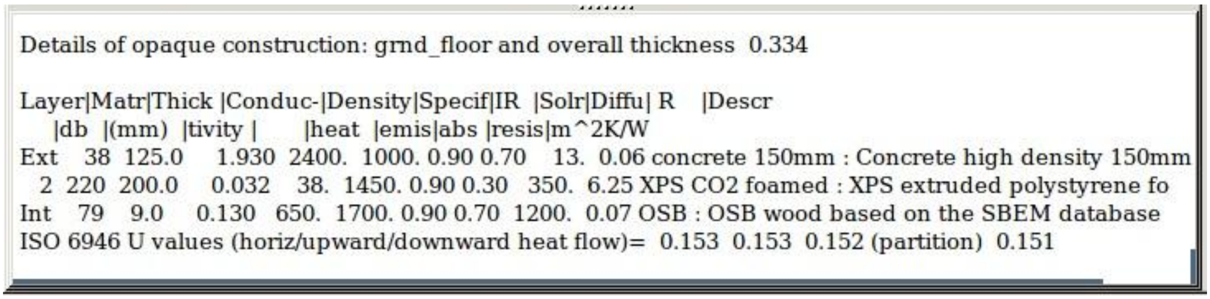
Heat Transfer Resistance [m²K/W] interior R_{si}: 0.17; exterior Rse: 0.00

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	Concrete slab	2.100					125
2.	Insulation XPS	0.032					200
3.							
4.							
5.							
6.							
7.							
8.							

Percentage of Sec. 2 | Percentage of Sec. 3 | Total 32.5 cm

U-Value: 0.154 W/(m²K)

Figure 21: Floor Slab: PHPP



```
Details of opaque construction: grnd_floor and overall thickness  0.334

Layer|Matr|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm)  |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext    38  125.0    1.930  2400.  1000. 0.90 0.70   13.  0.06 concrete 150mm : Concrete high density 150mm
   2  220  200.0    0.032    38.  1450. 0.90 0.30   350.  6.25 XPS CO2 foamed : XPS extruded polystyrene fo
Int    79    9.0    0.130   650.  1700. 0.90 0.70  1200.  0.07 OSB : OSB wood based on the SBEM database
ISO 6946 U values (horiz/upward/downward heat flow)=  0.153  0.153  0.152 (partition)  0.151
```

Figure 22: Floor Slab: ESP-r

In this case the respective U values are nearly identical at 0.154 W/m²K and 0.153 W/m²K.

The PHPP report does not specify construction details for either the ceiling of the ground floor rooms or the floor details for the first floor. Close inspection of the section drawings provided by Fyne Homes shows the dimensions of the floor level and it can be inferred that the makeup of the construction is plasterboard for the ceiling side, 300mm of insulation and a layer of OSB (oriented strand board) for the floor surface. As the Passive House standard only specifies that the exterior fabric of the building has high thermal insulation values, it can be inferred that interior walls and floors do not have an impact on the overall thermal performance of the building. As such the thermal performance of these constructions will not unduly influence the operation of the ESP-r model and so can be based upon the assumptions taken from the sectional drawings. All that is required is that the construction chosen for the ceiling of the ground floor rooms and floors of the first floor rooms match, that the number, materials and order of layers are the same though inverted. The details for the two constructions in ESP-r are detailed in the figures below.

```
Details of opaque construction: susp_ceil and overall thickness  0.322

Layer|Matr|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm)  |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext   79    9.0    0.130   650.  1700. 0.90 0.70  1200.  0.07 OSB : OSB wood based on the SBEM database
  2  292  300.0    0.032    12.  1000. 0.90 0.70    30.  9.38 Min wool quilt 250 mm tb : Quilt (Min wool q
Int  110   13.0    0.210   900.  1000. 0.91 0.26    11.  0.06 Plasterboard (wallboard) : Internal finish (
ISO 6946 U values (horiz/upward/downward heat flow)=  0.103  0.104  0.103 (partition)  0.102
```

Figure 23: Ceiling Construction: ESP-r

```
Details of opaque construction: floor_1 and overall thickness  0.322

Layer|Matr|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm)  |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext  110   13.0    0.210   900.  1000. 0.91 0.26    11.  0.06 Plasterboard (wallboard) : Internal finish (
  2  292  300.0    0.032    12.  1000. 0.90 0.70    30.  9.38 Min wool quilt 250 mm tb : Quilt (Min wool q
Int   79    9.0    0.130   650.  1700. 0.90 0.70  1200.  0.07 OSB : OSB wood based on the SBEM database
ISO 6946 U values (horiz/upward/downward heat flow)=  0.103  0.104  0.103 (partition)  0.102
```

Figure 24: First Floor Construction: ESP-r

As with the first floor and ceiling constructions, no details were given within PHPP for the internal wall constructions. The assumptions taken for the floor and ceiling can also be applied to these internal walls. To this end the construction was based on a standard internal wall; studwork creating an airgap and plasterboard used on each surface.

The final construction needed was that of the glazing. The building uses windows provided by Intranorm, these are certified Passive House windows with an overall U value of 0.8 W/m²K. There are also two Velux windows installed in the roof in the upstairs hall. The U values for Velux Passive House certified windows were not available from the Velux company and so it was assumed that while their thermal performance would not be as efficient as the Intranorm glazing, it would be feasible for the purposes of the model to use the same construction for Velux and Intranorm windows.

Information obtained from Intranorm provided details of the triple glazed units used in the Dunoon house, providing the thickness of each glazing panel, the gaps between the panels and that Argon gas was used to fill these voids. Within ESP-r standard materials database plate glass was chosen for the glazing layers and a standard airgap whose r value was modified to that of Argon was used for the void layers. ESP-r requires optical properties to be defined for any glazing construction. Within the optics database a triple glazed unit was also specified and was deemed suitable for use with the model. The final glazing construction is shown in the figure below.

```
Details of transparent construction: trpl_glaze with TCF6330_06nb optics and overall thickness  0.032

Layer|Matr|Thick |Conduc-|Density|Specif|IR  |Solr|Diffu| R    |Descr
     |db  |(mm)  |tivity |       |heat  |emis|abs |resis|m^2K/W
Ext  242   4.0    0.760  2710.   837. 0.83 0.05 19200.  0.01 plate glass : Plate glass with placeholder s
  2    0  16.0    0.000     0.     0. 0.99 0.99     1.  0.53 air  0.53 0.53 0.53
  3  242   4.0    0.760  2710.   837. 0.83 0.05 19200.  0.01 plate glass : Plate glass with placeholder s
  4    0   4.0    0.000     0.     0. 0.99 0.99     1.  0.53 air  0.53 0.53 0.53
Int  242   4.0    0.760  2710.   837. 0.83 0.05 19200.  0.01 plate glass : Plate glass with placeholder s
ISO 6946 U values (horiz/upward/downward heat flow)=  0.803  0.823  0.778 (partition)  0.749

6_12_6_12_6 2low_e(2,5) + Krypton: with id of: TCF6330_06nb
with 5 layers [including air gaps] and visible trn: 0.63
Direct transmission @ 0, 40, 55, 70, 80 deg
  0.294 0.264 0.218 0.122 0.041
Layer| absorption @ 0, 40, 55, 70, 80 deg
  1  0.250 0.272 0.289 0.324 0.278
  2  0.001 0.001 0.001 0.001 0.001
  3  0.109 0.114 0.115 0.103 0.077
  4  0.001 0.001 0.001 0.001 0.001
  5  0.113 0.115 0.108 0.083 0.039
```

Figure 25: Glazing Construction

4.5.1.3 Geometry and Zones

As discussed in the approach to building the model, it was decided to create zones for each room in the house. The figure below shows the full geometry of the building.

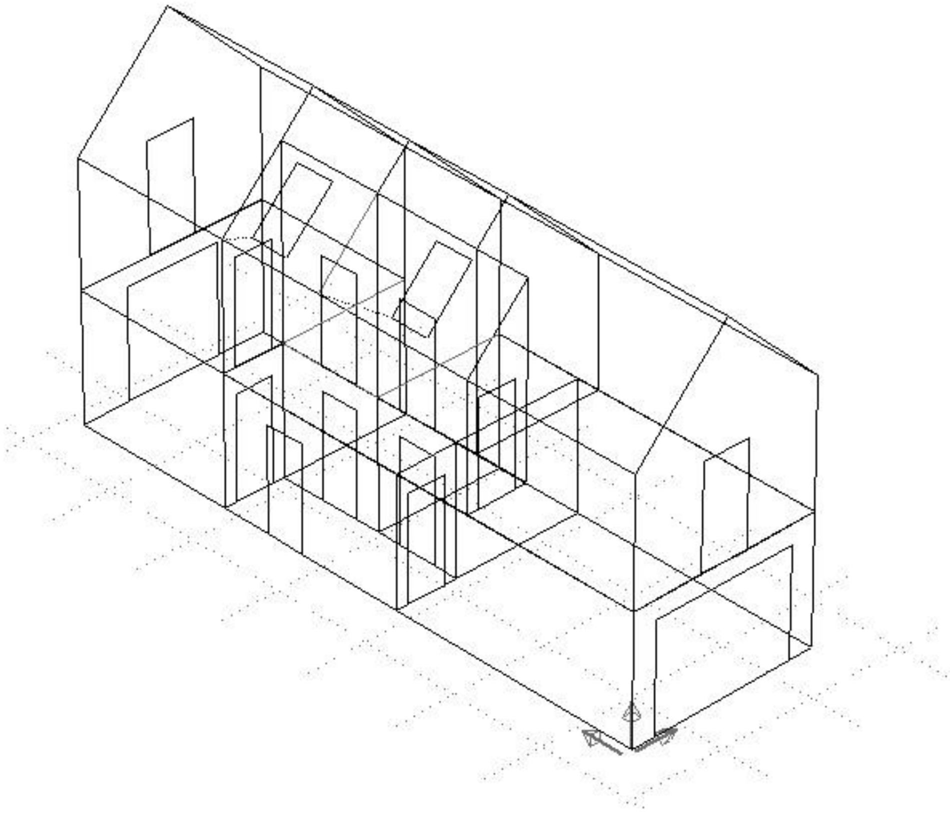


Figure 26: Dunoon House Geometry

The dimensions for each of the rooms were taken from the floor plans and sectional elevations provided by Fyne Homes, detailed in Appendix A. As with the Dunoon site, the building is orientated on an East/West axis, with the living room gable end facing east. The rooms of the first floor have cathedral ceilings, though the cross-sectional elevation only gave ceiling heights for the bedroom above the living room. The assumption was taken that while the upstairs bathroom and the staircase were likely to have a suspended ceiling, there were no construction details given for this and so it would be reasonable to implement a full height ceiling into the roof space of the building. Again the overall impact on the operation of the building would appear to be negligible – so long as the building envelope complied with the Passive House standards a small difference in the overall volume of each room would have minimal impact on the temperatures recorded within them.

The building was split into the following zones/rooms with the corresponding location for monitored data from the Dunoon house;

ESP-r Model Zone	Room Representation	Monitored Data
Liv	Living Room	Temperature
Kit	Kitchen	Temperature
Bed1	Bedroom above kitchen	Temperature
Bed2	Bedroom above living room	Temperature
Bath1	Bathroom on ground floor	
Bath2	Bathroom on first floor	
Hall1	Ground floor hall	
Hall2	First floor hall	

Table 8: Zone Representation

From the plans of the Dunoon house it could be seen that the exterior porch was out with the building envelope and is specified as being unheated. As such building a representation of the porch was deemed to be unnecessary for the operation of the building model.

As can be seen from the above table the zones to compare with the monitored data from the Dunoon house are the living room, kitchen and both bedrooms. The figures below illustrate their geometry and composition.

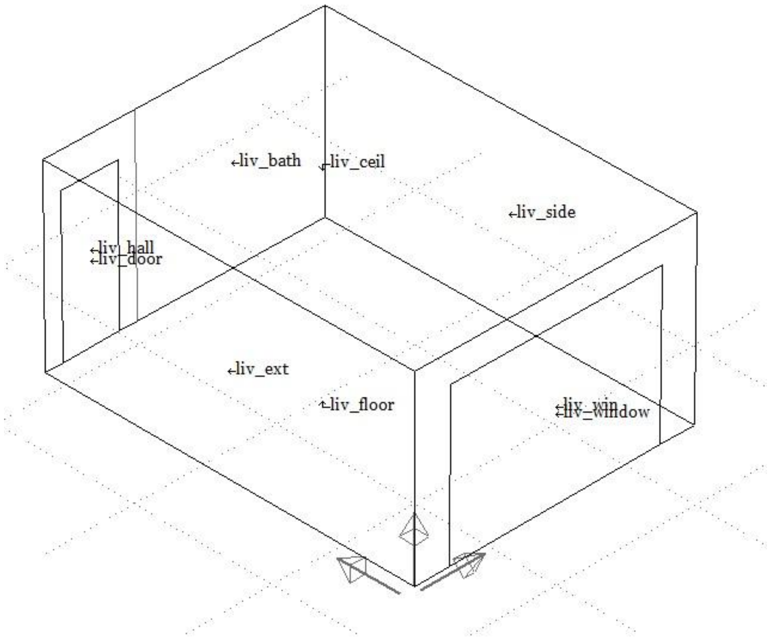


Figure 27: Living Room, ESP-r zone

Zone liv (1) is composed of 9 surfaces and 18 vertices.
It encloses a volume of 55.1m^3 of space, with a total surface area of 90.8m^2 & approx floor area of 21.2m^2
liv describes living room

A summary of the surfaces in liv(1) follows:

Sur	Area m^2	Azim deg	Elev deg	surface name	geometry optical	geometry locat	use	construction name	environment other side
1	3.80	180.	0.	liv_win	OPAQUE	VERT	-	extern_wall	EXTERIOR
2	13.8	90.	0.	liv_side	OPAQUE	VERT	-	extern_wall	SIMILAR
3	7.02	360.	-0.	liv_bath	OPAQUE	VERT	-	intern_wall	ANOTHER
4	1.70	0.	0.	liv_hall	OPAQUE	VERT	-	intern_wall	ANOTHER
5	13.8	270.	0.	liv_ext	OPAQUE	VERT	-	extern_wall	EXTERIOR
6	21.2	0.	90.	liv_ceil	OPAQUE	CEIL	-	susp_ceil	SIMILAR
7	21.2	0.	-90.	liv_floor	OPAQUE	FLOR	-	grnd_floor	GROUND
8	6.60	180.	0.	liv_window	Glaz_not	VERT	-	window_Not_G	EXTERIOR
9	1.68	0.	-0.	liv_door	OPAQUE	VERT	DOOR	int_doors	ANOTHER

Figure 28: Living Room Composition

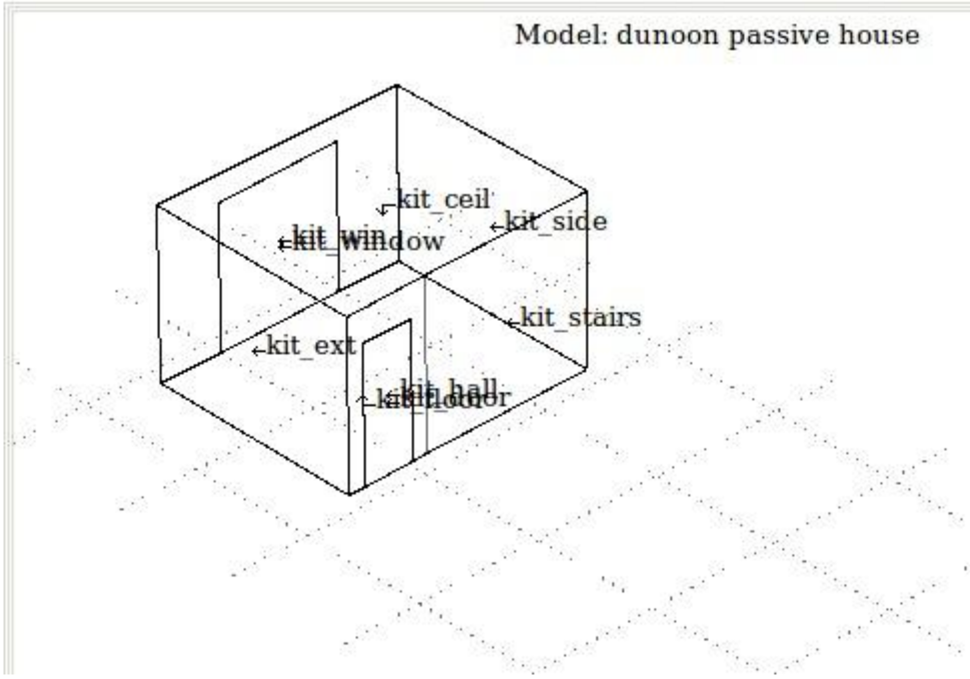


Figure 29: Kitchen, ESP-r Zone

Zone kit (4) is composed of 9 surfaces and 18 vertices.
It encloses a volume of 35.4m^3 of space, with a total surface area of 65.7m^2 & approx floor area of 13.6m^2
kit describes a kitchen

A summary of the surfaces in kit(4) follows:

Sur	Area m^2	Azim deg	Elev deg	surface name	geometry optical	geometry locat	use	construction name	environment other side
1	1.70	180.	0.	kit_hall	OPAQUE	VERT	-	intern_wall	ANOTHER
2	7.02	180.	0.	kit_stairs	OPAQUE	VERT	-	intern_wall	ANOTHER
3	8.84	90.	0.	kit_side	OPAQUE	VERT	-	extern_wall	SIMILAR
4	6.00	0.	0.	kit_win	OPAQUE	VERT	-	extern_wall	EXTERIOR
5	8.84	270.	0.	kit_ext	OPAQUE	VERT	-	extern_wall	EXTERIOR
6	13.6	0.	90.	kit_ceil	OPAQUE	CEIL	-	susp_ceil	ANOTHER
7	13.6	0.	-90.	kit_floor	OPAQUE	FLOR	-	grnd_floor	GROUND
8	1.68	180.	0.	kit_door	OPAQUE	VERT	DOOR	int_doors	ANOTHER
9	4.40	0.	0.	kit_window	TCF6330_	VERT	C-WIN	trpl_glaze	EXTERIOR

Figure 30: Kitchen Composition

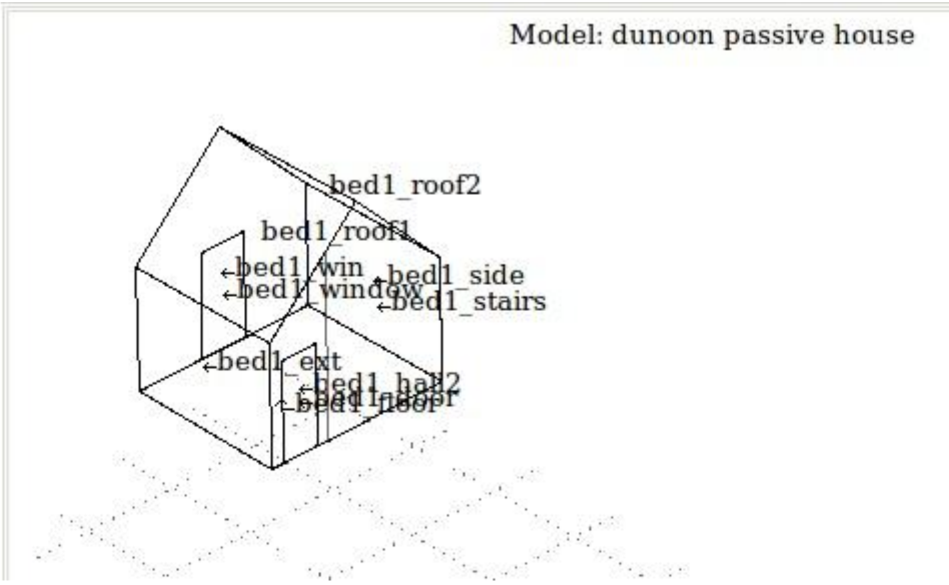


Figure 31: Bedroom 1, ESP-r Zone

Zone bed1 (6) is composed of 10 surfaces and 20 vertices.
It encloses a volume of 48.3m^3 of space, with a total surface area of 78.6m^2 & approx floor area of 13.6m^2
bed1 describes bedroom1

A summary of the surfaces in bed1(6) follows:

Sur	Area m^2	Azim deg	Elev deg	surface name	geometry optical	geometry locat	use	construction name	environment other side
1	2.48	180.	0.	bed1_hall2	OPAQUE	VERT	-	intern_wall	ANOTHER
2	10.0	180.	0.	bed1_stairs	OPAQUE	VERT	-	intern_wall	ANOTHER
3	8.67	90.	0.	bed1_side	OPAQUE	VERT	-	extern_wall	SIMILAR
4	12.0	0.	0.	bed1_win	OPAQUE	VERT	-	extern_wall	EXTERIOR
5	8.67	270.	0.	bed1_ext	OPAQUE	VERT	-	extern_wall	EXTERIOR
6	13.6	0.	-90.	bed1_floor	OPAQUE	FLOR	-	floor_1	ANOTHER
7	9.62	270.	45.	bed1_roof1	OPAQUE	SLOP	-	roof	EXTERIOR
8	9.62	90.	45.	bed1_roof2	OPAQUE	SLOP	-	roof	EXTERIOR
9	1.68	180.	0.	bed1_door	OPAQUE	VERT	DOOR	int_doors	ANOTHER
10	2.20	360.	0.	bed1_window	TCF6330_	VERT	-	trpl_glaze	EXTERIOR

Figure 32: Bedroom 1 Composition

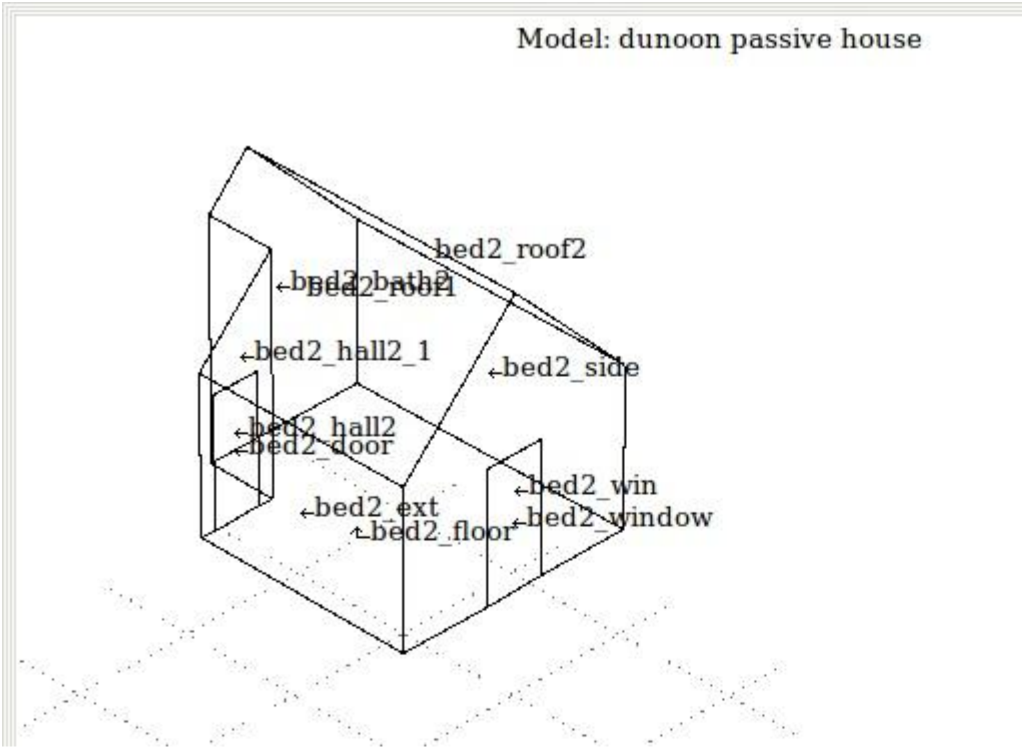


Figure 33: Bedroom, ESP-r Zone

Zone bed2 (8) is composed of 11 surfaces and 22 vertices.
It encloses a volume of 64.1m^3 of space, with a total surface area of 97.9m^2 & approx floor area of 17.9m^2
bed2 describes bedroom2

A summary of the surfaces in bed2(8) follows:

Sur	Area m^2	Azim deg	Elev deg	surface name	geometry optical	geometry locat	use	construction name	environment other side
1	12.1	180.	0.	bed2_win	OPAQUE	VERT	-	extern_wall	EXTERIOR
2	12.4	90.	0.	bed2_side	OPAQUE	VERT	-	extern_wall	SIMILAR
3	10.0	360.	0.	bed2_bath2	OPAQUE	VERT	-	intern_wall	ANOTHER
4	4.43	270.	-0.	bed2_hall2_1	OPAQUE	VERT	-	intern_wall	ANOTHER
5	2.48	0.	0.	bed2_hall2	OPAQUE	VERT	-	intern_wall	ANOTHER
6	9.44	270.	0.	bed2_ext	OPAQUE	VERT	-	extern_wall	EXTERIOR
7	17.9	0.	-90.	bed2_floor	OPAQUE	FLOR	-	floor_1	SIMILAR
8	11.6	270.	45.	bed2_roof1	OPAQUE	SLOP	-	roof	EXTERIOR
9	13.7	90.	45.	bed2_roof2	OPAQUE	SLOP	-	roof	EXTERIOR
10	1.68	0.	-0.	bed2_door	OPAQUE	VERT	DOOR	int_doors	ANOTHER
11	2.10	180.	0.	bed2_window	TCF6330_	VERT	C-WIN	trpl_glaze	EXTERIOR

Figure 34: Bedroom 2 Composition

4.5.2 Airflow Network

The model in ESP-r required an airflow network to simulate two processes; simulating the operation of the MVHR and simulating the airflow created by the opening of windows.

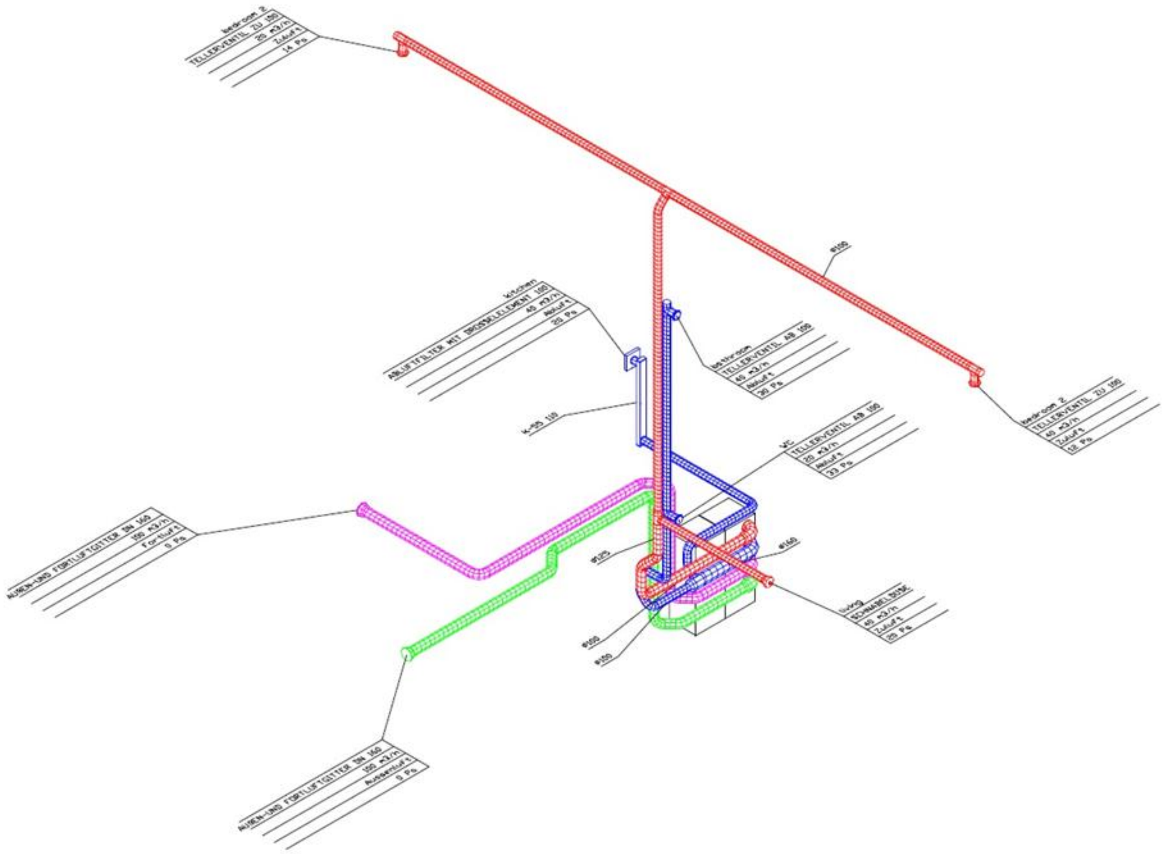


Figure 35: 3D Detail of MVHR Layout (source: Fyne Homes)

The network was built up in the following stages;

- Defining nodes for each zone and boundaries
- Defining components
- Defining connections

The first aspect of the network to be created was the interconnection between the model zones. Nodes were designated for each of the zones of the model; these internal nodes were located centrally within the volume of the zone rather than be attached to a specific surface. Next boundary nodes had to be defined to enable simulation of airflow through window openings. To enable connections to be made between these nodes components had to be defined to represent the paths of airflow within the model.

VENTILATION DATA

Building: Bethania, Typ D (Plot 15)

Treated Floor Area A_{TFA}	m²	88	*(Areas worksheet)*
Room Height h	m	2.5	*(Annual Heat Demand worksheet)*
Room Ventilation Volume (A_{TFA}*h) V_V	m³	221	*(Annual Heat Demand worksheet)*

Ventilation System Design - Standard Operation

Occupancy	m²/P	35				
Number of Occupants	P	2.5				
Supply Air per Person	m³/(P*h)	30				
Supply Air Requirement	m³/h	76				
Extract Air Rooms		Kitchen	Bathroom	Shower	WC	
Quantity		1	1	0	1	
Extract Air Requirement per Room	m³/h	40	40	20	20	
Total Extract Air Requirement	m³/h	100				
Design Air Flow Rate (Maximum)	m³/h	100				

Average Air Change Rate Calculation

Type of Operation	Daily Operation Duration h/d	Factors Referenced to Maximum	Air Flow Rate m³/h	Air Change Rate 1/h
Maximum		1.00	100	0.45
Standard	14.0	0.77	77	0.35
Basic	10.0	0.54	54	0.24
Minimum		0.40	40	0.18
x Residential Building	Average value	0.67	Average Air Flow Rate (m³/h): 67	Average Air Change Rate (1/h): 0.30

Table 9: Ventilation Data for Dunoon Passive House

The above figure details the airflow rates within the Dunoon house as specified in the PHPP report. The supply air requirement is given as 76 m³/h while the extraction requirement is given as 100 m³/h. Extraction occurs from the Kitchen and the two bathrooms whilst supply air is provided in the two bedrooms and the living room. Detailed plans of the ventilation network and MVHR can be found in Appendix D.

For the Passive House standard the airflow between the rooms is designed to take place via vents within the door frames – either as a grill in the door itself or as an opening in the door frame lintel. The simplest component to use from ESP-r was to define the opening as a specifically dimensioned crack in the door – this allows for variation in the flow of air through the component, rather than specifying a specific volume flow rate. From the Passive House certification course information this ventilation gap is 20-30mm in depth and runs the width of the door frame. This allows adequate flow of air between the rooms.

The window openings then had to be defined. These were designated as specific openings and were defined as an area for within ESP-r. From the questionnaire results (Appendix B) window openings were given as “a small gap.” The Intranorm windows that were installed in the Dunoon house have a standard tilt and turn mechanism for opening and so it was assumed that the tilt opening was used when the occupant opened a window in this manner. This results in an opening of 150mm. For both the kitchen and bedrooms the windows were 1m in width, resulting in an opening of 0.15m². For the living room there were two windows of 1m in width that could be opened, so for the airflow network the area of opening was defined as 0.3m².

As well as defining the window openings for the airflow network to work within the simulation a crack needed to be specified for air to flow when the windows were closed. From the PHPP report the air penetration through the fabric of the building was given as 0.032 air changes per hour where the building has several sides exposed.

Infiltration Air Change Rate according to EN 13790

Wind Protection Coefficients According to EN 13790		
Coefficient e for Screening Class	Several Sides Exposed	One Side Exposed
No Screening	0.10	0.03
Moderate Screening	0.07	0.02
High Screening	0.04	0.01
Coefficient f	15	20

			for Annual Demand:	for Heat Load:				
Wind Protection Coefficient, e			0.06	0.14				
Wind Protection Coefficient, f			15	15	Net Air Volume for Press. Test	V_{n50}	Air Permeability	q_{50}
Air Change Rate at Press. Test	n_{50}	1/h	0.40	0.40	317	m³	0.42	m³/(hm²)

Type of Ventilation System

				for Annual Demand:	for Heat Load:
x	Balanced PH Ventilation	*Please Check*			
	Pure Extract Air				
	Excess Extract Air		1/h	0.00	0.00
	Infiltration Air Change Rate	$n_{V,Res}$	1/h	0.032	0.079

Figure 36: Infiltration Air Change Rate

The cracks required for the airflow network to operate within the building simulation software would also allow for the infiltration air change rate through the buildings fabric.

The last components to be defined were those of the MVHR. As the simulations were taking place during the summer months with a view to overheating from solar gains it was taken as a reasonable assumption that the MVHR would only be providing minimal, if any, heating load. As such it would be performing purely on the basis of extracting and supplying air, not heating. This simplified the requirements of the ESP-r model, the MVHR could be abstracted as purely supplying and extracting air from specific zones. This resulted in defining components within ESP-r as detailed in the table below.

Zone	**Extract/Supply**	**Airflow Rate (m^3/h)**
Kitchen	Extract	40
Bathroom1	Extract	40
Bathroom2	Extract	40
Living Room	Supply	60
Bedroom1	Supply	20
Bedroom2	Supply	20

Table 10: Air Extract/Supply for Zones

Fan components were then created with the relevant airflow rates then connected to the airflow network. The final listing of nodes, components and connections is listed below.

Nodes

Name	Fluid	Type	Height	Data1	Data2
a liv	air	internal	1.30	0.0	55.1
b hall	air	internal	1.30	0.0	13.5
c bath1	air	internal	1.30	0.0	12.6
d kit	air	internal	1.30	0.0	35.4
e hall2	air	internal	4.53	0.0	23.3
f bed1	air	internal	4.88	0.0	48.3
g bath2	air	internal	4.88	0.0	22.6
h bed2	air	internal	4.88	0.0	64.1
i stairs	air	internal	3.58	0.0	37.5
j liv_window	air	bound wind P	2.20	1.0	180.0
k bed2_window	air	bound wind P	4.80	1.0	180.0
l kit_window	air	bound wind P	2.20	1.0	0.0
m bed1_window	air	bound wind P	4.80	1.0	1.0
n velux1	air	bound wind P	5.82	8.0	270.0
o velux2	air	bound wind P	5.82	8.0	270.0
p outside	air	bound wind P	1.17	1.0	270.0

\+ add/delete/copy node
? Help
\- Exit

Figure 37: Airflow Network Nodes

Components

Name	Type	Description ...	
a door_vent	110	Specific air flow opening	m = rho.f(A,dP)
b bed_win_cra	120	Specific air flow crack	m = rho.f(W,L,dP)
c liv_win_cra	120	Specific air flow crack	m = rho.f(W,L,dP)
d kit_win_cra	120	Specific air flow crack	m = rho.f(W,L,dP)
e liv_win_op	110	Specific air flow opening	m = rho.f(A,dP)
f kit_win_op	110	Specific air flow opening	m = rho.f(A,dP)
g bed_win_op	110	Specific air flow opening	m = rho.f(A,dP)
h vel_win_cra	120	Specific air flow crack	m = rho.f(W,L,dP)
i fan_ext	30	Constant vol. flow rate component	m = rho.a
j fav_liv	30	Constant vol. flow rate component	m = rho.a
k fan_bed1	30	Constant vol. flow rate component	m = rho.a
l fan_bed2	30	Constant vol. flow rate component	m = rho.a
m fan_bath	30	Constant vol. flow rate component	m = rho.a

\+ add/delete/copy component
? Help
\- Exit

Figure 38: Airflow Network Components

```
Connections
 Node +ve     |dHght|to| Node -ve    |dHght|via Component
a hall          0.0 --> liv           0.0  door_vent
b hall          0.0 --> kit           0.0  door_vent
c hall          0.0 --> bath1         0.0  door_vent
d hall          1.1 --> stairs       -1.1  door_vent
e stairs        0.5 --> hall2        -0.5  door_vent
f hall2         0.2 --> bed1         -0.2  door_vent
g hall2         0.2 --> bed2         -0.2  door_vent
h hall2         0.2 --> bath2        -0.2  door_vent
i liv_window   -0.4 --> liv           0.4  liv_win_op
j liv_window   -0.4 --> liv           0.4  liv_win_cra
k bed2_window   0.0 --> bed2         -0.0  bed_win_cra
l kit_window   -0.4 --> kit           0.4  kit_win_cra
m bed1_window   0.0 --> bed1         -0.0  bed_win_cra
n velux1       -0.6 --> hall2         0.6  bed_win_op
o velux1       -0.6 --> hall2         0.6  vel_win_cra
p velux2       -0.6 --> hall2         0.6  bed_win_op
q velux2       -0.6 --> hall2         0.6  vel_win_cra
r liv          -0.1 --> outside       0.1  fav_liv
s kit          -0.1 --> outside       0.1  fan_ext
t bath1        -0.1 --> outside       0.1  fan_bath
u bath2        -1.9 --> outside       1.9  fan_bath
v bed2         -1.9 --> outside       1.9  fan_bed2
w bed1         -1.9 --> outside       1.9  fan_bed1
 ____________________
+ add/delete/copy
? Help
- Exit
```

Figure 39: Airflow Network Connections

With the airflow network now defined controls could be created for the operation of the windows. From the anecdotal evidence gained from the questionnaire the MVHR was kept on the automatic setting. Referring to the manual for the MCVHR (Thermos 200/300 DC Unit) this meant that the unit maintained a constant flow of air within the building, with no variation of flow rates. The unit would automatically supply air heating dependant on the temperatures recorded in the home though as has previously been discussed heat was decided to be negligible for the time-frame of this project. As such the fan components used within the airflow network could be left as operational throughout the day.

For the window opening schedule the questionnaire provided a basis for the temperatures used to set the windows as open or closed. As described in chapter 3.3 the monitored data from the Dunoon house and the schedule of window opening provided by the occupants showed that windows were opened when the air temperature reached 22 °C, whilst they were closed when the air temperature of a room fell to 17 °C. These controls were set for each window, enabling a close approximation of the inhabitant's intervention when the air temperature reached an uncomfortable (for them) temperature.

4.5.3 Internal Gains

The main internal gains to be defined for the model are those of occupancy gains. The Dunoon house is home to a couple and their young teenage daughter. As part of the questionnaire process they were asked to define their average occupancy times of the house during the summer months of June, July and August. The table below is their response.

Day	**Time** (i.e. midnight – 9am, 12pm – 1pm, 6pm -midnight)
Monday	midnight – 9am, 5pm onwards
Tuesday	midnight – 9am, 5pm onwards
Wednesday	midnight – 9am, 5pm onwards
Thursday	midnight – 9am, 5pm onwards
Friday	midnight – 9am, 5pm onwards
Saturday	midnight – 10am,6pm onwards
Sunday	midnight – 10am,6pm onwards

Table 11: Average Occupancy Times

This response would form the basis of the occupancy gain schedule for the ESP-r model. As the model defined zones to represent each of the rooms of the home, these occupancy gains would need to be defined for each room. Occupancy gains for an individual are defined within ESP-r as a heat gain in Watts, a sensible gain and a latent gain. Within the software the average gain of an individual is defined as 100W sensible and 50W latent. For the occupants of the Dunoon house the number of occupants can be defined as 2.5 – two adults and one child. This provides an overall gain of 250W sensible and 125W latent to be distributed within the zones dependent upon the times individual zones are occupied.

It can be assumed that the main rooms that would be occupied would be the two bedrooms for sleeping, the living room, and for short periods the kitchen and bathrooms. The halls and stairwell are used to transit between these rooms and so would it can be assumed that they would have minimal occupancy times and so could be omitted from having occupancy gains in the model.

Occupancy periods for each zone were based on reasonable assumptions as to the use of these rooms, the time periods allocated then take the results of the questionnaire as a basis for defining these times. The occupancy schedule and associated gains are listed in the table below.

Zone	Occupancy Period & Gain	Occupancy Period & Gain
Kitchen	07-08hrs @250W	18-19hrs @250W
Living Room	08-09hrs @250W	19hrs – 22hrs @250W
Bedroom 1	00-07hrs @50W	21-24hrs @50W
Bedroom 2	00-07hrs @ 200W	22-24hrs @200W

Table 12: Occupancy Schedule

4.5.4 Simulations of Dunoon Model & Comparison to Monitored Data

With the ESP-r model now defined it was possible to begin simulations of the Dunoon model to see how the results obtained would compare with the monitored data from the actual home. Simulations were run to conform to the matrix of variables previously outlined in Chapter 3.2.

In order to compare the ESP-r simulation results it was first necessary to take the monitored data and determine the percentage of overheating for each temperature (and hence room) recorded. The data logs could be converted to Excel documents, with the range of temperatures recorded listed in a single column for each temperature sensor. The number instances of temperatures logged above 22 °C (as this was the temperature where the Dunoon occupants would be driven to regulate the room temperature by opening windows) could be counted using the COUNTIF function in Excel, this figure could then be divided by the number of cells to give the frequency of overheating for the Dunoon house for each of the rooms with temperature recorded.

For ESP-r the results analysis program can give provide a frequency distribution of temperatures for all zones in 1 degree increments. This allows the model to be analysed for the frequency of overheating for any given temperature used as the threshold for thermal comfort.

Finally graphed results from the ESP-r model can be compared with similar periods of monitored data to ascertain if the temperature fluctuations within the simulated model were similar to that of the recorded data.

4.5.4.1 Frequency of Overheating from Monitored Data

The table below provides the percentage overheating at 22 °C for the monitored rooms of the Dunoon house. The table shows the percentage overheating for each room for each date of recorded data with an overall average for each room given in the bottom row. This gives an overall frequency of overheating for the Dunoon house as 2.9% which matches that predicted by the PHPP report for Dunoon. However PHPP sets the boundary for overheating at 25 °C and has been said the occupants of the Dunoon house were opening windows to ventilate heat at 22 °C.

Date of Monitored Data	**Kitchen**	**Bedroom 2**	**Bedroom 1**	**Living Room**
07 June 2011	0.81	0.67	3.50	0.00
16 June 2011	1.07	0.00	11.56	0.00
26 June 2011	2.89	0.19	0.00	0.00
12 July 2011	0.00	0.00	0.00	1.11
21 July 2011	4.67	11.76	0.00	12.10
05 August 2011	1.01	7.47	0.00	1.99
16 August 2011	12.75	5.37	2.16	0.00
25 August 2011	4.92	0.17	5.30	3.64
Average frequency of overheating (% >22C)	3.52	3.21	2.81	2.35

Table 13: Frequency of Overheating of Dunoon House from Monitored Data

It is reasonable to assume that if the threshold was set to 25 °C then the frequency of overheating would be less, though there would be a possibility of it being the same.

4.5.4.2 Frequency of Overheating for ESP-r Simulations of Dunoon Model

Simulations were carried out in line with those set out by the matrix of variables. The most pertinent of these are detailed below. The first set to be completed ran the Dunoon model as close to the existing building as possible; MVHR operational, windows with a control system for opening and an occupancy gain schedule based on the current owners average occupancy times.

Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri- bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<10.5	0	0.0	0.0	0.0
1	10.50-11.50	24	0.02	24	0.02
2	11.50-12.50	115	0.10	139	0.12
3	12.50-13.50	166	0.14	305	0.26
4	13.50-14.50	421	0.35	726	0.61
5	14.50-15.50	1128	0.95	1854	1.55
6	15.50-16.50	2348	1.97	4202	3.52
7	16.50-17.50	4510	3.78	8712	7.31
8	17.50-18.50	6693	5.61	15405	12.92
9	18.50-19.50	10501	8.81	25906	21.73
10	19.50-20.50	15585	13.07	41491	34.80
11	20.50-21.50	20151	16.90	61642	51.70
12	21.50-22.50	18786	15.76	80428	67.46
13	22.50-23.50	13736	11.52	94164	78.98
14	23.50-24.50	9701	8.14	103865	87.11
15	24.50-25.50	6258	5.25	110123	92.36
16	25.50-26.50	3913	3.28	114036	95.64
17	26.50-27.50	2569	2.15	116605	97.80
18	27.50-28.50	1158	0.97	117763	98.77
19	28.50-29.50	763	0.64	118526	99.41
20	29.50-30.50	266	0.22	118792	99.63
21	30.50-31.50	148	0.12	118940	99.76
22	31.50-32.50	102	0.09	119042	99.84
23	32.50-33.50	64	0.05	119106	99.89
24	33.50-34.50	45	0.04	119151	99.93
25	34.50-35.50	52	0.04	119203	99.98
26	35.50-36.50	8	0.01	119211	99.98
27	36.50-37.50	5	0.00	119216	99.99
28	37.50-38.50	7	0.01	119223	99.99
29	38.50-39.50	9	0.01	119232	100.00
30	>39.5	0	0.0	0.0	0.0

Figure 40: Temperature Frequency Distribution of Dunoon Model

There are both similarities and discrepancies between this model and that of the existing house. The frequency of overheating with the threshold at 25.5 °C is 4.36% and while this is higher than that of the PHPP package it is well within the 10% level set by the package. With the threshold set to 22.5 °C it does not compare well to the monitored data with a frequency of 21%.

Lib: dunoon_rotate.res: Results for passive_house
Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri-bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<12.5	0	0.0	0.0	0.0
1	12.50-13.50	56	0.05	56	0.05
2	13.50-14.50	121	0.10	177	0.15
3	14.50-15.50	251	0.21	428	0.36
4	15.50-16.50	555	0.47	983	0.82
5	16.50-17.50	1558	1.31	2541	2.13
6	17.50-18.50	2530	2.12	5071	4.25
7	18.50-19.50	4969	4.17	10040	8.42
8	19.50-20.50	9685	8.12	19725	16.54
9	20.50-21.50	20621	17.29	40346	33.84
10	21.50-22.50	29049	24.36	69395	58.20
11	22.50-23.50	18934	15.88	88329	74.08
12	23.50-24.50	11662	9.78	99991	83.86
13	24.50-25.50	7741	6.49	107732	90.35
14	25.50-26.50	4343	3.64	112075	94.00
15	26.50-27.50	2886	2.42	114961	96.42
16	27.50-28.50	1719	1.44	116680	97.86
17	28.50-29.50	947	0.79	117627	98.65
18	29.50-30.50	639	0.54	118266	99.19
19	30.50-31.50	345	0.29	118611	99.48
20	31.50-32.50	206	0.17	118817	99.65
21	32.50-33.50	156	0.13	118973	99.78
22	33.50-34.50	99	0.08	119072	99.87
23	34.50-35.50	59	0.05	119131	99.92
24	35.50-36.50	37	0.03	119168	99.95
25	36.50-37.50	36	0.03	119204	99.98
26	37.50-38.50	11	0.01	119215	99.99
27	38.50-39.50	7	0.01	119222	99.99
28	39.50-40.50	10	0.01	119232	100.00

Figure 41: Frequency Distribution with Site Orientation N/S

With the building rotated 90° so that the living room was now facing south there is a marked rise in the frequency of overheating with a threshold of 25.5 °C with a 9.65% occurrence. The figure is even greater for a threshold of 22.5 °C, with a frequency of 41.8% - this would definitely prove to be uncomfortable for the current occupants of the Dunoon house. Due to the difference between the two sets of above results it was assumed that for simulations with variances of window and MVHR operation, changing the orientation of the building to north/south would result in a greater frequency of overheating no matter the variables used. As such running further simulations changing the building orientation was not necessary.

The performance of the model when the windows were not opened and only the MVHR provided ventilation was next to be simulated. The figure below gives the frequency distribution for the model where the windows were not opened and only the MVHR provided ventilation.

Lib: dunoon2.res: Results for passive_house
Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri- bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<12.5	0	0.0	0.0	0.0
1	12.50-13.50	51	0.04	51	0.04
2	13.50-14.50	132	0.11	183	0.15
3	14.50-15.50	253	0.21	436	0.37
4	15.50-16.50	673	0.56	1109	0.93
5	16.50-17.50	1450	1.22	2559	2.15
6	17.50-18.50	2375	1.99	4934	4.14
7	18.50-19.50	4571	3.83	9505	7.97
8	19.50-20.50	8467	7.10	17972	15.07
9	20.50-21.50	18405	15.44	36377	30.51
10	21.50-22.50	29303	24.58	65680	55.09
11	22.50-23.50	22649	19.00	88329	74.08
12	23.50-24.50	12068	10.12	100397	84.20
13	24.50-25.50	8122	6.81	108519	91.01
14	25.50-26.50	4800	4.03	113319	95.04
15	26.50-27.50	2794	2.34	116113	97.38
16	27.50-28.50	1698	1.42	117811	98.81
17	28.50-29.50	944	0.79	118755	99.60
18	29.50-30.50	291	0.24	119046	99.84
19	30.50-31.50	113	0.09	119159	99.94
20	31.50-32.50	51	0.04	119210	99.98
21	32.50-33.50	15	0.01	119225	99.99
22	33.50-34.50	7	0.01	119232	100.00
23	>34.5	0	0.0	0.0	0.0

Figure 42: Frequency Distribution for Closed Windows

Not surprisingly with the windows closed the model experiences a greater frequency of overheating at nearly 26% where the threshold is given as 22.5 °C, though there is a frequency of 4.96% where the threshold is given as 25.5 °C. While within the temperature boundary used by PHPP, this does raise concerns for thermal comfort within the model as there are occasional spikes in temperatures up to 34.5 °C though these spikes may be aberrations in the model itself.

To counterbalance this result a simulation was run with the MVHR switched off but the windows opened with the control loops set at 22 °C as the opening threshold.

Lib: dunoon_mvhr_off.res: Results for passive_house
Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri- bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<11.0	0	0.0	0.0	0.0
1	11.00-13.00	122	0.10	122	0.10
2	13.00-15.00	360	0.30	482	0.40
3	15.00-17.00	685	0.57	1167	0.98
4	17.00-19.00	1871	1.57	3038	2.55
5	19.00-21.00	4466	3.75	7504	6.29
6	21.00-23.00	9775	8.20	17279	14.49
7	23.00-25.00	15389	12.91	32668	27.40
8	25.00-27.00	20477	17.17	53145	44.57
9	27.00-29.00	22904	19.21	76049	63.78
10	29.00-31.00	18081	15.16	94130	78.95
11	31.00-33.00	13178	11.05	107308	90.00
12	33.00-35.00	7518	6.31	114826	96.30
13	35.00-37.00	2828	2.37	117654	98.68
14	37.00-39.00	1079	0.90	118733	99.58
15	39.00-41.00	357	0.30	119090	99.88
16	41.00-43.00	113	0.09	119203	99.98
17	43.00-45.00	19	0.02	119222	99.99
18	45.00-47.00	10	0.01	119232	100.00
19	>47.0	0	0.0	0.0	0.0

Figure 43: Frequency Distribution: MVHR Off, Windows Open

With the MVHR not running, the temperatures within the building increase, even with the opening of windows. Indeed the frequency of overheating at 25 °C is 55%! This may at first appear too large a frequency, however the design of the Passive House standard ensures that as much heat is retained within the building as possible. The high levels of thermal insulation of the building, plus the airtightness levels for the fabric of the building would appear retain heat within the building, even with the ventilation provided by the opening of windows. It would appear that the continual supply and circulation of fresh air provided by the MVHR does influence the air temperature quite strongly and that the opening of windows only provides a “top-up” of ventilation.

The results of these simulations led to the decision of which simulations to run for the other sites to be appraised within Scotland. There appears to be no need to run further simulations with variations on the operation of the MVHR and windows. Indeed as the model provided a close approximation of how the Dunoon Passive House currently operates, with the assumed level of occupancy, the operation of MVHR and control schedule for operating windows, it seems logical that the simulations run for other sets of climate data would be those that would generate results using the same model as that which was closest to the actual Dunoon house.

5 Results

5.1 ESP-r Simulation Results for Scottish Sites

5.1.1 Aberdeen Results

Lib: aberdeen1.res: Results for passive_house
Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri- bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<10.5	0	0.0	0.0	0.0
1	10.50-11.50	10	0.01	10	0.01
2	11.50-12.50	43	0.04	53	0.04
3	12.50-13.50	152	0.13	205	0.17
4	13.50-14.50	443	0.37	648	0.54
5	14.50-15.50	754	0.63	1402	1.18
6	15.50-16.50	1704	1.43	3106	2.61
7	16.50-17.50	3083	2.59	6189	5.19
8	17.50-18.50	5322	4.46	11511	9.65
9	18.50-19.50	8145	6.83	19656	16.49
10	19.50-20.50	11320	9.49	30976	25.98
11	20.50-21.50	17200	14.43	48176	40.41
12	21.50-22.50	23436	19.66	71612	60.06
13	22.50-23.50	18036	15.13	89648	75.19
14	23.50-24.50	11029	9.25	100677	84.44
15	24.50-25.50	6072	5.09	106749	89.53
16	25.50-26.50	4776	4.01	111525	93.54
17	26.50-27.50	2944	2.47	114469	96.01
18	27.50-28.50	1891	1.59	116360	97.59
19	28.50-29.50	1097	0.92	117457	98.51
20	29.50-30.50	729	0.61	118186	99.12
21	30.50-31.50	401	0.34	118587	99.46
22	31.50-32.50	373	0.31	118960	99.77
23	32.50-33.50	189	0.16	119149	99.93
24	33.50-34.50	49	0.04	119198	99.97
25	34.50-35.50	34	0.03	119232	100.00
26	>35.5	0	0.0	0.0	0.0

Figure 44: Frequency Overheating Distribution: Aberdeen

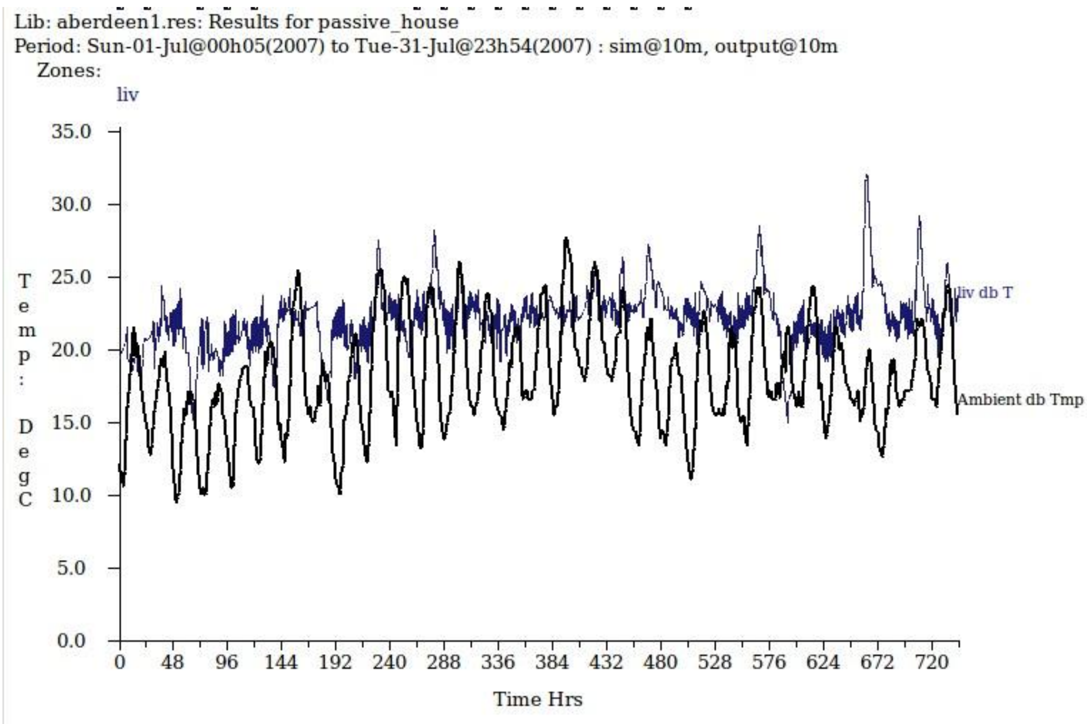


Figure 45: Living Room Temp & Ambient Temp (°C)

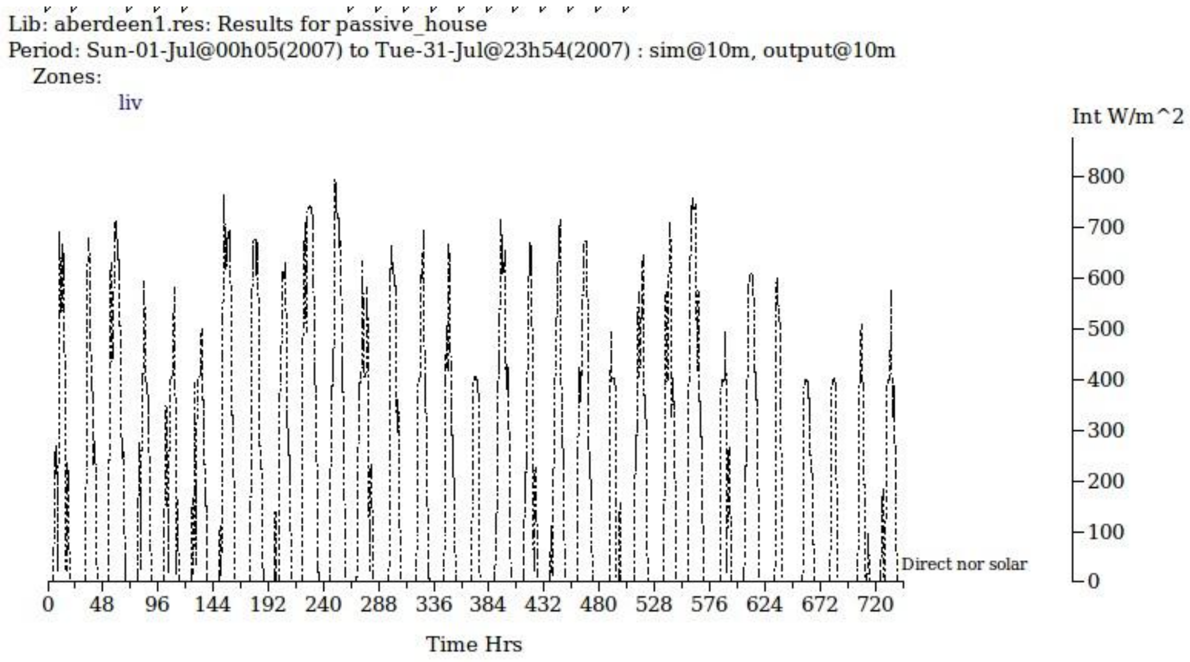


Figure 46: Solar Gains for Aberdeen in July

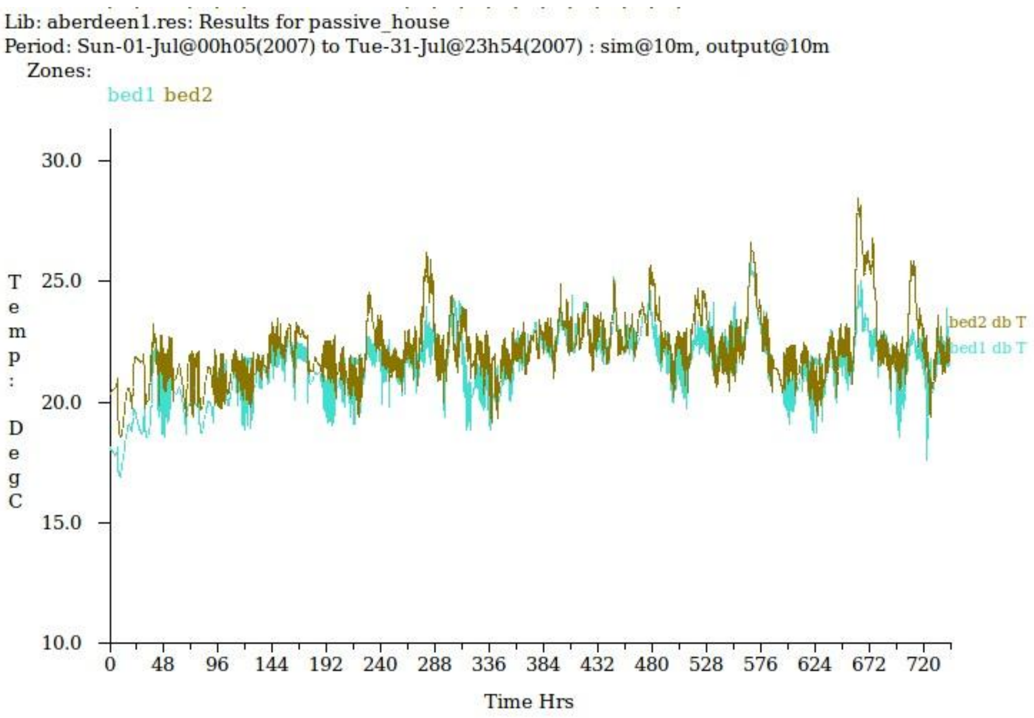


Figure 47: Bedrooms 1 & 2 Temperatures (°C)

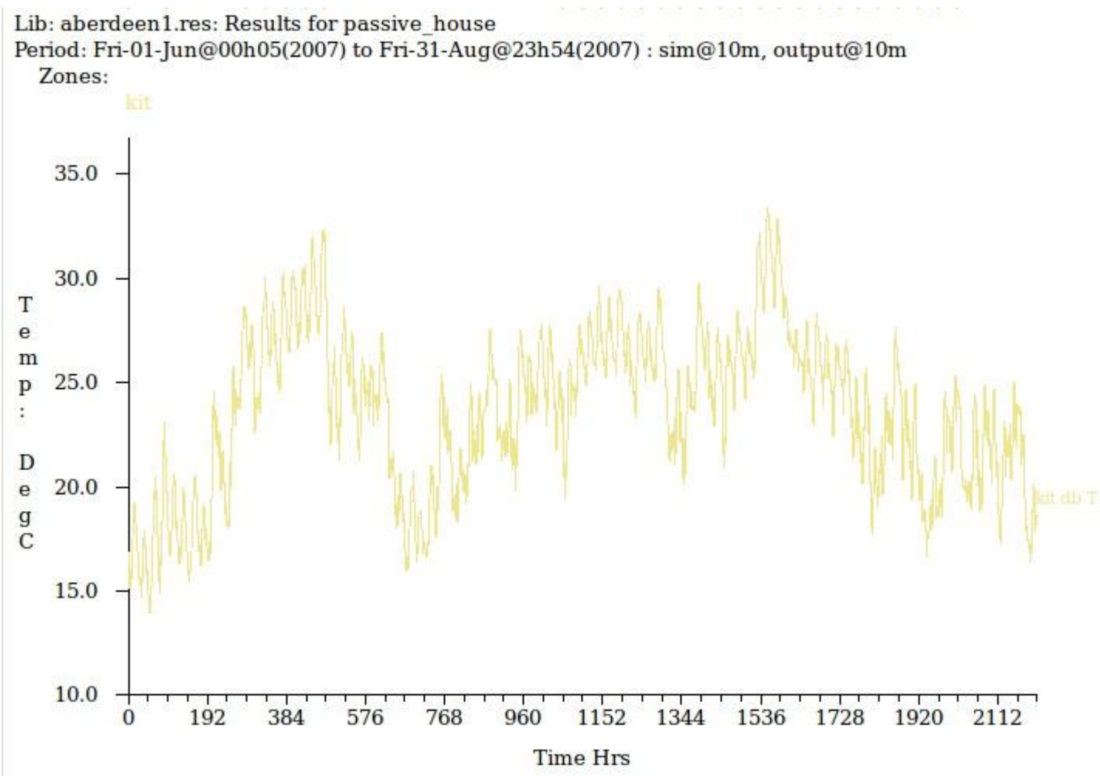


Figure 48: Kitchen Temperatures (°C)

5.1.2 Braemar Results

Lib: braemar1.res: Results for passive_house
Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri- bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<10.5	0	0.0	0.0	0.0
1	10.50-11.50	18	0.02	18	0.02
2	11.50-12.50	20	0.02	38	0.03
3	12.50-13.50	35	0.03	73	0.06
4	13.50-14.50	110	0.09	183	0.15
5	14.50-15.50	326	0.27	509	0.43
6	15.50-16.50	624	0.52	1133	0.95
7	16.50-17.50	1188	1.00	2321	1.95
8	17.50-18.50	2453	2.06	4774	4.00
9	18.50-19.50	5790	4.86	10564	8.86
10	19.50-20.50	9957	8.35	20521	17.21
11	20.50-21.50	16038	13.45	36559	30.66
12	21.50-22.50	21755	18.25	58314	48.91
13	22.50-23.50	19799	16.61	78113	65.51
14	23.50-24.50	13881	11.64	91994	77.16
15	24.50-25.50	8919	7.48	100913	84.64
16	25.50-26.50	6364	5.34	107277	89.97
17	26.50-27.50	4852	4.07	112129	94.04
18	27.50-28.50	3190	2.68	115319	96.72
19	28.50-29.50	2051	1.72	117370	98.44
20	29.50-30.50	1025	0.86	118395	99.30
21	30.50-31.50	472	0.40	118867	99.69
22	31.50-32.50	208	0.17	119075	99.87
23	32.50-33.50	94	0.08	119169	99.95
24	33.50-34.50	36	0.03	119205	99.98
25	34.50-35.50	20	0.02	119225	99.99
26	35.50-36.50	5	0.00	119230	100.00

Figure 49: Temperature Frequency Distribution Braemar

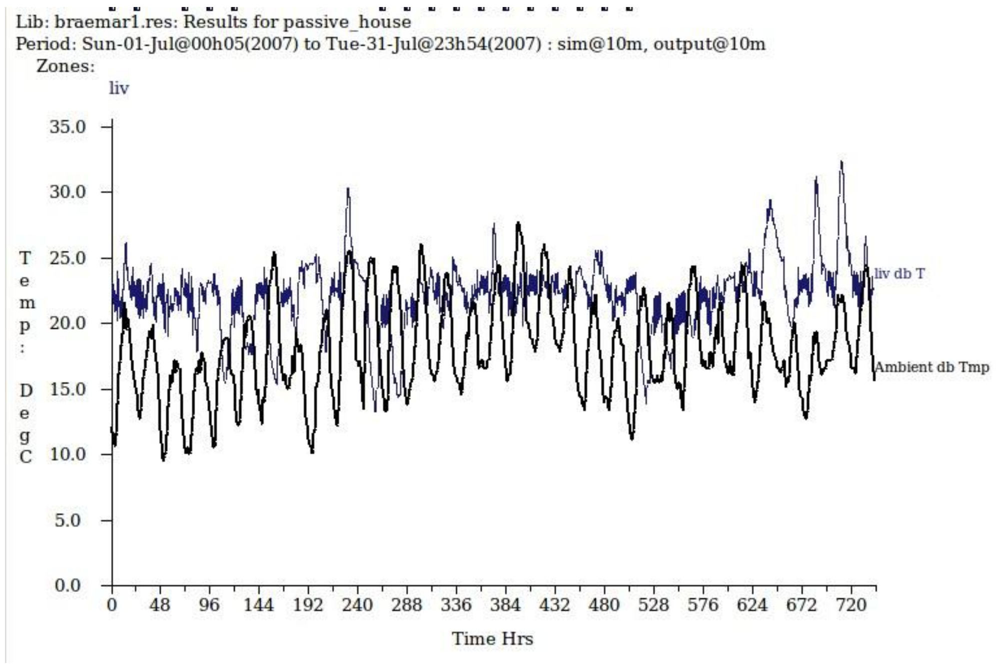


Figure 50: Living Room Temp & Ambient Air Temp (°C)

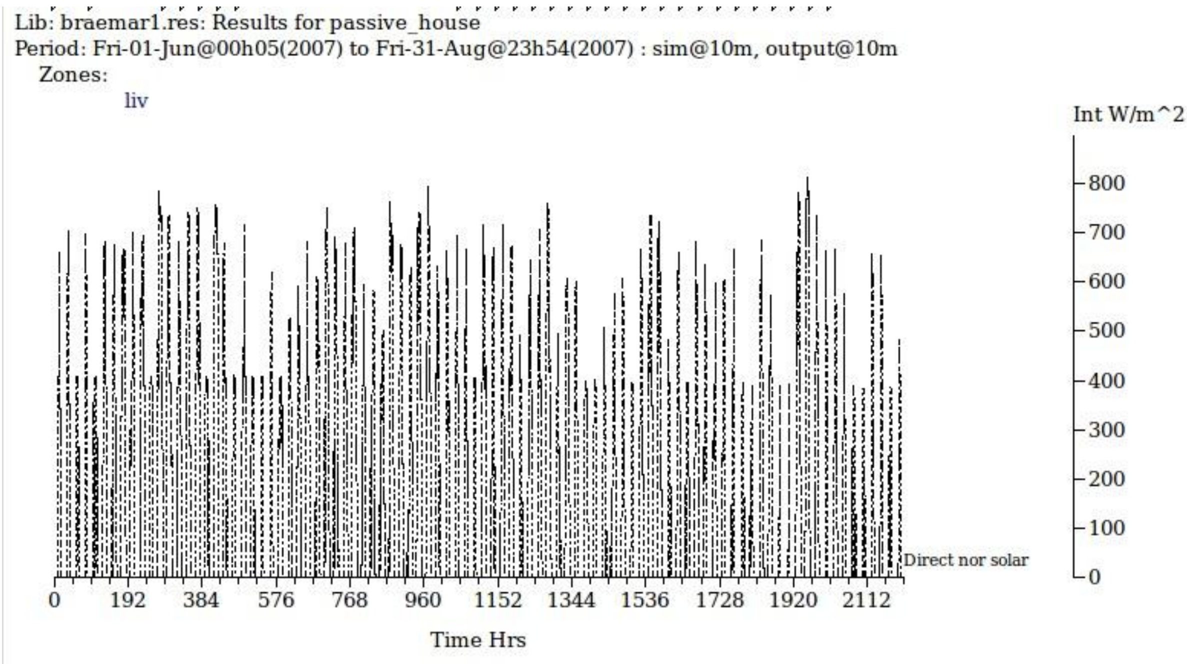


Figure 51: Solar Gains for Braemar in July

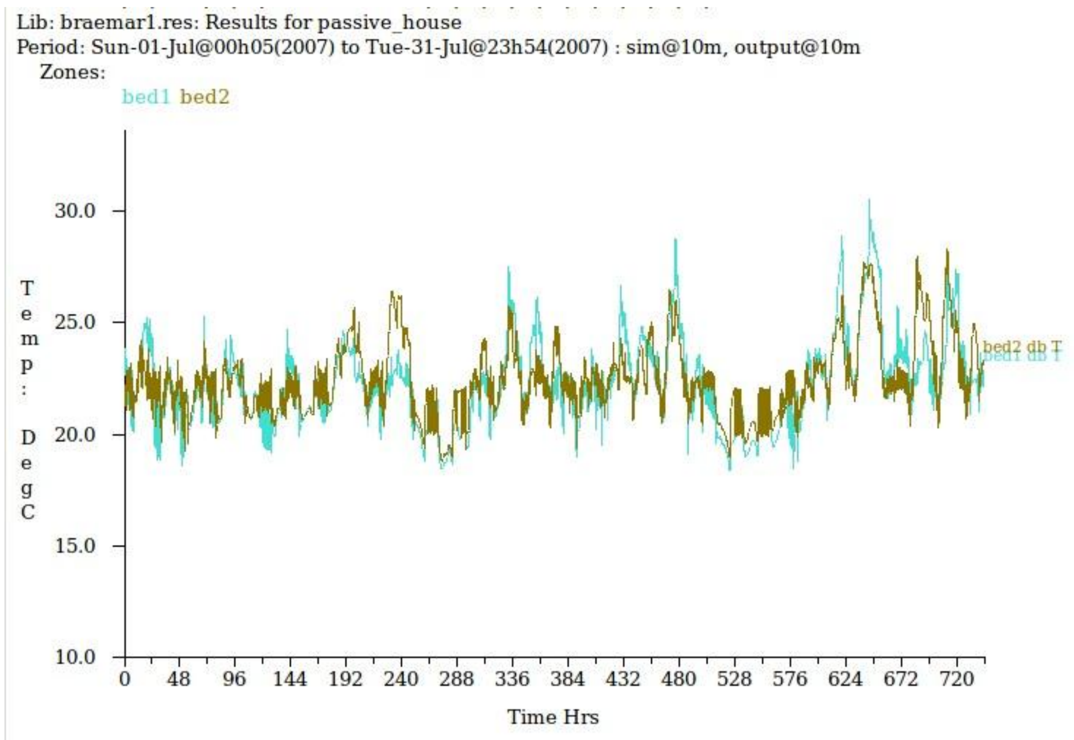


Figure 52: Bedrooms 1 & 2 Temperatures (°C)

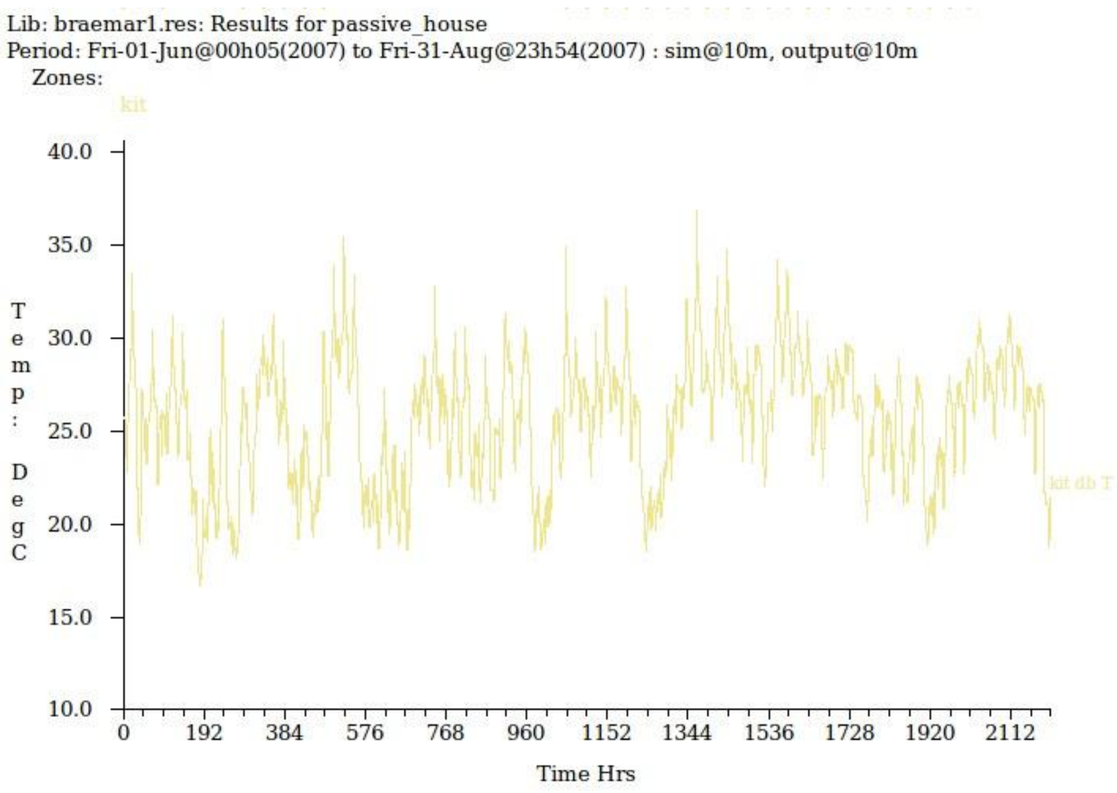


Figure 53: Kitchen Temperature (°C)

5.1.3 Tiree Results

Lib: tiree2.res: Results for passive_house
Period: Fri-01-Jun@00h05(2007) to Fri-31-Aug@23h54(2007) : sim@10m, output@10m
Zones: liv hall bath1 kit hall2 bed1 bath2 bed2 stairs
Not filtered by occupancy
Zone db temperature (degC)

Bin	data range	Distri- bution	freq. (%)	cumulative distribution	cumulative freq (%)
0	<11.5	0	0.0	0.0	0.0
1	11.50-12.50	4	0.00	4	0.00
2	12.50-13.50	21	0.02	25	0.02
3	13.50-14.50	91	0.08	116	0.10
4	14.50-15.50	189	0.16	305	0.26
5	15.50-16.50	574	0.48	879	0.74
6	16.50-17.50	1147	0.96	2026	1.70
7	17.50-18.50	2340	1.96	4366	3.66
8	18.50-19.50	5211	4.37	9577	8.03
9	19.50-20.50	9816	8.23	19393	16.26
10	20.50-21.50	20086	16.85	39479	33.11
11	21.50-22.50	26580	22.29	66059	55.40
12	22.50-23.50	20205	16.95	86264	72.35
13	23.50-24.50	12726	10.67	98990	83.02
14	24.50-25.50	7270	6.10	106260	89.12
15	25.50-26.50	4205	3.53	110465	92.65
16	26.50-27.50	2680	2.25	113145	94.89
17	27.50-28.50	2000	1.68	115145	96.57
18	28.50-29.50	1440	1.21	116585	97.78
19	29.50-30.50	893	0.75	117478	98.53
20	30.50-31.50	560	0.47	118038	99.00
21	31.50-32.50	484	0.41	118522	99.40
22	32.50-33.50	440	0.37	118962	99.77
23	33.50-34.50	135	0.11	119097	99.89
24	34.50-35.50	83	0.07	119180	99.96
25	35.50-36.50	41	0.03	119221	99.99
26	36.50-37.50	11	0.01	119232	100.00
27	>37.5	0	0.0	0.0	0.0

Figure 54: Temperature Frequency Distribution Tiree

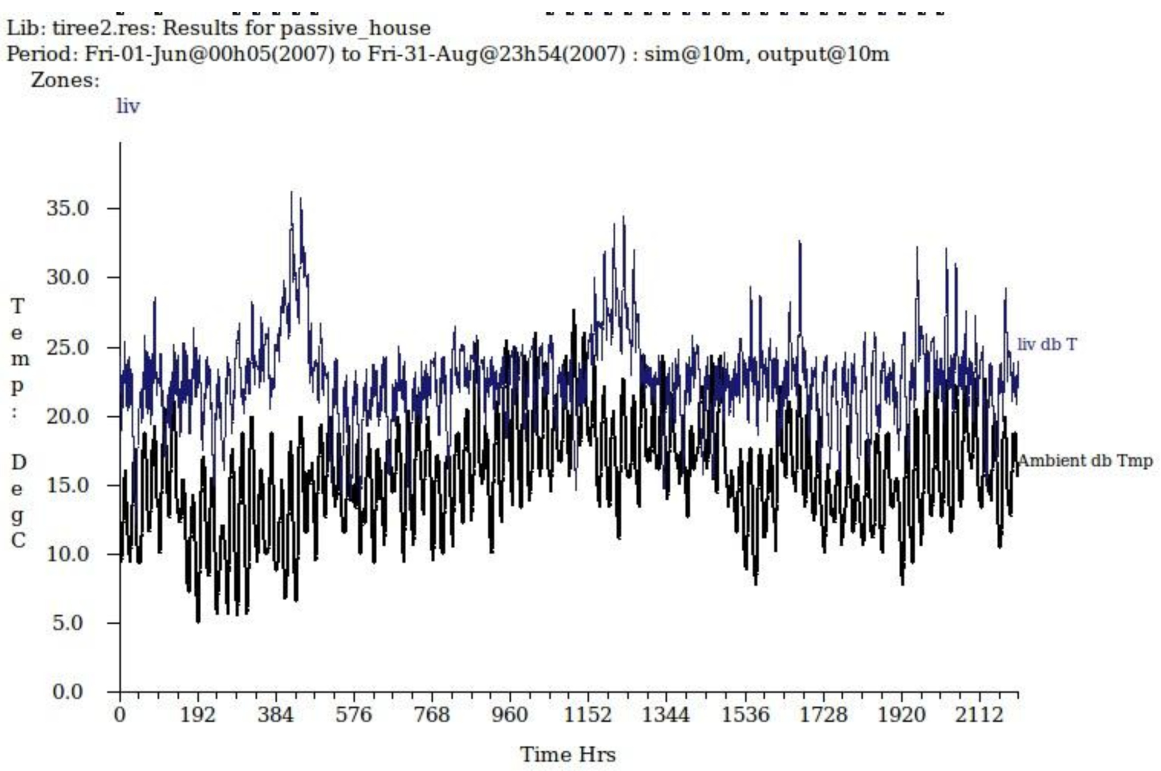


Figure 55: Living Room Temp & Ambient Air Temp (°C)

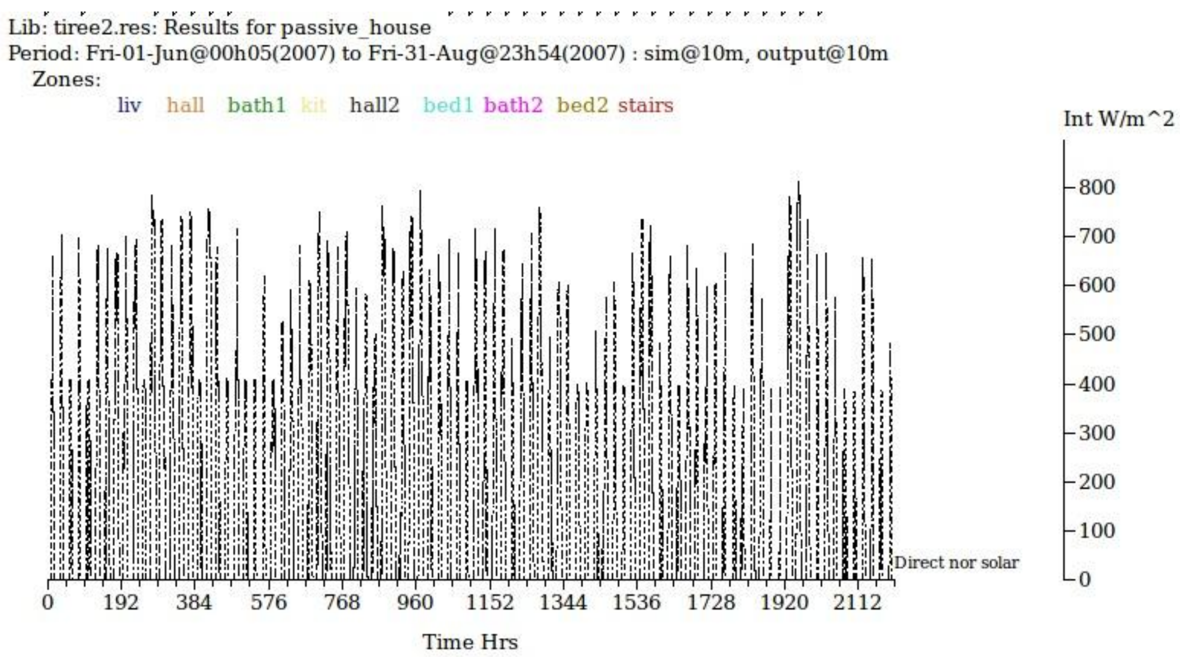


Figure 56: Solar Gains for Tiree in July

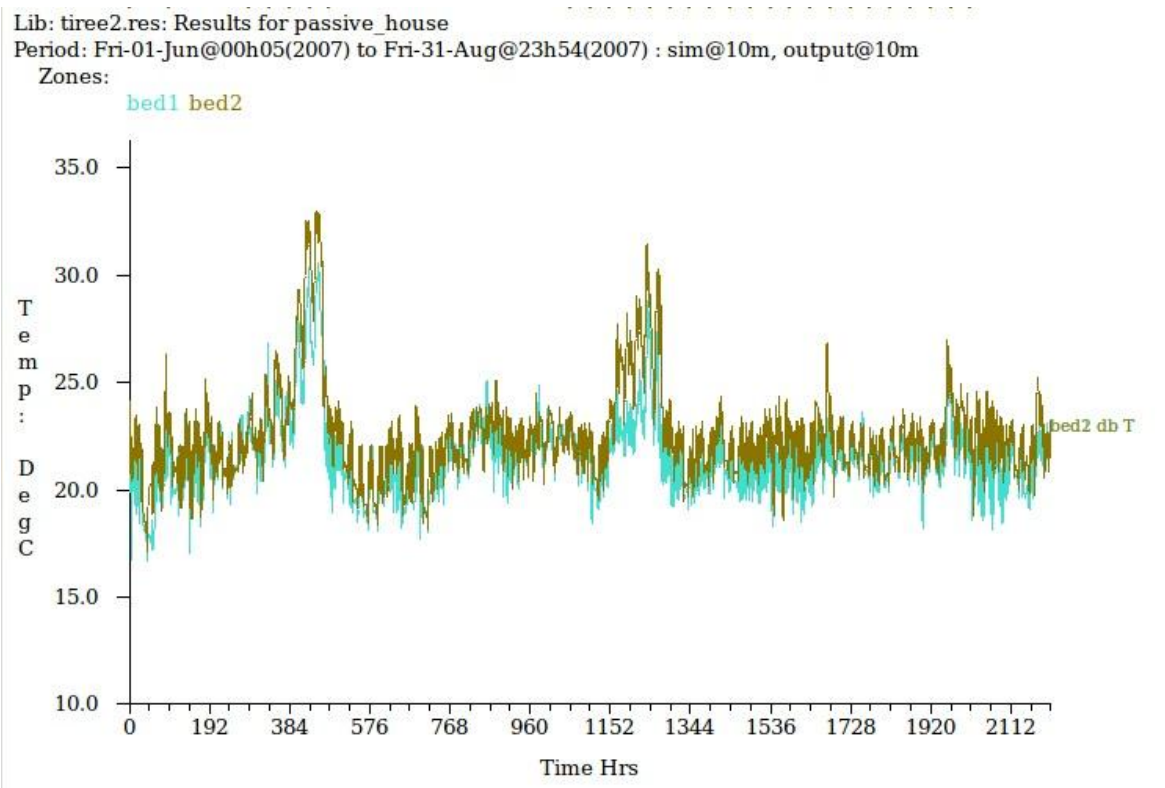


Figure 57: Bedrooms 1 & 2 Temperatures (°C)

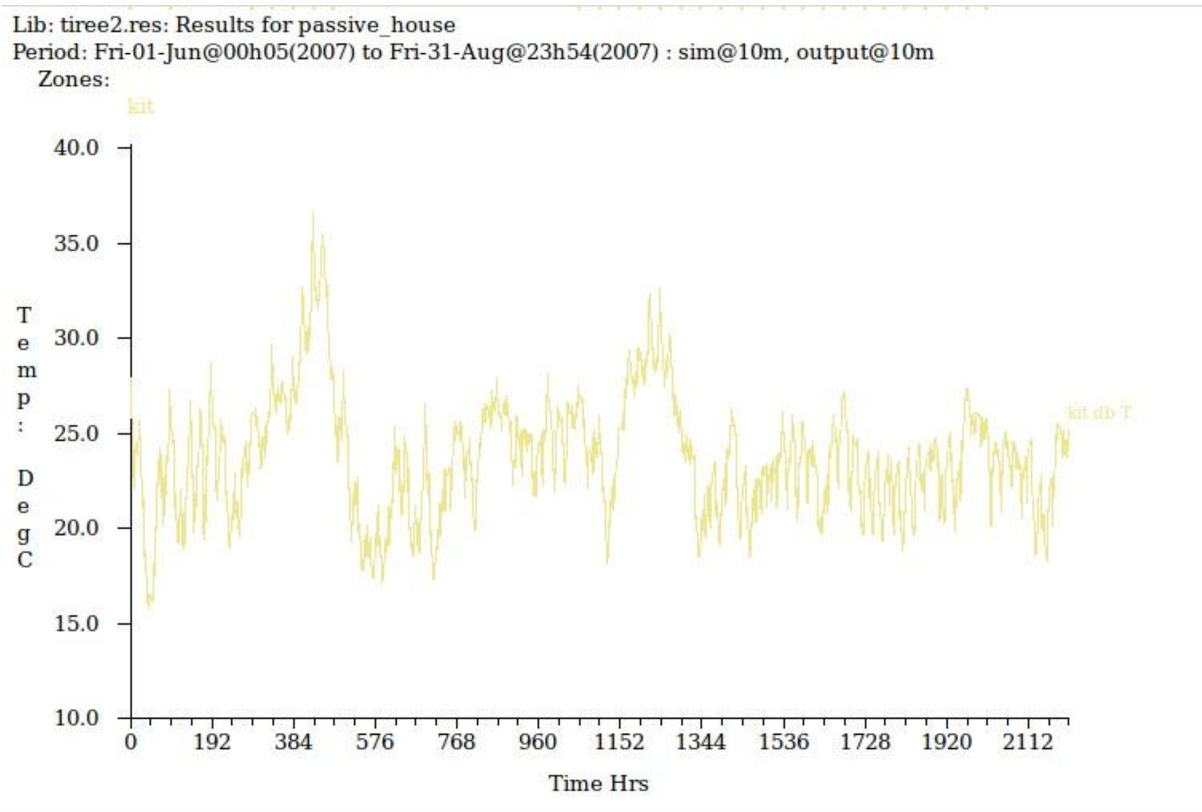


Figure 58: Kitchen Temperatures (°C)

5.2 PHPP Results for Scottish Sites

For each of sites selected for ESP-r simulation a PHPP report was generated from the original report for the Dunoon house, using the climate data from BRE to see if any change would occur in the potential for overheating. Reports were created for each site with the following variations;

- Using region specific climate data
- The above plus changing the building orientation 90° from East/West to North/South
- Region specific climate data plus removing exterior shading
- Specific climate data, building orientation as above and no exterior shading

The results obtained from these reports are detailed in the table below.

Site	**Percentage of overheating at the limit of 25°C**			
	Region Specific Climate Data	**Building Orientation**	**No Exterior Shading**	**Building Orientation & No Shading**
Dunoon	2.9%	2.6%	2.8%	2.8%
Aberdeen	0%	0%	0%	0%
Tiree	2.9%	2.6%	2.8%	2.8%
Braemar	0%	0%	7.3%	0%

Table 14: Percentage of Summer Overheating for PHPP

The results are quite conclusive that the calculations for summer overheating with PHPP show little overheating of the building within the Scottish climate. The package itself states that any figure over 10% the additional measures would be required in the building design.

6 Analysis

The results shown in Chapter 5.1 are based upon the model of the Dunoon house where basic occupancy levels are used, the MVHR is operational and controls are set for opening the windows when internal room temperatures exceed 22 °C. Climate data for the three previously determined sites were then used in the resulting simulations to generate these results.

The first set of results to look at are the frequency of overheating for thresholds of 22 °C to follow the thermal comfort level defined from the Dunoon monitoring and also at 25 °C to correspond with the thermal comfort level defined by PHPP. The table below gives these results for the three climate locations;

Location	Frequency of Overheating @ > 22 °C	Frequency of Overheating @ > 25 °C	PHPP Result (No Shading)
Aberdeen	24%	6.5%	0%
Braemar	35%	10%	7.3%
Tiree	27%	7%	2.8%

Table 15: Frequency of Overheating

The results from PHPP have been included using the no shading results, this is due to the ESP-r model not including shading from the surrounding area.

The first thing of note is the difference in frequency of overheating between the threshold of 22 °C and that for 25 °C. The monitored data from Dunoon has shown that the current occupants experience a feeling of thermal overheating when the interior temperature reaches 22 °C and it is at this point that they intervene and introduce extra ventilation in the form of opening windows. For PHPP the temperature for thermal discomfort is set at 25 °C and this highlights the discrepancies that can occur due to personal comfort. In the discussion of thermal discomfort in Chapter 3.3 the graph in Figure 3 shows the range of temperatures that thermal discomfort can occur, dependent upon the exterior temperature and the minimum, median and maximum extremes that can be experienced by individuals. Referring to this graph the occupants of the Dunoon Passive House appear to be within the lower levels of this range of thermal discomfort. If this were taken into account then whilst the model would be acceptable for potential thermal discomfort according to the PHPP results, the percentage of overheating at 22 °C would be much greater than the acceptable 10%, leading to thermal discomfort for the buildings occupants if their level of thermal tolerance was in line with the current occupants of the Dunoon house.

The discrepancies between the frequency of overheating in the ESP-r models and those defined by PHP are quite marked, particularly those of Aberdeen. Braemar is close to the PHPP result, while the differences in results for Tiree between ESP-r and PHPP are larger. For both Braemar and Tiree it can be inferred that the differences are due to the more detailed climate data used with the ESP-r models. PHPP's use of an average figure for ambient temperature and solar gains will only provide an overall impression of the possibilities of overheating while the more detailed data used by ESP-r will provide a greater degree of detail in the simulation results, with variations in spikes of solar gain corresponding to spikes in overheating experienced in the ESP-r models.

The difference in results for Aberdeen between PHPP and ESP-r is more difficult to define. It may be discrepancies within the ESP-r model that have resulted in this difference or it may be down to the average data used by BRE. The Passive House website from which the BRE climate data is sourced does state that;

"Global radiation and temperature values can be very site specific, as a result the PHPP outputs can differ for sites which have extreme exposures such as very dense urban, highly exposed or height above sea level compared to the default data sets for the region. This could affect the heating and cooling load results significantly."

Whilst it is a slight stretch to put the difference in Aberdeen results down to this, it could be a potential reason.

What can be seen from the results for the frequency of overheat at 25 °C is that all three sites do conform to the standard as laid out by Passive House, though as the Aberdeen result is right on the margin at 10% the building design would have to be reconsidered, all be it in the form of minimising glazing or introducing some form of solar shading.

The graphed results shown in Chapters 5.1.1 – 5.1.3 are given for the month of July, purely for clarity of display. The results obtained for each site for the months of June and August are similar in form.

Of note with these graphed results are those obtained for the kitchen in all three sites. Compared to the other rooms in the model, particularly the two bedrooms, the internal temperatures of the kitchen vary quite wildly. This may be as a result of the model, the kitchen is an extraction zone for the MVHR and as such the swings in temperature may be down to oscillations in the model attempting to balance the extraction of air to the exterior whilst dealing with the solar gains through the kitchen windows. The kitchen will receive solar gains during the late evening, when the sun is relative low on the horizon and these gains may contribute to this pattern of fluctuating temperatures.

The two bedrooms appear to experience a range of temperatures between 20 °C and 25 °C with occasional spikes in temperature. Indeed, for the Tiree results all four zones experience two large spikes in temperature at the same periods of the month. This may be due to solar gains though this is not obvious from the solar gains shown in Figure 56.

Of note in the graphed results, particularly for the living room in all three climates, is that the internal temperatures of the living room tend to follow the pattern of the exterior ambient temperature. This may in part be due to the living room being a supply zone for the MVHR. The decision was made during the modelling process to neglect the heating element of the MVHR. This decision was taking partly to simplify the model but also based on the assumption that due to the ability of the Passive House to retain latent heat gained during the day to the high thermal efficiency of the building fabric and that the resulting need for additional heat gains form the MVHR would be minimal and so could omitted from the model. As such the living room is being continually supplied with air from the exterior in order to maintain airflow in the building and as was shown in the simulations of the Dunoon site in Chapter 4.5.4.2 the model produced similar results to the monitored data so long as the MVHR was in operation, governed by the control loops that were set in place. This may go some way to describing the change in temperatures of the living room zone in the ESP-r model.

7 Conclusions & Recommendations

The results of this project show that the potential for overheating of a Passive House design within the Scottish climate is within the boundaries of those set by the Passive House Planning Package. The ESP-r model simulations do show that there are differences in performance between differing locations, which is to be expected, but that the results obtained by simulating each site do show differences in results for estimating potential overheating compared to those predicted by PHPP. This is a useful result for the project in that it shows that whilst PHPP will give a reasonable estimation of the performance of a building design with regard to potential overheating, the use of building simulation will provide a more accurate result and enable designers and architects to make design alterations accordingly.

The project has also highlighted the need to take into account an individual's level of thermal comfort and discomfort. The occupants of the Dunoon house appear to feel thermal discomfort at 22 °C. What has been seen in the results obtained through the simulations is that while a home may have a result of 6.5% for frequency of overheating, as is the case for the Aberdeen site, with 25 °C given as the threshold for thermal discomfort as used by PHPP, the simulated results can show a frequency of overheating at 22 °C to be as much as 24%. This would impact quite significantly upon the comfort levels of such an occupant as the owners of Dunoon, and indicates that designers of a Passive House would be best served to take into account the expectations of the future homeowners, as well as ensuring the design will perform to the standards given in PHPP.

8. Future Work

This project provides a starting point into investigating summer overheating for Passive House residential buildings in the Scottish climate. Future work could be made into developing more accurate occupancy data to finesse the impact this would have upon the performance of the building, rather than the general assumptions that were derived from a single week's average data from the occupants in the Dunoon house.

Investigation into obtaining more localised climate data would also be worthwhile, current sets of data available for use only cover a small number of locations within Scotland and indeed the rest of the UK. This limits the accuracy of any building simulation model and would be of benefit to a further range of investigations.

References

1. The Passivhaus Standard. *Passive House Institute.* [Online] [Cited: 14th June 2011.] http://www.passivhaus.org.uk/standard.jsp?id=37.

2. Built Passive House Projects. *Paaive House Institute.* [Online] [Cited: 14th June 2011.] http://www.passivhausprojekte.de/projekte.php?search=2.

3. The Goals of CEPHEUS. *The CEPHEUS Project.* [Online] [Cited: 31 July 2011.] http://www.cepheus.de/eng/.

4. Passive House Planning Package. *The Passive House Institute.* [Online] [Cited: 14 June 2011.] http://www.passivhaus.org.uk/page.jsp?id=25.

5. Basic Principles. *Passive House Institute.* [Online] [Cited: 14th June 2011.] http://www.passivhaus.org.uk/standard.jsp?id=17.

6. Outline Specification. *Passive House Institute.* [Online] [Cited: 14th June 2011.] http://www.passivhaus.org.uk/standard.jsp?id=18.

7. *BS EN ISO 7730:2005 - Ergonomics of the Thermal Environment.* s.l. : British Standard Institute, 2007.

8. *BS EN 15251:2007 - Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings.* s.l. : British Standards Institute, 2007.

9. ESP-r. *University of Strathclyde, ESRU Department.* [Online] [Cited: 2nd June 2011.] http://www.esru.strath.ac.uk/Programs/ESP-r.htm.

10. Regional Climate Data. *MET Office.* [Online] [Cited: 10th July 2011.] http://www.metoffice.gov.uk/climate/uk/regional/.

11. Western Scotland: Climate. *MET Office.* [Online] [Cited: 10th July 2011.] http://www.metoffice.gov.uk/climate/uk/ws/print.html.

12. Northern Scotland: Climate. *MET Office.* [Online] [Cited: 10th July 2011.] http://www.metoffice.gov.uk/climate/uk/ns/print.html.

13. Eastern Scotland: Climate. *MET Office.* [Online] [Cited: 10th July 2011.] http://www.metoffice.gov.uk/climate/uk/es/print.html.

14. Building Energy Software Tools Directory - IWEC. *US Department of Energy.* [Online] [Cited: 12th July 2011.] http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=369/pagename=alpha_list.

15. EnergyPlus Energy Simulation Software - Weather Data. *US Department of Energy.* [Online] [Cited: 12th July 2011.] http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=6_europe_wmo_region_6/country=GBR/cname=United%20Kingdom.

16. Historic Station Data. *MET Office.* [Online] [Cited: 12th July 2011.] http://www.metoffice.gov.uk/climate/uk/stationdata/.

17. Regional Climate Data. *Passive House Institute.* [Online] [Cited: 28th July 2011.] http://www.passivhaus.org.uk/regional-climate-data.jsp?id=38.

Bibliography

Badescu. V., Laaser. N., Crutescu. M., Crutescu. R., Dobrovicescu. A., Tsatsaronis. G. (2011). Modelling, Validation and Time-Dependent Simulation of First large Passive Building in Romania. *Renewable Energy 36,* 142-157.

Boqvist. A., Claeson-Jonsson. C., Thelandersson. S. (2010). Passive House Construction – What is the Difference Compared to Traditional Construction? *The Open Construction and Building Technology Journal 4,* 9-16.

Clarke. J.A., (2001). Domain Integration in Building Simulation. *Energy and Buildings 33,* 303-308.

Dorer. V., Feist. W., Haas. A., Schneiders. J. (2005). Re-inventing Air Heating: Convenient and Comfortable Within the Frame of the Passive House Concept. *Energy and Buildings 37,* 1186-1203.

Haghighat. F., Li. L., (2004). Building Airflow Movement – Validation of Three Airflow Models. *Journal of Architecture and Planning Research 21:4,* 331 – 349.

Hens. H., (2010). Energy Efficient Retrofit of an End of Row House. *Energy and Buildings 42,* 1939-1947.

Karlsson. J.F., Moshfegh. B., (2006). Energy Demand and Indoor Climate in a Low Energy Building. *Energy and Buildings 38,* 315-326.

Mlakar. J., Strancar. J. (2010). Overheating in Residential Passive House. *Energy and Buildings 43,* 1443-1451.

Smeds. J., Wall. M., (2007). Enhanced Energy Conservation in Houses Through High Performance Design. *Energy and Buildings 39,* 273-278.

Appendix A

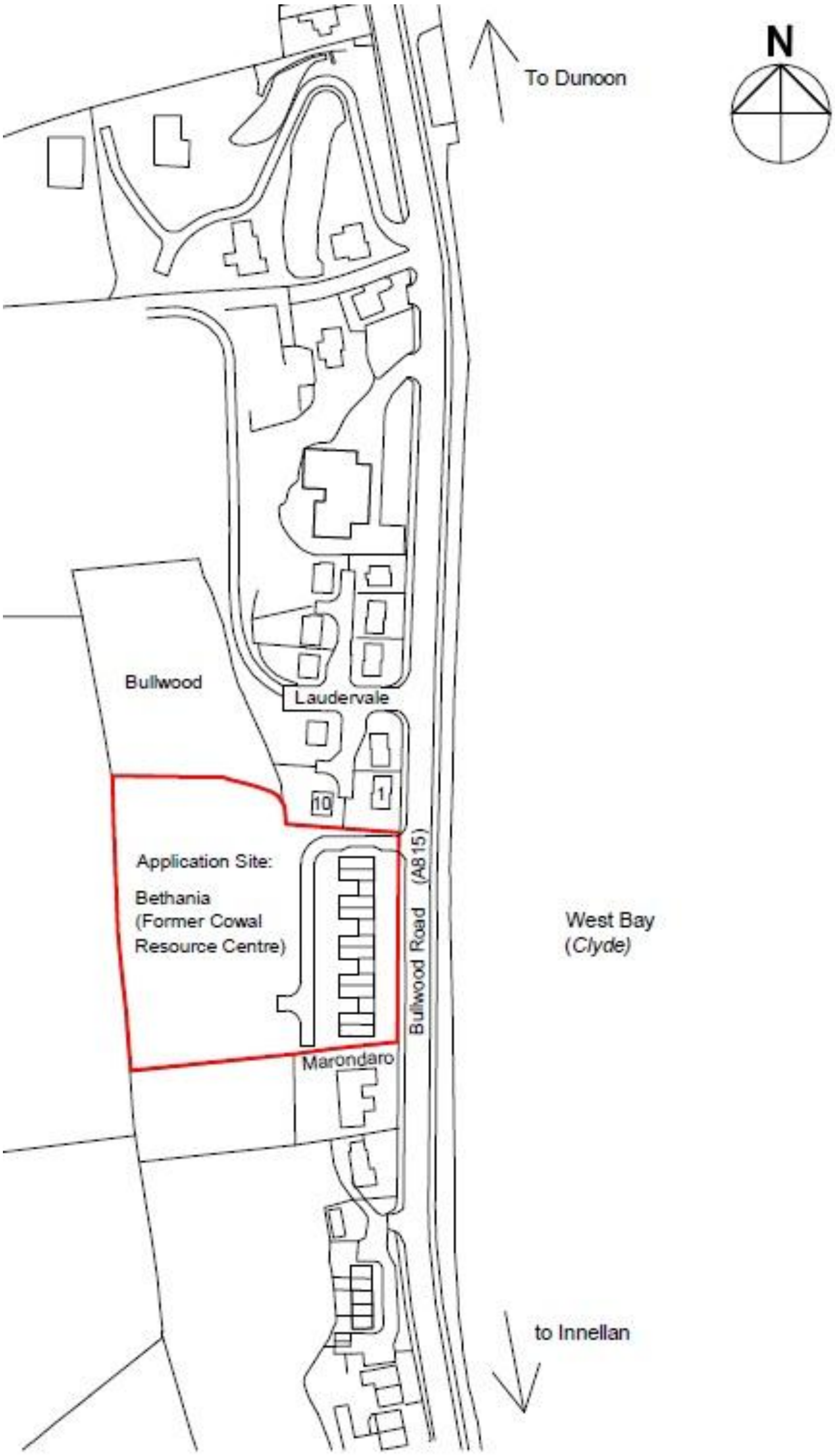


Figure 59: Dunoon Site Map (source: Fyne Homes)

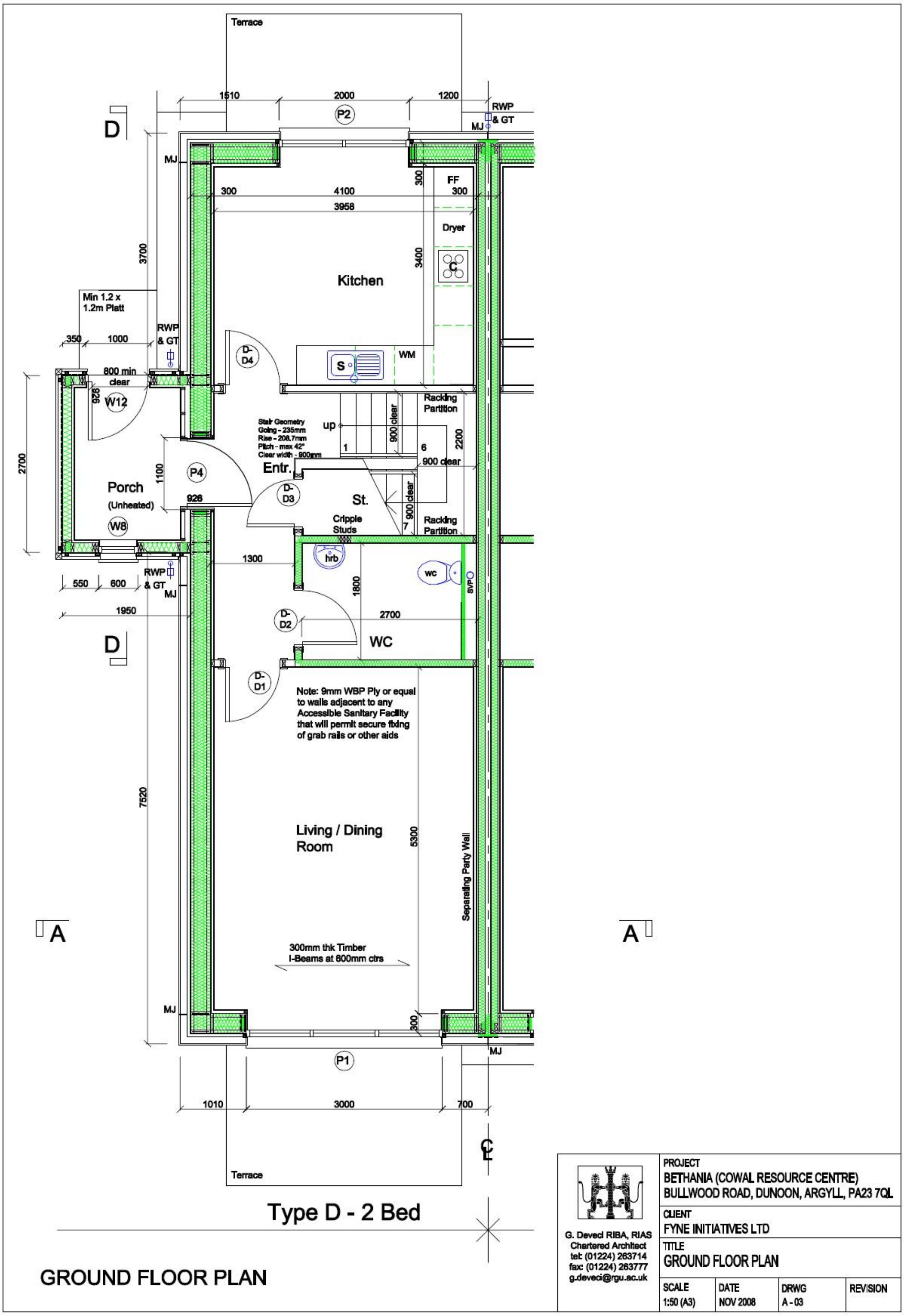


Figure 60: Ground Floor Plan (source: Fyne Homes)

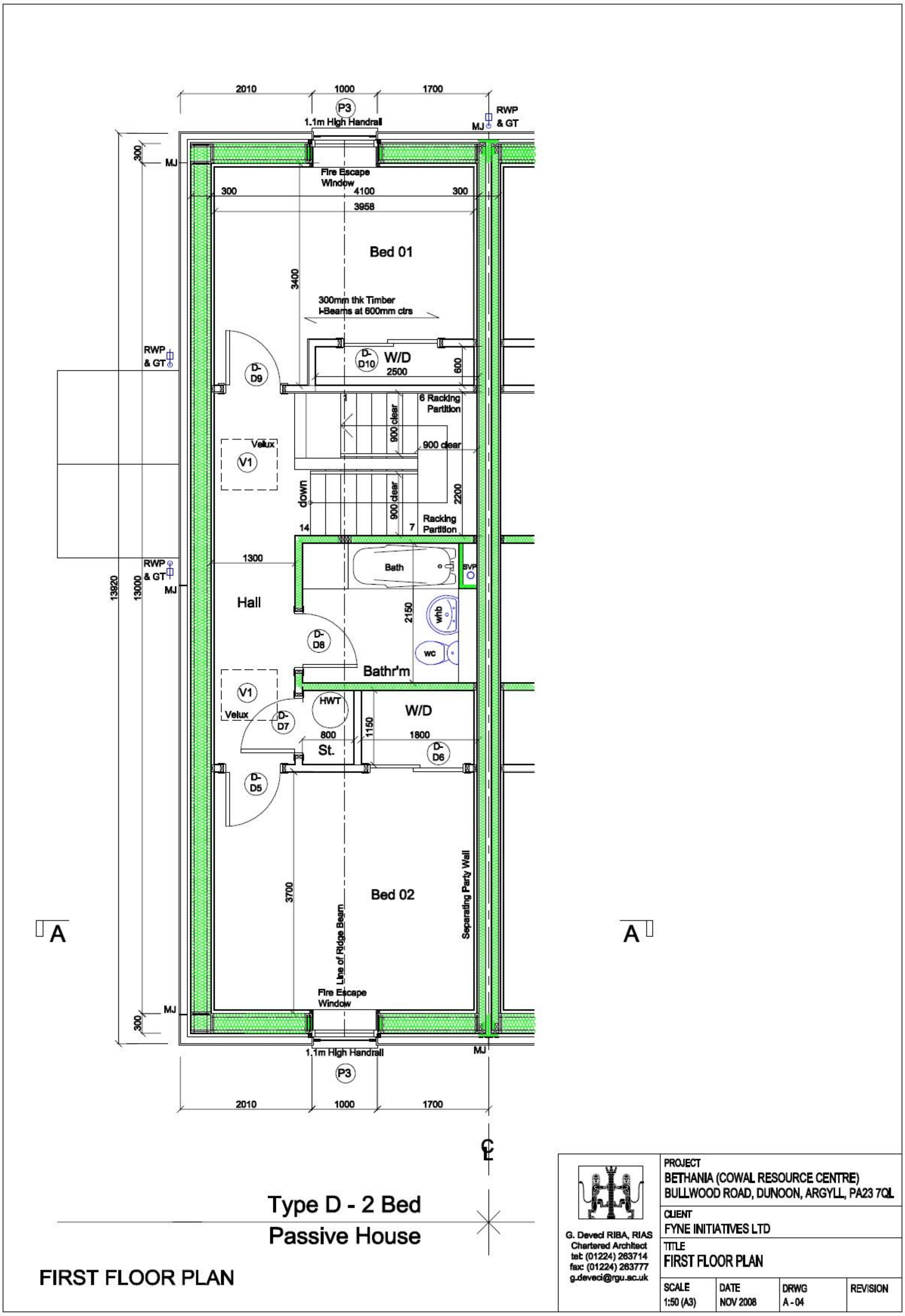


Figure 61: First Floor Plan (source: Fyne Homes)

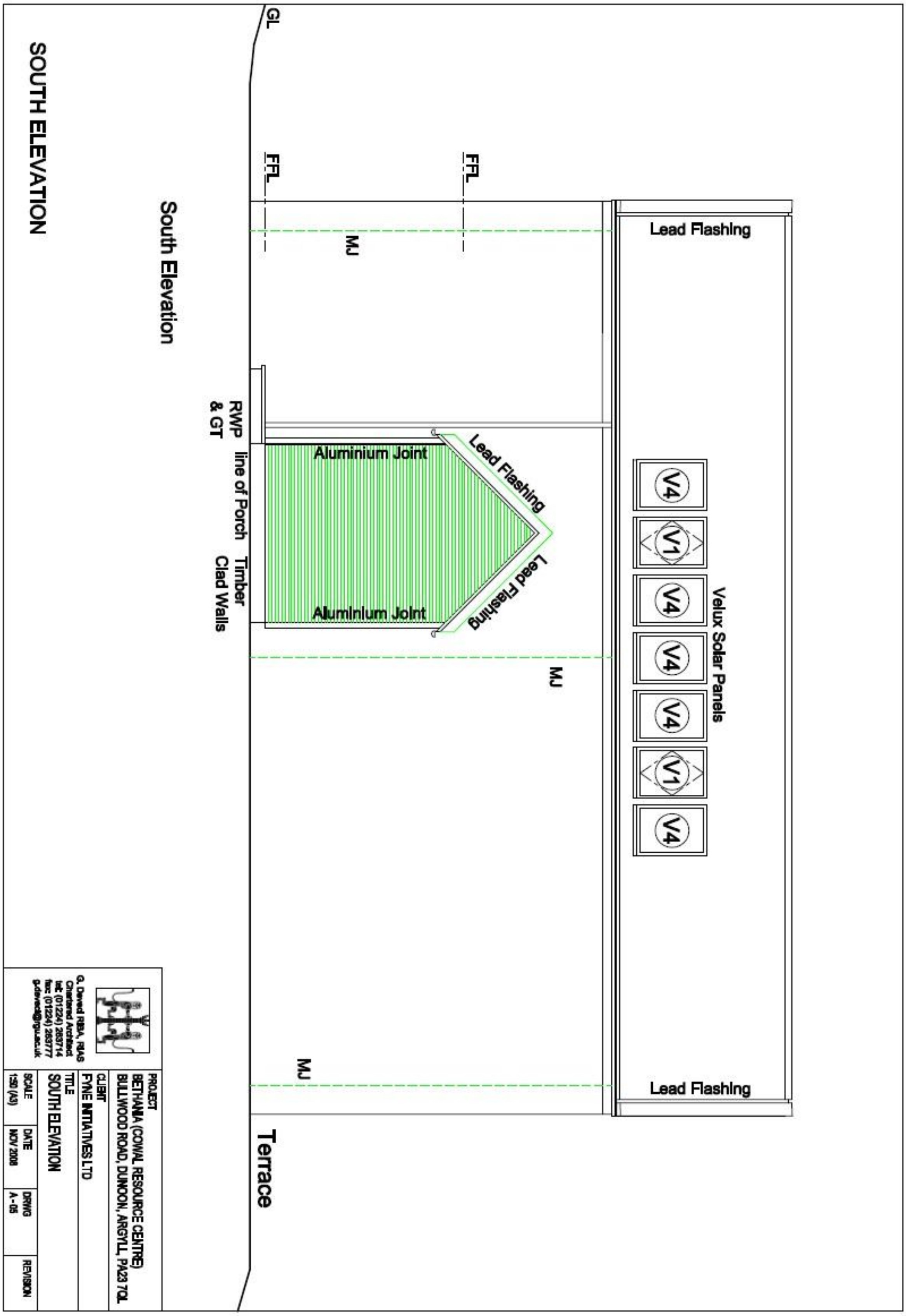


Figure 62: South Elevation (source: Fyne Homes)

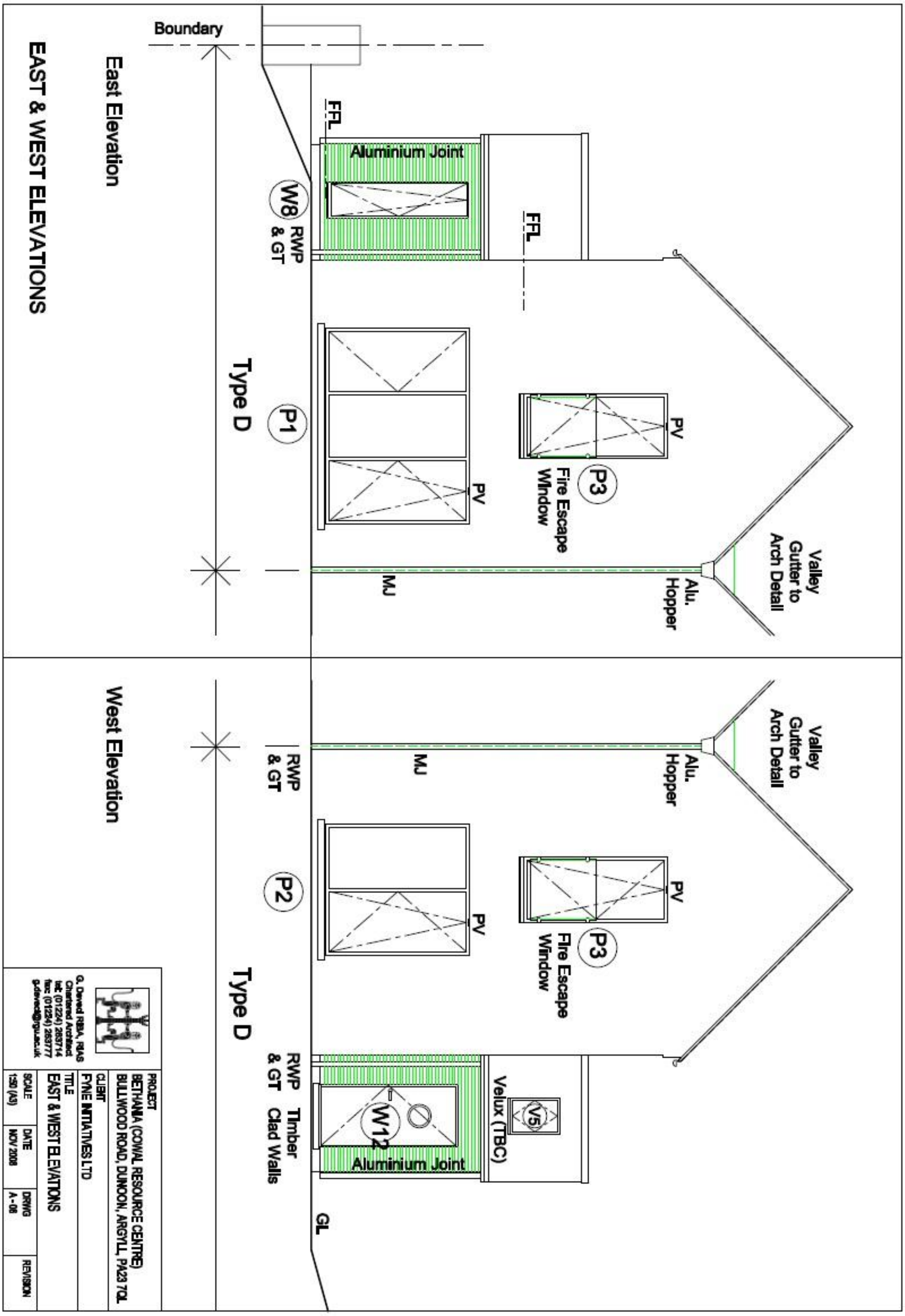


Figure 63: East and West Elevations (source: Fyne Homes)

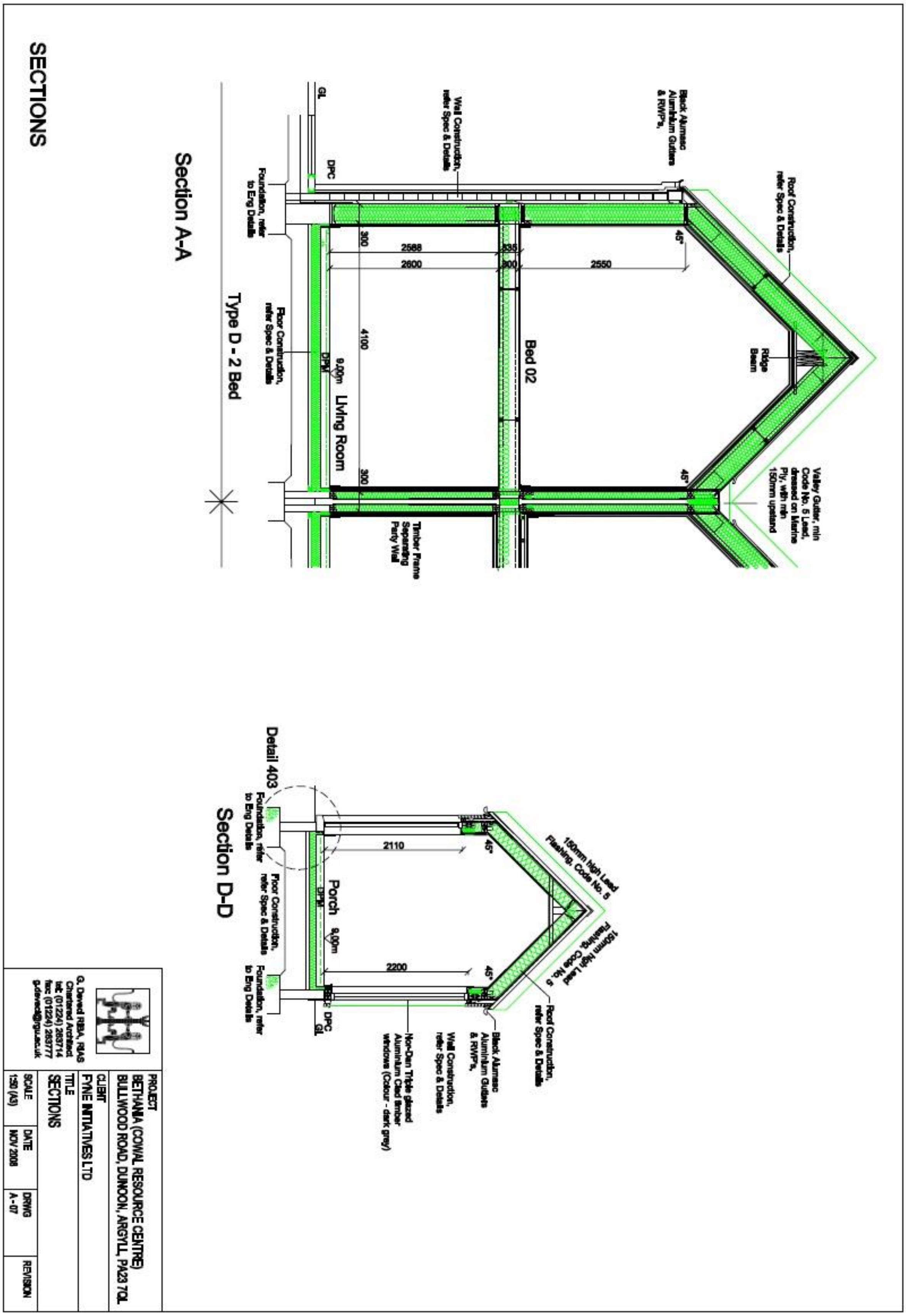


Figure 64: Sections (source: Fyne Homes)

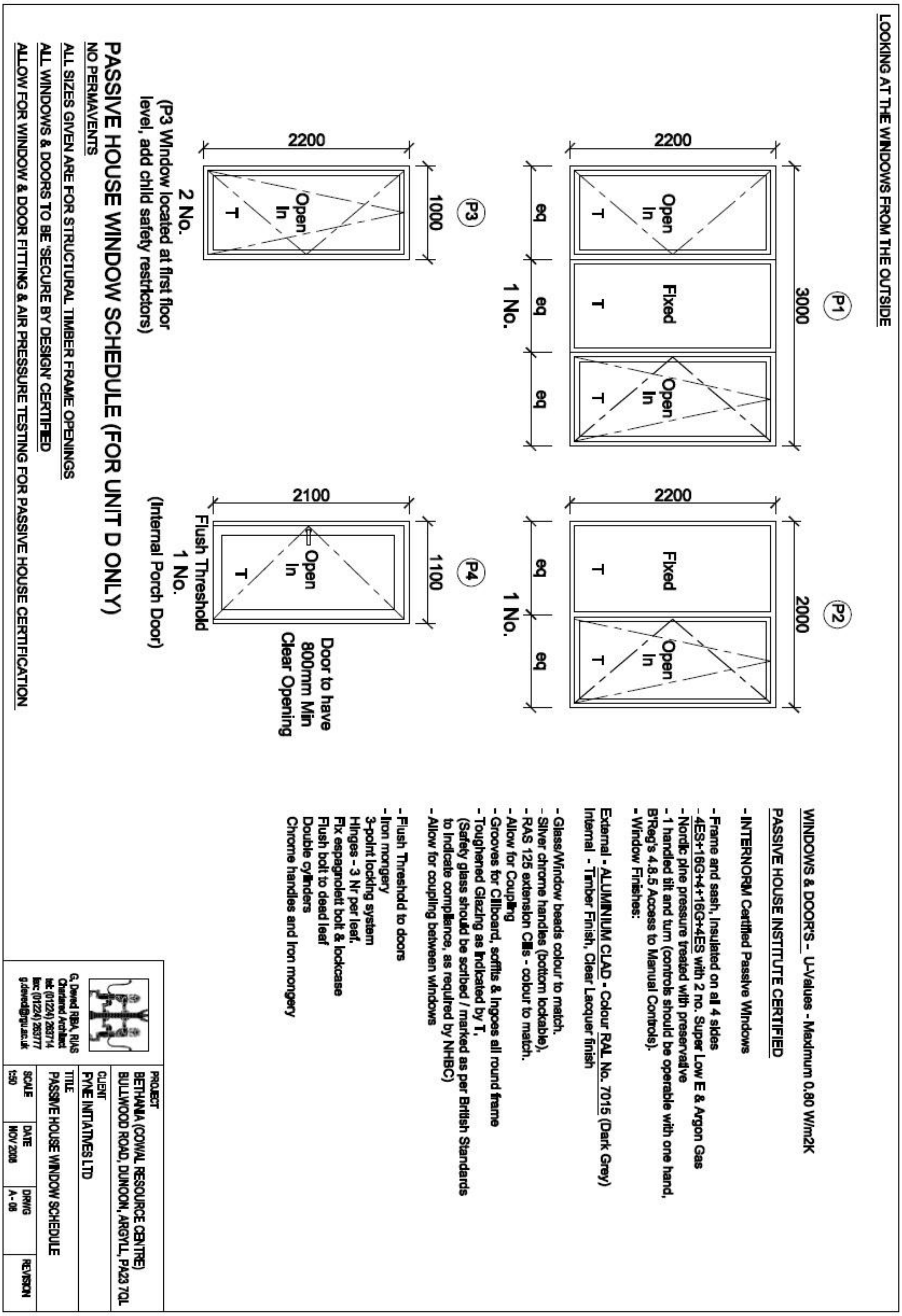


Figure 65: Window Details (source: Fyne Homes)

Appendix B

Passive House Questionnaire

Introduction

The purpose of this questionnaire is to help in establishing the comfort levels of inhabiting a passive house design during the summer season. The information obtained will be used in the production of a computer simulation of the house, enabling a greater degree of accuracy in simulations.

Questionnaire

6. During the summer months what setting do you keep the Mechanical Ventilation (MVHR) during summer?

It is on an automatic setting where the air flow changes throughout the day, I have not used summer/winter bypass

7. During summer months do you feel the need to open windows more often to regulate room temperature than in other seasons?

Yes

8. How would you describe the general use of windows throughout the summer? i.e. need to leave some open overnight, effects of weather on whether you open them etc.

The windows are generally open if the weather is sunny as this causes the front and upstairs of the house to heat up. They are normally closed at night with (last year I did have them open but the midges were too bad!). If the weather is cloudy but warm I also open them even during rain if it is warm enough. If it gets very warm I would also open the Velux on the top floor as this quickly releases any heat. Generally between April and October the windows can be opened.

9. In an average summer week, what are the usual hours of occupation of the building?

Day	**Time** (i.e. midnight – 9am, 12pm – 1pm, 6pm -midnight)
Monday	midnight – 9am, 5pm onwards

Tuesday	midnight – 9am, 5pm onwards
Wednesday	midnight – 9am, 5pm onwards
Thursday	midnight – 9am, 5pm onwards
Friday	midnight – 9am, 5pm onwards
Saturday	midnight – 10am,6pm onwards
Sunday	midnight – 10am,6pm onwards

10. Would you be willing to keep a log for a period of seven days of when windows are opened and closed in the building? Below are tables for each day with the windows of the home listed. The times are the most important information but if you are able to provide the motivation (i.e. too warm, air stuffy) for opening the windows it would be worthwhile as would be whether the windows are opened fully or just a small gap.

11. **Window Log**

Day 1 (17/8/11)

Window	**Motivation/ Size of gap**	**Open (time)**	**Close (time)**	**Motivation/ Size of gap**	**Open**	**Close**
Kitchen	Warm/small gap	08.30	15.00			
Living Room (Left)	Warm/small gap	08.30	15.00			
Living Room (Right)						
Velux @ Stairs						
Velux @ Bathroom						

Front Bedroom	Warm/small gap	08.30	15.00			
Rear Bedroom						
Front Door						

MVHR switched off during window open times

Day 2 (18/8/11) No windows open

Day 3 (19/8/1)

Window	**Motivation/ Size of gap**	**Open (time)**	**Close (time)**	**Motivation/ Size of gap**	**Open**	**Close**
Kitchen						
Living Room (Left)	Warm/small gap	08.30	16.00			
Living Room (Right)						
Velux @ Stairs						
Velux @ Bathroom						
Front Bedroom	Warm/small gap	08.30	16.00			
Rear Bedroom						
Front Door						

MVHR switched off during window opening times

Day 4 (20/8/11) No windows open

Day 5 (21/8/11)

Window	Motivation/ Size of gap	Open	Close	Motivation/ Size of gap	Open	Close
Kitchen						
Living Room (Left)	Warm/small gap	12.45	17.00			
Living Room (Right)						
Velux @ Stairs						
Velux @ Bathroom						
Front Bedroom	Warm/small gap	12.45	17.00			
Rear Bedroom						
Front Door						

MVHR switched off during window opening times

Day 6 (22/8/11) No windows open

Day 7 (23/8/11) No windows open

Appendix C

Temperature Graphs from MET Office.

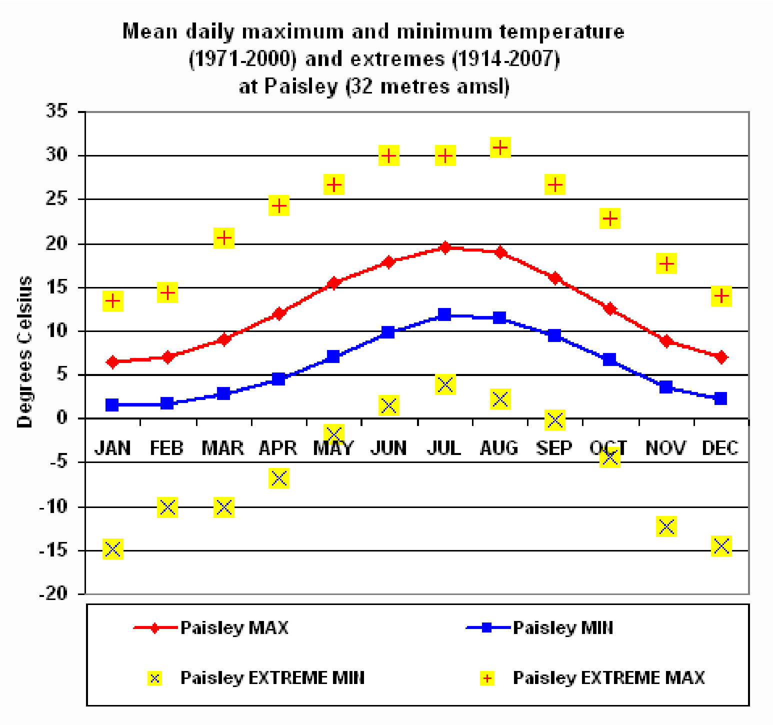


Figure 66: Daily Maximum & Minimum Temperature for Paisley (source: MET Office)

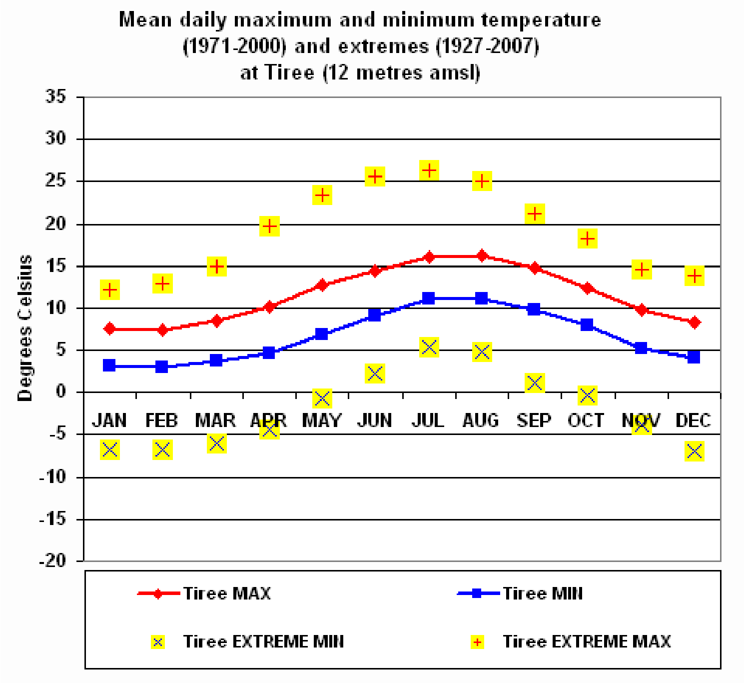


Figure 67: Daily Maximum & Minimum Temperature for Tiree (source: MET Office)

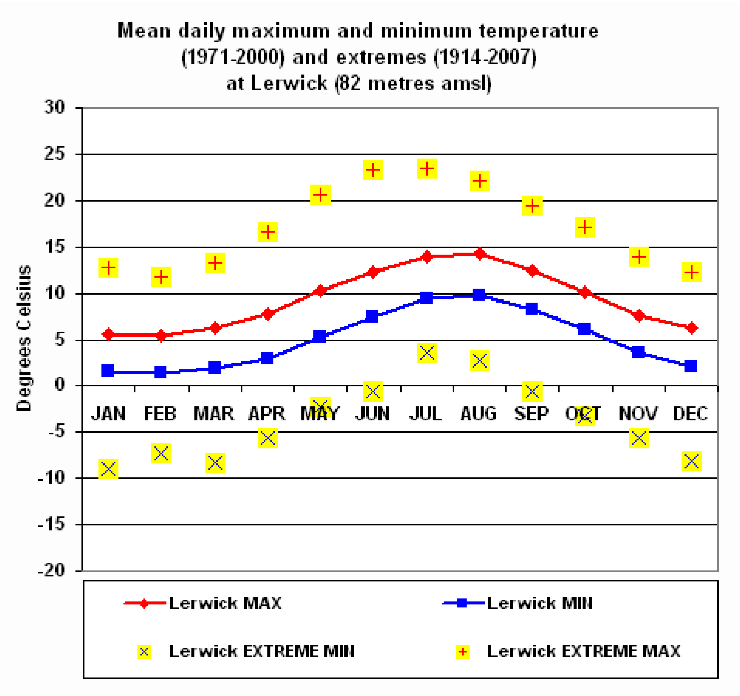


Figure 68: Daily Minimum & Maximum Temperatures for Lerwick (source: MET Office)

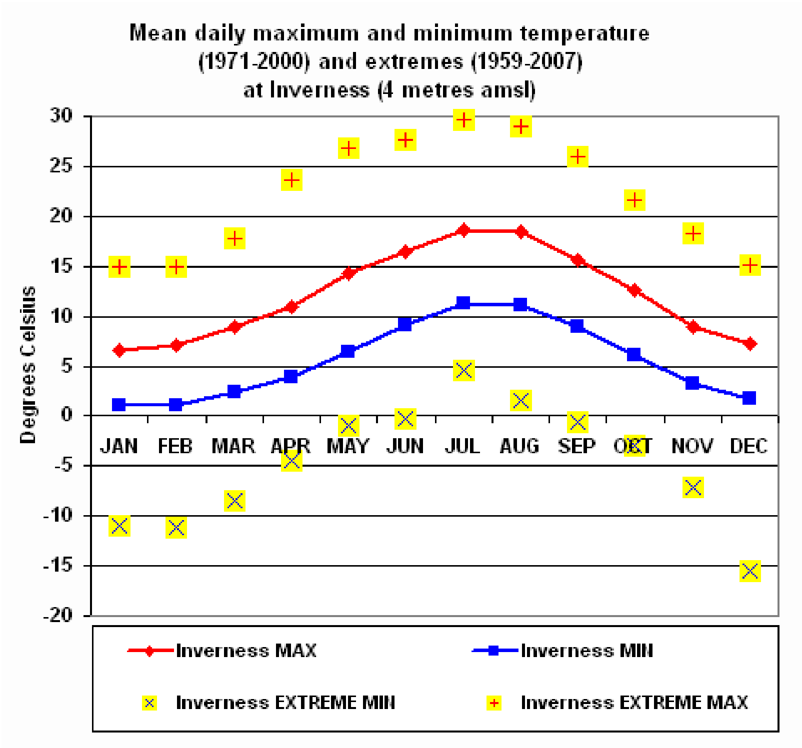


Figure 69: Daily Maximum & Minimum Temperatures for Inverness (source: MET Office)

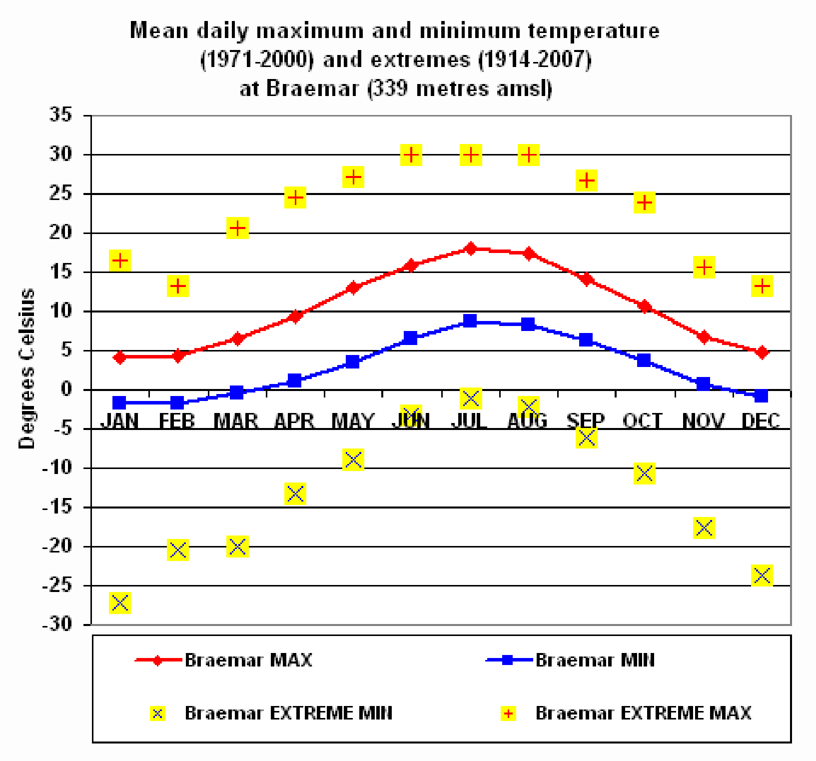


Figure 70: Daily Maximum & Minimum Temperatures for Braemar (source: MET Office)

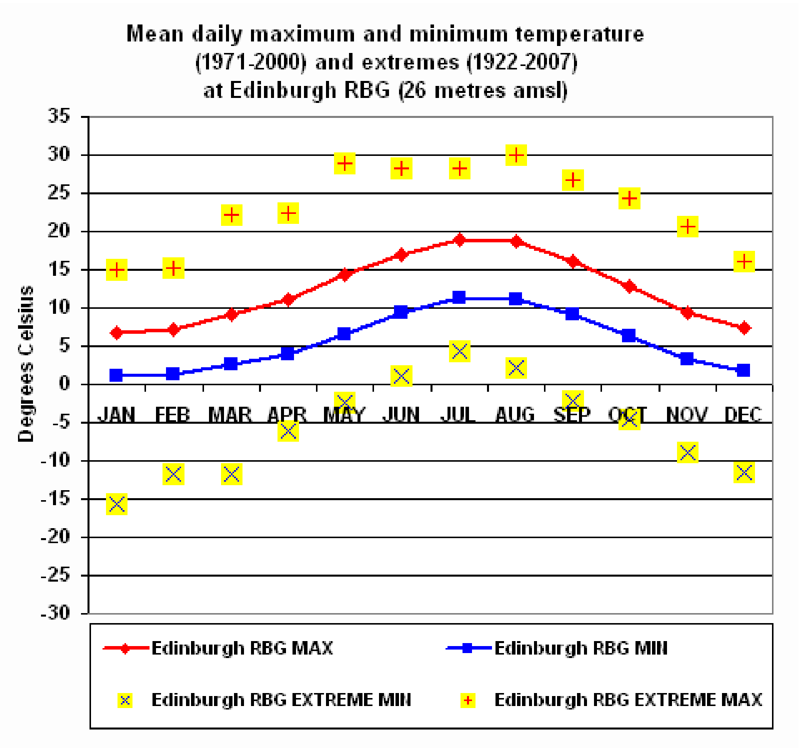


Figure 71: Daily Maximum & Minimum Temperatures for Edinburgh (source: MET Office)

Appendix D

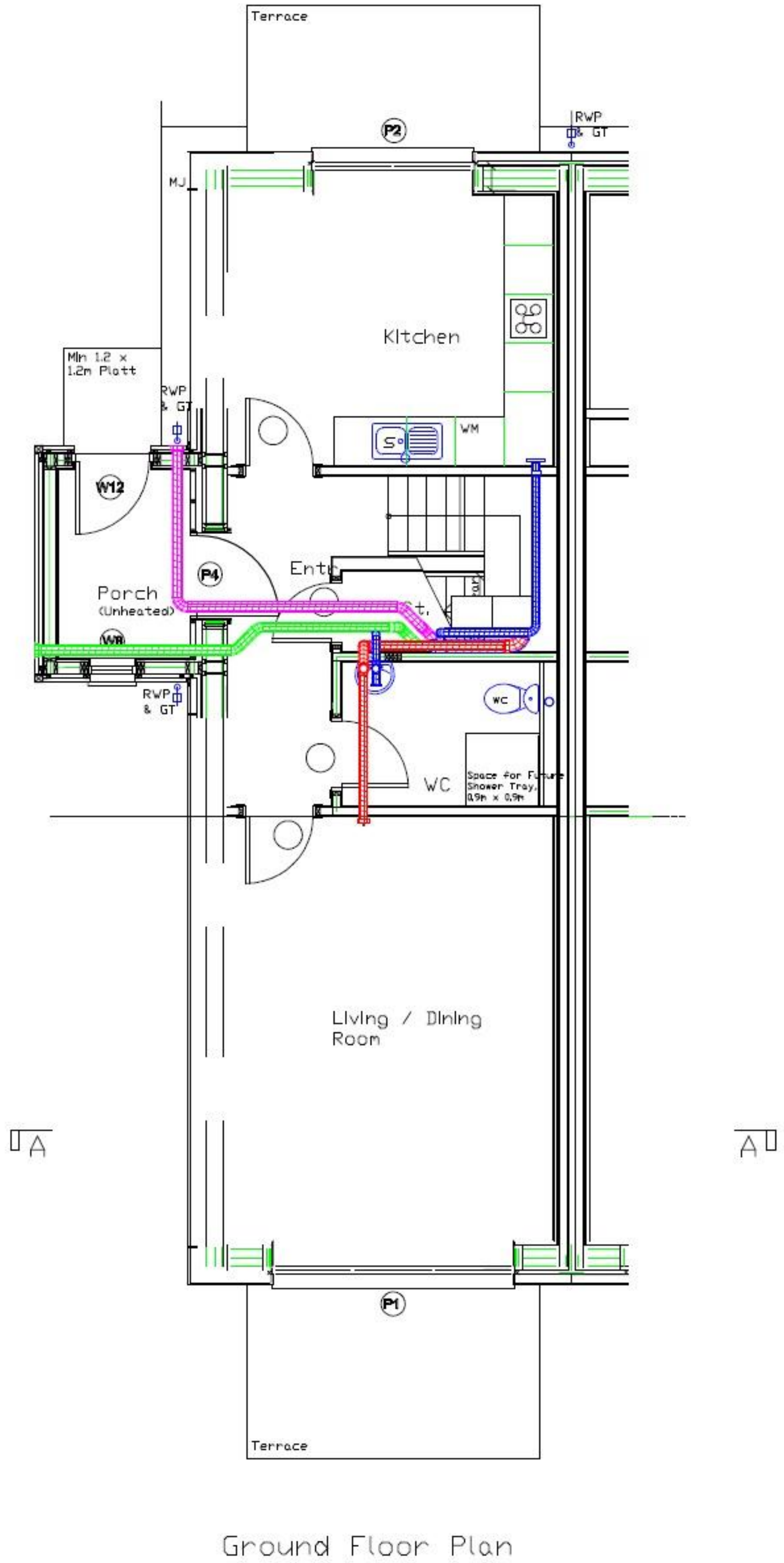


Figure 72: Ventilation Configuration: Ground Floor (source: Fyne Homes)

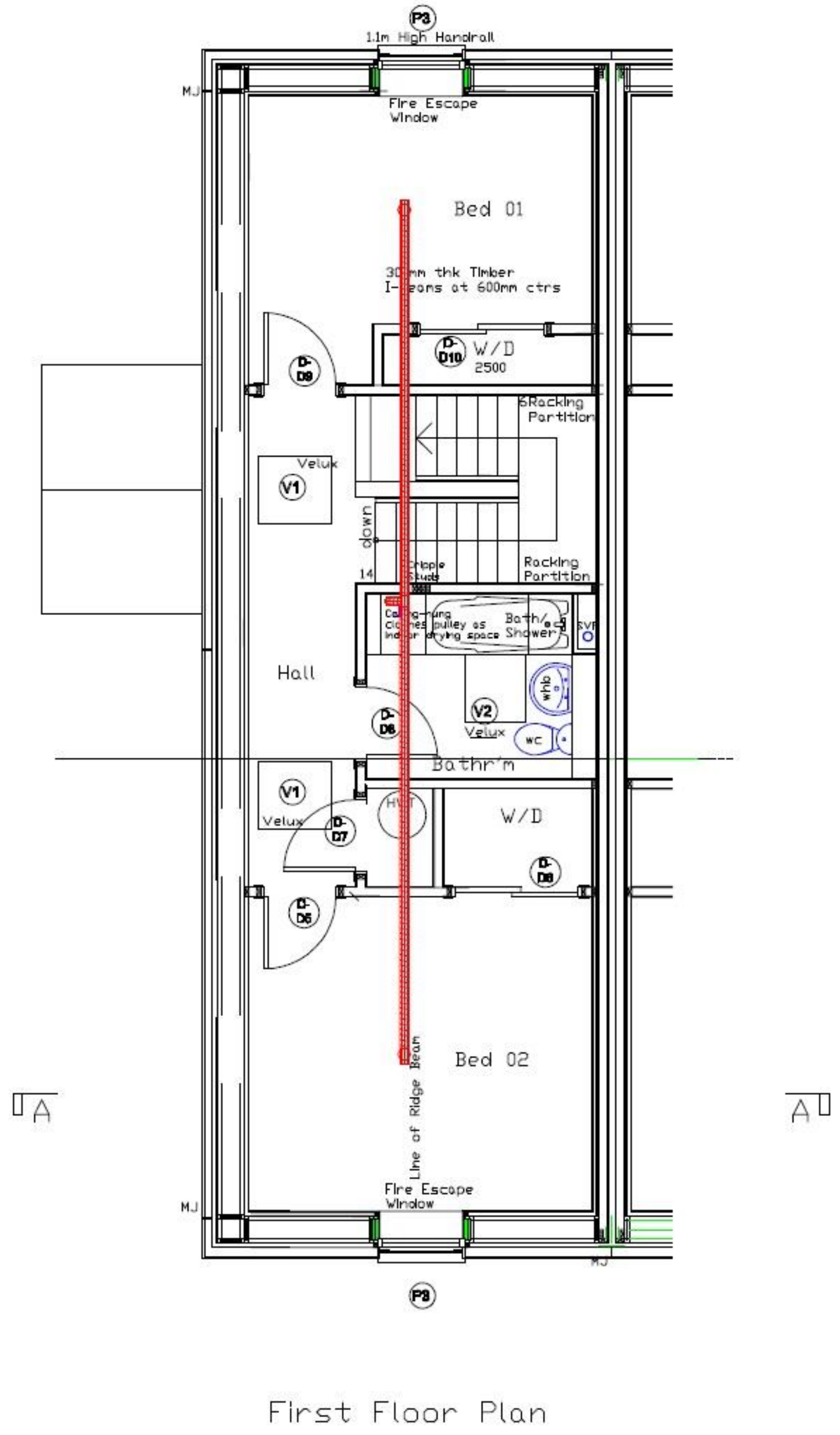


Figure 73: Ventilation Configuration: First Floor (source: Fyne Homes)

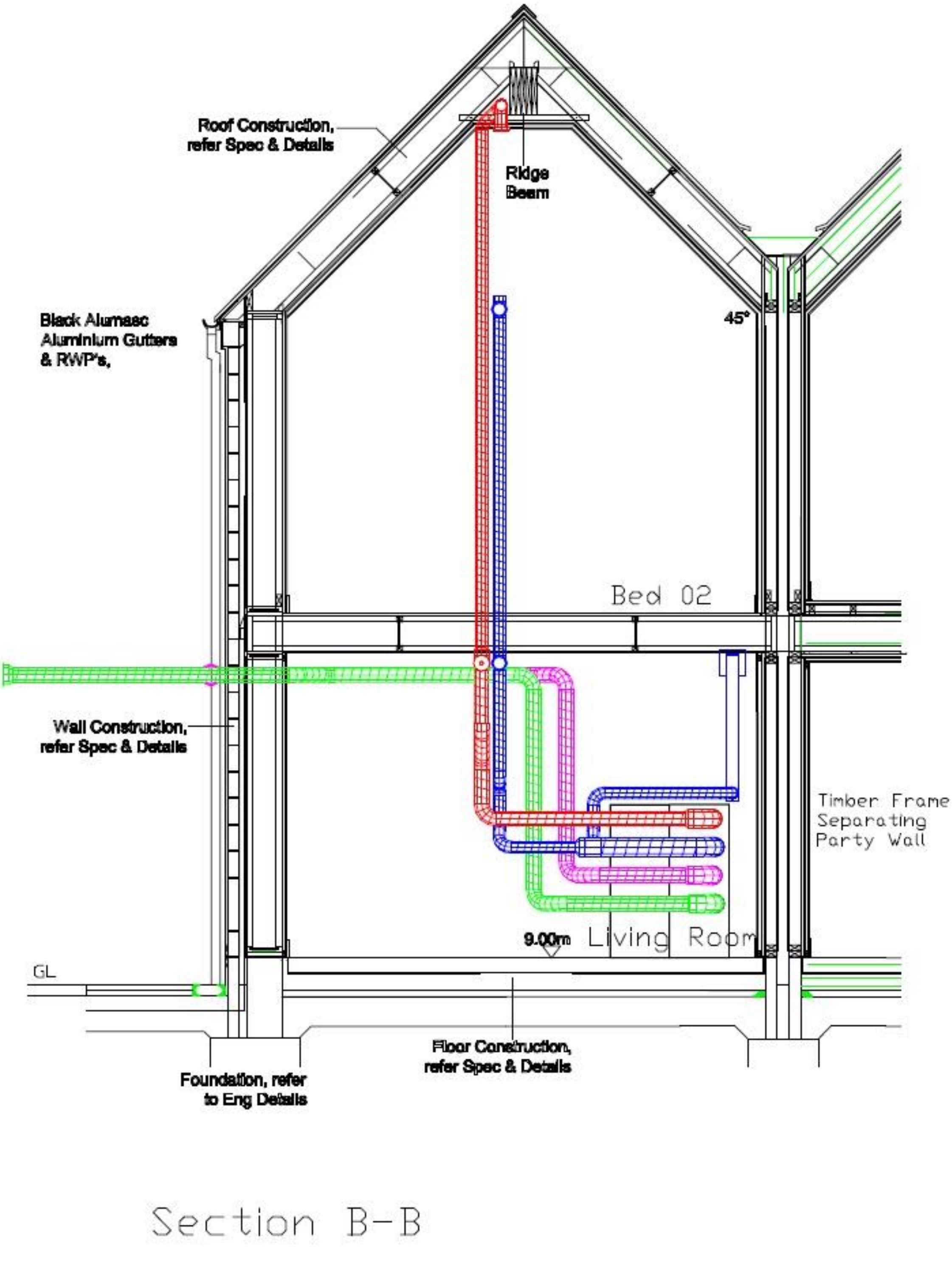


Figure 74: Ventilation Configuration: Section (source: Fyne Homes)