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Energy autarkic buildings

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Copyright Declaration

Abstract

This thesis aims to analyse the energy performance of buildings in order to achieve energy autarky with the application of appropriate renewable energy and storage systems on them.

517 Whins house, located at Findhorn eco-village of Scotland, was selected as case study of this thesis because it fulfils the prerequisites towards energy autarchy direction. It was constructed under very strict building regulations and works very close to passive house standards. On the other hand, there is a considerable number of PV panels installed on its roof making that case attractive for further investigation around the possibility to make it work firstly under Net Zero Energy standards and consequently autonomously.

Modelling of the house carried out in PHPP software, a planning tool which provides all the required information to design a passive house properly. Space heating balances were calculated at monthly and annual method. Additionally, calculations related with maximum heating and cooling load, household and auxiliary electricity, primary energy demand and solar thermal contribution in hot water production were carried out. Consequently, the possibility of the house to work under Net Zero Energy standards was examined, considering energy production of PV panels installed on its roof based on monitoring data from origin project's data-base. Finally, demand supply matching simulations were performed in order to realise as whether the subject dwelling can work autonomously. Merit software was used to undertake these simulations. Under this dynamic demand/supply matching-design tool for renewable energy systems, the energy produced by the installed PV panels was simulated and contrasted with the total energy demand of the house. Additionally, storage requirements, towards energy autarchy direction, were evaluated.

Results interpretation indicated that energy autarchy is possible only under specific conditions such as installation of additional renewable energy systems capable to boost energy production during periods where solar irradiation is weak and appropriate storage system in order to increase the matching between energy demand and supply.

Keywords: Energy autarchy, DSM, Net Zero Energy, Passive House, PHPP

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1. Introduction

Buildings are responsible for 40% of energy consumption and 36% of EU CO2 emissions. Main impacts from energy use are, firstly, the exhaustion of fossil fuel resources and, secondly, the environmental degradation in various ways such as atmospheric pollution (e.g. CO2, greenhouse gases emissions), water and soil contamination (e.g. with radioactive waste materials), damage to the ecosystem etc. (EuropianCommission, 2012)

In building sector as main responsible factors related with the increased energy usage are considered to be; the heating energy demand and the electrical consumption. In line with this, a number of building standards have been released last decades in order to reduce heating energy demand, like the Thermal Protection Regulations (WSchVO) and the Energy Saving Regulations (EnEV), with significant success. However it is considered that by strengthening provisions for energy performance further, a 70% reduction on greenhouse gasses emissions in the EU are possible as well as significant economic benefits for the EU citizens and the construction and building renovation industry. Therefore, a legal framework has been agreed in order to upgrade the national building codes setting a challenging target policy of nearly zero energy buildings, so that all new buildings will be nearly zero energy as of 2020. This means that, heating energy demand must decrease further taking advantage of the passive house standards which can be applied in both new build and retrofit cases. Passive houses are capable to combine with noticeable effectiveness energy efficiency, comfort, affordability being the same time eco-friendly. Their exact definition is as follows: “A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air.” (Passipedia, n.d.)

Finally, going a step further, in order energy autarchy to be achieved energy demand must reduce and also must be controlled and shifted in such a way that can be covered by in situ renewable generation. This means that, on the one hand heating and cooling energy demand as well as household electricity must reduce ensuring that magnitude of supply corresponds to the one of demand and on the other hand that supply and demand phases are matching ascertaining that energy is not wasted. Technically, this can be possible with the use of advanced household appliances, communication and control of energy demand supply matching and implementation of passive house standards to houses. This project uses data gathered as part of the ORIGIN research project which is being funded by the European Commission and will be piloted over three years in three eco-villages in different climatic settings: northern Scotland, southern Portugal and the Italian alpine foothills. The project's mission is to develop an intelligent ICT system for the management of energy in communities, and associated business models. In this way, ORIGIN will orchestrate efficient and balanced use of locally generated energy from renewable sources, such as wind or solar energy. User-friendly tools will provide demand and supply forecasting and propose energy habits. (Origin concept, n.d.) (Passipedia, n.d.)

1.1. Objectives

The main deliverable of this study is to analyze theoretical and actual data (building performance and energy production) in order to figure out as whether it is feasible energy autarchy at advanced buildings, working close to passive house standards, with the use of energy produced by renewable systems installed to them. In addition to this further suggestions have to be proposed, based on the findings of the above analysis, in order to indicate improvements which can lead to energy autarchy.

1.2. Approach/methods

In order to achieve the objectives being described previously the following stages were introduced.

Firstly, a literature review on the fundamental principles deal with the passive houses took place in order to understand in depth how under these standards energy performance of buildings can improve, resulting to lower energy consumption and leading to energy autarchy under conditions.

Secondly, the performance of the case study house assessed and evaluated after had been modeled using PHPP (Passive House Planning Package). In order to model and determine energy balances for the subject buildings a tool like Passive House Planning Package is required. The heating and cooling demand as well as household electricity and primary energy demand identified in order to examine as whether the case study dwelling works under Passive House or EnerPHit standards. Findings from the subject modeling were used at later stages for further investigation.

Then, the possibility for the house to work under Net Zero Energy standards were examined taking into account energy production of PV panels installed on its roof based on monitoring data from origin project data-base.
Subsequently, the possibility of energy autarchy was investigated through MERIT software which is an ideal tool for supply demand matching analysis. As input was used the PHPP's modeling output data as well as the PV panel's energy production.
Finally, suggestions were proposed for further improvements of the subject dwelling in order energy autarchy to be carried out.
The main steps to achieve the objectives were:

- Background reading in order to understand in depth the subject
- Identification of case study house
- Performance quantification and modeling of relevant house in PHPP
- Analysis of the existing monitoring data available by the Origin research project
- Examination around Net Zero Energy Building standards
- Investigation of energy autarky via MERIT
- Suggestions for improvements and future studies

The Whins (Origin research project's classification of the houses according to the type of renewable systems implemented to them) house with tag number 517 located at Findhorn eco-village North of Scotland was chosen as the case study.

2. Reduced primary energy requirement - Literature

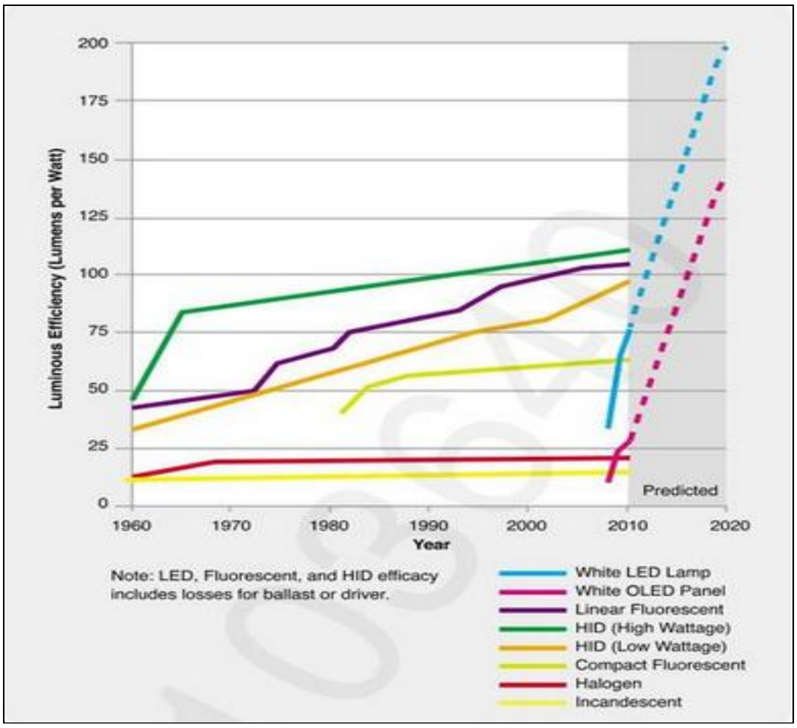
In this section factors, which affect mainly the heating, cooling and electrical requirement of a house, are analyzed based on relevant literature review. The main target is to achieve energy autarchy with the lowest investment on renewable energy and storage systems; hence the reduction of energy demand is of great importance.

Factors which influence the primary energy requirement of a building during its operation are mainly two. Firstly, during construction process of the house, the building standards which have to be followed must ascertain that thermal losses during winter as well as thermal gains during summer will be the lowest possible. Passive house standards are considered to be the strictest one towards this direction. Under these standards, a high level of insulation is applied in order to minimize heat transfer through the walls, highly efficient windows are used ensuring low U-Values regarding the glazing and the frames and air tight construction technics are applied in order to keep the infiltration rate as low as possible. Ventilation systems with heat recovery units are used not only in order to guaranty the required indoor air quality but also as heating means because the incoming cold fresh air entering the house can raise its temperature from the exhaust air's temperature at the heat recovery unit. In addition to this emphasis has to be given at passive solar design. Especially orientation of the house has to be selected in such a way to take advantage from solar irradiation in order to increase solar gains that contribute to heating demands while minimising the solar contribution to overheating or cooling energy demands. If all the above mentioned, applied properly then the required domestic hot water and heating and cooling demand from a supplementary device will be very low resulting to an extremely reduced primary energy demand.

Another yet important factor which influences the primary energy demand of a house is the electricity consumption by the appliances being used and the lighting of the house. (Passipedia, n.d.), (Stamatis D. Perdios, 2005)

2.1. Household electricity reduction

To start with, household electricity can be reduced in various ways. The design of a house must take advantage of daylight in order artificial lighting to be supplementary to it. There are a lot of active and passive day lighting technics which aiming to reduce the electrical demand. Specifically, proper orientation of openings must be selected in order to maximize solar illumination and also must be ensured that openings when natural light is available are free of shading. As far as it concerns the cases during which natural lighting is not enough, there is plethora of low energy sources such as various types of lamps with low energy consumption which can be used. However artificial lighting must be provided only when and where it is needed with the incorporation of proper control and zoning system integrated within an automated system. In order to design properly the lighting system of a building, lighting simulations have to be carried out. This will dictate for each space of the building how artificial lighting must supplement natural lighting and will also indicate in which lighting zone will be each space. Moreover, motion and natural light sensor photocells could have great contribution to energy saving. Once the appropriate lighting system and procedure has been designed, the lowest energy light source technology has to be used. The technology of light sources is improving rapidly as regards the life of lamps, the possibility for control and the extremely improved efficiency. There are many types of lamps with high efficiency such as High Intensity Discharge (HID), Compact and Linear Fluorescent, Light Emitting Diode (LED) and Organic Light Emitting Diode (OLED). Halogen lumps and incandescent are not suitable for energy reduction purposes. The improvement on the efficiency of each type of lumps during the passing decades is shown on Graph 1 below.



Graph 1: Lumps technology efficiency improvement
Source: Hootman, T., 2012. Net Zero Energy Design. New Jersey: John Wiley & Sons, Inc.

Moreover implementation of renewables contributes to electrical demand reduction minimizing the required electricity drawn from the central grid. For instance, solar irradiation can be captured from PV panels in order to provide the required electricity. Finally, the use of appliances, which are suitable for low energy buildings and have achieved high level of efficiency standards, can have significant contribution to primary and final energy demand reduction. (Hootman, 2012), (Stamatis D. Perdios, 2007)

2.2. Passive houses

With the term Passive house we mean a building concept which ensures comfort, affordability, energy efficiency and environmental protection simultaneously. Under the subject building standards, it is ensured less energy consumption compared even with the one of low-energy buildings. In fact, a 90% reduction can be achieved on energy demand for heating and cooling in relation with the house stock while the reduction compared with the new-build houses can be over 75% as can be seen at Figure 1. Less than 1.5 l/(m^2yr) of oil are required for space heating which is far less compared with the consumption of a low-energy house.

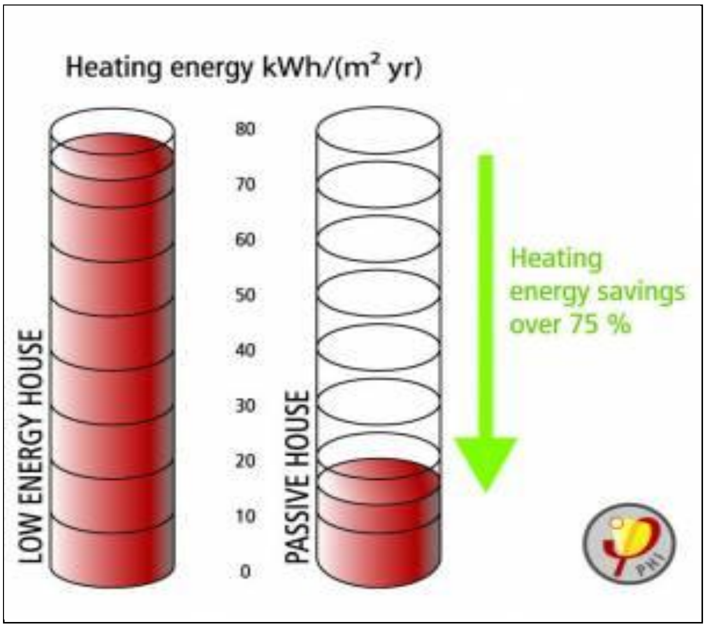


Figure 1: Reduction on energy demand due to passive house standards construction.
Source: Passipedia

In addition to this, significant energy saving can occur at hot climates because passive houses do not require any active cooling system. Furthermore, the effective use of sun, the correct use of internal heat gains and the heat recovery ventilation system make useless the heating systems even at the coldest days of the year while proper shading strategy and opening's orientation can ensure thermal comfort during warm days just with the use passive cooling means. Thermal comfort of passive houses mainly lay on the fact that the interior surface's temperatures vary a little compared with the one of the internal air. This is mainly a matter of proper thermal envelope construction as well as of special windows installation. This means that, thermal bridges either on the walls or the windows are eliminated. Exterior walls, floor slabs and roofs reach to an extremely high quality level of insulation and air tightness ensuring thermal comfort to the residents on both cold and hot months. Heat recovery units are used on ventilation system in order to capture part of the exhaust's air heat and re-use it in order to warm up the incoming fresh air while indoor air quality ascertained by the use of highly efficient ventilation systems which supply constant air at the ideal conditions. The whole concept is demonstrated at Figure 2 bellow.

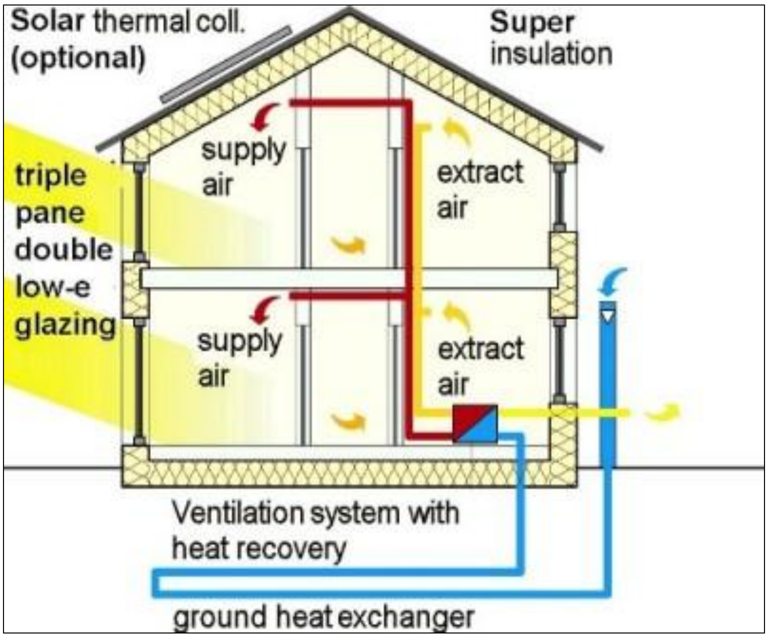


Figure 2: Typical passive house arrangement.
Source: Passipedia

Passive houses are considered to have a great contribution to the sustainable development as their energy demand is very limited contributing to the prevention of energy resource's exhaustion ensuring their existence for the next generations. Due to their special construction, primary energy demand is very limited in order to ensure thermal comfort. The additional amount of energy required for their construction is very few compared to the energy saving during their usage by the occupants. It is very important to note that passive house standards are capable to be applied either in retrofit or new-build cases at an affordable price. (Passipedia, n.d.), (PausivhausTrust, n.d.), (CEPH-DevelopingGroup, 2014), (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

2.3. Passive house criteria

The Space heating energy demand of a passive house is almost 10% of the energy being used by a conventional house. Therefore, in order a house to be certified as passive should meet the following criteria:

- The annual heating and cooling demand must not exceed 15kWh$/(m^2$yr) and the equivalent load for both cases must be equal or less than 10 W/m^2.

- The primary energy use for space heating and cooling, hot water, dehumidification and household electricity should not be more than 120kWh/(m^2yr).
- Airtightness must be ensured; hence air changes must be as low as n50≤0.6ac/hr in a standard pressurisation test.
- During warmer months over-heating (temperatures more than 25°C) must not occur more than 10% of the time ensuring thermal comfort.

In cases where the passive house criteria cannot be met like retrofit projects, where the existing architecture and special conditions render the certification not feasible, another slightly relaxed certification can be attributed like the EnerPHit standards. According the EnerPHit criteria, space heating must be less than 25kWh/(m^2yr), the primary energy demand 120kWh/(m^2yr) + heat load factor and the airtightness n50≤10ac/hr. (Passipedia, n.d.), (PausivhausTrust, n.d.), (CEPH-DevelopingGroup, 2014), (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

2.4. Passive house details

The main requirement for a house in order to meet the passive house standards is to be air-tight in order thermal losses during cold months and thermal gains during the warmer ones to be minimized. This means that, it is impossible sufficient ventilation to occur through cracks, joints and open windows. As the supply of fresh air is of great importance for the occupants not only for thermal comfort but also for ensuring healthy leaving, ventilation systems are the key technology has to be used. Despite the fact that this equipment requires a higher capital investment by the owner, its installation will result to a great decrease of the running cost. The large amount of air being supplied to the house can be used not only for the ventilation process but also for heating purposes saving a lot of money for the owner. In order this concept to work properly it is required an appropriate level of insulation as well as a heat recovery system to ensure that a significant fraction of the heat which exist at the exhaust air will be transferred to the intake fresh air. A more précised presentation of the requirements need to be met, in each one of the construction details of a passive house, follows to the next sections. Summarizing the details have to be taken into account during construction in order a house to meet the passive house requirements are the following:

- Insulation (external walls, roofs, ground floors)
- Thermal bridge free design
- Airtight construction
- Heat recovery ventilation systems
- Highly insulating windows

(Passipedia, n.d.), (CEPH-DevelopingGroup, 2014)

2.4.1. Insulation

The contribution of external walls, floor slabs and roofs to thermal losses is as much as 70%. Hence, in order to save energy for heating and cooling, the improvement of building's thermal envelope is the most effective way. U-Values of passive houses as regards opaque elements vary from 0.10 to 0.15 W/m^2K maintaining thermal comfort and eliminating construction damages like mould as their interior surfaces are almost on the same temperature with the inside air, preventing the concentration of moisture. These values are the most cost effective based on today's energy prices and installation cost. Proper insulation in relation with correct shading and ventilation system can work reverse also, protecting the house from overheating during warm months. U-Values, when the building element consists of homogeneous material layers, are calculated via the following equation:

$$U = \frac{1}{Rsi + R1 + R2 + \ldots + Rn + Rse}$$

Equation 1: Opaque elements U-Value calculation

Where, R_{si}, R_{se} is the thermal resistance of the exterior and interior surfaces and $R1 \ldots Rn$ the resistance of every construction layer.

The thermal resistance is:

$$Ri = di/\lambda i$$

Equation 2: Thermal resistance calculation

Where, di is the thickness and λi the thermal conductivity. Thermal conductivities of typical materials listed on Table 1 below.

Table 1: Thermal conductivities of typical materials
Source: Passipedia

Material	Thermal conductivity *W/mK*
Reinforced concrete	2.3
Solid brick	0.80
Perforated brick	0.40
Softwood	0.13
Porous brick, Porous concrete	0.11
Straw	0.055
Typical insulation material	0.040
High-quality conventional insulation material	0.025
Nanoporous super-insulating material normal pressure	0.015
Vacuum insulation material(silica)	0.008
Vacuum insulation material (high vacuum)	0.002

U-Value defines the rate of heat transfer through a building material for a given area when the temperature difference is 1K, hence, its units are $W/(m^2 \times K)$. In order to calculate the heat losses occur at a building element U-Values must be multiplied with the difference of interior and exterior temperatures as well as with the area of the subject building element. Subsequently, if the previous result multiplied with the heating degree hours (duration of heating period) the annual heat losses can be calculated. The whole process is shown at Figure 3 below.

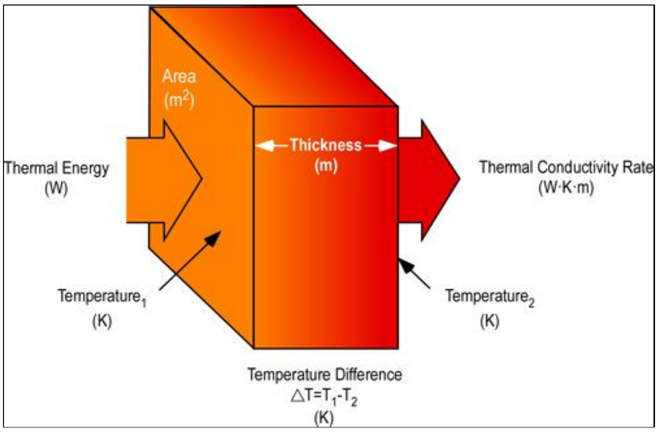


Figure 3: Heat transfer
Source: http://cfbt-us.com/wordpress/?p=1110

In order, compact heating systems of passive houses to be capable to provide sufficient heating, the energy demand should remain very low. Thus, U-Values must restrict to 0.10 to 0.15 W/m^2K in order heat losses to be minimized.

It is obvious that, using materials with less thermal conductivity results to lower U-Values, thus in combination with the climate condition prevailing in the area and building's orientation can lead to reduced heat transmission from each construction element. Therefore, U-Values of passive houses must be limited to the previously mentioned range. This means that, either thickness of the material must increase or materials with very low thermal conductivity have to be used in order to achieve U-Values like the one described before. Repeating thermal bridges are accounted for in the U-Value. Typical example of such super insulated walls appears at Figure 4 bellow.

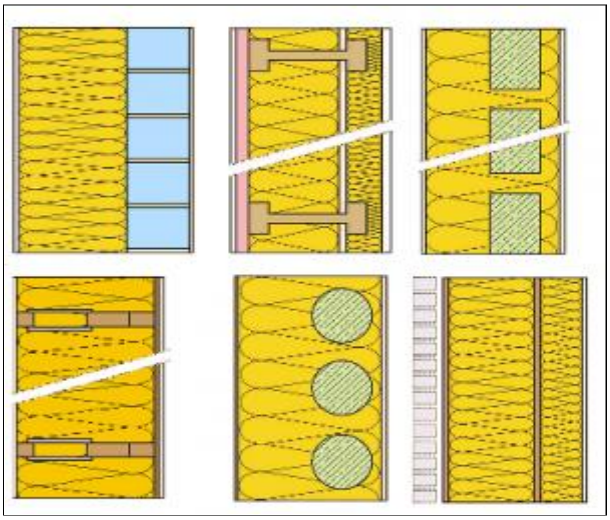


Figure 4: Super insulated walls suitable for passive houses.
Source: Passipedia

The improvement of U-Value is resulting to less thermal losses and finally to significant energy saving. This has a great impact on the financial balance of the occupant as the amount of money being spent for the application of the correct insulation is relatively low in relation with the running cost's saving. The prices of fossil fuels is very likely to increase following years exacerbating the benefits derive from the application of the appropriate insulation. (Passipedia, n.d.), (PausivhausTrust, n.d.), (CEPH-DevelopingGroup, 2014), (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

2.4.2. Thermal bridge free design

A specific area of a building, where heat transfer is significantly higher compared to the areas beside it, is called thermal bridge. The bridges typically occur at junctions between building elements such as wall to window, wall to floor etc., areas constructed by materials with higher thermal conductivity compared with the one of the adjacent areas, through penetrations of the thermal envelope and improper or inadequate application of the insulation material. Due to this phenomenon not only increased heat losses can occur but also construction damages like mould because of moisture's concentration. When the transmission losses by taking into account thermal bridges do not differ from the ones being calculated using only the normal U-Values and external surfaces of the building elements, the building is considered to be classified as thermal bridge free. In order thermal bridge free requirement to be met the value of thermal bridge coefficient "ψ" must be equal or less than $0.01W/(mK)$. When this thermal bridge criterion is fulfilled thermal losses due to thermal bridges are considered negligible and the internal surface temperature remains high enough not to reach the air's dew point temperature ensuring that adverse conditions like mould's development will not occur. Thermal bridge free design can be achieved at a lower cost if applied during planing phase of the building in order to have the chance to do the appropriate changes. On the other hand despite the fact that interventions can be done after completion of the construction works, significant higher costs can occur.

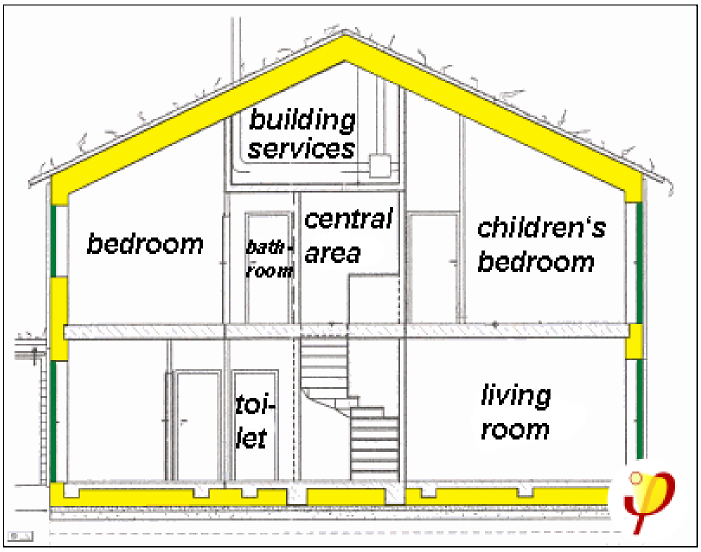


Figure 5: Thermal bridge free design
Source: Passipedia

In order to achieve a thermal bridge free design, after the requirement of passive houses for 20cm insulation thickness has been fulfilled it must be possible to outline the perimeter of the insulation envelope without any interruption as it is shown on Figure 5 above. This technique can be applied for all types of construction such as massive constructions, low thermal conductivity blocks, timber beams constructions, formwork elements, prefabricated concrete blocks. At the Figure 6 bellow is shown how using porous brick with low thermal conductivity at first row on a slab on grade the thermal bridge can be eliminated. (Passipedia, n.d.), (PausivhausTrust, n.d.), (CEPH-DevelopingGroup, 2014), (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

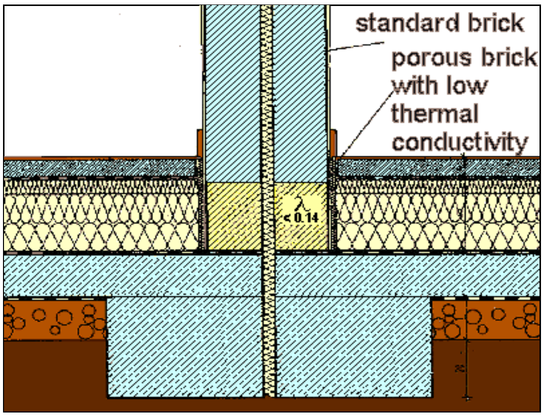


Figure 6: Thermal bridge free construction in slab on grade
Source:http://passiv.de/former_conferences/Passive_House_E/passive_house_avoiding_thermal_brigdes.html

2.4.3.Airtight construction

Thermal envelope should be constructed at an air-tight manner mainly in order to prevent construction damages. Specifically, indoor warm air which has high vapor content during its transmission from inside to outside through gaps is cooled down, its temperature drops below its dew point and condensing at the coldest point within the construction causing significant damage as it is shown at Figure 7. The correct application of an airtight layer can eliminate this phenomenon.

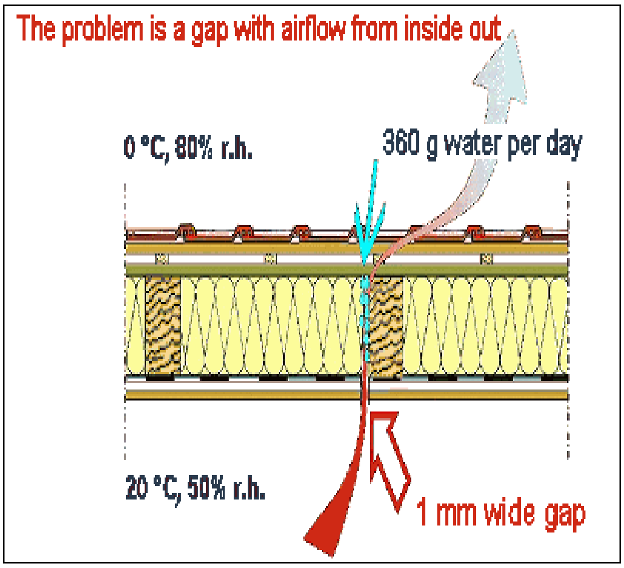


Figure 7: Water condensation at the coldest part of the construction material
Source: Passipedia

In addition to this, the appropriate airtight layer may increase the level of thermal comfort as reduces the appearance of cold air pockets and draughts at the living space. Furthermore, air tightness is a prerequisite in order the ventilation system to work effectively at its highest performance saving significant amount of energy and ensuring the same time that air changes happen at a controlled manner and air's quality is the ideal one. Finally it can work as sound protection measurement.

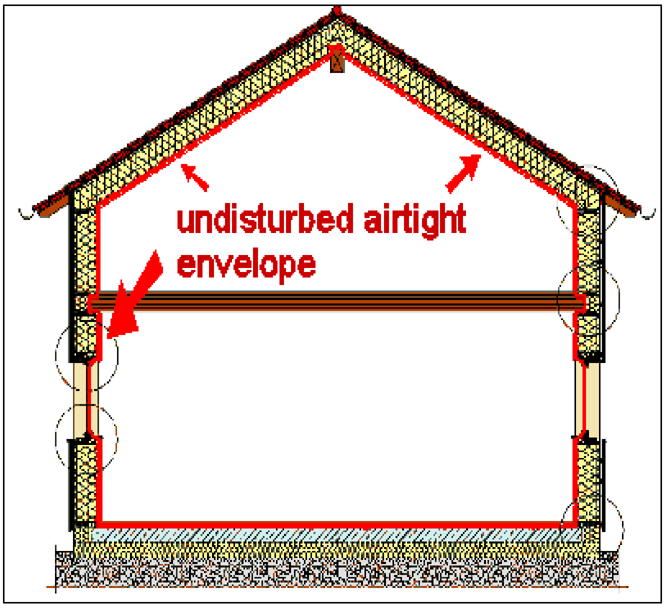


Figure 8: Air tight construction
Source: Passipedia

The air tight layer must be applied throughout thermal envelope without any interruptions in the same way described in the previous paragraph for the thermal bridge free design construction and as it is shown on Figure 8 above. Additional attention should be paid at the connections between the ends of the airtight layers or between the airtight layer and other components like the window's frame. An air leakage value equal or lower than n_{50}=0.6h^{-1} is the passive house requirement and despite the fact that seems to be really demanding it is a fact that significant lower values such as n_{50}=0.3h^{-1} have been achieved by experienced construction teams using careful planning without any significant increase on cost. The leakage value is measured after airtightness tests are carried out. Using blowers attached to buildings openings, like doors, positive and negative pressure is created at the interior of the building and then air leakages are measured. Airtightness planning carried out at three stages:

- The airtight layer should be specified with a red line either in the floor plan or the sectional drawing (figure 8).
- It must be specified the detail of the permanent and airtight connections at the ends of the airtight layer. For instance the connection of the airtight layer with the window's frame.
- Penetrations for cables and pipelines if can't be avoided should be planned in such a way to be the fewer possible by concentrating in specific places. Also where penetrations are necessary to be done, suitable materials and solutions there are for this purpose.

Air tightness must not be confused with thermal insulation and diffusion permeability also. A material can have low thermal conductivity, so ideal insulating ability, but this does not mean that the same material will have the same level of airtight or diffusion permeable ability and vice versa. The most resistant layer of an air-tight construction needs to be near the inside of the building component, ensuring good moisture performance as the indoor air which has high vapour content cannot even enter at the construction component in order to condensate and damage it. A vapour and wind barrier needs to be at the internal surface in order to stop diffusion of moisture through the construction element as it is shown on the following Figure 9.

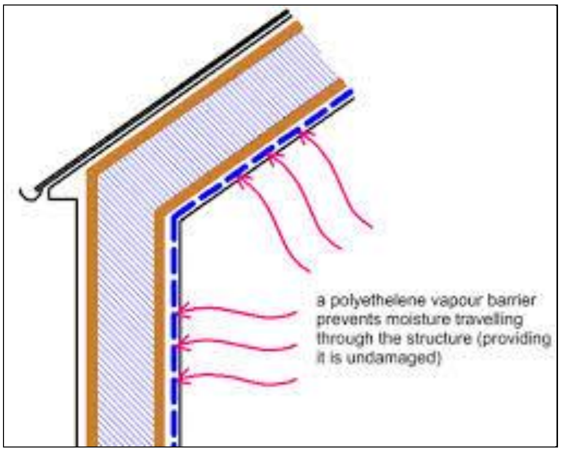


Figure 9: Vapour barrier
Source: http://www.selfbuild-central.co.uk/construction/main-structure/

(Passipedia, n.d.), (PausivhausTrust, n.d.), (CEPH-DevelopingGroup, 2014), (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

2.4.4. Heat Recovery Ventilation Systems

Ventilation system is a fundamental component, as far as it concerns the function of a passive house, not only from an energy saving point of view but also from a hygiene perspective as it ascertains increased indoor air quality. The last can be ensured replacing polluted used air with odours from the interior of a building with new one fresh air at a controlled manner in right quantities. This can be achieved only with the use of a ventilation system. Needless to say that, neither gap or windows ventilation can work properly towards this direction. To start with, ventilation through gaps can result to intolerable heat losses and draughts at houses which are not airtight during times in which air and temperature fluctuations occur. Additionally warm air with high moisture content can cause construction damages when escaping from gaps due to condensation. On the contrary when airtight layer is applied properly the amount of exchange air is not sufficient to ensure the required indoor air quality but on the other hand, ventilation through windows is uncontrollable. As nobody is capable, even an expert, to realise the indoor air quality and the amount of air being supplied by open windows, it is impossible to achieve the fresh air to be supplied at the correct quantity. An analysis done for the adequate air exchange showed that windows must remain open for at least 4 times every day and for the largest intervals between each opening. It is worth mentioning that in order to achieve 0.33 air changes per hour, windows must remain open for at least 5-10 minutes every 3 hours even the nights something which seems very difficult to happen. At any other case, the amount of exchanging air either will be very low, causing increased concentration of vapours, radon, dust and other toxic substances or very high, causing draughts and very high thermal losses. Both cases will result to bad air quality, construction damages, adverse health effects for the occupants and significant increase on the energy consumption. Therefore, in order both requirements for indoor air quality and low energy consumption to be met, the only solution it is considered to be the use of mechanical ventilation system with heat recovery system. It is an undeniable fact that, a simple exhaust air system cannot work properly in passive houses as the heating demand will be double due to the cold incoming fresh air and because it will be necessary the use of a heater very close to air's inlet. Therefore, in order ventilation system to guaranty the required indoor air quality and also passive house's heating demand requirements to be met, air should be extracted at a controlled manner from areas with humid air like kitchens, toilets and bathrooms and fresh air to be supplied at the other living areas and rooms using the same time an efficient heating recovery system. The process is shown in the following Figure 10.

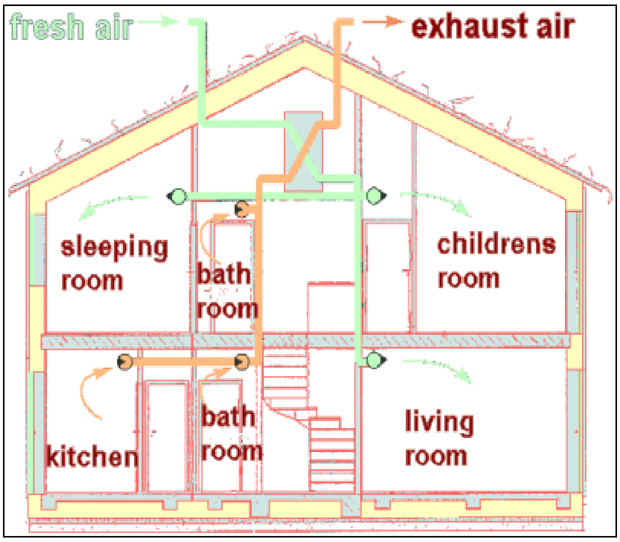


Figure 10: Ventilation system with heat recovery
Source: Passipedia

With the use of this system a portion of heat is recovered by the exhaust air and is supplied to the fresh air through a counter flow heat exchanger without mixing the two air streams. 75% to 90% of heat recovery is possible to be achieved using this type of heat exchangers as well as special energy efficient fans. The recovered heat is 8-15 times the electricity being consumed by the recovery system. In order to improve the efficiency of ventilation systems subsoil heat exchangers are used. They take advantage from the fact that soil has lower temperature during summer and higher during winter than the one of ambient air. As a conclusion the use of a ventilation heat recovery system has the following advantages:

- Fresh, high quality air is supplied to the rooms
- Humid air is dehumidified
- Stale used air and odours is removed
- Ventilation heat losses reduce from 20-30 kWhr/m^2yr to 2-7 kWhr/m^2yr which inside the passive house restrictions as the supplied air is not cold thus significant energy saving take place
- Construction damages like mould growth are prevented.

(Passipedia, n.d.), (PausivhausTrust, n.d.), (CEPH-DevelopingGroup, 2014), (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

2.4.5. Highly insulating windows

Insulating windows are another yet important factor to achieve thermal comfort and energy saving simultaneously at passive houses. Normal windows with high U-Values provide poor insulation hence need an active heating component near them in order to tackle successfully cold radiation, draughts and cold air streams due to their cold surface. With the use of insulating windows a reduction of 50% in heat losses is possible in comparison with the normal one while they provide thermal comfort and reduced energy demand even the coldest days. In order to meet passive house standards, insulating windows, must be installed properly, should be either triple or low-e glazing (For the UK they must be triple and low-E and gas fill), should have warm edge spacers to reduce the heat lost around the perimeter of the window, can be argon or other gas filled to reduce heat transmission from the exterior pane to the interior and must maintain high level of insulation on the frame and the glass edge respectively as shown on Figure 11 below.

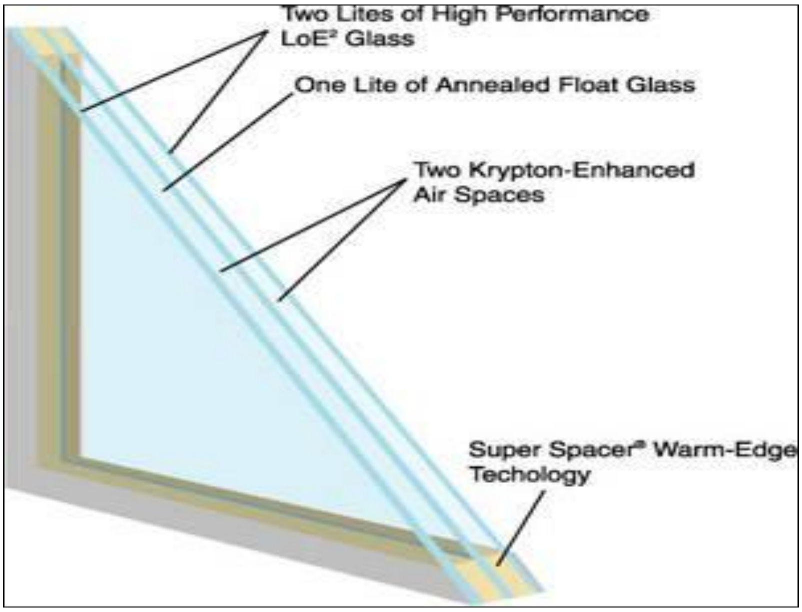


Figure 11: Window with multiple panes, Gas fill and warm spacer
Source: http://www.treforestglass.co.uk/triple-glazing/

Their U-Value, including all the previously mentioned components, should be equal or less than 0.8W/(m^2K) something which helps their inside surface temperature to remain higher than 17°C or 3°C below indoor air's temperature the most, even when cold is too much providing the resident with a high level of thermal comfort and preventing condensation. The calculation of window's U-Value takes into account the U-Value and the area of the glazing and the frame U_g, A_g, U_f, A_f respectively as well as the linear thermal transmittal and the length of the edge Ψ_g and I_g and also the thermal bridge due to installation of the window to the external wall Ψ_{inst}, $I_{inst.}$ The equation which covering the calculation of windows U-Value is as follows:

$$U_{window} = [Ag \times Ug + Af \times Uf + Ig \times \Psi g(Iinst \times \Psi inst)]/(Ag + Af)$$

Equation 3: Windows U-Value calculation

The components of a passive house window are shown in Figure 12.

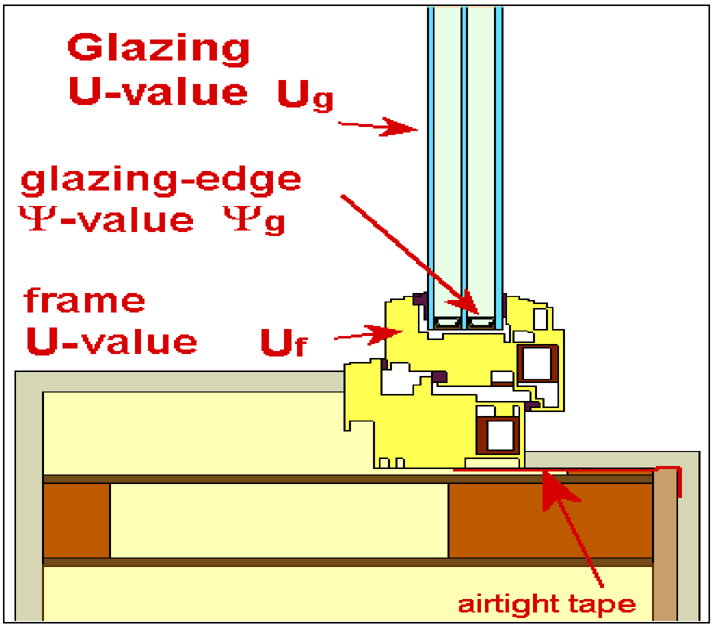


Figure 12: Passive house window
Source: Passipedia

Another requirement of passive house windows is the total energy transmittance (g-value) which indicates the portion of solar radiation pass from the glazing. The requirement summarized to the following equation:

$$Ug - 1.6\, W/(m^2\, K) \times g \leq 0$$

Equation 4: Total energy transmittance

Where, g: the total energy transmittance

Ug: the heat transfer coefficient of the glass itself

When this requirement is fulfilled the window's contribution through passive solar gains compensates their thermal losses. A typical g-value is approximately around 0.5 and when heat transfer coefficient of the glass is $0.8 W/(m^2\, K)$ the solar energy pass from the glazing offset the energy losses from the same surface. Nevertheless the value of total energy transmittance "g" should be the highest possible. (Passipedia, n.d.), (PausivhausTrust, n.d.) (CEPH-DevelopingGroup, 2014) (The indipendent institute for outstanding energy efficiency in buildings, n.d.)

3. Monthly and Annual Energy Balance using PHPP

In this section, takes place the modelling of the case study's house at passive house planning package in order to realise its final and primary energy requirement. These values will indicate as whether the house works with a very small energy requirement and will be used later in following sections for further investigation around Net Zero Energy standards and Energy Autarky as well.

Passive house planning package is planning tool which provide all the required information to design a passive house properly. Mainly calculate space heating balances at a monthly or annual method, the maximum heating load and performs calculations related with heating distribution, household and auxiliary electricity and the primary energy demand. Additionally it takes into account contribution of solar thermal in hot water production if any and extracts it automatically from the primary energy demand. It calculates also cooling demand if an active cooling is present or the frequency of overheating when passive cooling is applied. It also deals with a number of aspects like dimensioning house's building components, opaque elements U-Values, windows quality and U-Value, calculation of shading and ventilation system in order to determine how these factors interact each other and affect the heating demand during winter and the cooling load during summer. Also through PHPP is achieved the dimensioning of heating and cooling load as well as building's mechanical systems dimensioning. Finally, through PHPP can be performed the verification of a house as far as it concerns its energy performance either as Passive house or EnerPHit.

Various climate data can be selected from an existing list with standard profiles. It consists of monthly climatic conditions and especially provides information for the ambient temperature and the solar irradiation for each selected area. Based on this, PHPP calculates monthly heating and cooling demand for the modelled building after internal heat gains from passive solar systems has been taken into consideration. All the process being followed by PHPP and described above in order to verify a building as passive is presented below on Figure 13. (Passipedia, n.d.), (Wolfgang Feist, 2012), (The indipendent institute for outstanding energy efficiency in buildings, n.d.), (CEPH-DevelopingGroup, 2014)

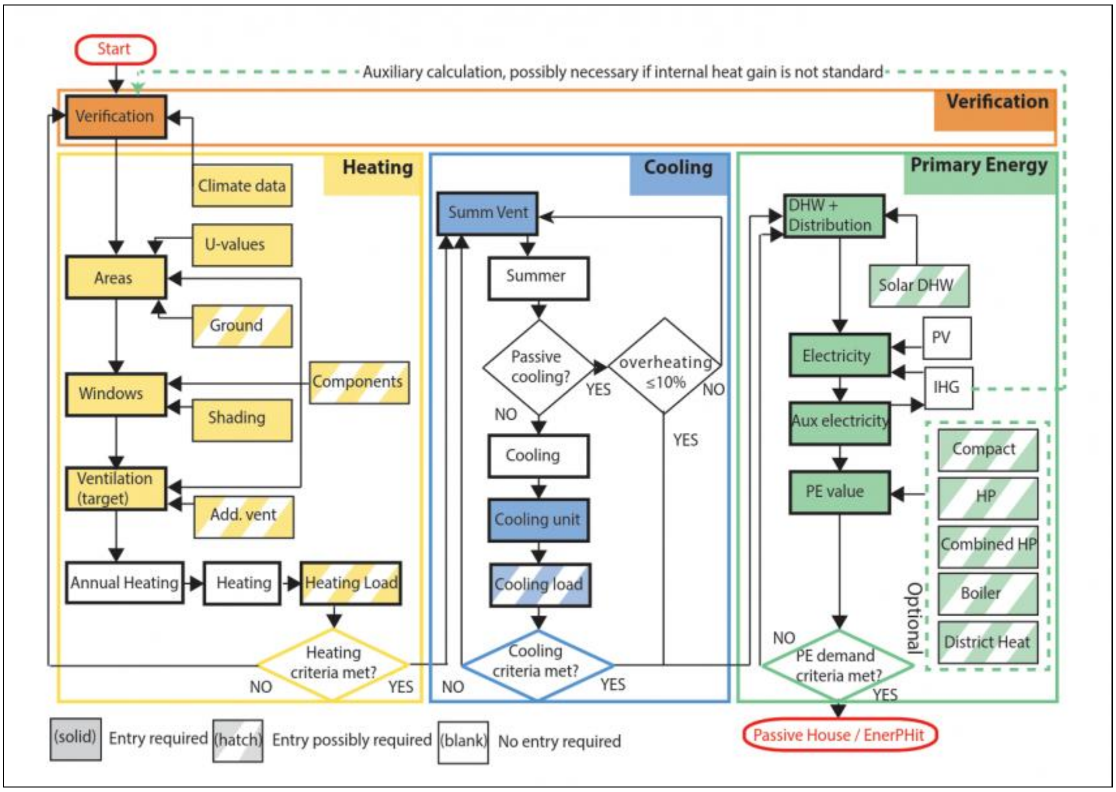


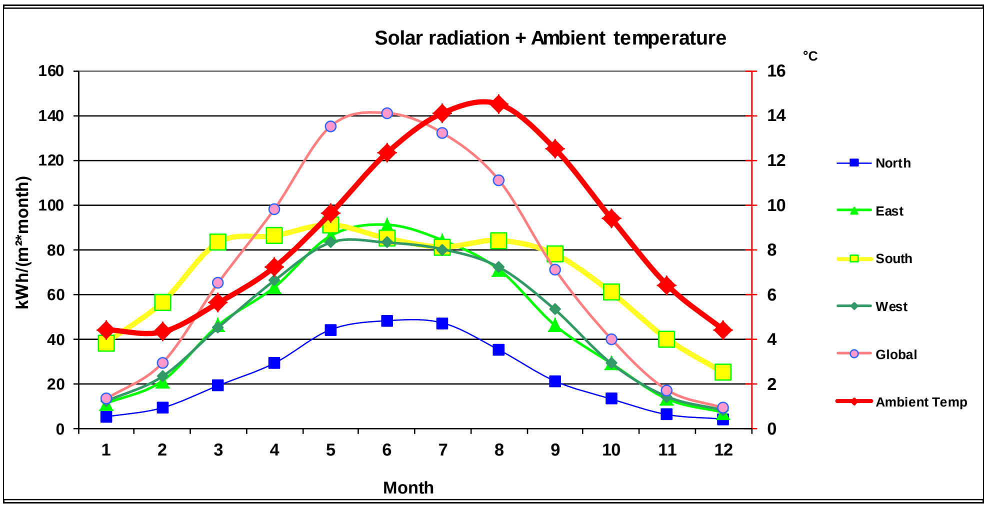
Figure 13: PHPP verification process flow chart
Source: Passive Hause Planning Package. Version 7 ed. Darmstadt: Passive House institute

3.1. Approximations and calculation procedure

Due to the lack of appropriate documents and drawings approved for construction a number of approximations were done in order to carry out satisfactorily the required modelling at PHPP software. The approximations which were done as well as the procedure which was followed for the modelling of 517 Whins house follow to the coming sections.

3.1.1. Climate data selection

To start with the climate data in order to do the required modelling was selected. There is plethora of different standard climate profiles available on PHPP but it was not available Findhorn’s climate data. Therefore, it was chosen the data refers to the closest available area; which was the climate data of north-east Scotland (Aberdeen). Climate data worksheet coordinates with the most of the rest one such as Cooling, Summer and Windows worksheets and plays a very significant role as regards the calculation of heating demand and the heating and cooling loads. Every data includes the average temperature and solar irradiation for a horizontal surface and the four vertical surfaces. The ambient temperature and solar irradiation for the subject location is shown on the Graph 2 below.



Graph 2: Selected climate data

3.1.2. Areas calculation

In order to fill the "Areas" worksheet the following drawings were used:

- Drg No: N-02 title: "Dunelands Eco Village - Type B"
- Drg No: PS100 title: "BLOCK 1_SECTION A-A' Two bedroom house"
- Drg No: PS101 title: "BLOCK 1_SECTION B-B' Two bedroom house"
- Drg No: PS102 title: "BLOCK 1_SECTION C-C' Flexi unit"
- Drg No: PP102WEST title: "FOUNDATION PLAN TYPE A: SETTING OUT"
- Drg No: [25]01 title: "Porch Details House type A & B"

All the above mentioned drawings are attached at appendix A. The listed drawings in most cases do not include all the required dimensions to calculate the area of each space and some of them refer to east Whins houses type A instead of type B which is the one we are looking for. Nevertheless, the required areas can be calculated with satisfactory accuracy doing the assumption that type "A" houses are pretty similar with the one of type "B" and also by scaling down missing dimensions. Finally orientation of house's openings were found using Google earth. Elaboration of all useful information included to the above drawings led us to calculation of total thermal envelope, area of each building element and associated thermal bridges.

Finally, for the calculations of all existing thermal bridges dimensions a lot of approximations were done as the above mentioned drawings used again. As "Ψ" coefficient two typical values were used; 0.025W/mK for thermal bridges related with ground floor slab and 0.016 W/mK for all the rest. All results are presented on the following Table 2 extracted from PHPP software.

Table 2: Area calculation of each building element

Group Nr.	Area group	Temp. zone	Area	Unit
1	Treated Floor Area		150,09	m²
2	North Windows	A	5,18	m²
3	East Windows	A	6,22	m²
4	South Windows	A	16,01	m²
5	West Windows	A	0,00	m²
6	Horizontal Windows	A	0,00	m²
7	Exterior Door	A	9,08	m²
8	Exterior Wall - Ambient	A	99,25	m²
9	Exterior Wall - Ground	B	0,00	m²
10	Roof/Ceiling - Ambient	A	104,19	m²
11	Floor slab / basement ceiling	B	91,21	m²
12			0,00	m²
13			0,00	m²
14		X	0,00	m²
15	Thermal Bridges Ambient	A	187,03	m
16	Perimeter Thermal Bridges	P	0,00	m
17	Thermal Bridges Floor Slab	B	40,80	m
18	Partition Wall to Neighbour	I	60,16	m²
Total thermal envelope			331,15	m²

3.1.3. U-Values calculation of opaque elements

Consequently, U-Values of opaque building elements calculation carried out based on the following drawings which are also attached at appendix A:

- Drg No: [22]05 title: "FRONT SUNSPACE WALL MAKE_UP HOUSES"
- Drg No: [22]06 title: "HOUSE / FLAT _ FLEXI UNIT WALL MAKE -UP"
- Drg No: [23]10 title: "FLOOR MAKE UPS HOUSE & FLAT FLOORS"
- Drg No: [37]01 title: "EAVES AT 45°"
- Drg No: [37]02 title: "VERGE DETAIL ROOF/PARTY WALL"
- Drg No: [37]04 title: "RIDGE DETAIL Flats and Houses"

A lot of approximations were made as regards the thickness of each material, their type, their quality and the value of their thermal conductivity. The last one was found by searching lists related with "λ" of construction materials assuming that the material, from which our wall is made, has similar thermal conductivity with them. Furthermore, in cases where dimensions were missing has been assumed that relevant drawings are on scale, thus required dimensions were calculated accordingly. The U-List is shown on the below Table 3:

Table 3: U-List of opaque elements

Passive House verification

U - LIST

Compilation of the building elements calculated in the U-Values worksheet and other construction types from databases.

	Type		
Assembly No.	Assembly description	Total thickness	U-Value
		m	W/(m²K)
1	Exterior wall sunspace	0,301	0,193
2	Roof	0,592	0,089
3	Ground Floor	0,255	0,290
4	Exterior wall extension	0,398	0,120
5	Exterior wall	0,448	0,140
6	Partition wall	0,406	0,139

The U-Value of the external doors were decided to be 0.7W/m^2K fairly typical for a passive house's external door.

3.1.4. Windows calculation

As far as it concerns the U-Value of the windows, the information stated at Dwg No [31]04 "Window Schedule Elevations sheet 2", were taken into consideration. Based on this information windows U-Value should be equivalent to 1.2W/m^2K but the type of frame and glazing is not mentioned. Therefore, a frame and glazing profile, from the existing ones of PHPP, was selected in such a way to ensure a U-Value as close as possible to the one mentioned on the subject drawing. The relevant dimensioning information were extracted, after in depth examination of the same drawing and the Drawing with No: PP102WEST and title: "FOUNDATION PLAN TYPE A: SETTING OUT", following again scaling process. Values related with shading like height of the shading object, horizontal distance, windows reveal depth, distance from glazing edge to reveal, overhang depth and distance from upper glazing edge to overhang were estimated by scaling down, once again, the relevant drawings and listed on Table 4.

Table 4: Windows information

Window area orientation	Global radiation (cardinal points)	Shading	Dirt	Non-perpendicular incident radiation	Glazing fraction	g-Value	Reduction factor for solar radiation	Window area	Window U-Value	Glazing area	Average global radiation
maximum:	kWh/(m²a)	0,75	0,95	0,85				m²	W/(m²K)	m²	kWh/(m²a)
North	111	0,55	0,95	0,85	0,473	0,60	0,21	5,18	1,37	2,5	111
East	240	0,65	0,95	0,85	0,661	0,60	0,34	6,22	1,31	4,1	240
South	440	0,76	0,95	0,85	0,709	0,60	0,44	16,01	1,30	11,4	453
West	245	1,00	0,95	0,85	0,000	0,00	0,00	0,00	0,00	0,0	245
Horizontal	350	1,00	0,95	0,85	0,000	0,00	0,00	0,00	0,00	0,0	350
	Total or Average Value for All Windows.					0,60	0,37	27,42	1,32	17,9	

3.1.5. Ventilation and cooling systems

As sufficient information regarding the ventilation system was not available, it was decided for the heat recovery unit to be considered placed within the thermal envelope. It was selected a unit with heat recovery efficiency of n_{hr}=75%. The insulation thickness of both exhaust and supply air duct was set to 50mm and the corresponding thermal conductivity to 0.04W/mK. Taking into account losses occur in ducts the effective heat recovery efficiency is calculated to $n_{hr,eff}$=73.5%. Subject ventilation unit's selection is presented at the following Table 5.

Table 5: Ventilation unit

Selection of ventilation unit with heat recovery

x	Central unit within the thermal envelope.
	Central unit outside of the thermal envelope.

	Heat recovery efficiency Unit η_{HR}	Specific power input [Wh/m³]	Application range [m³/h]	Frost protection required	Unit noise level < 35dB(A)
Ventilation unit selection: Heat Recovery Unit	0,75	0,40	n.s.	n.s.	n.s.

Conductance value of outdoor air duct Ψ	W/(mK)	0,328	See calculation below
Length of outdoor air duct	m	1,5	
Conductance value of exhaust air duct Ψ	W/(mK)	0,328	See calculation below
Length of exhaust air duct	m	1,5	
Temperature of mechanical services room	°C		
(Enter only if the central unit is outside of the thermal envelope.)			

Room Temperature (°C)	20
Av. Ambient Temp. Heating P. (°C)	6,3
Av. Ground Temp (°C)	9,8

Effective heat recovery efficiency $\eta_{HR,eff}$ **73,5%**

As no any specific document is present containing information related to the pressure test, which was done to the house, the coefficients and pressurization test's result remained same as the one of the example house of PHPP. The calculation of the infiltration air change rate performed using the following equation:

$$nv, Res = n50 \times e \frac{Vn50}{Vv}$$

Equation 5: Infiltration air change rate calculation

It is specified at PHPP's manual that due to the absence of pressure test at the house, a typical value of $0.042h^{-1}$ can be applied to the rate of air leakage instead of $0.047h^{-1}$ which is calculated keeping the same metrics with PHPP's example house. Anyway, the result is almost same and any difference is there does not cause any significant impact. The infiltration air rate calculation is shown on Table 6 below.

Table 6: Infiltration air change rate calculation

Infiltration air change rate

Wind protection coefficients e and f		
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 Heating Load:				
Wind protection coefficient, e			0,07	0,18				
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	0,22	0,22	460	m³	0,31	m³/(hm²)

			for Annual Demand:	for Heating Load:
Excess extract air		1/h	0,00	0,00
Infiltration air change rate	$n_{V,Res}$	1/h	0,019	0,047

In order average air change rate to be identified both supply air and extract air requirement have to be calculated. Consequently the design air flow rate is determined. This flow rate usually is the maximum between extract and supply air rate or at least must be that much to cover the extract air rate. For the calculation of supply air rate it is enough just to specify the number of occupants while for the one of extract air the number and type of extract rooms must be entered. Another yet important requirement is to ensure that with the applied design air flow rate and after multiplication with the residential factor (case study) of 0,77 an average air change rate of $0{,}3h^{-1}$ is maintained. Finally, it is very important the average air change rate not to be very high as draughts and increased heating requirement can be caused. The whole procedure is shown on the following Table 7.

Table 7: Average air change flow rate calculation

STANDARD INPUT FOR BALANCED VENTILATION

Ventilation dimensioning for systems with one ventilation unit

Occupancy	m²/P	35				
Number of occupants	P	4,3				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	**129**		Bathroom		
Extract air rooms		Kitchen	Bathroom	(shower only)	WC	
Quantity		1	3	0	0	
Extract air requirement per room	m³/h	60	40	20	20	
Total Extract Air Requirement	m³/h	**180**				
Design air flow rate (maximum)	m³/h	180				

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	180	0,48
Standard	24,0	0,77	138	0,37
Basic		0,54	97	0,26
Minimum		0,40	72	0,19
	Average value	0,77	Average air flow rate (m³/h) **138**	Average air change rate (1/h) **0,37**

During summer time, manual window ventilation type was selected as the temperature and wind, at climate region of Findhorn, caused by the difference in the density of the air are ensuring that no overheating will occur without mechanical ventilation. This type of ventilation is cost effective and controlled by the occupant. A lot of assumptions were done to summer ventilation sheet in order to organize the strategy for windows ventilation. A number of windows were selected for sided and cross ventilation during day and night in such a way to ensure an average air change rate between $0.3h^{-1}$ and $0.6h^{-1}$. Especially for the night time when there is little or no wind the method of temperature difference is used. Interior doors are left open and cross ventilation take place from windows with different altitude taking advantage of chimney effect. The dimensions of windows used in this sheet were entered based on dimensions from area sheet and they considered as tilted. Finally, the fraction of opening duration remained same as the one of PHPP's example as it is not specified otherwise.

During day and for the ground floor sided ventilation is selected between the 3 south openings of the house with an opening fraction of 13%. For the upper floor it is selected cross ventilation between the two side windows and the two north ones with an opening fraction of 50%. Finally, during the whole night cross ventilation is performed using the south opening of the extension room of the ground floor and the two side openings of the upper floor taking advantage of the chimney effect due to the altitude's difference. All the windows are opened to tilted position. All the information is gathered to Table 8 below.

Table 8: Windows summer ventilation strategy

Passive House verification

SUMMER VENTILATION

Building: End-of-Terrace Passive House East Whins 58 | Building Type/Use: Terraced House/Dwelling

Building Volume: 375 m³

Description	Day GF	Day UF	Night				
Fraction of Opening Duration	13%	50%	100%				
Climate Boundary Conditions							
Temperature Diff Interior - Exterior	4	4	1				K
Wind Velocity	1	1	0				m/s

Note: for summer night ventilation please set a temperature difference of 1 K and a wind velocity of 0 m/s otherwise the cooling effects of the night ventilation will be overestimated!

Window Group 1							
Quantity	3	2	1				
Clear Width	5,70	1,20	2,00				m
Clear Height	4,80	1,50	1,55				m
Tilting Windows?	x	x	x				
Opening Width (for tilting windows)	0,055	0,055	0,055				m
Window Group 2 (Cross Ventilation)							
Quantity		2	2				
Clear Width		1,00	1,20				m
Clear Height		1,60	1,50				m
Tilting Windows?		x	x				
Opening Width (for Tilting Windows)		0,055	0,055				m
Difference in Height to Window 1			3,00				m

Single-Sided Ventilation 1 - Airflow Volume	628	67	19	0	0	0	m³/h
Single-Sided Ventilation 2 - Airflow Volume	0	69	33	0	0	0	m³/h
Cross Ventilation Airflow Volume	628	204	137	0	0	0	m³/h
Contribution to Air Change Rate	0,21	0,27	0,36	0,00	0,00	0,00	1/h

Summary of Summer Ventilation Distribution

Description Ventilation Type	Daily Average Air Change Rate	
Night time Window Ventilation (@1K)	0,36	1/h
Daytime Window Ventilation	0,48	1/h

To sum up the above described summer ventilation strategy results to a 0% overheating as can be seen to the following output from the program (Table 9).

Table 9: Frequency of overheating

Passive House verification

SUMMER

Climate:	North East Scotland (Aberdeen)	Interior Temperature:	20 °C
Building:	End-of-Terrace Passive House East Whins 517	Building Type/Use:	Terraced House/Dwelling
		Treated Floor Area A_{TFA}:	150,1 m²

Spec. Capacity: 204 Wh/K pro m² TFA

Overheating limit: 25 °C

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Red. Factor $f_{T,Summer}$		H_{Summer} Heat Conductance
1.	Exterior Wall - Ambi	A	99,2	*	0,132	*	1,00	=	13,1
2.	Exterior Wall - Grou	B		*		*	1,00	=	
3.	Roof/Ceiling - Ambie	A	104,2	*	0,089	*	1,00	=	9,3
4.	Floor slab / basemen	B	91,2	*	0,290	*	1,00	=	26,4
5.		A		*		*	1,00	=	
6.		A		*		*	1,00	=	
7.		X		*		*	0,75	=	
8.	Windows	A	27,4	*	1,315	*	1,00	=	36,1
9.	Exterior Door	A	9,1	*	0,700	*	1,00	=	6,4
10.	Exterior TB (length/	A	187,0	*	0,013	*	1,00	=	2,5
11.	Perimeter TB (length	P		*		*	1,00	=	
12.	Ground TB (length/m)	B	40,8	*	0,025	*	1,00	=	1,0

Exterior Thermal Transmittance, $H_{T,e}$ 67,3 W/K

Ground Thermal Transmittance, $H_{T,g}$ 27,5 W/K

				A_{TFA} m²		Clear Room Height m		m³
Heat Recovery Efficiency	η_{HR} 73%	Effective Air Volume V_V		150,1	*	2,50	=	375
SHX Efficiency	η^*_{SHX} 0%							

Summer Ventilation continuous ventilation to provide sufficient indoor air quality

Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation, Summer: 0,48 1/h

Mechanical Ventilation Summer: 0,37 1/h   x with HR (check if applicable)

	$n_{L,nat}$ 1/h		$n_{V,system}$ 1/h		Φ_{HR}			$n_{V,Rest}$ 1/h		1/h
Energetically Effective Airchange Rate n_V	0,480	+	0,370	* (1 -	0,735	)	+	0,000	=	0,578

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)			
Ventilation Transm. Ambient $H_{V,e}$	375	*	0,578	*	0,33	=	71,6	W/K
Ventilation Transm. Ground $H_{V,g}$	375	*	0,000	*	0,33	=	0,0	W/K

Additional Summer Ventilation for Cooling   Temperature amplitude summer 7,0 K

Select: x Window Night Ventilation, Manual   Corresponding Air Change Rate 0,36 1/h

Mechanical, Automatically Controlled Ventilation   (for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum Acceptable Indoor Temperature 22,0 °C

	Orientation of the Area	Angle Factor Summer		Shading Factor Summer		Dirt		g-Value (perp. radiation)		Area m²		Portion of Glazing		**Aperture** m²
1.	North	0,9	*	0,62	*	0,95	*	0,60	*	5,2	*	47%	=	0,8
2.	East	0,9	*	0,77	*	0,95	*	0,60	*	6,2	*	66%	=	1,6
3.	South	0,9	*	0,82	*	0,95	*	0,60	*	16,0	*	71%	=	4,8
4.	West	0,9	*	1,00	*	0,95	*	0,00	*	0,0	*	0%	=	0,0
5.	Horizontal	0,9	*	1,00	*	0,95	*	0,00	*	0,0	*	0%	=	0,0
6	Sum Opaque Areas													0,7

Solar Aperture   Total 7,9   0,05 m²/m²

	Specif. Power q_I W/m²		A_{TFA} m²		W	W/m²
Internal Heat Gains Q_I	2,10	*	150	=	315	2,1

Frequency of Overheating $h_{\vartheta \geq \vartheta max}$ **0,0%**   **at the overheating limit ϑ_{max} = 25 °C**

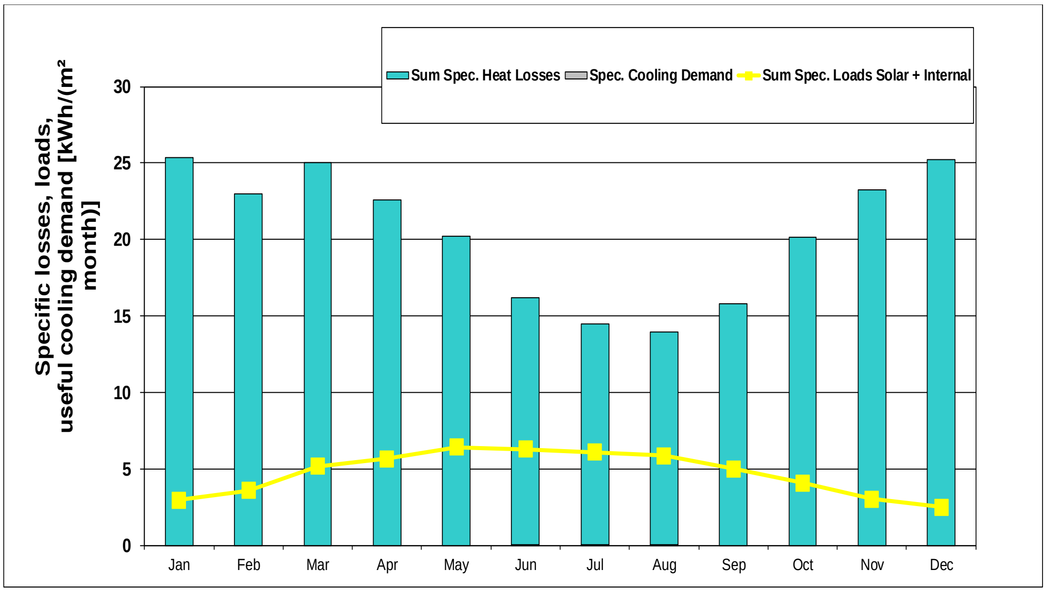
If the "frequency over 25°C" exceeds 10%, additional measures to protect against summer heat waves are necessary.

	Solar Load kWh/d		1/k		Spec. Capacity Wh/(m²K)		A_{TFA} m²			
Daily Temperature Swing due to Solar Load	22,0	*	1000	/ (	204	*	150	) =	**0,7**	**K**

It is obvious that it is not required additional cooling system to obtain thermal comfort during warm months. The cooling requirement as can be seen to the following Table 10 and Graph 3 is 0.0kWhr/m^2yr.

Table 10: Cooling requirement

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	15,5	14,1	14,6	13,0	11,7	9,3	8,3	8,0	9,2	11,8	13,6	15,5	144	kKh
Heating Degree Hours - (	10,9	10,2	11,2	10,4	9,9	8,7	8,2	7,9	7,7	8,5	9,0	10,2	113	kKh
Losses - Exterior	2155	1957	2033	1807	1619	1295	1150	1108	1272	1635	1884	2154	20069	kWh
Losses - Ground	300	281	309	285	272	239	226	216	211	232	247	280	3097	kWh
Losses Summer Ventilati	1346	1211	1418	1294	1140	898	795	765	883	1156	1359	1346	13612	kWh
Sum Spec. Heat Losses	25,3	23,0	25,0	22,6	20,2	16,2	14,5	13,9	15,8	20,1	23,3	25,2	245,0	kWh/m²
Solar Load North	4	7	15	23	35	38	37	27	16	10	5	3	220	kWh
Solar Load East	18	34	74	102	139	147	136	115	74	47	21	11	918	kWh
Solar Load South	175	266	408	439	478	451	429	436	389	295	187	115	4069	kWh
Solar Load West	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Load Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Load Opaque	11	20	42	58	77	80	75	64	43	27	13	7	517	kWh
Internal Heat Gains	235	212	235	227	235	227	235	235	227	235	227	235	2761	kWh
Sum Spec. Loads Solar +	2,9	3,6	5,2	5,7	6,4	6,3	6,1	5,8	5,0	4,1	3,0	2,5	56,5	kWh/m²
Utilisation Factor Losses	12%	16%	21%	25%	32%	39%	42%	42%	32%	20%	13%	10%	23%	
Useful Cooling Energy De	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Spec. Cooling Demand	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	kWh/m²



Graph 3: Cooling requirement

3.1.6. Space heating and DHW

Control and supply of DHW and space heating performed through an air source heat pump and a solar thermal as it is shown on schematics 002/2012 "Whins control schematic" and 001-2010 "LT-SIMPLE-SOLAR-SCHEMATIC". Both schematics are attached at Appendix B. Based on these drawings and a number of assumptions in order to overtake missing information it is concluded that Whins 517 house uses a solar thermal which contributes 61% of energy required for DHW production as well as an air source heat pump as an additional heating system to cover space heating demand because heating power from ventilation system is not sufficient. The same heat pump provides the required energy to produce a fraction of DHW for the days during which solar radiation is not enough for hot water production by solar thermal. Also, there is a booster heater connection to raise hot water's temperature to the required level once it is required.

3.1.6.1. Space heating

Fresh air being supplied to passive houses can work as heat source if the maximum heating power $P_{supply,max}$ transported by ventilation system is equal or higher from the required heating load $P_{h.}$ In order to determine if this can work in the subject case the transmission heat losses, the ventilation heat losses, the internal heat gains and the solar heat gains were entered to an equation and the required heating load were calculated. Then, through the following equation the maximum heating power $P_{supply,max}$ transported by ventilation system was calculated.

$$Psupply, max = (\theta supply, max - \theta supply, min) \times \mathrm{Cair} \times \mathrm{Vv, system}$$

Equation 6: Heating power transported by ventilation

Where, C_{air}: heat capacity of air

$V_{v,system}$: The volume of air flowing through the ventilation system

Results interpretation indicated that heating power from ventilation system is not sufficient, thus a supplementary heating system is required. In the whins house this is supplied through the heat pump and a low temperature floor heat distribution system. All the above mentioned procedure is shown on the following abstracted Table 11 from PHPP calculation sheet.

Table 11: Heating load calculation

Transmission Heat Losses P_T															
											Total	=	1780	or	1632
Ventilation Heating Load P_V															
	V_L		n_L		n_L		c_{Air}		TempDiff 1		TempDiff 2		**P_V 1**		**P_V 2**
	m³		1/h		1/h		Wh/(m³K)		K		K		W		W
	375,2	*	0,147	or	0,147	*	0,33	*	21,9	or	19,7	=	**399**	or	**359**
													P_L 1		**P_L 2**
Total Heating Load P_L													W		W
											$P_T + P_V$	=	**2178**	or	**1990**
Solar heating power P_S											Total	=	**165**	or	**132**
									Spec. Power		A_{TFA}		**P_I 1**		**P_I 2**
Internal heating power P_I									W/m²		m²		W		W
									1,6	*	150	=	**240**	or	**240**
													P_G 1		**P_G 2**
Heating power (gains) P_G													W		W
											$P_S + P_I$	=	**405**	or	**373**
											$P_L - P_G$	=	**1774**	or	**1618**
Heating Load P_H												=		**1774**	**W**
Specific Heating Load P_H / A_{TFA}												=		**11,8**	**W/m²**
Input Max. Supply Air Temperature	52	°C											°C		°C
Max. Supply Air Temperature $\vartheta_{Supply,Max}$	52	°C					Supply Air Temperature Without Heating				$\vartheta_{Supply,Min}$		14,2		14,8
For Comparison: Heating Load Transportable by Supply Air. $P_{Supply\ Air,Max}$											=	1727	W specific:	11,5	W/m²
														(Yes/No)	
													Supply Air Heating Sufficient?	**No**	

As far as it concerns the distribution losses of space heating, they are calculated using the DHW+Distribution worksheet of PHPP. It is assumed that the approximately 25m of piping is totally located inside the thermal envelop and the supply temperature of the water is 35°C as we have under-floor heating. The rest of data and coefficients as well as the equations used by the software to perform the relevant calculations are presented to the following Table 12.

Table 12: Space heating distribution losses

Building:	End-of-Terrace Passive House East Whins 517	
Interior Temperature:	20	°C
Building Type/Use:	Terraced House/Dwelling	
Treated Floor Area A_{TFA}:	150	m²
Occupancy:	4,3	Pers
Number of Residences:	1	
Annual Heating Demand qHeating	3558	kWh/a
Length of Heating Period:	232	d
Average heating load Pave:	0,6	kW
Marginal Utilisability of Additional Heat Gains:	90%	

			Parts					
			Warm Region	Cold Region		Total		
Space Heat Distribution			1	2	3			
Length of Distribution Pipes	L_H *(Project)*		25,00				m	
Heat Loss Coefficient per m Pipe	Ψ *(Project)*		0,140				W/(mK)	
Temperature of the Room Through Which the Pipes	ϑ_X *Mechanical Room*		20				°C	
Design Flow Temperature	ϑ_{dist} *Flow, Design Value*		35,0				°C	
Design System heating load	$P_{heating}$ *(exist./calc.)*		2,0				kW	
Flow Temperature Control (check)			x					
Design Return Temperature	ϑ_R	$=0.714*(\vartheta_{dist}-20)+20$	30,7				°C	
Annual Heat Emission per m of Plumbing	q^*_{HL}	$=\Psi\,(\vartheta_m-\vartheta_X)\,t_{Heating}*0.02$	4			Total 1,2,3	kWh/(m·a)	
Possible Utilization Factor of Released Heat	η_G		90%				-	
Annual Losses	Q_{HL}	$= L_H \cdot q^*_{HL} \cdot (1-\eta_G)$	10	0	0	10	kWh/a	
Specif. Losses	q_{HL}	$= \Sigma Q_{HL} / A_{TFA}$					kWh/(m²a)	0,1
'Performance ratio of heat distribution	$e_{a,HL}$	$= (q_H + q_{HL}) / q_H$				100%	-	

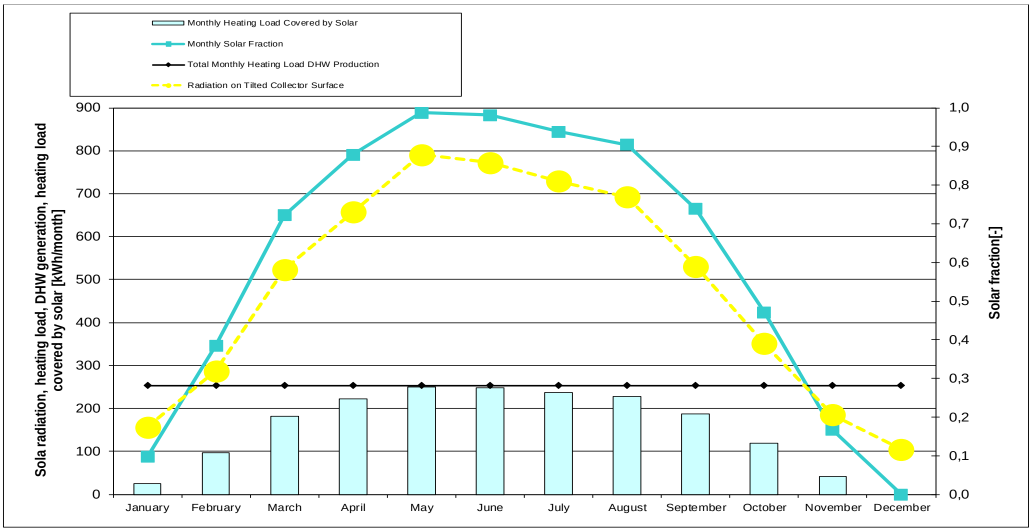
3.1.6.2. DHW

Accordingly, the DHW demand is calculated. Specifically, the hot water consumption per day and person, the supply of cold water temperature and the non-electric wash and dish demand were kept same as they were at the example house of PHPP resulting to a useful DHW demand of 2590kWhr/yr. Following, the distribution and storage losses are calculated and being added to the useful DHW heat. A high quality stratified solar storage system was selected with 26W heat release. Storage losses are then calculated to 97kWhr/yr. Subsequently, heat losses occur to circulation lines and individual pipes are calculated to 284kWhr/$yr$and 64kWhr/yr accordingly. All the relevant data entered to this sheet for the calculations of hot water distribution is kept same with the example house of PHPP as it is not specified otherwise to any document and is presented on Table 13 below. The total heating demand for DHW is then being calculated to 3035kWhr/yr.

Table 13: DHW heating demand

DHW: Standard Useful Heat								
DHW Consumption per Person and Day (60 °C)	V_{DHW}	*(Project or Average Value 25 Litres/P/d)*				25,0	Litre/Person/d	
Average Cold Water Temperature of the Supply	ϑ_{DW}	*Temperature of Drinking Water (10°)*				9,8	°C	
DHW Non-Electric Wash and Dish		*(Electricity worksheet)*				309	kWh/a	
Useful Heat - DHW	Q_{DHW}					**2590**	kWh/a	
Specif. Useful Heat - DHW	q_{DHW}	$= Q_{DHW} / A_{TFA}$					kWh/(m²a)	**17,3**
DHW Distribution and Storage			Warm Region	Cold Region		Total		
Length of Circulation Pipes (Flow + Return)	L_{HS}	*(Project)*	13,5	2,0			m	
Heat Loss Coefficient per m Pipe	Ψ	*(Project)*	0,140	0,140			W/m/K	
Temperature of the Room Through Which the Pipes I	ϑ_X	*Mechanical Room*	20	11,0			°C	
Design Flow Temperature	ϑ_{dist}	*Flow, Design Value*	60,0	60,0			°C	
Daily circulation period of operation.	td_{Circ}	*(Project)*	18,0	18,0			h/d	
Design Return Temperature	ϑ_R	$=0.875*(\vartheta_{dist}-20)+20$	55	55			°C	
Circulation period of operation per year	t_{Circ}	$= 365\ td_{Circ}$	6570	6570			h/a	
Annual Heat Released per m of Pipe	q^*_Z	$= \Psi\ (\vartheta_m - \vartheta_X)\ t_{Circ}$	34	43			kWh/m/a	
Possible Utilization Factor of Released Heat	η_{GDHW}	$=t_{heating}/365d * \eta_G$	57%	0%			-	
Annual Heat Loss from Circulation Lines	Q_Z	$= L_{HS} \cdot q^*_Z \cdot (1-\eta_{GDHW})$	**198**	**86**		**284**	kWh/a	
Total Length of Individual Pipes	L_U	*(Project)*	9,00				m	
Exterior Pipe Diameter	d_{U_Pipe}	*(Project)*	0,012				m	
Heat loss per tap opening	$q_{Individual}$	$=(c_{pH2O}V_{H2O}+c_{pMat}V_{Mat})(\vartheta_{dist}-\vartheta$	0,0322				kWh/tap opening	
Amount of tap openings per year	n_{Tap}	$= n_{Pers} . 3 . 365 / n_{LU}$	4696				Tap openings per year	
Annual Heat Loss	q_U	$= n_{Tap} \cdot q_{Individual}$	151				kWh/a	
Possible Utilization Factor of Released Heat	η_{G_U}	$=t_{heating}/8760*\eta_G$	57%				-	
Annual Heat Loss of Individual Pipes	Q_U	$= q_U \cdot (1-\eta_{G\_U})$	64			**64**	kWh/a	
						Total 1,2,3		
Average Heat Released From Storage	P_S		26				W	
Possible Utilization Factor of Released Heat	η_{G_S}	$=t_{heating}/8760*\eta_G$	57%					
Annual Heat Losses from Storage	Q_S	$= P_S \cdot 8.760\ kh \cdot (1-\eta_{G\_S})$	97			**97**	kWh/a	
						Total 1,2,3		
Total Heat Losses of the DHW System	Q_{WL}	$= Q_Z+Q_U+Q_S$				**445**	kWh/a	
Specif. Losses of the DHW System	q_{WL}	$= Q_{WL} / A_{TFA}$					kWh/(m²a)	**3,0**
Performance ratio DHW-distribution + storage	$e_{a,WL}$	$= (q_{TWW} + q_{WV}) / q_{TWW}$				**117,2%**	-	
Total Heating Demand of DHW system	Q_{gDHW}	$= Q_{DHW}+Q_{WL}$				**3035**	kWh/a	
Total Spec. Heating Demand of DHW System	q_{gDHW}	$= Q_{gDHW} / A_{TFA}$					kWh/(m²a)	**20,2**

Based on heating demand and taking into account region's climate data and orientation of the house as well as technical and dimensional characteristics of the solar collector it is calculated the contribution of solar thermal to heat required for domestic hot water's production. An improved flat plate collector is selected with collector's area $5{,}3m^2$,a little larger than the typical value of $1m^2$ per person which results to 50% solar fraction. Taking also into account losses from the lower part of the stratified storage tank, which is only heated from the solar thermal, the solar fraction of domestic hot water production is estimated to 61% as it is presented to the Graph 4 and the Table 14 below.



Graph 4: Solar fraction to DHW

Table 14: Solar fraction of DHW

Solar Fraction with DHW demand including washing and dish-washing				
Heating Demand DHW	q_{gDHW}	3035	kWh/a	from DHW+Distribution worksheet
Latitude:		57,2	°	from Climate Data worksheet
Selection of collector from list (see below):		7	Selection:	7 Improved Flat Plate Collector
Solar Collector Area		5,30	m²	
Deviation from North		180	°	
Angle of Inclination from the Horizontal		45	°	
Height of the Collector Field			m	
Height of Horizon	h_{Hori}		m	
Horizontal Distance	a_{Hori}		m	
Additional Reduction Factor Shading	r_{other}		%	
Occupancy		4,3	Persons	
Specific Collector Area		1,2	m²/Pers	
Estimated Solar Fraction of DHW Production		**61%**		
Solar Contribution to Useful Heat		**1838**	kWh/a	**12** kWh/(m²a)

3.1.7. Electricity calculation

Electricity demand in passive houses should be as low as possible to meet the primary energy requirement of qp≤120kWhr/$m^2 yr$. Related calculations take place in two different sheets which also take into account factors calculated in previous sheets like number of occupants, treated floor and reference volume of the house. Firstly, is the “Electricity” sheet where it is calculated only the household electricity. Space heating and DHW are excluded from this sheet even if provided by electricity. Because of the fact that there isn’t any information related with the appliances being used to the house it was assumed that all data and coefficients entered here are almost the same with the ones of PHPP’s example house. At the calculation procedure are indicated the following:

- The existence or not of the specified appliance
- The location of the appliance(inside or outside the thermal envelop)
- The energy consumption. That’s way is very important the selected appliances to have high efficiency
- The utilization factor
- The frequency of use
- Number of occupants
- The electric portion for the subject service

In addition to this, the “Aux electricity sheet” has to be filled. At this sheet is calculated the electricity used to run and control all the mechanical equipment, the heating system, the DHW and solar thermal as well as the ventilation system. The calculation of the primary energy is performed the same way with the one in “Electricity” sheet. For the most of the data entered here typical values were selected as we didn’t have the required details. Finally, at “PE demand sheet” , the energy demand outlined both in terms of final and primary energy taking into account energy demand for space heating, DHW production, efficiency factors of the equipment being used and subtracting the relevant heating energy produced by the solar thermal. The above mentioned calculations are described on the following Table 15:

Table 15: Final and primary energy

Passive House verification					
PRIMARY ENERGY VALUE					
Building: End-of-Terrace Passive House East Whins 517		Building Type/Use:	Terraced House/Dwelling		
		Treated Floor Area A_{TFA}:	150	m²	
		Space Heating Demand incl. Distribution	24	kWh/(m²a)	
		Useful Cooling Demand:	0	kWh/(m²a)	
			Final Energy	Primary Energy	Emissions CO_2-Equivalent
			kWh/(m²a)	kWh/(m²a)	kg/(m²a)
Electricity Demand (without Heat Pump)				PE Value	CO_2-Emissions Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	40%	2,6	680
Direct Electric Heating	$Q_{H,de}$		0,0	0,0	0,0
DHW Production, Direct Electric (without Wash&Dish)	$Q_{DHW,de}$	(DHW+Distribution, SolarDHW)	3,0	7,7	2,0
Electric Post heating DHW Wash&Dish		(Electricity, SolarDHW)	0,2	0,6	0,1
Strombedarf Haushaltsgeräte	Q_{EHH}	(Electricity worksheet)	8,2	21,2	5,6
Electricity Demand - Auxiliary Electricity			3,6	9,3	2,4
Total Electricity Demand (without Heat Pump)			**15,0**	**38,9**	**10,2**
Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		(Project)	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	60%	2,6	680
Energy Carrier - Supplementary Heating			Electricity	2,6	680
Annual Coefficient of Performance - Heat Pump		Separate Calculation	3,20		
Total System Performance Ratio of Heat Generator		Separate Calculation	0,45		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}		12,8	32,8	8,6
Non-Electric Demand, DHW Wash&Dish		(Electricity worksheet)	0,2	0,5	0,1
Total Electricity Demand Heat Pump			**13,0**	**33,9**	**8,9**

3.2. Results of PHPP analysis

Modelling of whins house 517 at PHPP software indicated that passive house standards are not met because heating demand is 24kWhr/m^2yr instead of 15kWhr/m^2yr which is the maximum value for a passive house. As can be seen at the following two tables which are an extract from PHPP's verification sheet the subject house cannot certified neither as passive house (Table 16) nor as Ener-PHit according to component quality (Table 17). However, it can be certified as Ener-PHit according to heating demand (Table 18).

Table 16: Passive house verification sheet.

Passive House verification

Building:	End-of-Terrace Passive House East Whins 517
Street:	
Postcode/City:	IV36 Findhorn
Country:	Findhorn, Scotland
Building Type:	Terraced House/Dwelling
Climate:	North East Scotland (Aberdeen)
Home Owner(s) / Client(s):	Findhorn eco-village
Street:	
Postcode/City:	IV36 Findhorn
Architect:	
Street:	
Postcode/City:	
Mechanical System:	
Street:	
Postcode/City:	D-64319 Pfungstadt

Year of Construction:	2015	Interior Temperature:	20,0	°C
Number of Dwelling Units:	1	Internal Heat Gains:	2,1	W/m²
Enclosed Volume V_e:	665,0			
Number of Occupants:	4,3			

Specific building demands with reference to the treated floor area — use: Monthly method

				Requirements	Fulfilled?*
	Treated floor area	150,1	m²		
Space heating	Annual heating demand	**24**	**kWh/(m²a)**	15 kWh/(m²a)	**no**
	Heating load	**12**	**W/m²**	10 W/m²	**no**
Space cooling	Overall specific space cooling demand	**0**	**kWh/(m²a)**	15 kWh/(m²a)	**yes**
	Cooling load	**0**	**W/m²**	-	**-**
	Frequency of overheating (> 25 °C)		%	-	**-**
Primary Energy	Space heating and cooling, dehumidification, household electricity.	**79**	**kWh/(m²a)**	120 kWh/(m²a)	**yes**
	DHW, space heating and auxiliary electricity	52	kWh/(m²a)	-	**-**
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	**-**
Airtightness	Pressurization test result n_{50}	**0,2**	**1/h**	0,6 1/h	**yes**

* empty field: data missing; '-': no requirement

Passive House?	**no**

Table 17: Ener-PHit, according to component quality, verification sheet.

EnerPHit (retrofit): according to component quality

Building envelope	Exterior insulation to ambient air	**0,11**	**W/(m²K)**	0,15 W/(m²K)	**yes**
average U-Values	Exterior insulation underground	**0,29**	**W/(m²K)**	0,24 W/(m²K)	**no**
	Interior insulation to ambient air		**W/(m²K)**	-	**-**
	Interior insulation underground		**W/(m²K)**	-	**-**
	Thermal bridges ΔU	**0,01**	**W/(m²K)**	-	**-**
	Windows	**1,32**	**W/(m²K)**	0,85 W/(m²K)	**no**
	External doors	**0,70**	**W/(m²K)**	0,80 W/(m²K)	**yes**
Ventilation System	Effective heat recovery efficiency	**73**	**%**	0,75 %	**yes**

* empty field: data missing; '-': no requirement

EnerPHit building retrofit (acc. to component quality)?	**no**

Table 18: Ener-PHit, according to heating demand, verification sheet.

EnerPHit verification

Building:	End-of-Terrace Passive House East Whins 517
Street:	
Postcode/City:	IV36 Findhorn
Country:	Findhorn, Scotland
Building Type:	Terraced House/Dwelling
Climate:	North East Scotland (Aberdeen)
Home Owner(s) / Client(s):	Findhorn eco-village
Street:	
Postcode/City:	IV36 Findhorn
Architect:	
Street:	
Postcode/City:	
Mechanical System:	
Street:	
Postcode/City:	D-64319 Pfungstadt

Year of Construction:	2015	Interior Temperature:	20,0	°C
Number of Dwelling Units:	1	Internal Heat Gains:	2,1	W/m²
Enclosed Volume V_e:	665,0			
Number of Occupants:	4,3			

Specific building demands with reference to the treated floor area — use: Monthly method

		Value	Unit	Requirements	Fulfilled?*
	Treated floor area	150,1	m²		
Space heating	Annual heating demand	24	kWh/(m²a)	25 kWh/(m²a)	yes
	Heating load	12	W/m²	-	-
Space cooling	Overall specific space cooling demand	0	kWh/(m²a)	-	-
	Cooling load	0	W/m²	-	-
	Frequency of overheating (> 25 °C)		%	-	-
Primary Energy	Space heating and cooling, dehumidification, household electricity.	79	kWh/(m²a)	130 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	52	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	0,2	1/h	1 1/h	yes

* empty field: data missing; '-': no requirement

EnerPHit building retrofit (acc. to heating demand)?	yes

It is obvious that, the "weak" components which result to significant higher thermal losses and prevent passive house certification to be awarded at the subject house are mainly the poor insulation of ground slab which is 0.29W/m^2K and listed at Table 19 below and the windows which have a U-Value 1.32W/m^2K.

Table 19: U-Value of ground slab

Assembly No.	Building assembly description	Interior insulation?
3	Ground Floor	

Heat transfer resistance [m²K/W] — interior Rsi : 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)]	Thickness [mm]
1.	Engineered timber	0,130					20
2.	Screed	0,130					30
3.	EPS non-compressible	0,030					25
4.	Concrete	2,100					110
5.	DPM	0,031					0
6.	EPS	0,035					70
7.							
8.							
			Percentage of Sec. 2		Percentage of Sec. 3		Total 25,5 cm

U-Value: 0,290 W/(m²K)

The U-Value of the ground slab was calculated based on the official drawing with Drg. No [23]10 and title "FLOOR MAKE UPS HOUSE AND FLAT FLOORS" which is listed at appendix A. As far as it concerns the windows, the type of frame and the glazing was selected in such a way that a U-Value of around 1.2W/m^2K to be maintained in line with Drg No [31]04 and title "WINDOW SCHEDULLE ELEVATIONS SHEET 2" which is also listed at appendix A. Both values are unacceptable not only in comparison with the passive house requirement but also with the EnerPHit (according the components quality) criteria. At first case the highest U-Value of each opaque element must not exceed 0.15W/m^2K, while the U-Value of the windows must be less or at least equal to 0.8W/m^2K. According EnerPHit standards the U-Value of ground slab must not be more than 0.24W/m^2K and the one of the windows must be restricted below of 0.85W/m^2K. The increased U-Values of these two elements result to significant high thermal losses as can be seen at Table 20 below. It is easily to realize that windows accounts for 43% of total thermal losses while the contribution of ground slab is 20%.

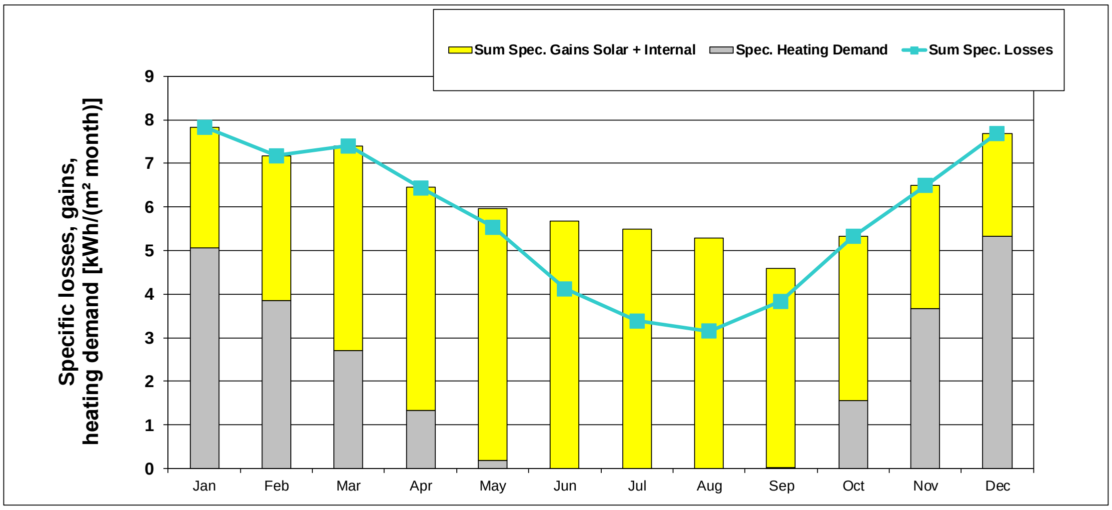
Table 20: Transmission heat losses

Building Element	Temperature Zone	Area m^2		U-Value $W/(m^2K)$		Month. Red. Fac.		G_t kKh/a		kWh/a	per m^2 Treated Floor Area
Exterior Wall - Ambient	A	99,2	*	0,132	*	1,00	*	93	=	1224	
Exterior Wall - Ground	B		*		*	1,00	*		=		
Roof/Ceiling - Ambient	A	104,2	*	0,089	*	1,00	*	93	=	863	
Floor slab / basement ceiling	B	91,2	*	0,290	*	1,00	*	60	=	1595	
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Windows	A	27,4	*	1,315	*	1,00	*	93	=	3360	
Exterior Door	A	9,1	*	0,700	*	1,00	*	93	=	592	
Exterior TB (length/m)	A	187,0	*	0,013	*	1,00	*	93	=	232	
Perimeter TB (length/m)	P		*		*	1,00	*		=		
Ground TB (length/m)	B	40,8	*	0,025	*	1,00	*	60	=	62	
											kWh/(m^2a)
Transmission Heat Losses Q_T									Total	7927	52,8

The increased transmission heat losses described previously result to an increased annual specific heating demand of 23.7kWhr/m^2yr as shown in table 21 and Graph 5 which is much higher than the one of passive house requirement.

Table 21: Energy balances

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	11,9	10,9	11,1	9,5	8,1	5,9	4,7	4,4	5,7	8,2	10,1	11,9	102	kKh
Heating Degree Hours - (	7,2	6,9	7,5	6,8	6,2	5,1	4,5	4,1	4,1	4,7	5,4	6,5	69	kKh
Losses - Exterior	977	889	905	781	661	479	383	358	464	669	825	976	8367	kWh
Losses - Ground	198	188	206	186	169	140	124	114	112	130	148	178	1894	kWh
Sum Spec. Losses	7,8	7,2	7,4	6,4	5,5	4,1	3,4	3,1	3,8	5,3	6,5	7,7	68,4	kWh/m²
Solar Gains - North	3	6	12	19	28	31	30	23	14	8	4	3	181	kWh
Solar Gains - East	14	27	59	81	111	117	108	91	59	37	17	9	731	kWh
Solar Gains - South	153	233	357	385	419	395	376	382	341	258	164	101	3563	kWh
Solar Gains - West	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	11	20	42	58	77	80	75	64	43	27	13	7	517	kWh
Internal Heat Gains	235	212	235	227	235	227	235	235	227	235	227	235	2761	kWh
Sum Spec. Gains Solar +	2,8	3,3	4,7	5,1	5,8	5,7	5,5	5,3	4,6	3,8	2,8	2,4	51,7	kWh/m²
Utilisation Factor	100%	100%	100%	100%	92%	73%	62%	59%	84%	100%	100%	100%	86%	
Annual Heating Demand	759	579	406	200	27	0	0	0	4	234	549	799	3558	kWh
Spec. Heating Demand	**5,1**	**3,9**	**2,7**	**1,3**	**0,2**	**0,0**	**0,0**	**0,0**	**0,0**	**1,6**	**3,7**	**5,3**	**23,7**	kWh/m²



Graph 5: Energy balances

3.3. Suggestions for improvements

In order the passive house requirements to be met and the house to be certified as passive a number of improvements can be done focusing on U-Values reductions of the said elements which consequently will result to lower specific heating demand. Firstly, it is essential another type of windows frame and glazing to be used. For instance, a glazing type like triple glazing low-e Kr08 seems to be suitable while a frame like PRE Passive House frame; medium thermal quality can ensure a significant reduced U-Value. On the other hand, it is necessary to increase the thickness of ground slab’s insulating material EPS so as to achieve an acceptable U-Value. An overall increase of 105mm at the subject material is capable to ensure a U-

Value of 0.147W/m^2K which is within the acceptable limits as it is listed on Table 22.

Table 22: Improved U-Value of ground slab

Assembly No.	Building assembly description					Interior insulation?
3	Ground Floor					

Heat transfer resistance [m²K/W] interior Rsi: 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)]	Thickness [mm]
1.	Engineered timber	0,130					20
2.	Screed	0,130					30
3.	EPS non-compressible	0,030					100
4.	Concrete	2,100					110
5.	DPM	0,031					0
6.	EPS	0,035					100
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							36,0 cm

U-Value: 0,147 W/(m²K)

As it is shown on Table 23 below, these changes are enough to reduce the heating load to acceptable limits leading to passive house certification.

Table 23: Verification sheet after application of improvements

Specific building demands with reference to the treated floor area				use: Monthly method	
				Requirements	**Fulfilled?***
	Treated floor area	150,1	m²		
Space heating	Annual heating demand	**18**	**kWh/(m²a)**	15 kWh/(m²a)	**-**
	Heating load	**10**	**W/m²**	10 W/m²	**yes**
Space cooling	Overall specific space cooling demand	**0**	**kWh/(m²a)**	15 kWh/(m²a)	**yes**
	Cooling load	**0**	**W/m²**	-	**-**
	Frequency of overheating (> 25 °C)		%	-	**-**
Primary Energy	Space heating and cooling, dehumidification, household electricity.	**73**	**kWh/(m²a)**	120 kWh/(m²a)	**yes**
	DHW, space heating and auxiliary electricity	46	kWh/(m²a)	-	**-**
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	**-**
Airtightness	Pressurization test result n_{50}	**0,2**	**1/h**	0,6 1/h	**yes**
EnerPHit (retrofit): according to component quality					
Building envelope average U-Values	Exterior insulation to ambient air	**0,11**	**W/(m²K)**	-	**-**
	Exterior insulation underground	**0,15**	**W/(m²K)**	-	**-**
	Interior insulation to ambient air		**W/(m²K)**	-	**-**
	Interior insulation underground		**W/(m²K)**	-	**-**
	Thermal bridges ΔU	**0,01**	**W/(m²K)**	-	**-**
	Windows	**1,05**	**W/(m²K)**	-	**-**
	External doors	**0,70**	**W/(m²K)**	-	**-**
Ventilation System	Effective heat recovery efficiency	**73**	**%**	-	**-**
				* empty field: data missing; '-': no requirement	
Passive House?					**yes**

4. Analysis of the Net zero building case.

In this section will follow an investigation around net zero energy case. Specifically energy requirement, calculated at the previous section based on PHPP modeling, will be contrasted with the energy production of the installed PV panels at the roof of 517 Whins house, based on Origin project's monitoring data base. Results interpretation will indicate as whether the said house meets the requirements of a Net Zero Energy Building.

Environmental pollution and energy resources exhaustion are two of the most important effects related with energy waste at building we are leaving and working. Specifically, climate change and fossil fuels quantities' reduction push the cost of energy to higher levels dictating that the issue is not only environment but also financial. It seems that 21st century will be the period during which the challenge of sustainable design, construction and use of our build environment has to be faced effectively. By this I mean that the way dwellings and cities will be built in the near future will be of high importance in facing the said challenge. Net zero building concept is a tool that has the ability to work successfully in this direction. The term net zero building can be explained through a conceptual equation which says that "net zero energy equals the accumulation of passive design plus energy-efficient building systems plus renewable energy systems, all over an integrated process".

In order to give a definition, it can be stated that net zero energy is an energy performance measurement according to which the energy being used over the period of operation is as much or less than the in situ renewable energy production. As we can easily understand, net zero energy means that nonrenewable energy can be used, however during a year of operation the same or higher amount of renewable energy must be generated in order to balance energy derives from other sources like fossil fuels and utilized by the building at the same period of time. Therefore, net zero does not mean that the house has not energy requirement (zero) but the balance between renewable energy generation and nonrenewable energy consumption reach to a net level. Furthermore net zero is an operational target; hence it is measured during a year of operation in order to take into account all seasonal variations. Net zero is not limited to designing stage but also is expanded to the operational one in order to ensure that net zero is achieved actually. This means that all stakeholders of the house has to move to the direction of achieving the successful delivery of the net zero concept resulting to real cost and energy saving as well as carbon reduction.

All the above do not mean that there are not challenges associated with net zero energy buildings which have to be undertaken. The cost seems to be one, but the most important one is the process has to be followed in order a net zero building to be constructed. It requires a change on the philosophy of the whole construction industry on the way building process of the houses is performed and this is very difficult to happen. On the other hand cost can be handled in different ways. This means that, net zero energy goal can be achieved either at an inefficient way by purchasing and installing to the house renewable energy systems in large quantity and in the most expensive technology or by trying to construct very low energy buildings like passive houses or EnerPHit in order to reduce the energy requirement as low as possible managing the cost at the most effective way. On the contrary, net zero energy case provides buildings with a lot of benefits that make it worthy. Specifically, that type of buildings has very low operational cost, very high market value, very high performance, very high interior environmental quality hence higher quality life for the occupants and finally helps environmental targets like energy resources conservation to be carried out. It seems that there is synergistic effect between net zero energy building’s objectives and other sustainable targets. For instance, strategies developed to an energy saving direction can result to better indoor environment quality which will result to better health for the occupants. This time net zero energy buildings are very rare but will increase over the time and must become an approach for building sector at the near future as the integration of renewable energy and energy performance is of very high significance. (Hootman, 2012)

4.1. Net zero energy approaches

According to National Renewable Energy Laboratory (NREL) the four following approaches of defining net zero energy there are:

- Net Zero Site Energy Building
- Net Zero Source
- Net Zero Energy Emissions
- Net Zero Energy Cost

(Paul Torcellini, 2006)

4.1.1. Net Zero Site Energy Building

To start with, according to Net Zero Site Energy Building approach the energy being produced by renewables, installed at the site, is as much as the energy used within the boundaries of the site at the course of a year (Figure 14). It is the most common way to measure net zero and is also the easiest one to understand as the whole energy, within a boundary drawn around a building, being measured and added up so it reflects exactly what is measured at the meter of the building. In this approach factors for the calculation of primary energy are not required. (Paul Torcellini, 2006)

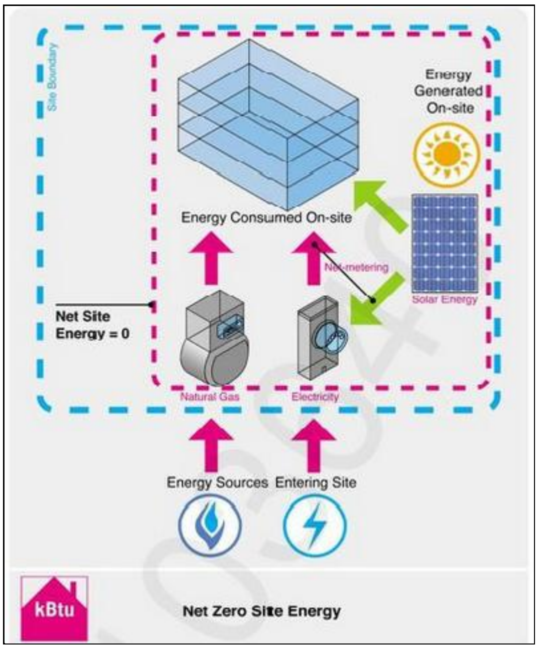


Figure 14: Net Zero Site Energy Building
Source: (Hootman, 2012)

4.1.2. Net Zero Source

On the other hand according to Net Zero Source the building produces or purchases the same amount of renewable energy with the one it uses over the course of a year where the amount of used energy is measured at the source. Therefore, factors for the calculation of primary energy are accounted for. For instance electricity being produced at a fire coal plant has to be considered triple the amount of what is measured at the building’s meter as there are significant losses during production and transmission of the energy. This approach pictures a more holistic way of the energy balance and is presented on Figure 15. (Paul Torcellini, 2006)

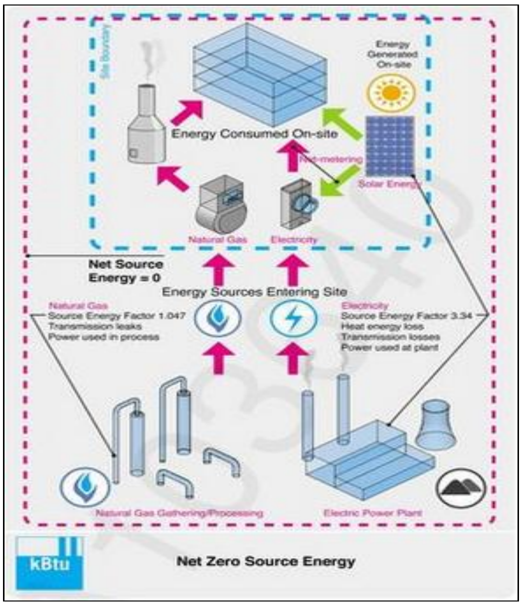


Figure 15: Net Zero Source
Source: (Hootman, 2012)

4.1.3. Net Zero Energy Emissions Building

Based on this approach the building produces equal or more emissions-free energy to counterbalance emissions being produced by the use of other energy forms during a year of operation. The emissions are measured in mass of CO_2 equivalent. In order to determine the quantity of emissions being produced an individual carbon emission factor is applied for every different source is used for energy production. The subject approach is shaping the net zero energy to its fundamental direction as it focuses on the elimination of greenhouse gas emissions (Figure 16). (Paul Torcellini, 2006)

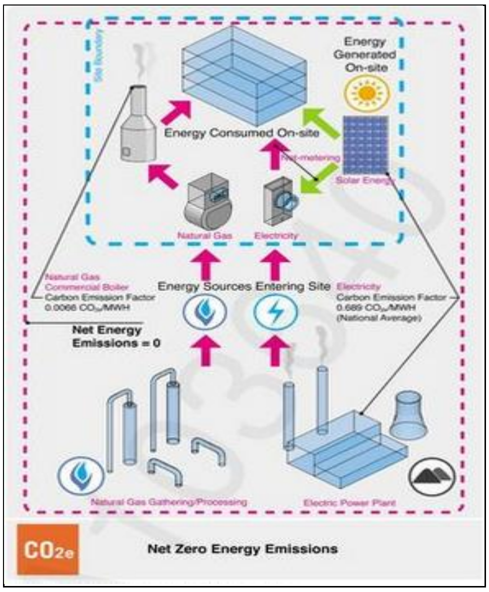


Figure 16: Net Zero Energy Emissions
Source: (Hootman, 2012)

4.1.4. Net Zero Energy Cost Building

According to this approach the financial credit being received by the utility company due to energy export to the grid must offset the cost being charged for the energy used by the utility during a year of operation. A lot of factors related with the value charged and credited by the utility have to be taken into account in order to determine as whether net zero energy being achieved based on this definition. Especially on the credited side the way that renewable energy being credited by the utility has to be carefully taken into account as renewable generation is highly variable. Therefore strategies related with demand management and energy demand reduction has to be implemented in order to ensure that renewable generation is used during peak demand or exported to the grid when credit values are higher. To sum up net zero energy is very difficult to be achieved via this way as it is extremely dependable to a number of external factors (Figure 17). (Paul Torcellini, 2006)

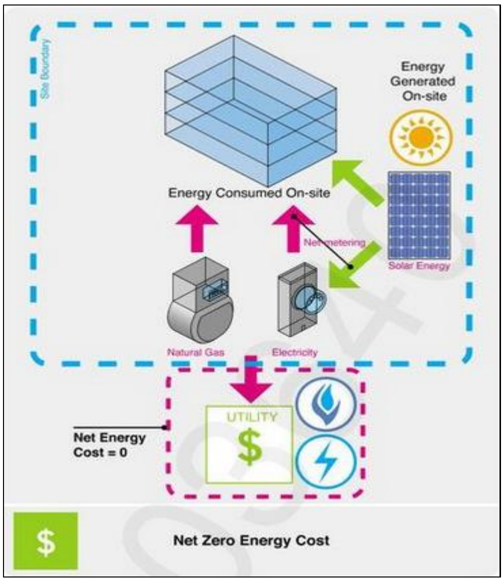


Figure 17: Net Zero Energy Cost
Source: (Hootman, 2012)

4.2. Net zero classification

As mentioned in the previous chapter there are four definitions in order to measure net zero energy. There is a problem associated with that fact. How is it possible to compare one house which achieves net zero via one of these definitions with another house achieves net zero with another one definition? For instance, it is not the same to meet net zero requirements producing renewable energy on site, compared with the case that renewable energy certificates are bought to do the same. For this purpose a classification system established according to which there four classes from A to D based mainly on where renewable energy were produced. Also for all cases it is a prerequisite for the building to be low energy. The all four classes are listed below:

- Classification A: a building is classified as A when is a low energy one and simultaneously there is a lot of renewable energy generation produced within the footprint of the house in order to meet the requirements of one or more net zero energy definitions. For example, a house with PV panels and Solar Thermal on its roof or an installed wind turbine falls into this category.

- Classification B: a building is classified as B when is a low energy one and simultaneously there is a lot of renewable energy generation produced within the boundaries of a site in order to meet the requirements of one or more net zero energy definitions. This means that renewable systems are located on areas owned commonly by a number of houses or a community. The classification may relate with individual houses or the whole community. For instance buildings at a community with PV panels, Solar Thermal and Wind Turbines located at common areas or biomass raised on site to produce energy at the same place.

- Classification C: a building is classified as C when is a low energy one and simultaneously prioritise the use of renewable energy produced within the footprint of the house or within the site's boundaries and then import renewable energy sources to generate supplementary energy in order to meet the requirements of one or more net zero energy definitions. A typical example of this case is when biomass imported on site to generate electricity or thermal energy.

- Classification D: a building is classified as D when is a low energy one and simultaneously prioritise the use of renewable energy produced within the footprint of the house or within the site's boundaries and then import renewable energy sources to generate supplementary energy in order to meet the requirements of one or more net zero energy definitions or import off-site renewable energy buying for example renewable energy certificates.

Classification A is the most difficult one to be gained because it is very challenging to build such a low energy building and the same time to ensure that there are installed, strictly within its footprint, enough renewable energy systems to offset non-renewable energy being used over the course of a year. However, when classification A cannot be met renewable generation which normally should lead to higher classification can be used to meet lower classification standards under specific condition. For example, if a building has PV panels installed on its roof but renewable generation is not enough to achieve classification A the said generation can be used in conjunction with on-site renewable generation for example from ground mounted PV panels to meet the requirements of classification B. That is why is better sometimes to design net zero energy for a district, community or a neighbourhood instead of individually houses. Factors which might be obstacles for the classification of a house as net zero energy for one house may be advantages for another, therefore duo to the synergistic effect the whole district can be classified as net zero energy. For instance, maybe there is a low energy building without space for installation of renewable systems and another which does not have the ideal energy performance but has enough room for PV panel’s installation. (Shanti Pless, 2010), (Hootman, 2012)

On the other hand when net zero energy requirements cannot be met completely but the construction of the subject buildings is driven by the same principles and aiming to same objectives cannot be consider as failure. In other words, Net Zero Energy requirements are very challenging and require tremendous values which in some cases cannot be met every year of operation; however a building which has been built under specific low energy design and with provision for renewable energy systems installation cannot be considered as an outstanding construction. Based on the above, when requirements of Net Zero Energy are partially be met buildings can be characterised as:

- Near Net Zero Energy Buildings where their performance is very close to the requirements or there is an inconsistence to carry out the target every year.

- Net Zero Electricity Buildings where renewable generation offset only the non-renewable energy used for electricity in annual basis.

- Net Zero Energy-Ready Buildings where buildings are designed as net zero energy but the renewable energy systems are not feasible to be procured at the time. However the provision for their installation already exists.

(Hootman, 2012)

4.3. Case Study Investigation

An investigation around net zero energy was performed regarding the case study of this thesis. In other words, we tried to figure out what is the energy requirement of 517 Whins house and what is the renewable energy production of the installed PV panels on it in order to examine as whether it comply with any of the definition mentioned at 5.1 Section previously.

To start with, as shown by the modelling of the house in the PHPP, it is a low energy building. It does not comply with passive house requirements but it is classified as EnerPHit according to heating demand. Furthermore, all energy requirement of the house is covered by electricity. Specifically, as mentioned previously heating requirement is covered from an air source heat pump, a fraction of DHW production is covered from the same heat pump and the rest from a solar thermal and an electrical booster heater. In addition to these, there is an electrical demand to cover household electricity requirements and auxiliary electricity requirements such as energy required for operation of building’s mechanical systems and ventilation. The whole electrical demand of the house is shown on the following Table 24.

Table 24: Energy requirement

			Final Energy kWh/(m²a)	Primary Energy kWh/(m²a)	Emissions CO_2-Equivalent kg/(m²a)
Electricity Demand (without Heat Pump)				PE Value	CO_2-Emissions Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		(Project)	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	40%	2,6	680
Direct Electric Heating	$Q_{H,de}$		0,0	0,0	0,0
DHW Production, Direct Electric (without Wash&Dish)	$Q_{DHW,de}$	(DHW+Distribution, SolarDHW)	3,0	7,7	2,0
Electric Post heating DHW Wash&Dish		(Electricity, SolarDHW)	0,2	0,6	0,1
Strombedarf Haushaltsgeräte	Q_{EHH}	(Electricity worksheet)	8,2	21,2	5,6
Electricity Demand - Auxiliary Electricity			3,6	9,3	2,4
Total Electricity Demand (without Heat Pump)			15,0	38,9	10,2
Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		(Project)	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		(Project)	60%	2,6	680
Energy Carrier - Supplementary Heating			Electricity	2,6	680
Annual Coefficient of Performance - Heat Pump		Separate Calculation	3,20		
Total System Performance Ratio of Heat Generator		Separate Calculation	0,45		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}		12,8	32,8	8,6
Non-Electric Demand, DHW Wash&Dish		(Electricity worksheet)	0,2	0,5	0,1
Total Electricity Demand Heat Pump			13,0	33,9	8,9
Heating, Cooling, DHW, Auxiliary and Household Electricity			31,5	76,7	19,9
Total PE Value		76,7	kWh/(m²a)		
Total Emissions CO_2-Equivalent		19,9	kg/(m²a)		(Yes/No)
		Primary Energy Requirement	120	kWh/(m²a)	yes
Heating, DHW, Auxiliary Electricity (No Household Applications)			19,4	49,9	13,1
Specific PE Demand - Mechanical System		49,9	kWh/(m²a)		
Total Emissions CO_2-Equivalent		13,1	kg/(m²a)		

The main findings of the above table are that, the specific final energy used by the house over the course of a year is **31.5kWh/m^2yr** and the associated specific primary energy is **76.7kWh/m^2yr**. Considering the total 150.1m² area of the house the total final energy used for a year of operation is **4728.15kWh/yr**. As far as it concerns the specific primary energy, is calculated taking into account a factor of 2.6 for losses occur during generation and transmission. The required electricity to cover the space heating demand is 12.8kWh/m^2yr, the DHW production is 3 kWh/m^2yr excluding the solar collector's contribution (Table 14) and the rest 15.7kWh/m^2yr related with the household electricity and the auxiliary electricity. The same values used later at Merit section in order to perform the required DSM simulations. At this point is worthy to mention that, it would be preferable to use actual data instead of data from PHPP modeling for the energy requirements mentioned above but it was very difficult to gather it at a correct and useful manner. Net zero energy refers to an operation and that's why is related more with the actual data than with the one designed at a simulation software. Nevertheless, results from PHPP were used in order to proceed with the subject thesis objectives achieving.

On the other hand in order to figure out the installed PV's output; the monitoring data from Origin project were used. It was used the data with tag number 3679 (Solar PV) at a monthly basis and the following Table 25 was prepared.

Table 25: PVpanels annual energy production

Whins 517 Pv panels energy production							
Month		January	February	March	April	May	June
Production	kWhr	91,94	181,21	322,92	439,98	449,28	366,01
Month		July	August	September	Octomber	November	December
Production	kWhr	418,05	385,63	338,42	255,8	104,77	66,21
Total	kWhr	3420,22					

As previously, a lot of difficulties were faced in getting the monitoring data at a satisfactory level. More specific, data was stated to apparent power (kVAhr) but nothing was known for the PV panels technical features so it was impossible to find the power factor to calculate the real power. Therefore, the assumption that the power factor is 1 was done. Moreover, during some days power production was unreasonably higher compared with the one of the rest days during the same month. Thus, a value correction was performed and the highest value that appears on the rest days applied to the days with the unreasonable value. The values measured were checked against Merit's output for a system consisted of 31 Mono-crystalline PV panels installed at Dundee's standard climate profile for each one of the months and the results regarding the renewable energy generation were pretty similar as it can be seen in Graph 9 (Page 77). Despite the fact that, the houses seems to have 13 panels of 240Wp each, there wasn't any PV panel standard profile on Merit with this nominal power. Therefore it was assumed that another type of PV panels with less nominal power can be selected. The same time, were applied as much PV panels as required in order to achieve an annual production very close to the one of the monitoring data.

Doing the previously mentioned assumptions, an investigation was performed in order to figure out as whether the said house complies with the Net Zero Site Energy Building definition. It is obvious, contrasting the two tables 24 and 25, that the said house cannot meet the requirements of the said definition, as the energy it uses is 31.5 kWh/m^2yr. In other words considering the total area, which is 150.1m^2, the total energy requirement is 4728.15 kWh/yr. PV panel's annual production, based on Origin's monitoring data, is 3420.22 kWh/yr as it is shown at Table 25 above, therefore the renewable energy generated on-site does not offset the energy used by the house during a year of operation and as a result of that the house cannot be classified as Net Zero Energy.

4.4. Suggestions for improvements

A number of suggestions can be done aiming in net zero energy classification of the said house. These suggestions can be related either with the reduction of house's energy requirements or with the management and installation of adequate renewable energy systems. Specifically, the following suggestions are proposed:

- To improve the U-Value of the house by replacing windows and improving the insulation of other opaque building elements as specified in paragraph 4.3 aiming at thermal losses reduction and resulting to reduced energy requirements. This can reduce the energy requirement so much in order to be possible for the renewable generation to offset it and the house to achieve classification A.

- To install larger quantity of renewables and of better technology in order their energy production to be enough for the net zero energy classification. Especially the number of PV panels can increase or their type can change installing other PV panels with higher nominal power. Additionally, another renewable energy system such as domestic Wind Turbines can be installed in order the production to increase at satisfactory levels and the house to achieve classification A.

- To aim in certifying all the Whins community as Net Zero Energy and not every house individually taking advantage of the synergistic effect. For instance, at common areas within community's boundaries to install ground mounted PV panels or Wind Turbines which by providing the required supplementary renewable energy on the existing PV panels, located on the roof of the house, to result at a classification B of the said house.

- To insert renewable energy sources produced at another place (off-site) in order to use them to produce renewable energy enough to ascertain classification C for the house. For instance, biomass which is not produced at

Findhorn community can be bought in order to feed a biomass boiler that can be installed at the house.

- To buy renewable electricity from the grid. This can lead to classification type D for the house.

5. Energy Autarky

Since late 20th century the energy-conserving passive design has been promoted by environmentalists due to the ever growing concerns related with the vulnerability of the ecosystem to people actions and inventions aiming to energy utilization. The energy sources crisis as well as the greenhouse effect forced people related with construction industry to overtake difficulties and achieve to build according energy-conserving passive design keeping the same time the level of comfort as high as it is according energy consuming active design. This concept requires an intelligent use of energy utilising storage systems, sensors and energy converters to improve home environment. This building concept requires a very limited amount of energy for building operation which can be covered from in situ renewable energy generation leading under conditions to energy autarchy. A house is called autonomous when can operate without the need of support and services from public facilities maintaining simultaneously a high quality and comfortable leaving with the use of green energy technology. With the term autarchy in architecture it is implied autonomous control and self-sufficiency. Autonomous control means that one can control something without the influence and control of others and self-sufficiency means that one is capable to maintain sufficiency in resources like water food and energy. These two concepts are overlapping each other and are very difficult to separate them. Occupants in order to leave a comfortable life depend on use of clean energy as well as to household appliances. This means that occupants of autonomous houses do not have to live like nomads but they have to use alternative forms of energy and household appliances towards energy autarchy principles direction reducing the dependence on fossil fuels, the emissions of greenhouse gasses and maintaining the same time a high level of living standards. (Shang-Yuan Chen, 2009)

5.1. Investigation around energy autarchy

In order to carry out an investigation around autarchy in 517 Whins house Merit software was used. It is a dynamic demand/supply matching-design tool for renewable energy systems developed by university of Strathclyde. This tool gives to user the possibility to integrate renewable energy systems into a building and also to specify the type and capacity of the technology being used. Additionally it performs quantitative assessments providing graphs and tables about demand and supply energy helping the user to determine as whether the selected energy supply mixture each time is suitable for the investigation case or not. It targets to increase at the maximum the capacity utilisation factor from renewable energy systems while the capacity of the storage system has to be as low as possible and the residual temporal demand has to be met. There are a lot of standard supply profiles which can be loaded by the user mainly renewable energy systems such as PV panels, Wind Turbines and also low carbon technologies like heat pumps and CHP units. The modelling of those systems in order to simulate their energy production is based on specification data from the manufacturer, their geographic position and the weather data. On the other hand, there are a number of standard demand profiles available as regards electrical, heating and hot water demand while the user has also the opportunity to create his custom demand profile importing own data. It uses an open database in order to communicate with a remote SQL database through internet facilitating the exchange of data with other tools like ESP-r, which related with building simulation, and can provide virtual demand profiles, like geographical information system (GIS) and software which support energy monitoring and targeting. The output of the program provides the user with information related with demand and supply correlation, the reduction of greenhouse gasses and if the whole arrangement is financially feasible. The whole procedure is presented at the following Figure 18.

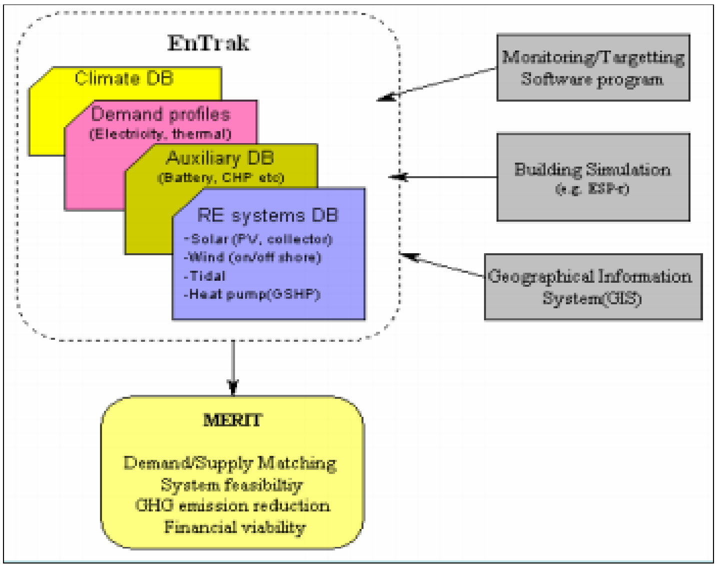


Figure 18: Merit's simulation procedure
Source: http://www.esru.strath.ac.uk

When Demand Supply Matching simulations are performed by Merit a number of metrics become available to the user. The total demand and RE supply energy, the deficit and surplus energy especially when the correlation coefficient, which indicates the dynamic fit, is very low and the inequality coefficient. Also auxiliary systems like storage system can be selected in order to reduce surplus energy production and to maximise the RE energy delivery. Their specifications are shown to the user. Finally, the user has the choice to specify as whether prefers the maximum utilization of renewables or prefers the maximum match rate between demand and supply. (University of Strathclyde, n.d.)

5.2. Demand side management within origin project

Demand Side Management (DSM) is the organization and management of measures which are able to impact the electricity demand by eliminating the need for additional energy during peak consumption and are implemented either directly or indirectly by the utility companies. It is consider that is better from a cost and social point of view to reduce the demand through investments in DSM measurements than increasing the power supply capacity. Utility companies, around the world, have developed policies related with demand side management in order to make easier the operation of electricity networks and also to facilitate renewable energy penetration into them as renewable energy cannot be stored cheaply and effectively. The most common methods followed by the governments towards to this direction are the dynamic demand response, the efficiency plans and the behavior changes at customer level.

To start with, dynamic demand response means that utility companies have the ability to reschedule the operation of occupant’s appliances in such a way to ensure that their operation happens during excess renewable energy generation and mainly to prevent them working during peak demand times. It is clear that, with this method energy consumption is not reduced but it shifted at times, during which it is easier to be covered by renewable generation and to be managed by the grid reducing the same time the peak loads relieving the electricity network.

On the other hand energy efficiency plans move towards energy reduction direction. It can be achieved either by using appliances with higher efficiency or by promoting construction technics which target to reduce energy consumption by the buildings. Specifically, household and auxiliary electricity and heating and cooling loads are minimized in order to relieve electricity network. For instance, buildings constructed under Passive or EnerPHit house standards are typical construction examples of this case.

Behavior changes at customer level strategy aiming in reducing energy consumption by educating customers in energy saving direction. For instance, customers learn how energy can be saved by turning off appliances which are not required to be open during this time or switching off unnecessary lighting.

The impacts derive from the application of the above mentioned strategies are shown on the Figure 19 below.

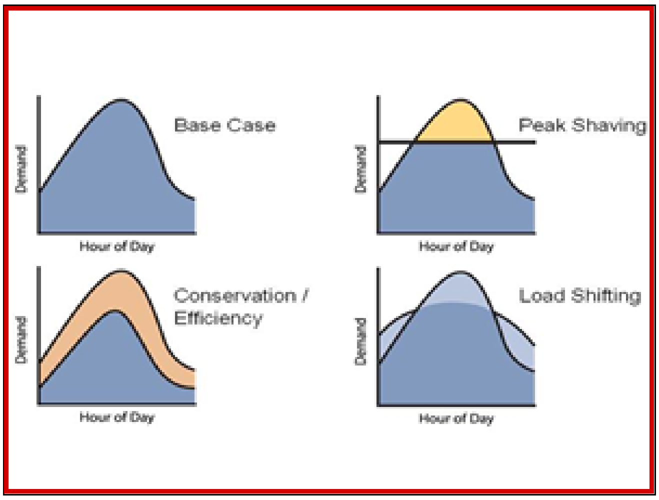


Figure 19: DSM strategies impacts
Source: http://www.powerwise.gov.ae/en/research/programmes-projects/demand-side-management.html

DSM strategies benefit not only utilities but also customers and society. From customers point of view the said strategies are beneficial because give them the opportunity to install highly efficient technologies such as lighting, ventilation, heating and cooling systems reducing, this way, their electricity bill. On the other hand, utilities also benefit from these strategies, because the fact that energy demand either reduce or shifted help them to lower their operational cost as well as help them to avoid investments for the construction of new power plants and transmission networks in order to increase their capacity. Finally, society benefit from DSM strategies as it facilitates the penetration of more green renewable energy into the grid resulting to its de-carbonization and also because the energy demand shifted to times there are not peaks, there is less air pollution.

The Origin concept, basically, is an intelligent control system which organizes the energy demand within a community in such a way to ensure the ideal utilization of local renewable generation. Forecasts for the expected energy supply and demand are provided by user-friendly tools to the citizens in order to know what the renewable energy supply will be each time of the day so as to prioritize their activities accordingly or to avoid doing some of them. For instance, based on weather forecast, the renewable energy production from PV panels or WT can be predicted accurately therefore, a device such as a washing machine can be operated the appropriate time. The whole operation and the origin user friendly tool can be seen on Figure 20.

Furthermore, one of the options being looked at in Origin's project is the addition of proper storage system. An investigation took place around aspects related with the procedure have to be followed in order the produced renewable energy to be stored and be provided to the customers the time is needed at the required quantity.(Andre Pina, 2011), (Hub DSM Information, n.d.), (Origin concept, n.d.)

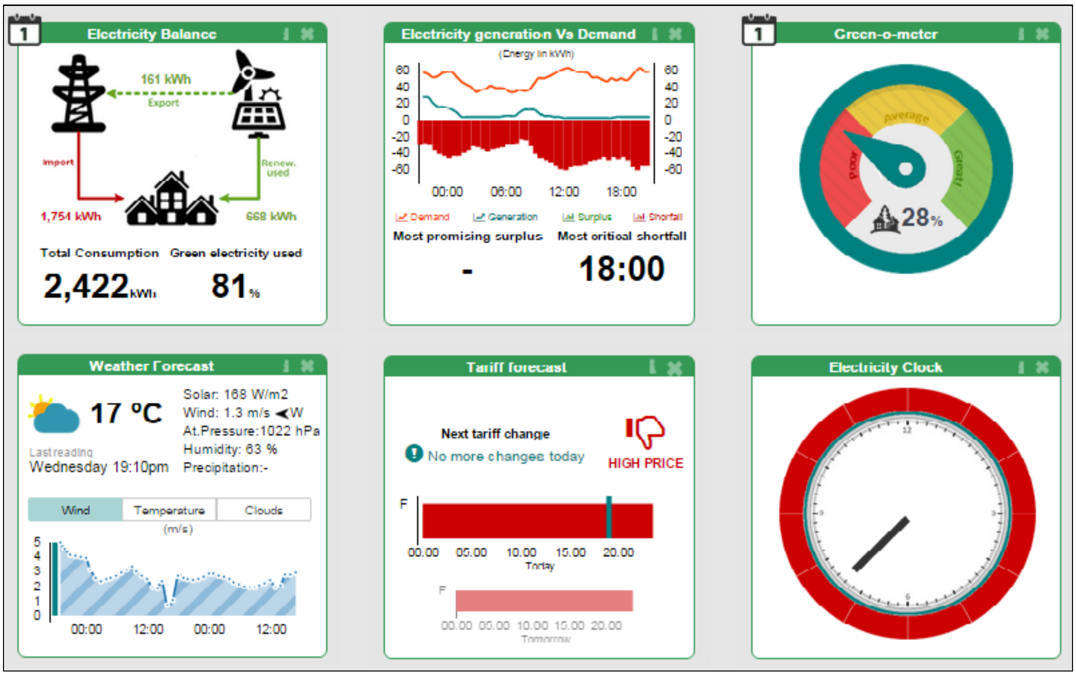


Figure 20: Origin's user friendly tool
Source: http://origin-energy.eu

5.3. Autarky investigation using Merit simulation

In this section aspects related with energy autarky are investigated. For this purpose Merit software was used in order to realise the following:

- As whether energy autarky is possible under the actual circumstances.
- Improvements can be done towards energy autarky.

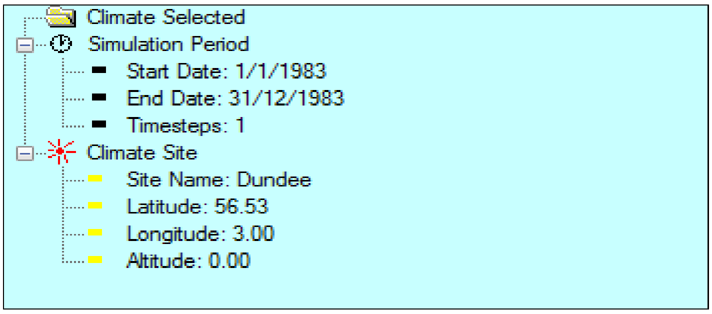
- The concept according which the system can work autonomously with the optimum way.

In order to achieve these objectives the following steps were introduced. Firstly a climate data, as close as possible to the actual one, was selected from the existing Merit's standard climate profiles. Then a thermal and an electrical demand profile from the existing one of Merit's standard demand profiles were selected. The consumption was modified accordingly in order to approach the demand being calculated by PHPP modelling. Then a renewable energy profile was applied. The RE profile which selected produces the same energy with the one derives from Origin's project monitoring data base. Finally an investigation around storage systems carried out in order to check possibilities towards energy autarky.

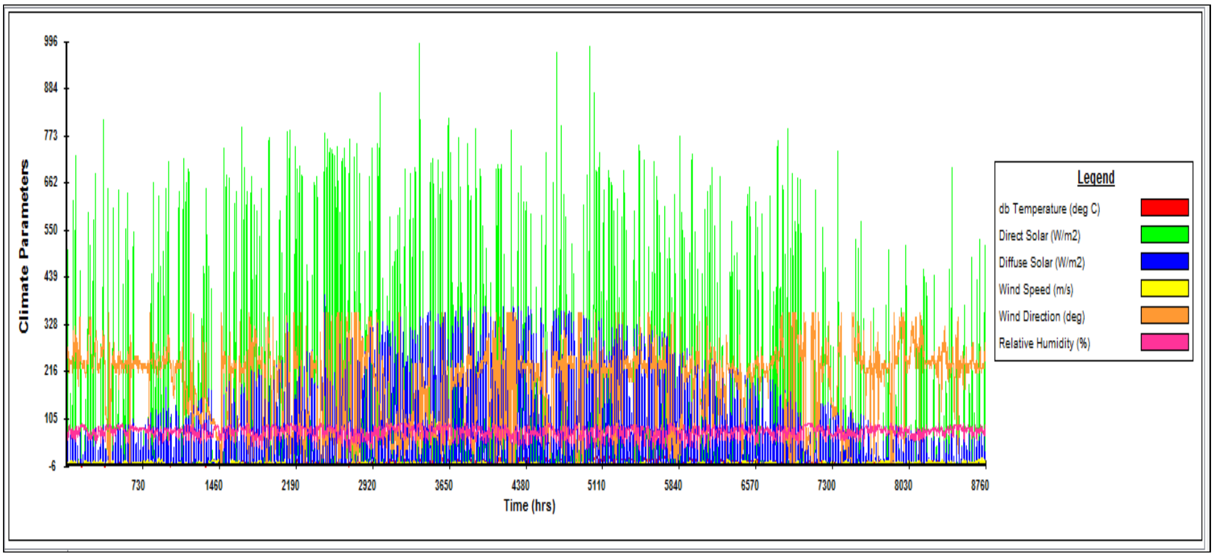
5.3.1. Climate data selection

In order to carry out the DSM simulation on Merit software for the 517 Whins dwelling it was assumed that Findhorn community is located close to Dundee because this is the closest standard climate data available on the software. Information related with this selection is shown on the Table 26 below.

Table 26: Climate data


Climate Selected
Simulation Period
Start Date: 1/1/1983
End Date: 31/12/1983
Timesteps: 1
Climate Site
Site Name: Dundee
Latitude: 56.53
Longitude: 3.00
Altitude: 0.00

Weather conditions occurred at the selected area, during 1983, such as db temperature, direct and diffuse solar radiation, wind speed, wind direction and relative humidity are presented on the Graph 6 which follows.



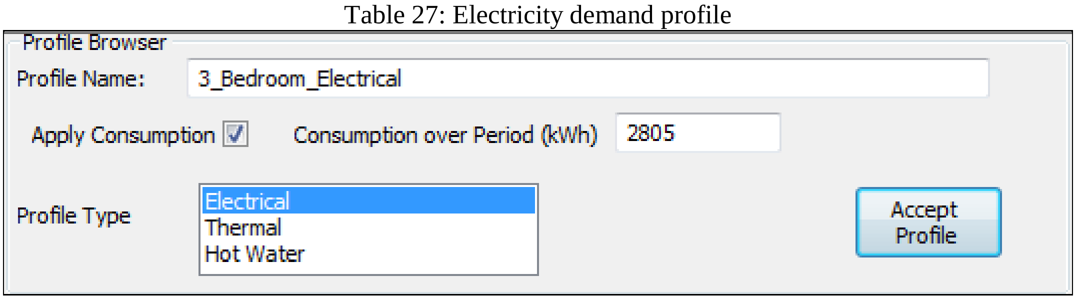
Graph 6: Weather condition for the given climate data

5.3.2. Demand profile selection

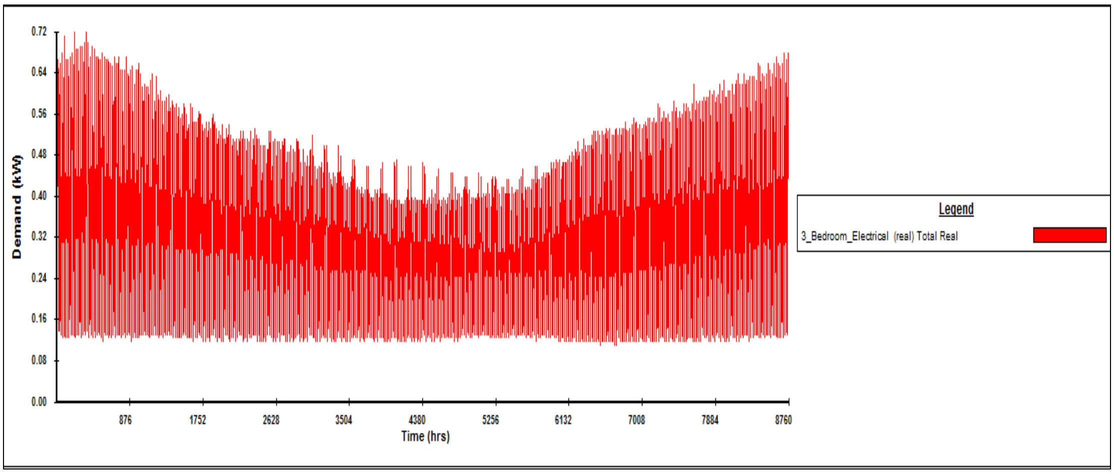
As described at paragraph 4.3 and shown on Table 24 all energy requirement of case study house comes from electricity.

Firstly the non-space heating demand was established as follows. According to PHPP modelling there is a final energy requirement related with household electricity, auxiliary electricity and the fraction of DHW production from electricity equal to 18kWh/m^2yr, something which means that for the whole 150m^2 there is an electrical energy requirement of 2805kWh/yr. Due to difficulties associated with monitoring data it was preferred to use data from PHPP modeling instead of monitoring data. Following, in order to save time it was selected a standard demand profile from the software which seems to be close to our house. It was selected the demand profile “3_Bedroom_Electrical” and it was applied our house’s electrical consumption which is 2805kWh/yr. The previously described selection is shown on the Table 27 below.

Table 27: Electricity demand profile



The pattern being followed by electricity's demand curve in hourly basis is the same with the one of the standard profiles has been chosen (customised to case study's building electrical requirement) and is shown on the Graph 7 below.

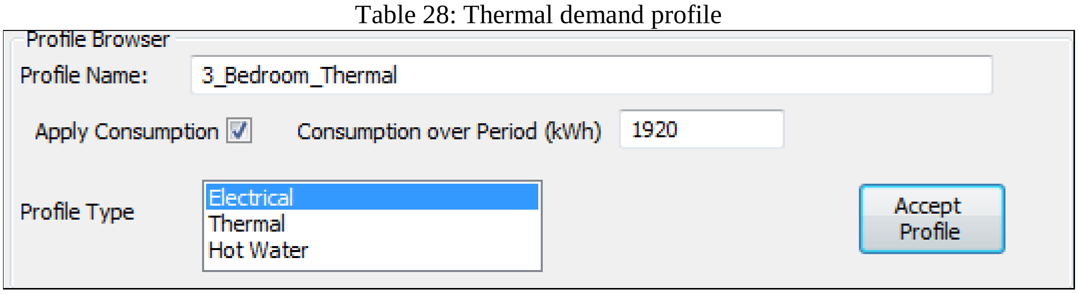


Graph 7: Electrical demand

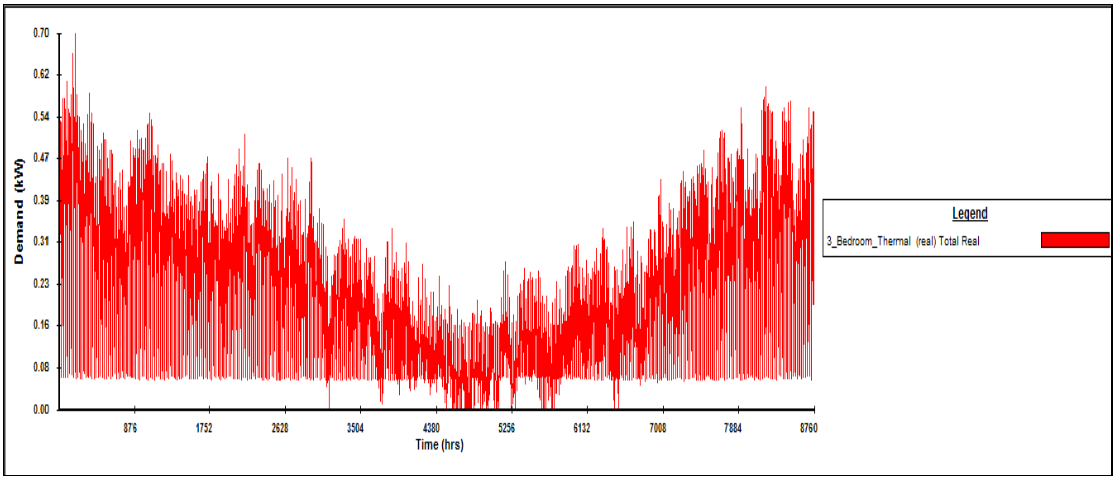
As can be seen in this Graph 7 electrical requirement is higher during winter. This can be explained considering that the day is smaller, hence natural lighting is inadequate and there is higher requirement for artificial lighting. In addition to this, occupants during colder months used to be more time indoors resulting to higher electrical consumption. Finally due to reduced solar irradiation during winter the contribution of solar thermal in DHW production is smaller, therefore the required DHW is produced by electrical means.

Then the space heating demand was added. As regards space heating demand there is an energy requirement of 12.8kWh/m^2yr which is supplied totally from an air source heat pump as it described at paragraph 4.3 and shown on Table 24. This means that there is an annual electrical heating demand of 1920kWh/yr. For simulation purposes the "3_Bedroom_Thermal" standard demand profile was selected customised for electrical energy consumption of 1920kWh as it is shown on the Table 28 below:

Table 28: Thermal demand profile



The pattern being followed by space heating's energy demand curve in hourly basis is the same with the one of the standard profile has been chosen, customised to case study's building space heating requirement and is shown on the Graph 8 below.



Graph 8: Thermal demand

5.3.3. Renewable energy system profile selection

Regarding the selection of the PV panels which are installed on the roof, the only known information was the energy production at the course of a year as derives by the Origin monitoring data and presented in table 25, as well as their orientation and their tilt angle. Therefore, the only criterion for the selection of the PV panels it was to produce 3420kWh/yr when are installed at south orientation and an angle of 45° from the horizontal. The type of panel which is demonstrated on the following Table 29, was selected from the existing Merit's list.

Table 29: PV panel type

PV Characteristic	Value
Name	110W Mono: Siemens S
Manufacturer	Siemens
Cell Type	Monocrystalline
Nominal Power (W)	110.00
Maximum Power Point Current (A)	6.30
Maximum Power Point Voltage (V)	17.50
Short Cicuit Current @ STC (A)	6.90
Open Circuit Voltage @ STC (V)	21.70
Standard Test Condition (STC) Temperature (C)	25.00
Standard Test Condition (STC) Isolation (W/m2)	1000.00
Panel Height (m)	1.32
Panel Width (m)	0.66

In order to ensure annual energy production of 3420kWh/yr for the given climate data and PV panel type it was realised that it is required to install 31 panels when facing at south orientation installed at an angle of 45° which is same with case study's house roof inclination. The total area of the installed 31 PV panels is given from the Equation 6:

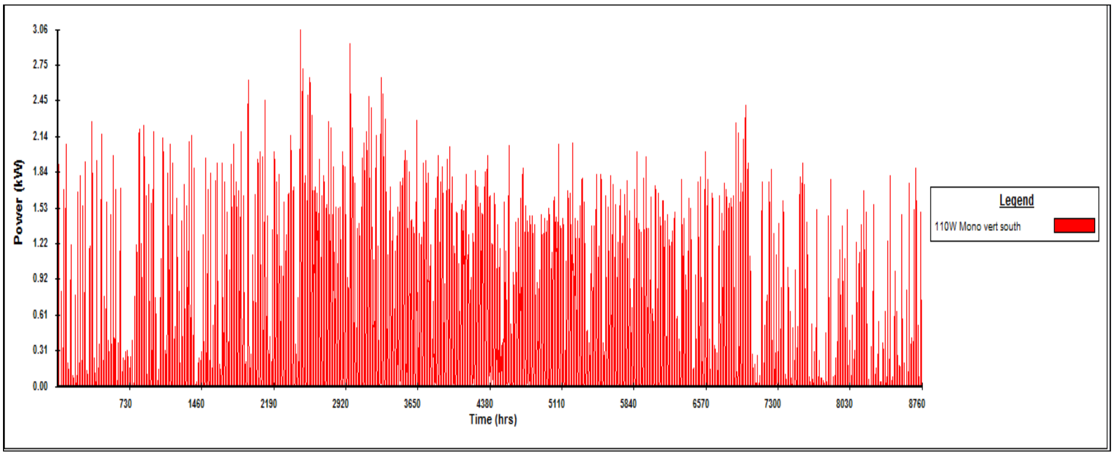
$$A = Panel\ height \times Panel\ Width \times QTY\ of\ panels = 1.32m \times 0.66m \times 31 = 27m^2$$

Equation 7: Area of the installed PV panels

Looking at the following picture (Figure 21) of 517 Whins house and taking into account on the one hand that the area of the installed PV panels is $27m^2$ and on the other hand that the total area of the roof facing on the south is $37,29m^2$ (calculated based on drawings of Appendix A) can be considered that the area covered by the panels assumed on Merit's simulation are approximately the same with the one actually installed on the said house.

Figure 21: Whins 517 House

The following Graph 9 shows the PV panels' energy production over a year of operation at an hourly basis.

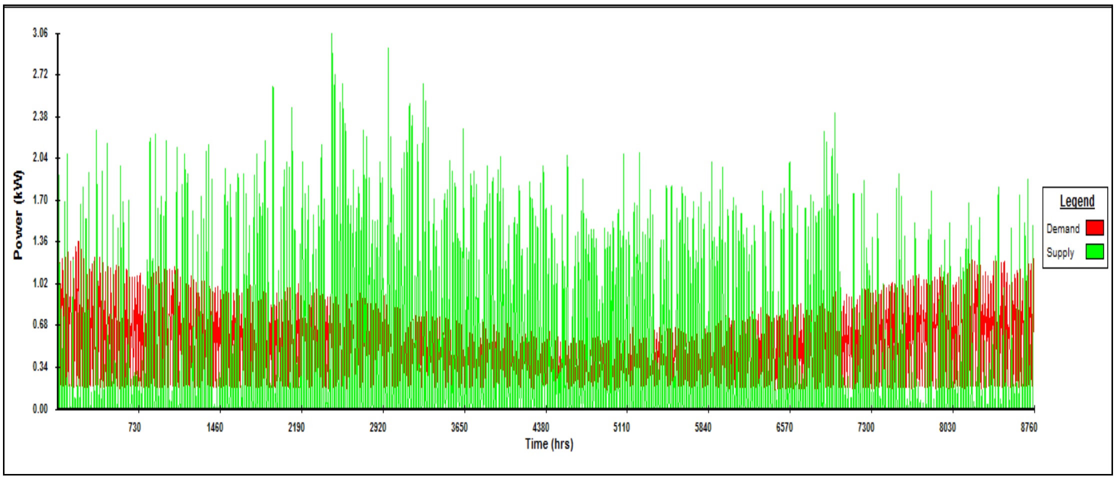


Graph 9: PV panels' production

At this point is worthy to mention that energy production of PV panels at the middle of summer period is not the highest in this specific case. This can be explained assuming that according the climate data used by Merit the weather during these days was cloudy, hence the energy production lower.

5.4. Results of MERIT simulations and interpretation

After DSM simulation of our system, it was realised, as expected from Net Zero Energy investigation, that 517 Whins house cannot operate at an autonomous mode with the current PV panels energy production. The renewable energy produced as discussed at paragraph 4.3 is less compared to the energy needed hence it was impossible for the house to work properly at an off-grid mode during the whole year. The Graph 10 which follows shows the demand and supply energy curves combined during a year of operation as revealed by the DSM simulation.



Graph 10: DSM simulation results (31 panels 0.110kW Mono)

Findings from the said simulation indicate a very poor matching of 48.8% between demand and supply curves something which means that the two of them do not follow the same pattern because they are not in the same phase. In other words renewable energy produced when demand by the occupants is very low and vice versa. The matching rate is calculated according the following formula:

$$Percentage\ Match(\%) = \frac{\sqrt{\frac{1}{n} \times \sum_{t=0}^{n} (Dt - St)^2}}{\sqrt{\frac{1}{n} \times \sum_{t=0}^{n} (Dt)^2} + \sqrt{\frac{1}{n} \times \sum_{t=0}^{n} (St)^2}}$$

Equation 8: Percentage match rate calculation

Where Dt is the demand at time t and St the supply at time t.

Matching rate is very important for the subject analysis as it indicates the amount of energy is wasted in order to achieve autarky. In other words, at a case with poor match rate, a very large amount of renewables and storage systems have to be applied in order to cover the demand therefore a very large amount of surplus energy will be produced.

Additionally, deficit energy, which indicates the energy was drawn from the grid, is 3060 kWh/yr. This value is well above the half of our house's energy requirement. On the other hand there is an amount of 1720kWh/yr surplus energy which means that over the 50% of energy produced by PV panels cannot be utilised on time by the occupants and due to the lack of appropriate storage system exported to the grid or wasted. All the above are shown on the following Table 30.

Table 30: DSM simulation results (31 panels 0.110kW Mono)

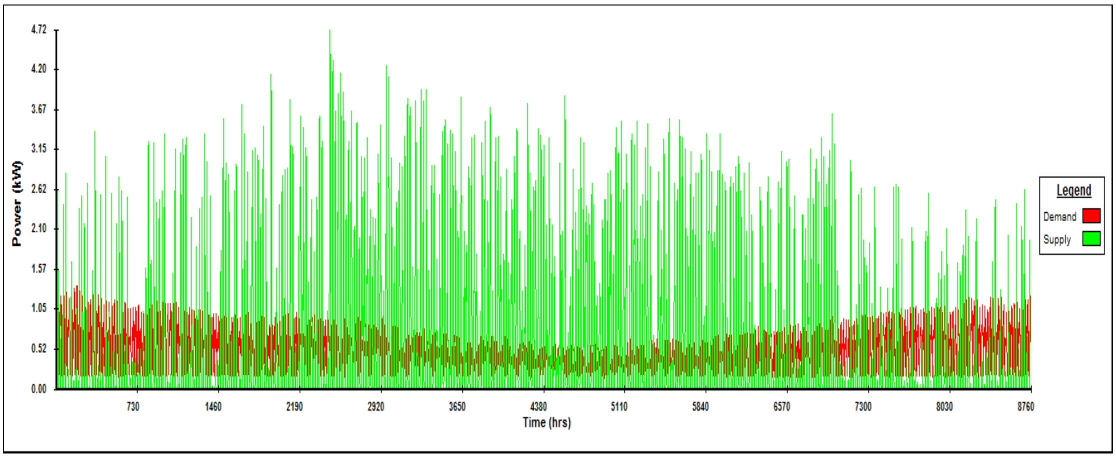
DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
110 Watt Mono vert south	3390
Aux name	**Total Aux Supply (kWh)**
NULL	-
Energy Deficit (kWh)	**Energy Surplus (kWh)**
3060	1720
% Match rate	**Corelation Coeficient**
48,88	-0,04
Energy delivered (kWh)	**Inequality Coeficient**
1620	0,51

5.5. Improvements towards energy autarchy

A thorough investigation at a variety of alternative configurations as regards the storage and renewable energy systems which can be installed to our system was carried out performing DSM simulations through Merit in order to ascertain as whether there are possibilities to achieve energy autarchy in case study's house.

5.5.1. Increase of installed renewable energy systems

To start with, an attempt was done to eliminate the main obstacle towards this direction which is the amount of energy produced by renewable energy systems. It is lower than the demand requirement and inherently prevents the target has been established from its fulfilment. Hence, 35 BP mono crystalline PV panels were selected to be installed. This type of panels has nominal power output 0.130kW, 4.30A current and 30V voltage at maximum power point. They were installed facing on the south at an angle of 45° from the horizontal. Under this arrangement the produced renewable energy is 5170kWh/yr something which means that is higher than the energy demand requirement. The Graph 11 which follows shows the demand and supply energy curves combined during a year of operation as revealed by the DSM simulation.



Graph 11: DSM simulation (35 panels, 0.130kW BP)

Findings, reference to the above graph, are listed on the Table 31 below:

Table 31: DSM simulation (35 panels, 0.130kW BP)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south	5170
Aux name	**Total Aux Supply (kWh)**
NULL	-
Energy Deficit (kWh)	**Energy Surplus (kWh)**
2940	3370
% Match rate	**Corelation Coeficient**
42,22	-0,05
Energy delivered (kWh)	**Inequality Coeficient**
1730	0,58

Despite the fact that, total renewable supply offset the total demand, a contrast between Table 31 with Table 30 reveals that actually the condition did not improved towards energy autarchy direction. Deficit and delivered energy remained same something which means that our system depends on the electricity grid to the same extent with the previous situation. On the other hand surplus energy increased as renewable energy production takes place when it is not required by the occupants and either exported to the grid or being wasted. As a result of this the match rate became worse indicating that demand and supply curves do not follow the same pattern.

5.5.2. Addition of storage system

The following stage related with the addition of a storage system aiming to reduce the surplus energy and increase the energy delivered as much as possible targeting to energy autarky. The same arrangement of renewable energy systems and energy demand profiles were selected. In addition to this, 16 Batteries were installed connected in series with capacity of 215Ah at 12V or a nominal rated capacity of 2.58kWh. The rest technical specifications of subject batteries are listed on the following Table 32.

Table 32: Battery characteristic

BATTERY Characteristic	Value
Capacity 1	215.00
Capacity 2	118.00
Discharge Time 1	20.00
Discharge Time 2	1.00
Nominal Voltage	12.00
Internal Resistance	0.06
Maximum Charge Current	53.00
Deep Discharge Level (%)	70.00
Liftime Cycles at DD Level	1200
Self Discharge Capacity	97.00
Self Discharge Period (months)	1.00

After thorough web research it was realised that that type of batteries is available on the market and their full specification manual is available at Appendix C. They are deep cycle type and their dimension based on their specification manual is 0.4m x 0.18m x 0.38m. It seems reasonable to assume, based on their dimensions, that a number of them, such as the selected one, can be installed at house's battery bank.

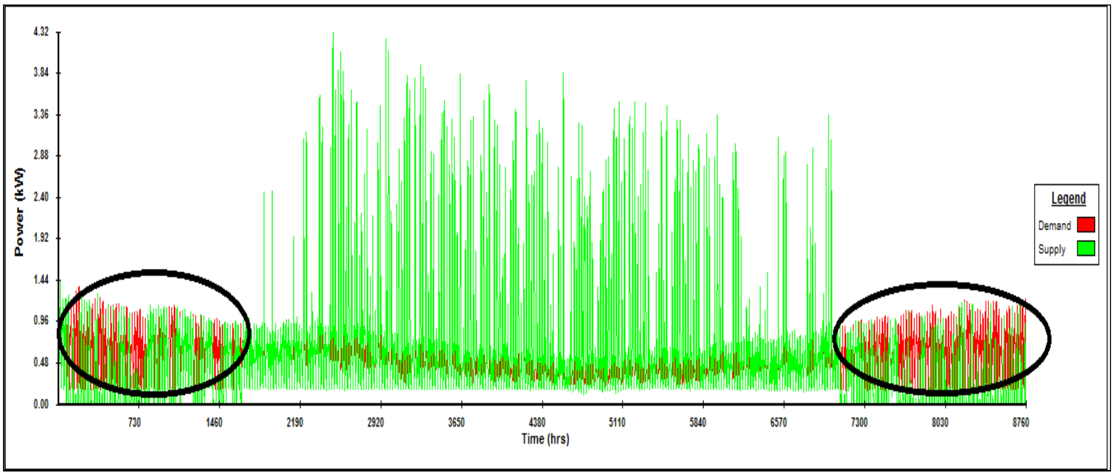
DSM simulation's results are presented on the following Table 33:

Table 33: DSM simulation (35 panels, 0.130kW BP plus 16 Batteries)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south	5170
Aux name	**Total Aux Supply (kWh)**
single 215@12	208,66
Energy Deficit (kWh)	**Energy Surplus (kWh)**
1240	1880
% Match rate	**Corelation Coeficient**
51,69	0,05
Energy delivered (kWh)	**Inequality Coeficient**
3490	0,48

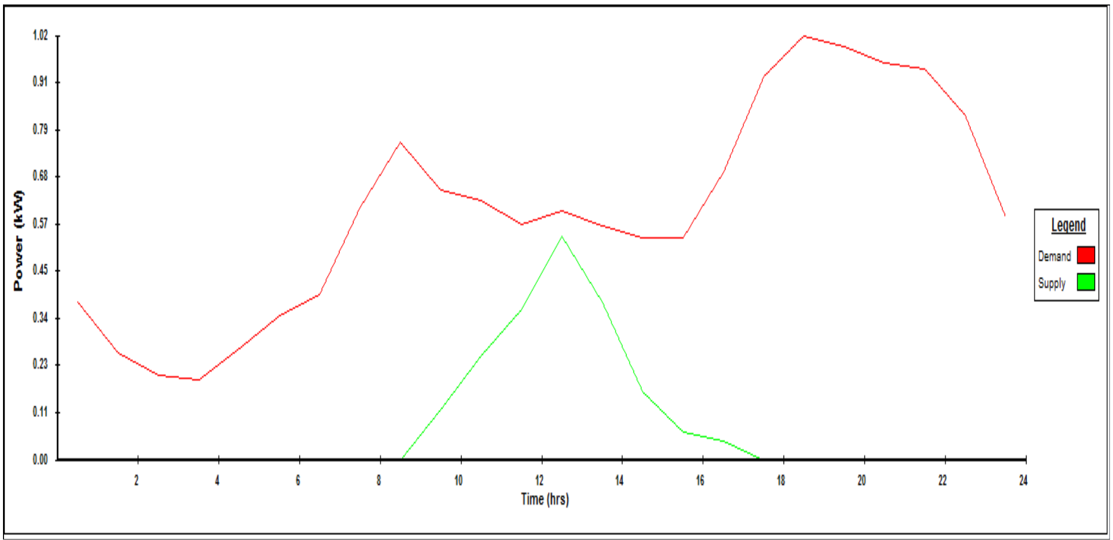
Results interpretation indicates that, with the use of the previously mentioned batteries a significant improvement was achieved, as surplus and deficit energy reduced while energy delivered and match rate increased significantly. This means that, a large amount of surplus energy shifted to times during which there is energy demand by the occupants, thus the pattern followed by energy's supply curve approached more satisfactorily the one of demand's curve. However, as it is clearly shown on the following Graph 12 during months of January, February, November and December

PV panel's energy production is not sufficient to cover the demand because solar irradiation is very weak and the batteries get discharged after some days of operation without providing the required autonomy to the house.



Graph 12: DSM simulation (35 panels, 0.130kW BP plus 16 Batteries)

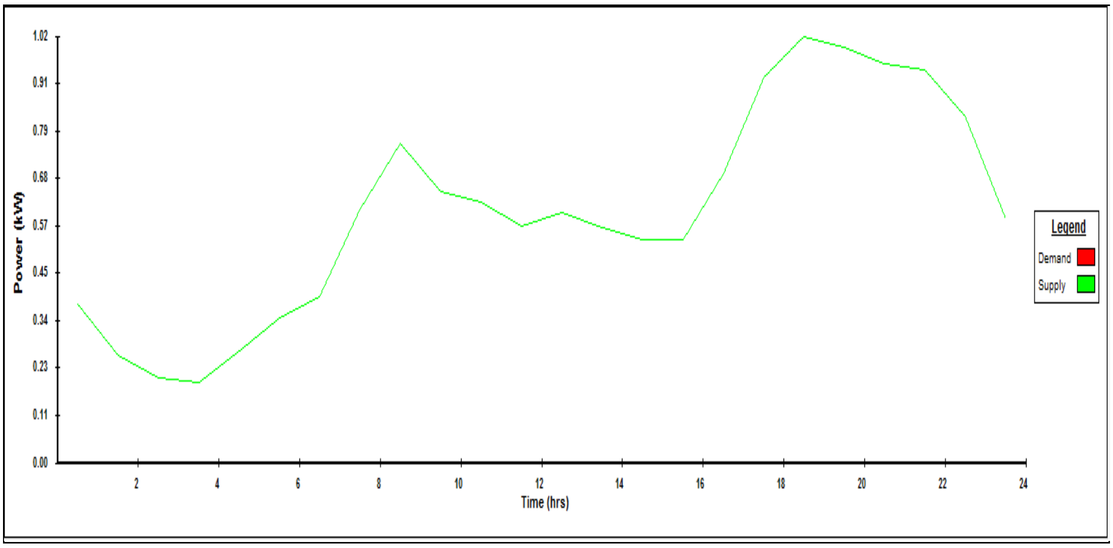
The above mentioned configuration creates a deficit energy value of 1240kWh which is on the one hand reduced compared to the same metric of previous situations but on the other hand dictates that the house must remain connected to the central grid as it is not able to work autonomously during the winter months. If we look graphically during a winter day individually, like 1st of February, we can figure out in a better way, drawbacks occur by the lower production of the PV panels during this period.



Graph 13: DSM simulation during 1st of February (35 panels, 0.130kW BP)

As it is shown on Graph 13 the energy supplied by the installed renewable energy systems does not offset the demand even during the midday time, when normally there is higher solar irradiation. Hence, a storage system will not be able to help towards energy autarchy direction during this period in long term, no matter how big it will be, as the renewable energy production cannot even cover the demand of the day. This means that, if renewable energy production is not sufficient for a number of days in sequence, the batteries will not recharge. As a result of this, they will be able to provide the required autonomy until they will get discharged from their initial charge.

This is clearly illustrated on the following Graph 14 where the initial charge of the 16 installed batteries is capable to make our system work autonomously for the 1st of February even if the renewable production is less than the energy demand.



Graph 14: DSM simulation during 1st day of February (35 panels, 0.130kW BP plus 16 Batteries)

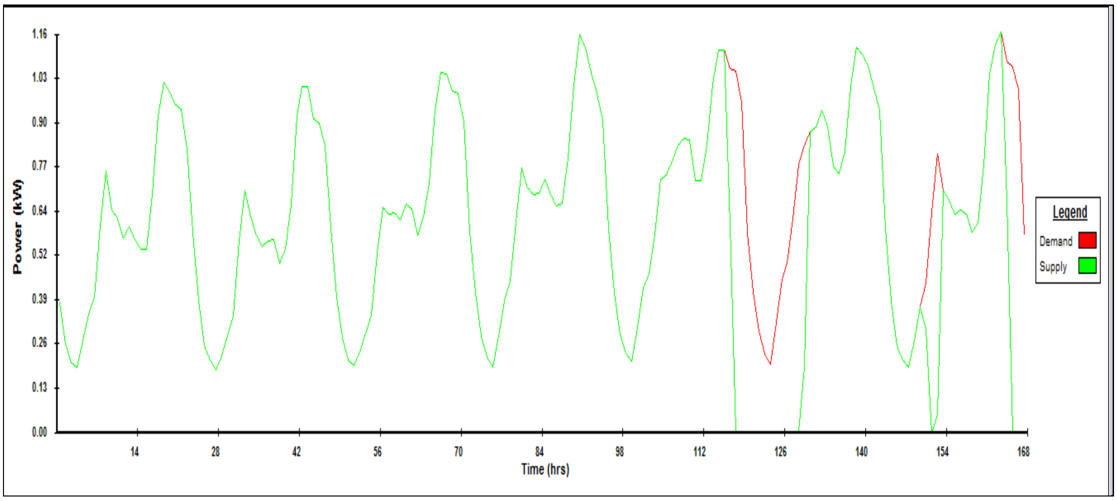
It can be easily observed that the demand's curve match totally with the one of supply mainly because of the fact that energy provided totally by the storage system. However, a more careful investigation on the results indicates that the system works autonomously just because the initial charge of batteries is capable to do it for the first day as shown on Table 34 below.

Table 34: DSM simulation during 1st day of February (35 panels, 0.130kW BP plus 16 Batteries)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	14,49
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south	1,95
Aux name	**Total Aux Supply (kWh)**
single 215@12	12,54
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	0
% Match rate	**Corelation Coeficient**
100	1
Energy delivered (kWh)	**Inequality Coeficient**
14,01	0

Batteries will not recharge, as renewable generation is insufficient, and when get discharge the house will not continue to work autonomously.

This can be crystal clear if a DSM simulation be carried out for the first week of February. As shown on Graph 15 below there are times, during the last 3 days of the week, where the energy demand cannot be met from the renewable generation and the storage system cannot maintain this gap in order to provide the required autarchy.



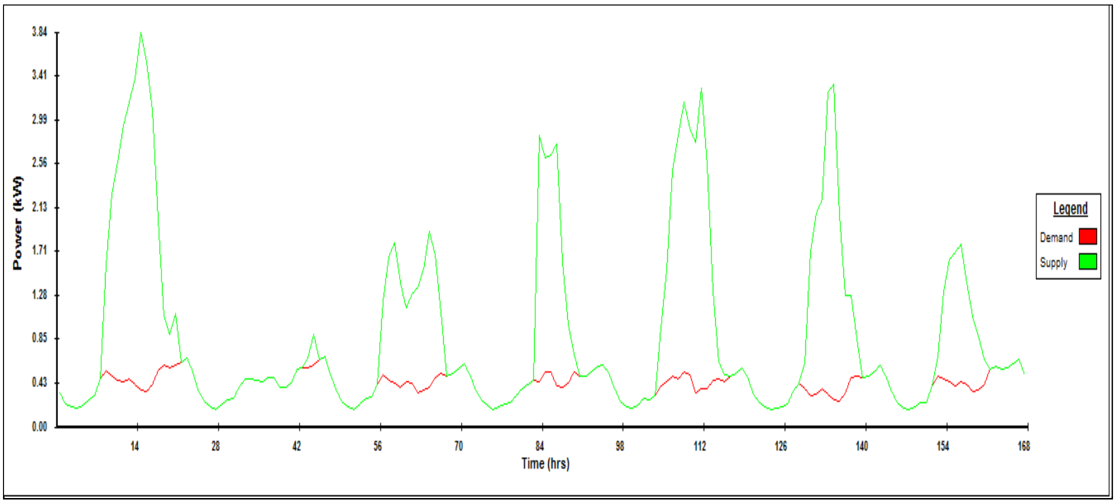
Graph 15: DSM simulation during 1st week of February (35 panels, 0.130kW BP plus 16 Batteries)

Results interpretation based on the below Table 35 indicates that the auxiliary supply is not enough to provide the required autonomy to the house for the whole week. With the current demand, supply and storage configuration as well as climate conditions autonomy can be achieved only for the first four days.

Table 35: DSM simulation during 1st week of February (35 panels, 0.130kW BP plus 16 Batteries)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	109,93
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south	65,88
Aux name	**Total Aux Supply (kWh)**
single 215@12	31,95
Energy Deficit (kWh)	**Energy Surplus (kWh)**
11,66	0
% Match rate	**Corelation Coeficient**
83,63	0,76
Energy delivered (kWh)	**Inequality Coeficient**
97,63	0,16

On the other hand during the first week of June where solar irradiation is stronger and the renewable energy production sufficient the problem does not appear as it is shown on the Graph 16.



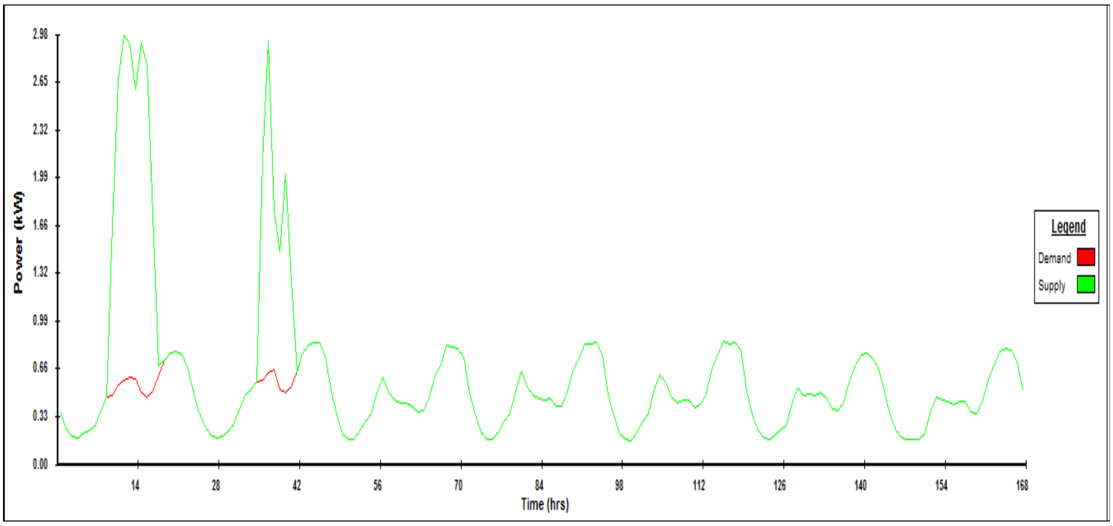
Graph 16: DSM simulation during 1st week of June (35 panels, 0.130kW BP plus 16 Batteries)

Results interpretation based on the following Table 36 shows that the house during summer period can work autonomously even with fewer installed PV panels than the selected 35 panels as the total renewable energy supply is approximately three times the demand and the surplus production higher than the same. It is clear that the batteries recharge sufficiently by the surplus renewable production and the supplied energy from the auxiliary system is less than the one during the winter week indicating that the autonomy of the system is less dependent on the storage system.

Table 36: DSM simulation during 1st week of June (35 panels, 0.130kW BP plus 16 Batteries)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	69,63
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south	152,61
Aux name	**Total Aux Supply (kWh)**
single 215@12	7,01
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	89,57
% Match rate	**Corelation Coeficient**
40,74	0,22
Energy delivered (kWh)	**Inequality Coeficient**
69,2	0,59

In order to have a global view at the subject matter a DSM simulation performed for an autumn week in order to note how our system work at an intermediate climate condition. Especially, the first week of October was investigated keeping the demand supply and storage system configuration as they were in the previous investigations. The DSM simulation results, for the said period, are presented at the following Graph 17 and Table 37.



Graph 17: DSM simulation during 1st week of October (35 panels, 0.130kW BP plus 16 Batteries)

At the above Graph 17 it is clear that the first two days, where the renewable energy production is sufficient, house's autonomy is less dependent on the storage system and that's why the pattern of supply's curve does not approach the one of demand's accurately. Next days, as we move towards winter and the solar irradiation becomes weaker, the required energy mainly provided by the batteries and the matching rate, between the two curves, increases significantly.

Table 37: DSM simulation during 1st week of October (35 panels, 0.130kW BP plus 16 Batteries)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	81,94
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south	82,98
Aux name	**Total Aux Supply (kWh)**
single 215@12	23,14
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	24,18
% Match rate	**Corelation Coeficient**
61,74	0,45
Energy delivered (kWh)	**Inequality Coeficient**
81,5	0,38

On the above Table 37, it is clear that energy autonomy is more dependent on the storage system as the total renewable energy supply is approximately as much as the total demand while there is surplus production during some times. As a result of this, total auxiliary supply is higher compared with the one of summer's week. As we move closer to winter the problem will be more significant and the house will not be able to operate autonomously.

To sum up, via the above investigation around storage system it was revealed that with the current supply configuration it is impossible to find adequate storage system to ensure the required autonomy to the house. The problem is that, according the climate data in this region the solar irradiation is very weak during 4-5 months in a sequence making impossible to resolve the problem without installing such a renewable energy system capable to produce energy under these cloudy climate conditions. Even the installation of a very large number of batteries will not resolve the problem. Additionally, this will result to investment cost increase at unreasonable high levels considering that a battery like the one used to the simulations costs, based on web market research, around 250£.

5.5.3. Use of other renewable systems types

In order to take advantage of the windy Scottish climate a Wind Turbine will be installed targeting to ensure energy autarchy of Whins 517 house. It was selected a wind turbine with the following characteristics (Table 38) keeping the demand profile and the PV panels same as previously while the number of batteries increased to 36 of the same type with the one used previously.

Table 38: Wind Turbine characteristics

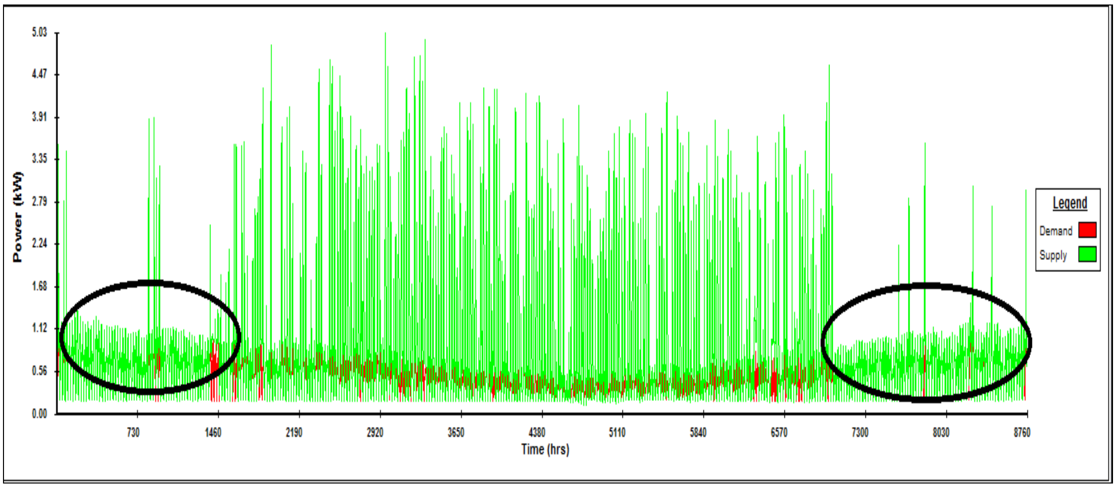
Wind Turbine characteristics	
Name	Generic 1kW
Manufacturer	Hommer
Power Factor	0,8
Swept Area (m2)	4,9
Turbine Hub Height (m)	10

Applying the above mentioned system's arrangement the following results obtained (Table 39).

Table 39: DSM simulation (35 panels, 0.130kW BP plus 36 Batteries plus Generic 1kW WT)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south+Generic 1kW	7870
Aux name	**Total Aux Supply (kWh)**
single 215@12	202,39
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	3330
% Match rate	**Corelation Coeficient**
50,24	0,18
Energy delivered (kWh)	**Inequality Coeficient**
4720	0,5

Result's interpretation indicates that under these circumstances it is possible to achieve energy autarchy for the case study's house. As can be seen on the above Table 39, the red highlighted energy's deficit value is 0kWh. This means that there is not even one time during a whole year of operation in which energy was drawn by the grid. On the contrary, renewable energy production in conjunction with the applied storage system ensures that all the times the amount of produced energy offset the demand requirement and in many cases there is surplus energy production which in a complete year is 3330kWh. The installation of the Wind Turbine fix the problem with the reduced renewable energy generation by the installed PV panels during winter months as can be seen on Graph 18. It is clear that renewable energy supply offset the energy demand at the highlighted areas and this happens mainly due to the use of the WT. The energy production during the said period remains constant around 1kW which is the power output of the Turbine, when wind speed is 12m/s which is the case in the area being examined.

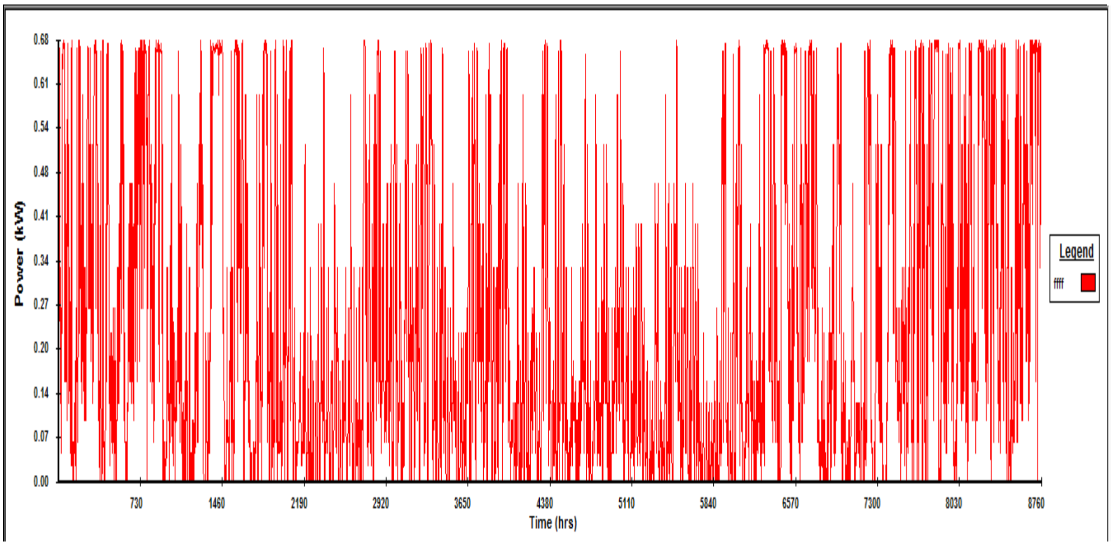


Graph 18: DSM simulation (35 panels, 0.130kW BP plus 36 Batteries plus Generic 1kW WT)

The fact that, energy autarchy can be obtained under the previously described configuration does not mean that everything is ideal and this designed can be applied easily. A number of drawbacks have to be addressed satisfactorily for the successful application of the previously mentioned arrangement. To start with, there is a large amount of surplus energy production which either has to be reduced taking the appropriate actions or to be exported to the central grid bringing cash profit to the owner. If the system is not connected to the grid and the surplus energy production cannot be reduced, unfortunately, will have to be wasted. Additionally, the installation of all these systems implies a large capital investment by the owner. A feasibility study and a financial investigation have to be performed in order to decide if the investment is worthy or not at the long term. Another significant challenge has to be faced is space availability in order to place all this equipment. Specifically, the installation of 35 PV panels, 1 WT turbine and 36 batteries requires a lot of free space with the appropriate orientation and at specific conditions (free of shading for the PV installation, free of obstacles and windy environment for the turbine, isolated cellar for the batteries). Finally, all the above renewable energy systems are weather dependent something which make our system’s autonomous operation very uncertain.

5.5.4. Arrangement's optimisation

A final investigation carried out around aspects can change aiming to the optimisation of the arrangement described at section 5.5.3. providing the same time the required autonomous operation on the house during a whole year of operation. As discussed at the previous section the main direction of the optimisation actions has to be the capital investment and surplus energy production's minimization. From Graph 18 it was concluded that all summer period there is a lot of surplus energy production while this is not the case during winter. Furthermore it was observed that the energy production of wind turbine is constant either during winter or summer for the selected climate conditions as it is shown on Graph 19.



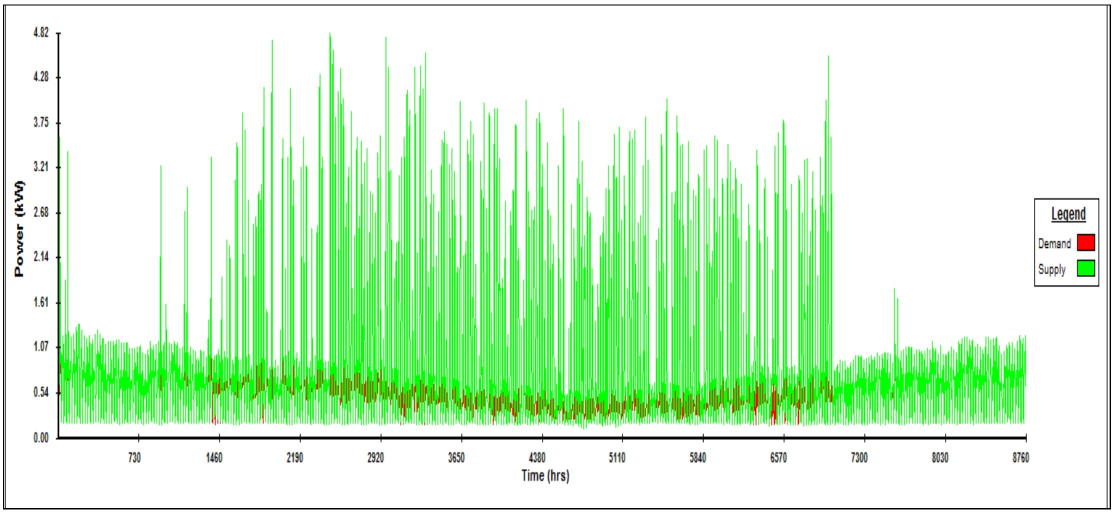
Graph 19:WT annual energy production curve

Based on this observation it was decided to use a smaller wind turbine in order to reduce the surplus electricity during summer and also to reduce the capital investment for the purchase of the WT. It was selected the Proven WT 0.6kW with the following characteristics (Table 40).

Table 40: Proven 0.6kW WT characteristics

Value	System Characteristic
Name	Proven WT600
Turbine Hub Height	10.00
Orientation	0.00
Turbine Type	Pitch/Stall/Unregulated
Number of Turbines	1
Wind Speed Measurement Type	Standard Meteorological Data
Surrounding Surface Type	Water Surface
Turbine Database Reference	Proven WT600
Financial Database Reference	costtest

It has 0.6kW rated power which is almost the half of the one used previously. In addition to this, the energy produced by the PV panels during winter should be increased in order to supplement and enhance the WT production during the same period. On the contrary during summer period their production could decrease, without any significant impact towards energy autarchy, as there was a lot of surplus energy production. Based on this was decided to increase the tilt angle of PV panel's installation to 60° in order to take advantage from the fact that sun during winter is at lower position compared to summer. Hence, the energy production increases during winter and decreases during summer when tilt angle increases. Doing this, it was realised that by installing one more PV panel (36 pcs) and increasing the batteries by 4 (20 batteries in series and other 20 in parallel) it was possible to achieve energy autarchy with the almost half size WT and slightly increased PV panels and storage systems. The Graph 20 below show the described arrangement.



Graph 20: DSM simulation (36 panels, 0.130kW BP @ 60° plus 40 Batteries plus Generic 0.6kW WT)

Contrasting the below Table 41 with the Table 39 it is observed that there is a reduction at the total renewable energy supply as well as the surplus energy. The auxiliary supply is higher as the system drawn energy from the batteries more frequently due to the reduced energy production of the new WT and that's why the match rate has slightly increased. A further financial analysis can be done in order to ascertain that the cost saving by the reduced WT is higher than the investment for the additional 1 PV and the 4 batteries.

Table 41: DSM simulation (36 panels, 0.130kW BP @ 60° plus 40 Batteries plus Generic 0.6kW WT)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south+Proven600W	7390
Aux name	**Total Aux Supply (kWh)**
single 215@12	442,81
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	3090
% Match rate	**Corelation Coeficient**
51,41	0,19
Energy delivered (kWh)	**Inequality Coeficient**
4720	0,49

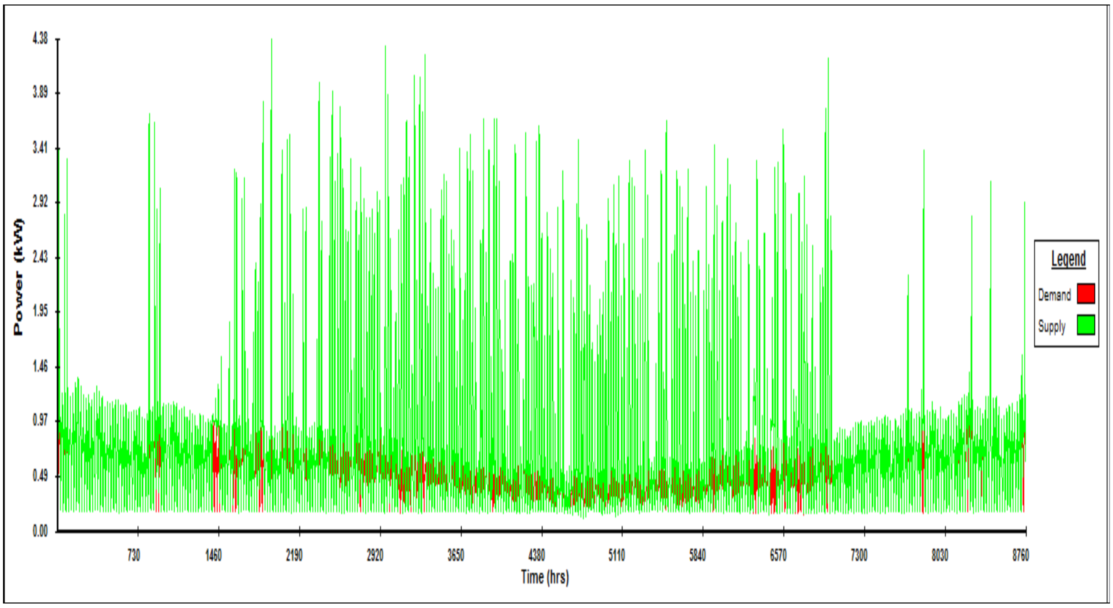
On the other hand if the requirement is to reduce as much as possible the surplus energy and achieve a very high match rate, 2 Proven WT of 600W can be used. According to this arrangement only 13PV panels same type as previously are required and 40 batteries (20 batteries in series and other 20 in parallel). The results from the DSM simulation are presented on the Table 42 below.

Table 42: DSM simulation (13 panels, 0.130kW BP @ 45° plus 40 Batteries plus 2XGeneric 0.6kW WT)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south+Proven600W	6250
Aux name	**Total Aux Supply (kWh)**
single 215@12	313,58
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	1830
% Match rate	**Corelation Coeficient**
68,04	0,42
Energy delivered (kWh)	**Inequality Coeficient**
4720	0,32

Results interpretation indicates that the surplus energy reduced amazingly to 1830kWh while the match rate from 51% increased to 68%. It is obvious that under this arrangement the pattern of supply's curve approaches more accurately the one of the demand's resulting to better utilization of the produced renewable energy. On the other hand it is not so clear if it is financially worthy this arrangement compared to previous. A financial analysis can indicate if the saving cost from the reduced installed PV panels offset the cost for the purchase of the second Wind Turbine.

Finally, another arrangement also developed under which the storage system is reduced slightly. It seems to be closer on the arrangement of 5.5.3. Section as the Generic WT of 1kW used again but the quantity of PV panels reduced to 30 from 35 and their tilt angle change from 45° to 60° in order to increase their production during winter. Furthermore the amount of batteries reduced to 32 (16 in series and 16 in parallel). The Graph 21 shows the demand and supply curves of the subject concept for a year of operation.



Graph 21: DSM simulation (30 panels, 0.130kW BP @ 60° plus 32 Batteries plus Generic 1kW WT)

Contrasting the below Table 43 with Table 39 it can be easily observed that surplus energy production reduced and despite the fact that battery system also reduced, it was utilized more by the system as total auxiliary energy supply is more under this arrangement. Under this arrangement it is very clear that there is a cost saving compared with the arrangement described at 5.5.3. section as there is a reduction at the installed PV panels and the batteries.

Table 43: DSM simulation (30 panels, 0.130kW BP @ 60° plus 32 Batteries plus Generic 1kW WT)

DSM Simulation Results	
Demand name	**Total Demand (kWh)**
3_Bedroom Electrical (real)+3_Bedroom Thermal (real)	4730
Renewable name	**Total Re Supply (kWh)**
130 Watt BP Mono vert south+Generic 1kW	7050
Aux name	**Total Aux Supply (kWh)**
single 215@12	357,96
Energy Deficit (kWh)	**Energy Surplus (kWh)**
0	2670
% Match rate	**Corelation Coeficient**
55,62	0,24
Energy delivered (kWh)	**Inequality Coeficient**
4720	0,44

6. Conclusions and proposals for further research

Findings from the subject study indicated that net zero energy standards and even more energy autarchy is a difficult task to be achieved. First of all, very high quality materials have to be used during construction process in order to minimise heat transmission from the interior areas to external environment and vice versa. In this way it is possible to reduce energy demand for heating, cooling and electricity as low as it is required in order to be feasible energy produced by potential installed Renewable Energy systems to offset the energy demand. To start with, in order to achieve these building standards it is required a detailed design which should have the ability to take into account not only the construction details for the integration of all building components to an entity but also the fundamental principles of the bioclimatic design. This means that proper building's orientation must be selected in order to ascertain that thermal gains during colder months will increase while the same will reduce during the warmer ones resulting to reduced energy demand ensuring thermal comfort. Specifically, as can be seen at chapter 3 of the subject study, where the findings from the modelling of 517 Whins house with PHPP software are listed, the selection of insulation materials impact significantly U-Values of the building opaque and transparent components. Also thermal gains are affected from the orientation of building's openings. For instance, the insufficient use of insulating material (EDS) at ground slab of our case study resulted to relatively higher thermal losses from this surface while thermal gains from windows facing to south are comparatively higher in comparison with the other ones. This building concept implies the use of more expensive material and higher construction costs in general. In addition to this, a very big challenge during construction process is the proper application of all the required technics in order to reach these construction standards and ensure that all requirements have been met resulting to building's certification as Passive House. At this point, it can be noted that further research can be done in order to perform more accurate modelling at PHPP software gathering more detailed data for the house which is under investigation. Also it will be worthy to examine alternative materials can be used into construction components aiming in reducing the energy requirement even more.

Consequently, after thorough investigation around actual energy production of the installed PV panels at 517 Whins house from data gathered by Origin project's monitoring data base, it was examined as whether it is possible for the subject building to be classified as Net Zero Energy. The investigation carried out based on Net Zero Site Energy definition indicating that the produced energy from the installed PV panels is not sufficient to offset the energy demand of the subject house. Optimisation of the said research can be achieved using Origin's project monitoring data base, as regards the energy demand of the house, instead of using PHPP modelling output. Also, will be very interesting additional investigations, around Net Zero Energy concept, to be done based on the rest 3 definitions looking the same time on the one hand on how is possible to improve construction process and building components in order to reduce energy demand and on the other hand how Renewable Energy production can be improved in order to meet Net Zero Energy standards.

Finally, we looked for the conditions under which the case study house could work autonomously. Merit DSM software was used for this purpose. A number of deferent supply arrangements were applied in order to find out the most suitable one against the demand profile of our case which derived from PHPP modelling. It was obvious from the simulations performed that energy storage systems did not have the capacity to store adequate amount of energy for long period in order to provide it when it is required from the occupants. Therefore, despite the fact that energy production was higher than energy demand under some supply arrangements at the course of a year, it was impossible to achieve energy autarchy as there was a lot of surplus and deficit energy production. This means that, it was necessary a storage system in order to store the energy when the production was surplus and to provide it when it was deficit. This couldn't happen because of the fact that, summer surplus PV panel's energy production could not be stored for such a very long period up to winter months, during which their production was fewer than the demanded one. After thorough investigation during January month it was decided that Scottish weather does not allow room for energy production from PV panels during winter months as solar irradiation is very weak and produced energy does not offset the demand even the mid-day hours. This challenge was faced satisfactorily by the installation of a supplementary renewable energy system like a residual wind turbine combined with proper storage system to maintain demand and supply matching during the whole day. However, despite the fact that the required target was achieved there is a lot of surplus energy production. That’s why a further investigation followed related with the optimisation of DSM simulation. This means that, alternative configurations were proposed in order to identify the ideal renewable energy supply system which could provide adequate energy quantity the time it is needed. Also, as it was mentioned previously it would be very interesting to investigate how the improvement of building construction quality can minimise the necessity for additional renewable energy systems installation in order to achieve energy autarchy.

Finally, it would be very interesting a financial analysis to be performed at a future research. This study covered the technical part of the subject topic and there was not sufficient time to investigate aspects around a so extended field.

To sum up, in this study it was shown that the combination of very strict building standards application with the appropriate dimensioning of installed renewable energy and storage systems can lead to energy autarchy while there is a lot of room for investigation around aspects which can optimise the whole process.

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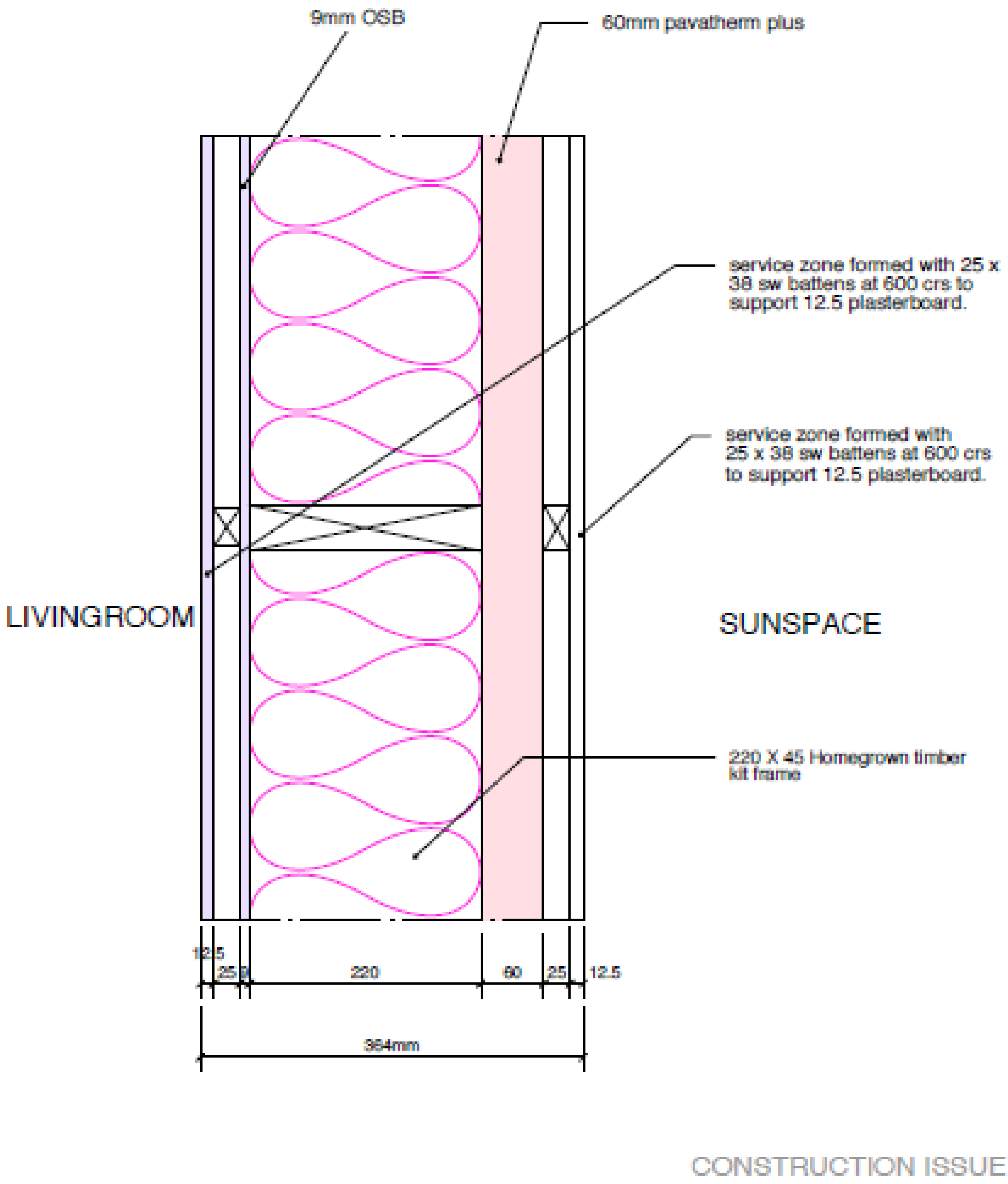
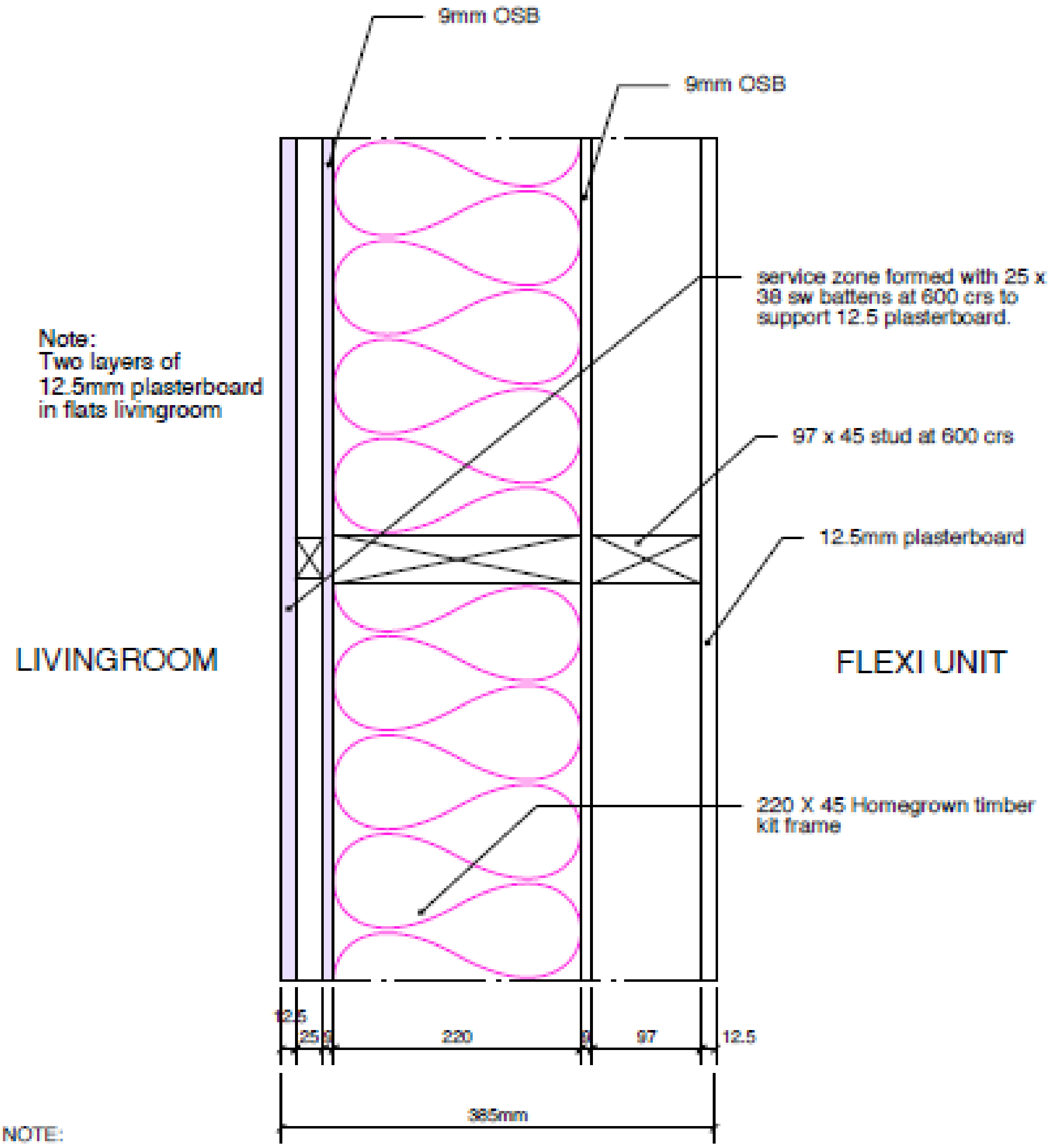
Appendix A: Architect drawings



John Gilbert ARCHITECTS	Title: FRONT SUNSPACE WALL MAKE_UP HOUSES	Project: EAST WHINS
		Job No: 03088 / Scale: 1:5
	Rev / Alteration / Date	Date: 120111 / Drawn by: NM / Size: A4
		Dwg No: [22]05 / Rev:



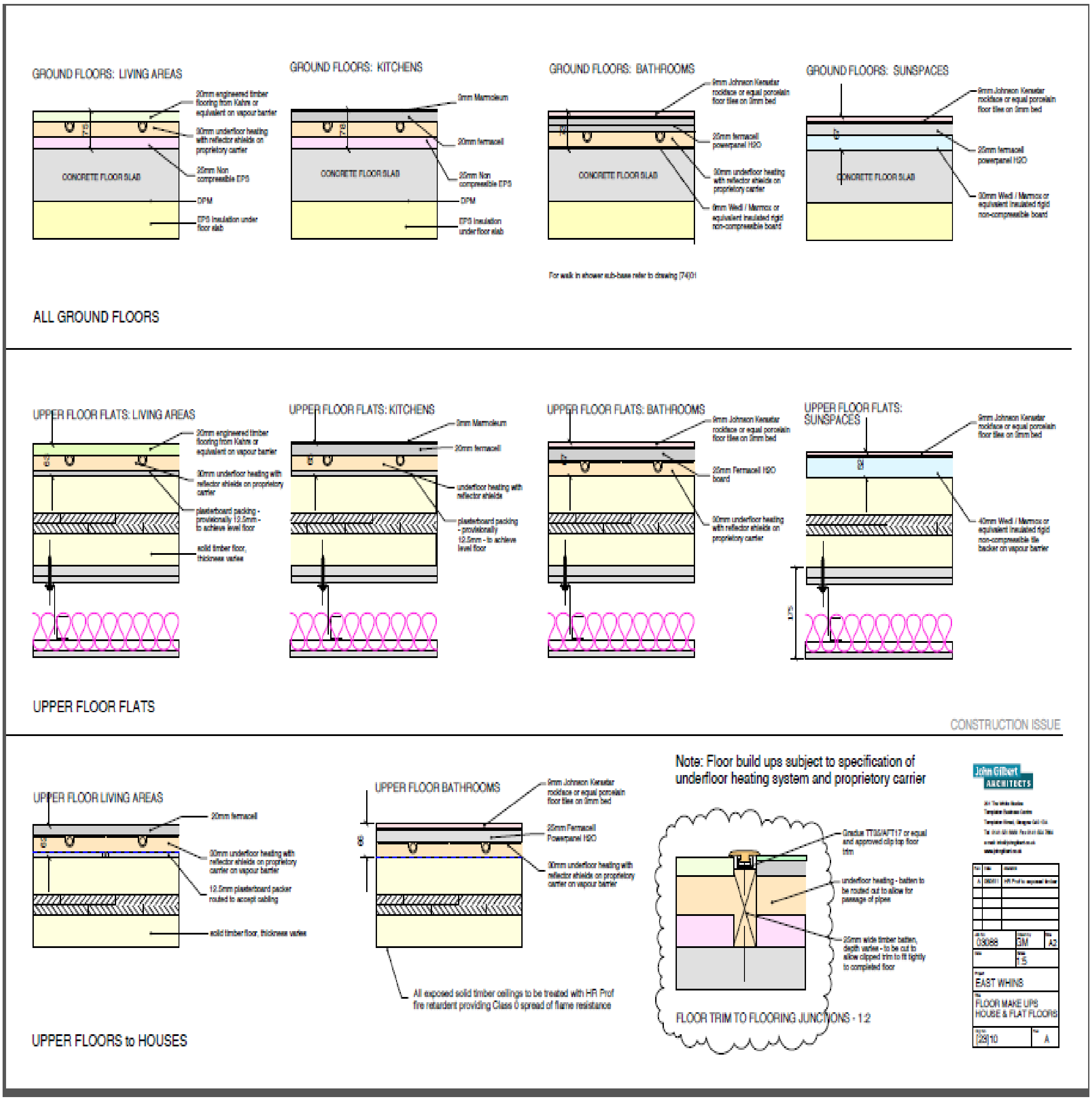
NOTE:

Internal wall make-up between
Block 1_Unit 529 and 530
Block 1_Unit 527 and 528
Block 2_ Unit 517 and 518
Block 3 _Unit 514 and 516

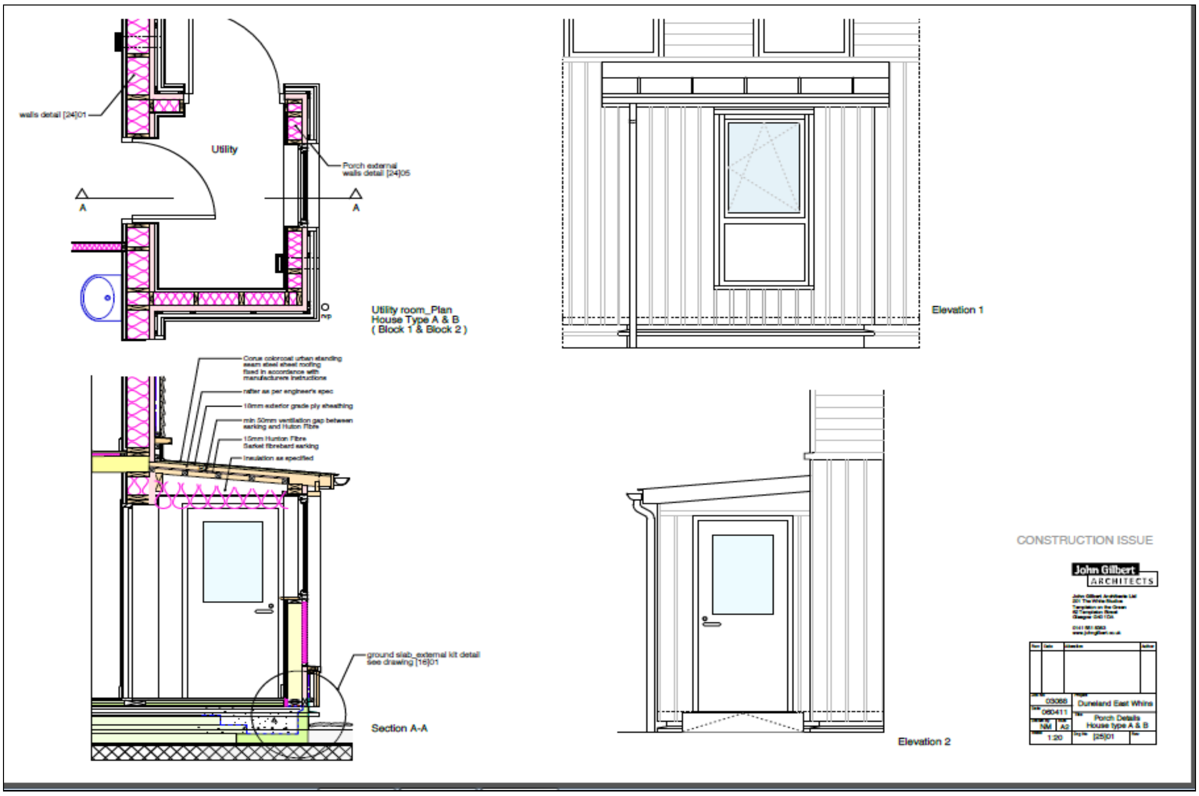
CONSTRUCTION ISSUE

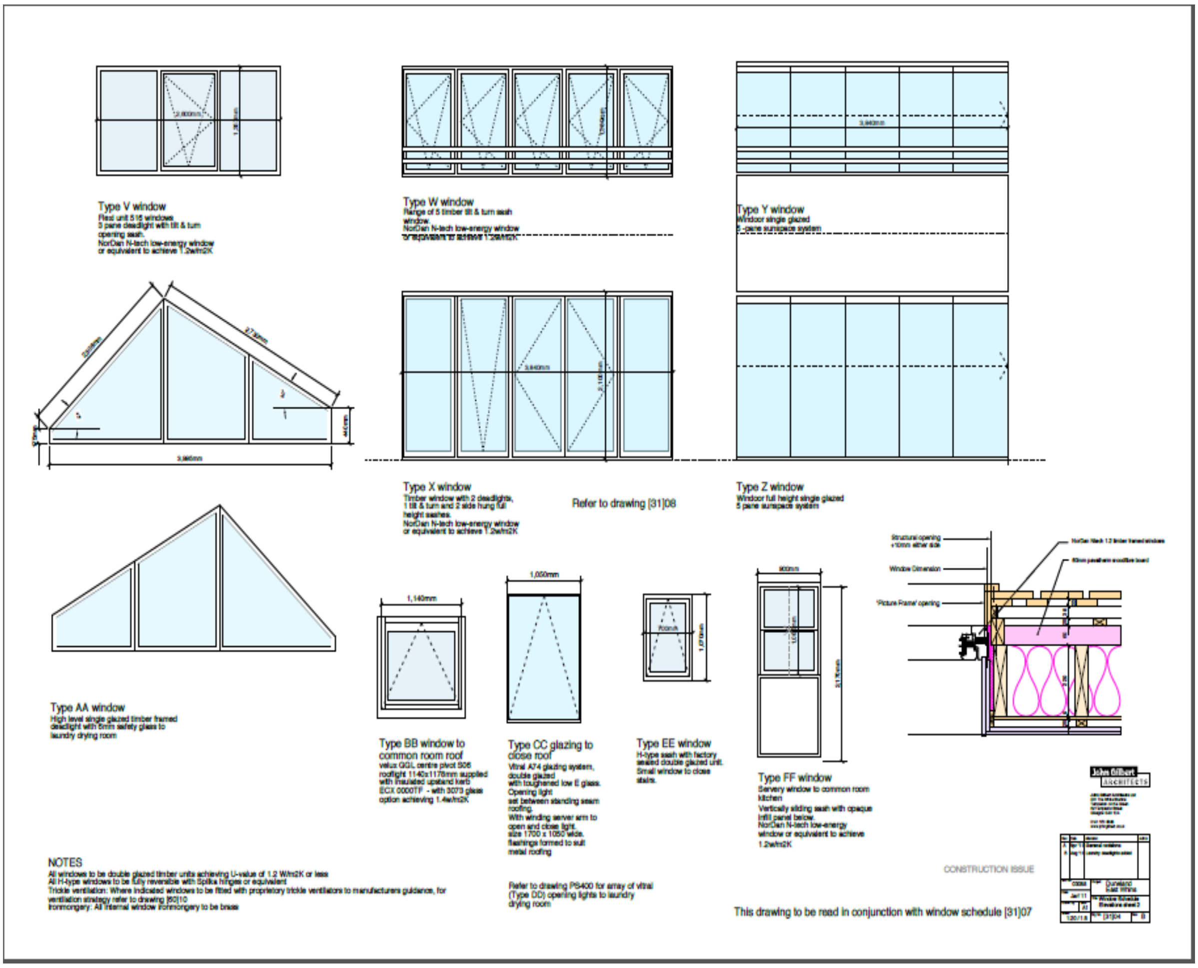
John Gilbert ARCHITECTS

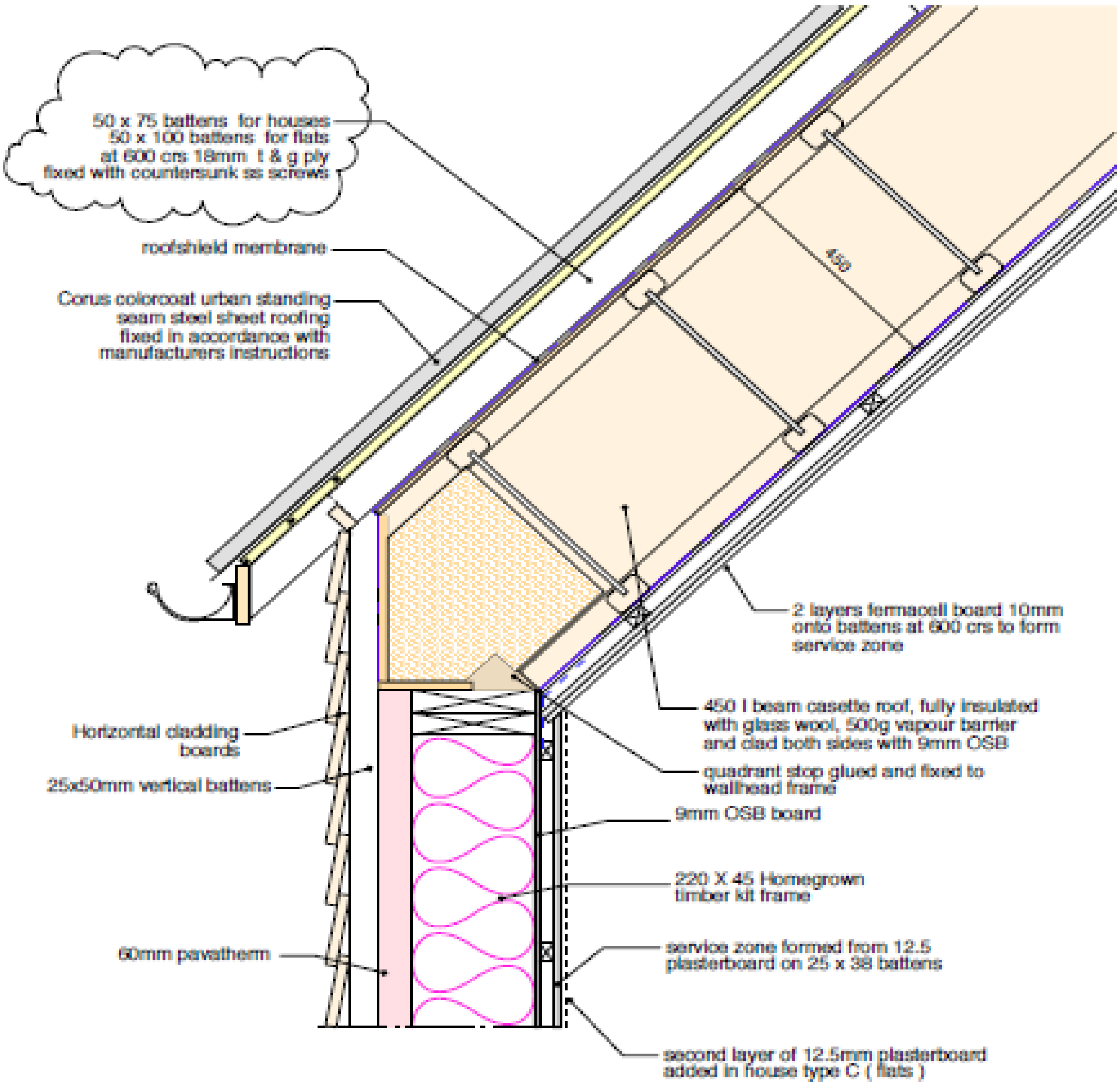
Title: HOUSE / FLAT _ FLEXI UNIT WALL MAKE -UP			Project: EAST WHINS	
			Job No 03088	Scale 1:5
Rev	Alteration	Date	Date 130111	Drawn by NM / Size A4
A	Note added and Title box amended.	080411	Dwg No [22]06	Rev A



GROUND FLOORS: LIVING AREAS
20mm engineered timber flooring from Kahrs or equivalent on vapour barrier
30mm underfloor heating with reflector shields on proprietory carrier
25mm Non compressible EPS
CONCRETE FLOOR SLAB
DPM
EPS insulation under floor slab
GROUND FLOORS: KITCHENS
3mm Marmoleum
20mm fermacell
25mm Non compressible EPS
DPM
EPS insulation under floor slab
GROUND FLOORS: BATHROOMS
9mm Johnson Kerastar rockface or equal porcelain floor tiles on 3mm bed
25mm fermacell powerpanel H2O
30mm underfloor heating with reflector shields on proprietory carrier
6mm Wedi / Marmox or equivalent insulated rigid non-compressible board
For walk in shower sub-base refer to drawing [74]01
GROUND FLOORS: SUNSPACES
25mm fermacell powerpanel H2O
30mm Wedi / Marmox or equivalent insulated rigid non-compressible board
ALL GROUND FLOORS
UPPER FLOOR FLATS: LIVING AREAS
30mm underfloor heating with reflector shields on proprietory carrier
plasterboard packing - provisionally 12.5mm - to achieve level floor
solid timber floor, thickness varies
UPPER FLOOR FLATS: KITCHENS
20mm fermacell
underfloor heating with reflector shields
UPPER FLOOR FLATS: BATHROOMS
25mm Fermacell H2O board
UPPER FLOOR FLATS: SUNSPACES
40mm Wedi / Marmox or equivalent insulated rigid non-compressible tile backer on vapour barrier
UPPER FLOOR FLATS
CONSTRUCTION ISSUE
UPPER FLOOR LIVING AREAS
30mm underfloor heating with reflector shields on proprietory carrier on vapour barrier
12.5mm plasterboard packer routed to accept cabling
solid timber floor, thickness varies
UPPER FLOOR BATHROOMS
25mm Fermacell Powerpanel H2O
All exposed solid timber ceilings to be treated with HR Prof fire retardant providing Class 0 spread of flame resistance
Note: Floor build ups subject to specification of underfloor heating system and proprietory carrier
Gradus TT35/AFT17 or equal and approved clip top floor trim
underfloor heating - batten to be routed out to allow for passage of pipes
25mm wide timber batten, depth varies - to be cut to allow clipped trim to fit tightly to completed floor
FLOOR TRIM TO FLOORING JUNCTIONS - 1:2
UPPER FLOORS to HOUSES
John Gilbert ARCHITECTS
03088
1:5
EAST WHINS
FLOOR MAKE UPS HOUSE & FLAT FLOORS
[28]10
A

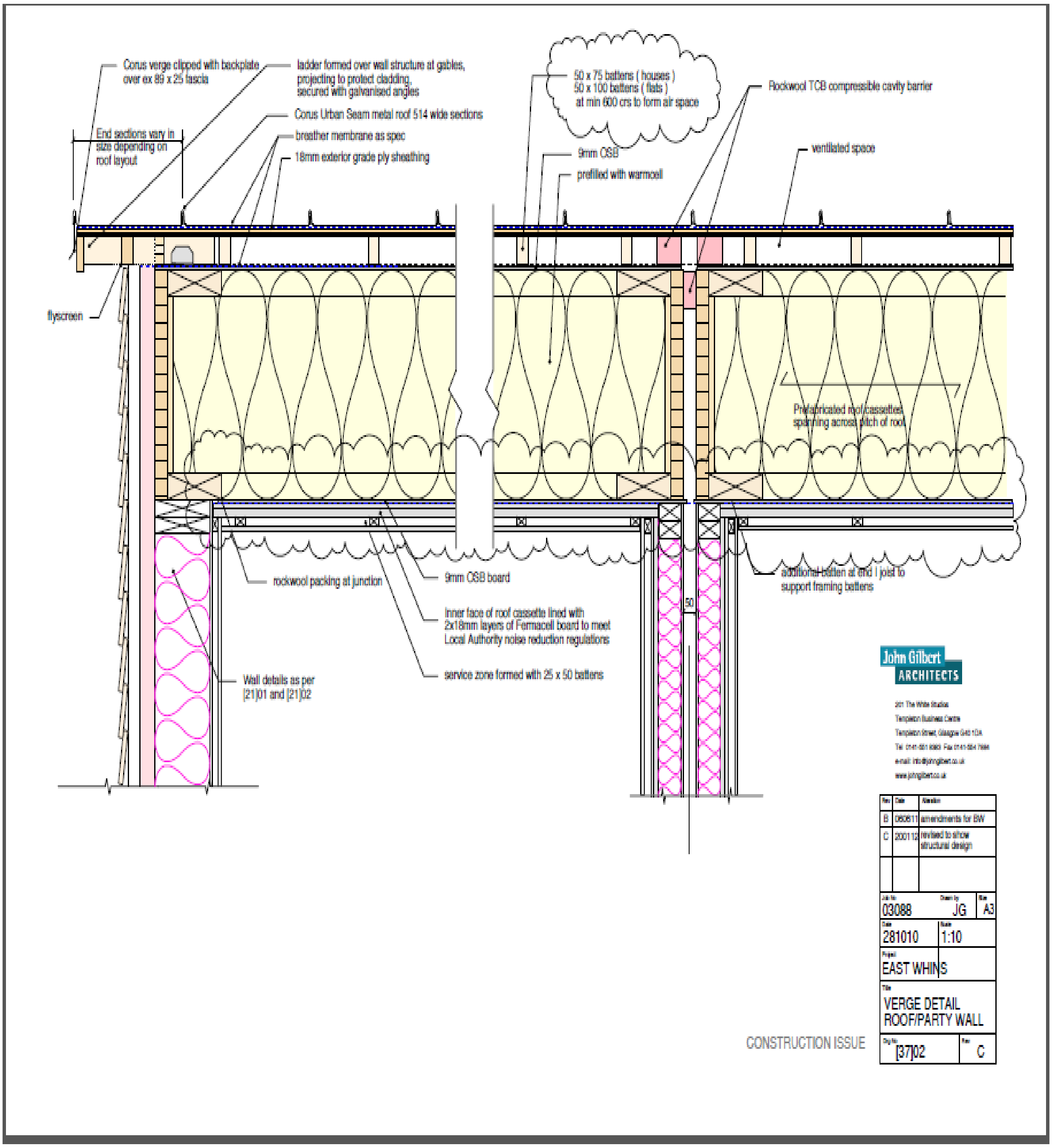

Utility
Utility room_Plan
House Type A & B
(Block 1 & Block 2)
Elevation 1
Section A-A
Elevation 2
CONSTRUCTION ISSUE
John Gilbert
ARCHITECTS
Dunelend East Whins
Porch Details
House type A & B

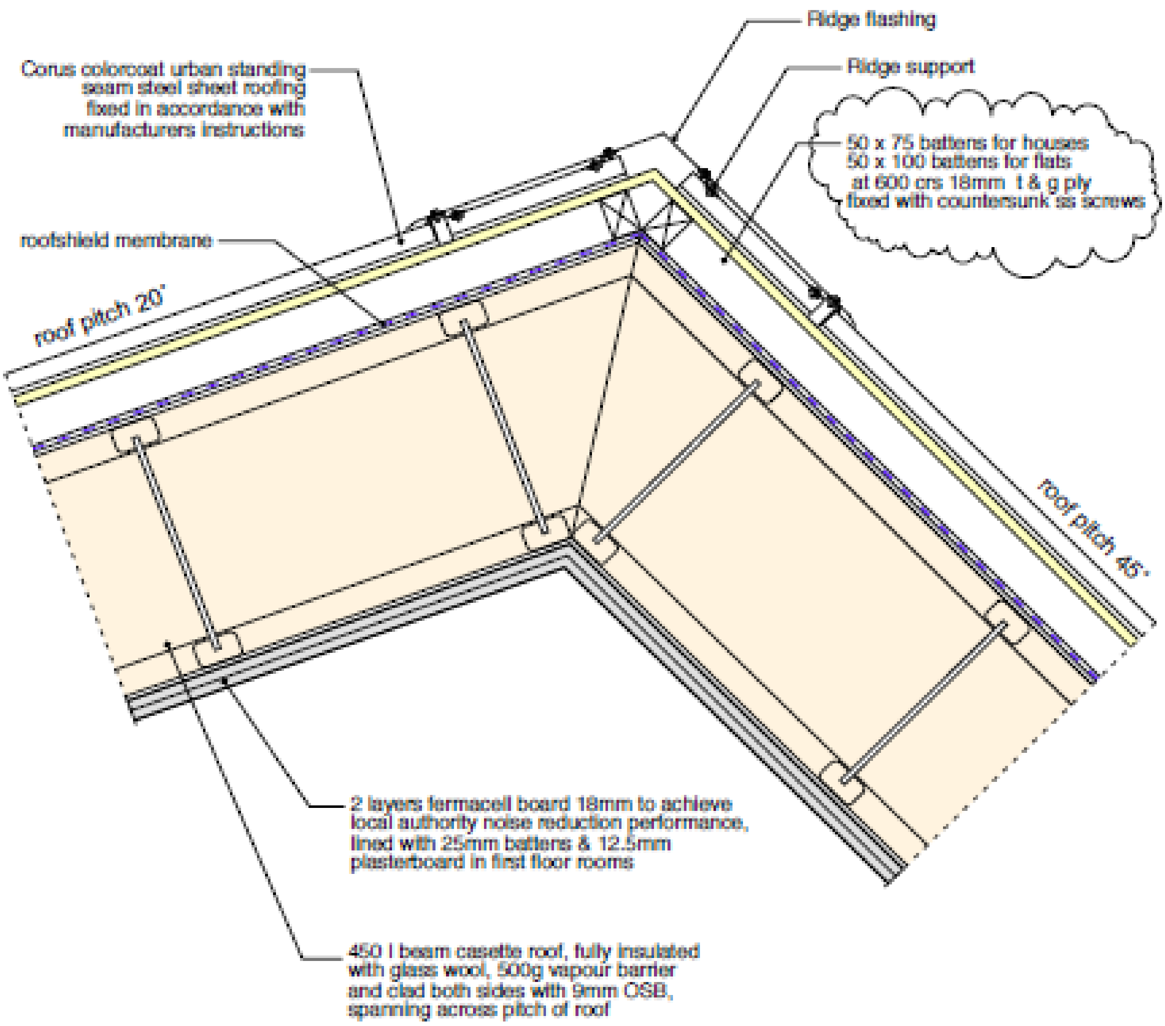

Type V window
Type W window
Type Y window
Type X window
Refer to drawing [31]08
Type Z window
Type AA window
Type BB window to
common room roof
Type CC glazing to
close roof
Type EE window
Type FF window
NOTES
CONSTRUCTION ISSUE
This drawing to be read in conjunction with window schedule [31]07
John Gilbert
ARCHITECTS



CONSTRUCTION ISSUE

John Gilbert ARCHITECTS	Title: EAVES AT 45º			Project: EAST WHINS		
				Job No 03088	Scale 1:10	
	Rev	Alteration	Date	Date 181010	Drawn by JG	Size A4
	A	Note for second layer of plasterboard added	050111	Drg No [37]01		Rev B
	B	Note for air space battens amended.	190411			


Corus verge clipped with backplate over ex 89 x 25 fascia
ladder formed over wall structure at gables, projecting to protect cladding, secured with galvanised angles
Corus Urban Seam metal roof 514 wide sections
breather membrane as spec
18mm exterior grade ply sheathing
End sections vary in size depending on roof layout
50 x 75 battens (houses)
50 x 100 battens (flats)
at min 600 crs to form air space
9mm OSB
prefilled with warmcell
Rockwool TCB compressible cavity barrier
ventilated space
flyscreen
Prefabricated roof cassettes spanning across pitch of roof
rockwool packing at junction
9mm OSB board
Inner face of roof cassette lined with 2x18mm layers of Fermacell board to meet Local Authority noise reduction regulations
service zone formed with 25 x 50 battens
additional batten at end I joist to support framing battens
Wall details as per [21]01 and [21]02
50
John Gilbert
ARCHITECTS
201 The White Studios
Templeton Business Centre
Templeton Street, Glasgow G40 1DA
e-mail: info@johngilbert.co.uk
www.johngilbert.co.uk
B 060611 amendments for BW
C 200112 revised to show structural design
03088
JG
A3
281010
1:10
EAST WHINS
VERGE DETAIL
ROOF/PARTY WALL
[37]02
C
CONSTRUCTION ISSUE



NOTE:

Roof above closes at Block 3 and 4 have the roof pitch at 20˚ at both sides

CONSTRUCTION ISSUE

John Gilbert ARCHITECTS

Title: RIDGE DETAIL
Flats and Houses

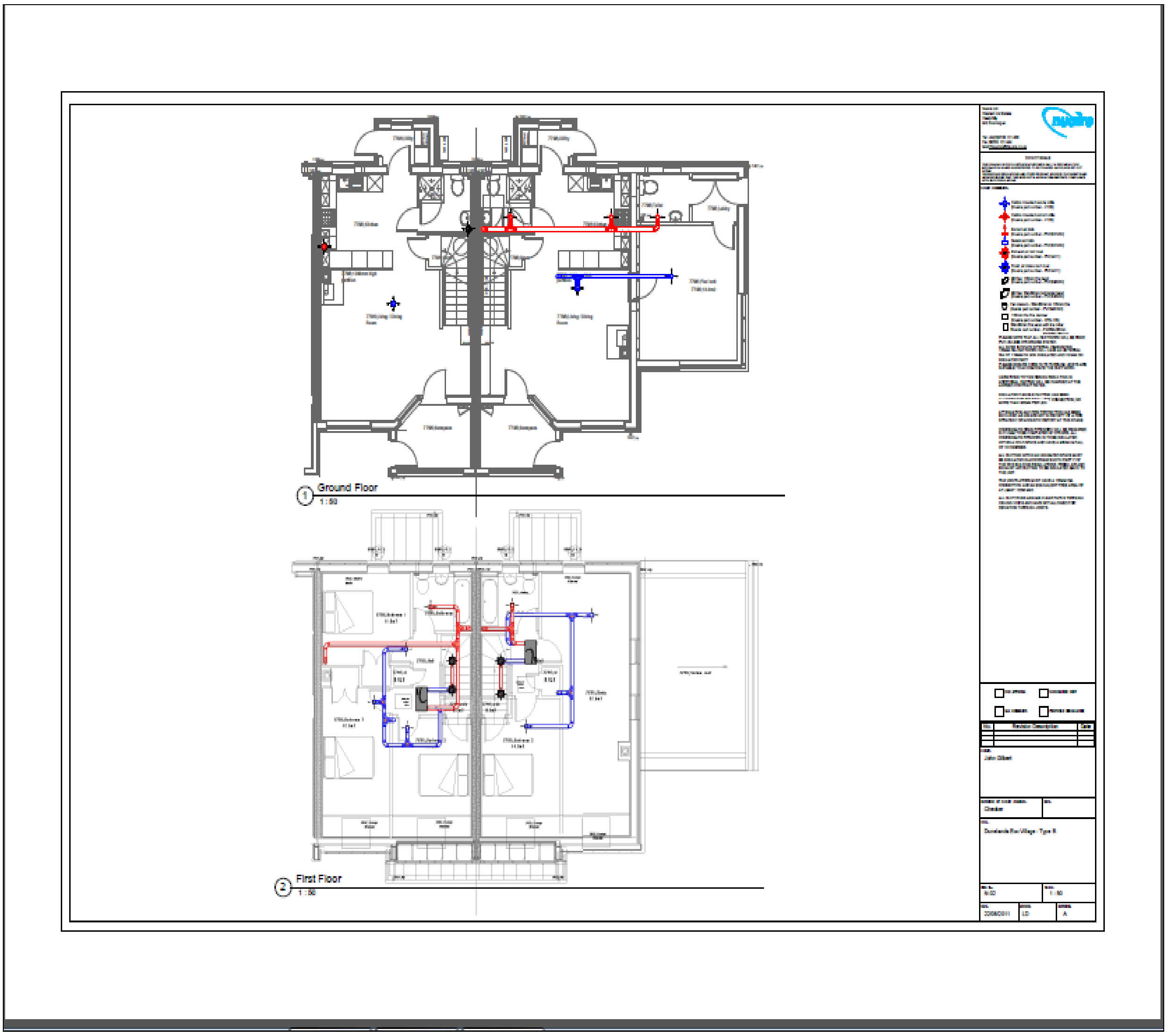
Project: EAST WHINS

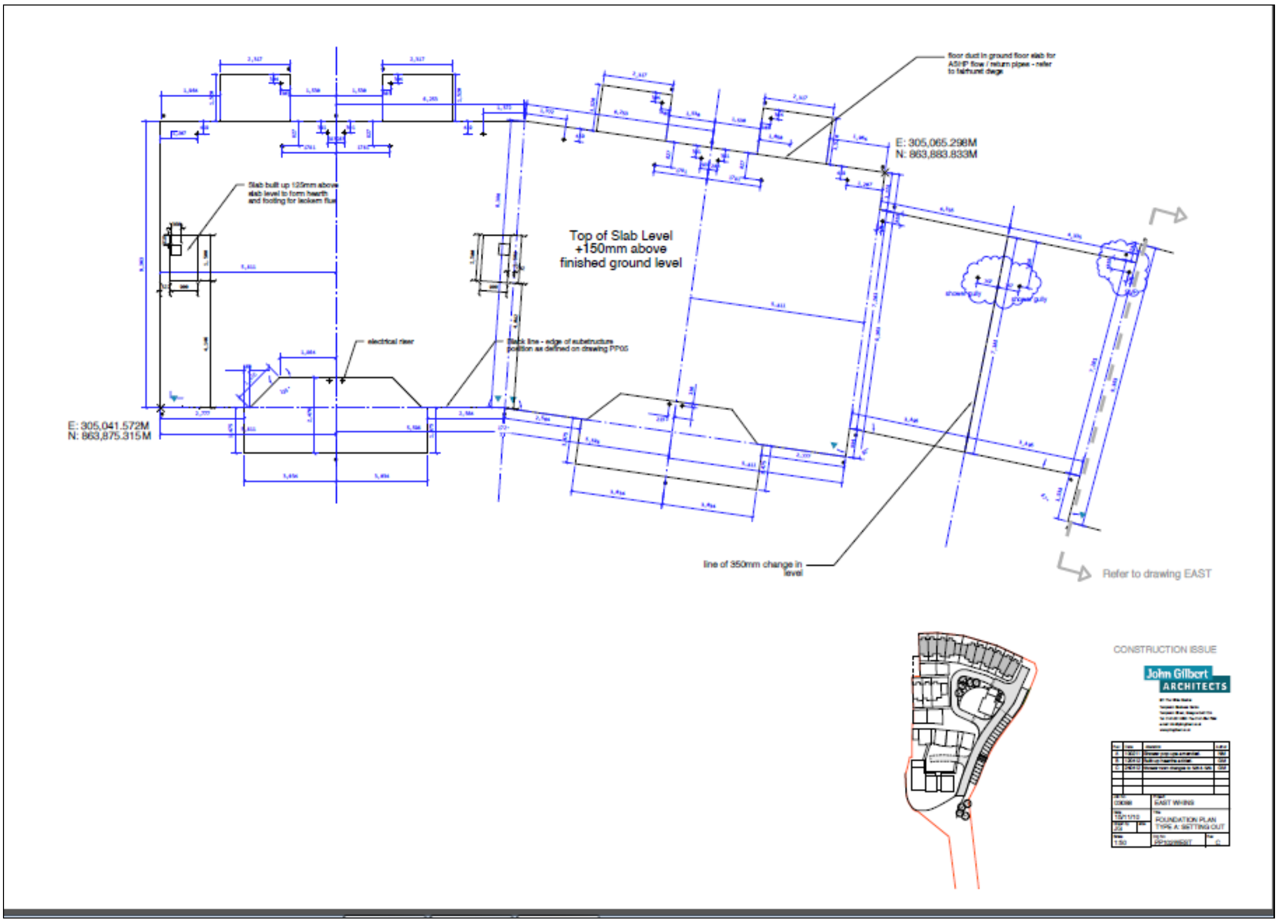
Job No: 03088 | Scale: 1:10

Date: 130111 | Drawn by: NM | Size: A4

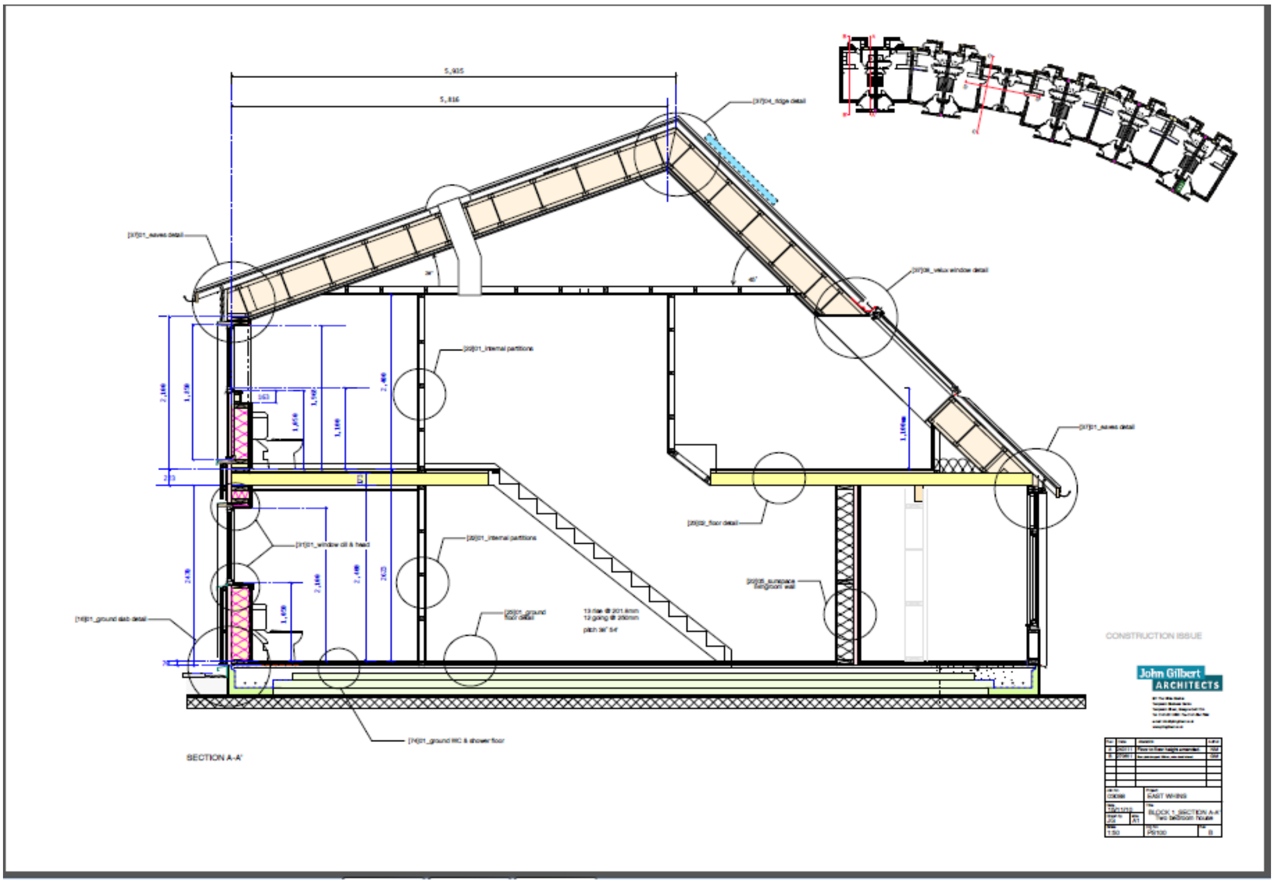
Dwg No: [37]04 | Rev: B

Rev	Alteration	Date
A	Note for air space battens amended.	190411
B	Ridge beam omitted.	060611

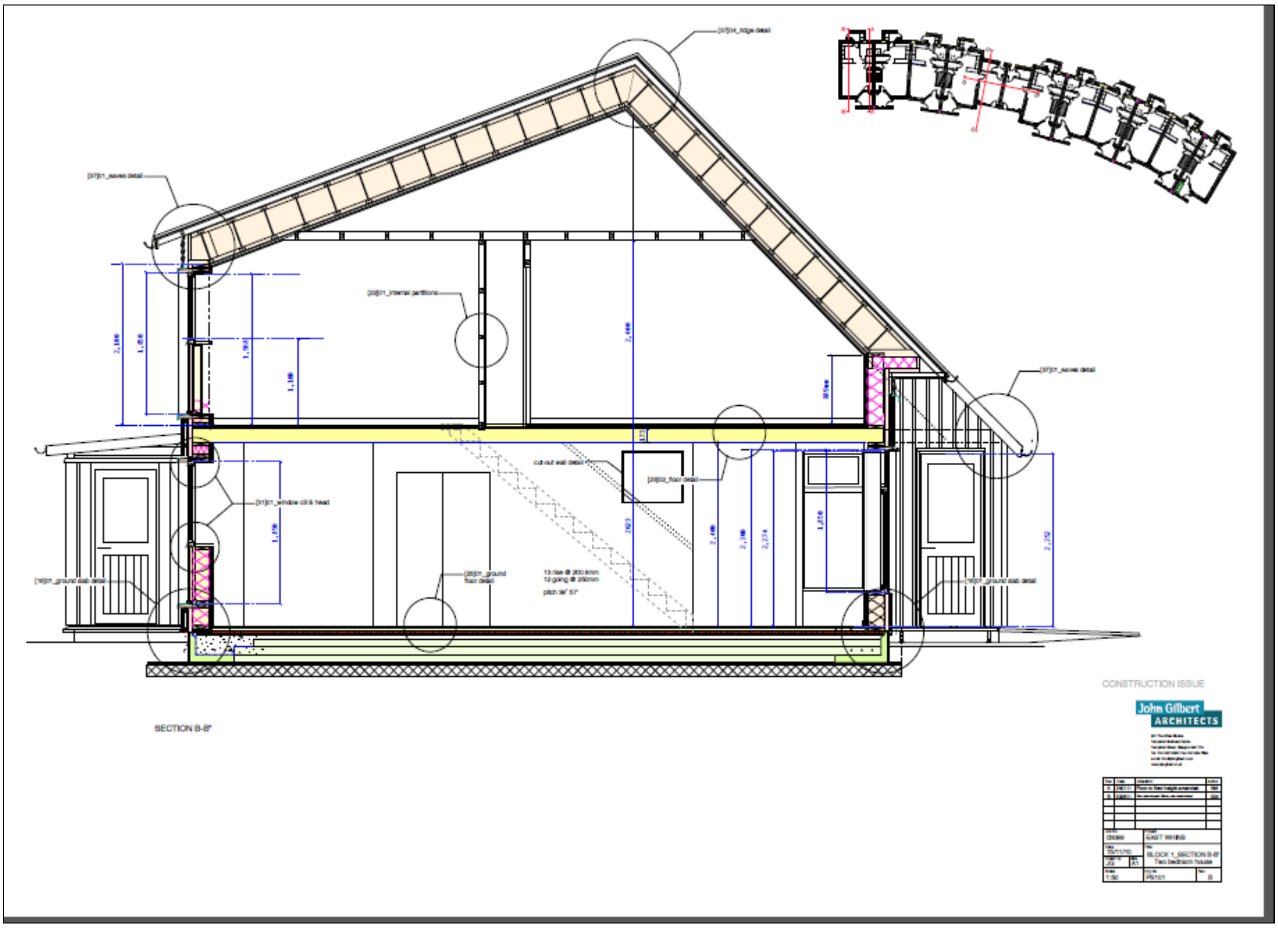

Ground Floor
1 : 50
First Floor
1 : 50

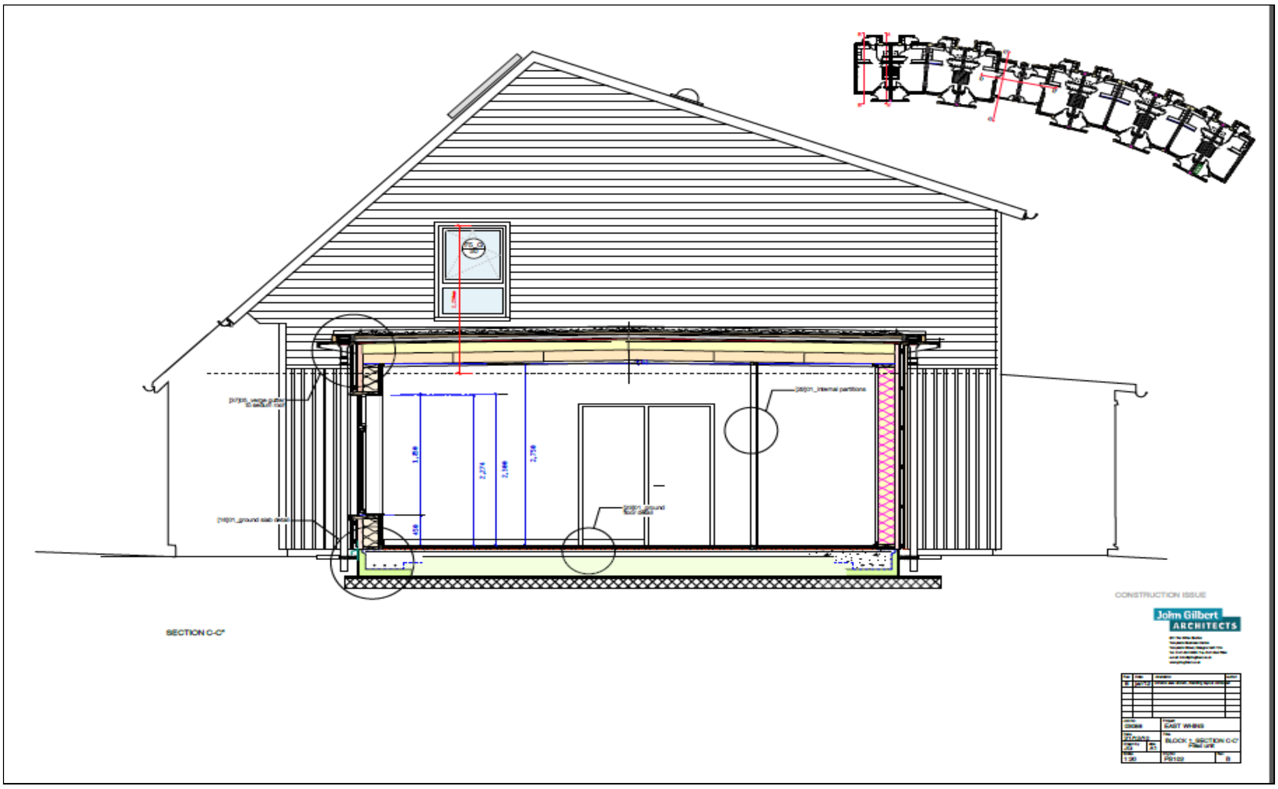


Top of Slab Level
+150mm above
finished ground level
E: 305,065.298M
N: 863,883.833M
E: 305,041.572M
N: 863,875.315M
line of 350mm change in level
Refer to drawing EAST
CONSTRUCTION ISSUE
John Gilbert
ARCHITECTS

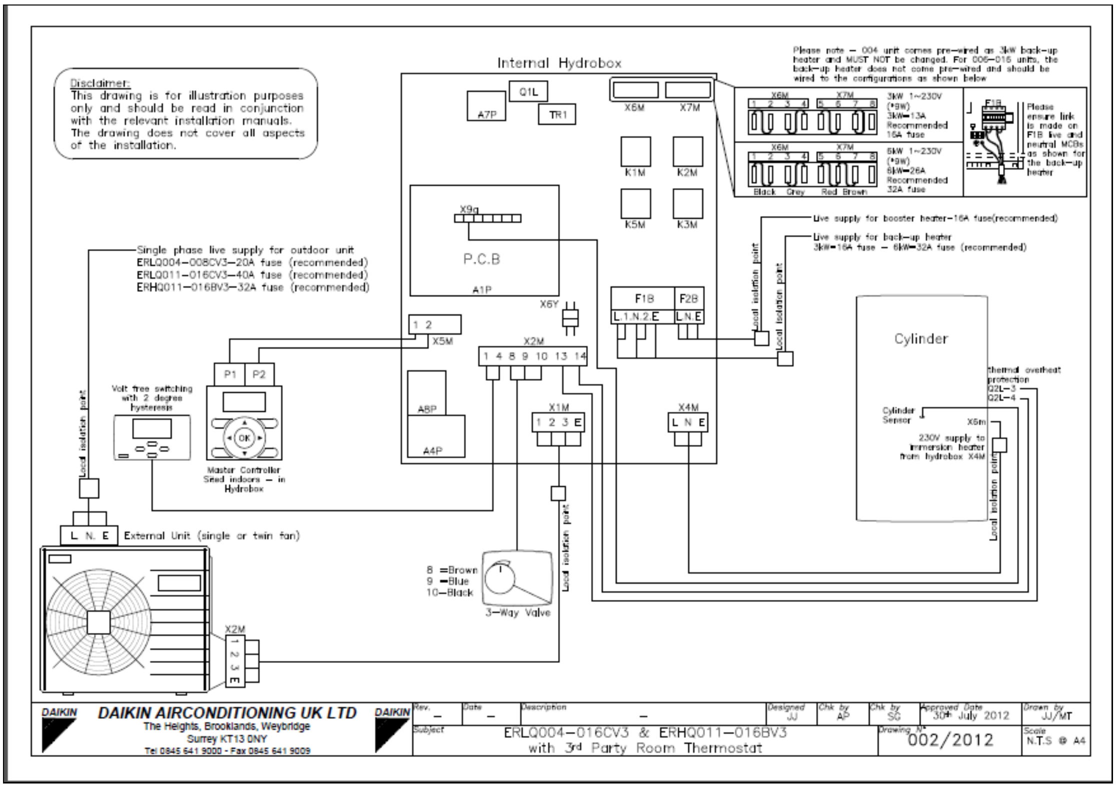


SECTION A-A'
CONSTRUCTION ISSUE
John Gilbert
ARCHITECTS

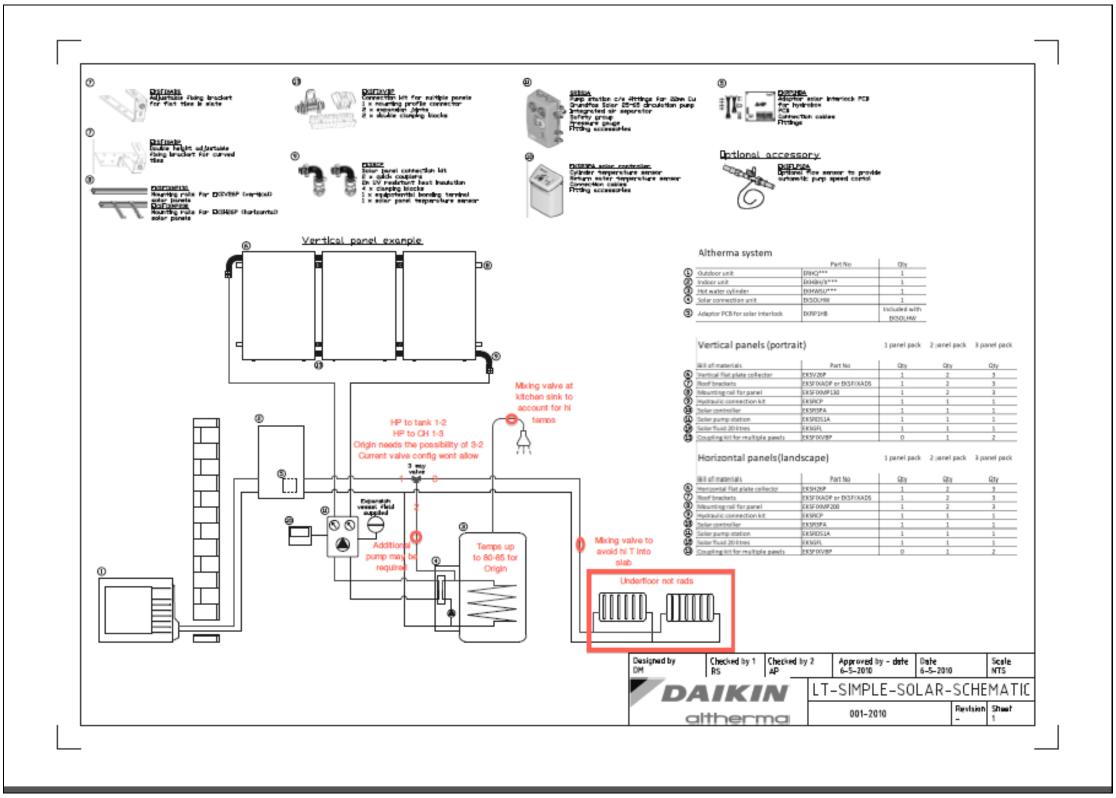

SECTION B-B'
CONSTRUCTION ISSUE
John Gilbert
ARCHITECTS
EAST WHINS


SECTION C-C'
CONSTRUCTION ISSUE
John Gilbert
ARCHITECTS
EAST WHINS

Appendix B: Services schematics



Disclaimer:
This drawing is for illustration purposes only and should be read in conjunction with the relevant installation manuals.
The drawing does not cover all aspects of the installation.
Internal Hydrobox
Single phase live supply for outdoor unit
ERLQ004-008CV3-20A fuse (recommended)
ERLQ011-016CV3-40A fuse (recommended)
ERHQ011-016BV3-32A fuse (recommended)
Live supply for booster heater-16A fuse(recommended)
Live supply for back-up heater
3kW=16A fuse - 6kW=32A fuse (recommended)
P.C.B
Cylinder
External Unit (single or twin fan)
Master Controller Sited indoors - in Hydrobox
Volt free switching with 2 degree hysteresis
8 =Brown
9 =Blue
10=Black
3-Way Valve
Local isolation point
DAIKIN AIRCONDITIONING UK LTD
The Heights, Brooklands, Weybridge
Surrey KT13 0NY
Tel 0845 641 9000 - Fax 0845 641 9009
ERLQ004-016CV3 & ERHQ011-016BV3
with 3rd Party Room Thermostat
002/2012



Vertical panel example
Optional accessory
Altherma system
Vertical panels (portrait)
Horizontal panels(landscape)
HP to tank 1-2
HP to CH 1-3
Origin needs the possibility of 3-2
Current valve config wont allow
Mixing valve at kitchen sink to account for hi temps
Temps up to 80-85 for Origin
Mixing valve to avoid hi T into slab
Underfloor not rads
DAIKIN
altherma
LT-SIMPLE-SOLAR-SCHEMATIC
001-2010

Appendix C: Technical characteristics of batteries

US 185E XC2, US 185 XC2, US 185HC XC2

DATA SHEET Deep Cycle 12 -Volt

Application: Wherever Deep Cycle 12-volt batteries are needed.

Dimensions: 15-5/8 (397)L x 7-1/16 (179)W x 14-7/8 (378)H

Type: Flooded Lead Acid (FLA) non-sealed.

Case material: Polypropylene / Heat Sealed

US 185E XC2, US 185 XC2, US 185HC XC2 - SPECIFICATIONS

BCI Group Size	Model	1-hr Rate	2-hr Rate	5-hr Rate	6-hr Rate	10-hr Rate	20-hr Rate	48-hr Rate	72-hr Rate	100-hr Rate	Voltage	Standard Terminal Type	AMP HOURS	MINUTES @ 75 AMPS	MINUTES @ 56 AMPS	MINUTES @ 25 AMPS	Length	Width	Height	wet Weight Lbs (kg)
921	US 185E XC2	107	122	144	148	163	185	196	201	206	12	Offset "S"	185	93	133	355	15-5/8 (397)	7-1/16 (179)	14-7/8 (378)	105 (47.8)
921	US 185 XC2	120	135	158	163	178	200	212	217	222	12	Offset "S"	200	106	151	398				109 (49.4)
921	US 185HC XC2	130	147	172	178	195	220	233	239	244	12	Offset "S"	220	117	167	443				120 (54.4)

TERMINAL OPTIONS:

VENT CAP OPTIONS:

CHARGING INSTRUCTIONS:

Following is the charging recommendation and charging profile using 2 stage chargers for US Battery deep cycle products.
*Equalization and float charge modes are not considered to be one of the stages in a charging profile.

1. **Bulk Charge** — Constant current @~10% of C/20 Ah in amps to 2.45+/-0.05 volts per cell (e.g. 7.35 volts +/-0.15 volts per 6 volt battery)
2. **Absorption Charge** — Constant voltage (2.45+/-0.05 vpc) to 3% of C/20 Ah in amps then hold for 2-3 hours and terminate charge. Charge termination can be by maximum time (2-4 hr) or dV/dt (4 mv/cell per hour)

- **(Optional Float Charge)** — Constant voltage 2.17 vpc (6.51 volts per 6 volt battery) for unlimited time
- **Equalization Charge** — Constant voltage (2.55+/-0.05 vpc) extended for 1-3 hours after normal charge cycle (repeat every 30 days)

Notes: Charge time from full discharge is 9-12 hours.
Absorption charge time is determined by the battery but will usually be ~3 hours at 2.45 volts per cell.
Float time is unlimited at 2.17 volts per cell.
Specific gravity at full charge is 1.270 minimum

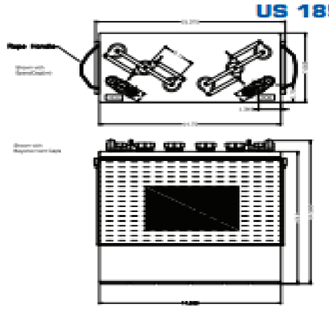
Battery temperature adjustment: reduce the voltage by 0.028 Volts per cell for every 10°F above 80°F, increase by the same amount for temperatures below 80°F.

Deep cycle batteries need to be equalized periodically. Equalizing is an extended, low current charge performed after the normal charge cycle.
This extra charge helps keep all cells in balance. Actively used batteries should be equalized once per month.
Manually timed chargers should have the charge time extended approximately 3 hours.
Automatically controlled chargers should be unplugged and reconnected after completing a charge.

For more information or questions, please visit **WWW.USBATTERY.COM**

US 185E XC2, US 185 XC2, US 185HC XC2

DATA SHEET Deep Cycle 12 -Volt



U.S. Battery Recommended Terminal Torque and Connection Hardware

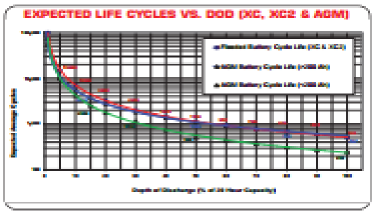
U.S. Battery Terminal Type	Recommended Torque (in-lb)	Recommended Torque (ft-lb)	Recommended Connection Hardware
UTL	95-105	7.9-8.8	SS Hexnut with Lock Washer
UT	95-105	7.9-8.8	SS Hexnut with Lock Washer
Flat Block	95-105	7.9-8.8	SS Hexnut with Lock Washer
Dual	95-105	7.9-8.8	SS Hexnut with Lock Washer
DC Marine	95-105	7.9-8.8	SS Hexnut with Lock Washer
Off-Set "S"	100-120	8.3-10	Zn or SS Bolt/Hexnut & Lock Washer
Flag	100-120	8.3-10	Zn or SS Bolt/Hexnut & Lock Washer
Large "L"	100-120	8.3-10.0	Zn or SS Bolt/Hexnut & Lock Washer
Small "L"	100-120	8.3-10.0	Zn or SS Bolt/Hexnut & Lock Washer
Bus Lug	120-180	10.0-15.0	SS Hexnut with Lock Washer
SAE	50-70	4.2-5.8	No Hardware Supplied

Proper connection is to position a lock washer between the nut and the connector (never between the connector and lead terminal) and apply the recommended torque or enough torque to completely compress the lock washer without deforming the lead terminal.

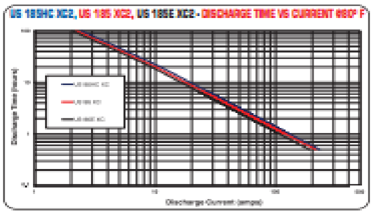
[1] Stainless Steel Hexnut with Stainless Steel Split-Ring Lock Washer (5/16" Positive & Negative)
[2] Stainless Steel Hexnut with Stainless Steel Split-Ring Lock Washer (3/8" Positive & 5/16" Negative)
[3] Square-Head, SS or Zinc-Plated Bolt with SS or Zinc-Plated Hexnut & Split-Ring Lock Washer
[4] Square-Head or Hex-Head, SS or Zinc-Plated Bolt with SS or Zinc-Plated Hexnut & Split-Ring Lock Washer
[5] Stainless Steel Hexnut with SS Split-Ring Lock Washer (1/2" Positive or 3/8" Positive & 3/8" Negative)
[6] No Hardware Supplied - Application Uses SAE Clamp for Positive & Negative Tapered Post

Note: The use of flanged nuts and other types of nuts with captive washers or other hardware not listed above is not recommended by US Battery and their use may void the battery warranty.

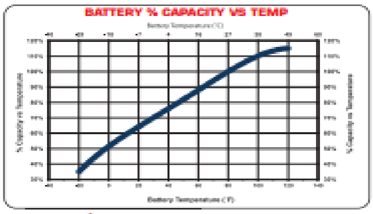
EXPECTED LIFE CYCLES VS. DOD (XC, XC2 & AGM)



US 185HC XC2, US 185 XC2, US 185E XC2 - DISCHARGE TIME VS CURRENT @80° F



BATTERY % CAPACITY VS TEMP



U.S. Battery Operating Temperature Guidelines
For charging, we recommend staying within 0°F to 120°F (-18 to 49°C) to avoid charging frozen batteries at low temperature or going into thermal runaway at high temperature.
For discharging, we recommend -20°F to 120°F (-29 to 49°C).
Batteries discharged at temperatures below 32°F (0°C) should be recharged immediately to avoid freezing.
Batteries discharged at temperatures above 120°F (49°C) should be allowed to cool before recharging.

1675 Sampson Avenue
Corona, CA 92879
(800) 695-0945

1895 Tobacco Road
Augusta, GA 30906
(800) 522-0945

717 North Belair Rd.
Evans, GA 30809
(888) 811-0945

For more information or questions, please visit **WWW.USBATTERY.COM**