Department of Mechanical and Aerospace Engineering

Project

Title

A Commission Stage Evaluation of a Prototype Net Zero Carbon Home in Scotland

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Abstract

Both the Scottish and U.K governments have set optimistic targets to reduce their CO_2 emissions by 2050, an especially important sector for this reduction is in the housing sector which accounts for over a quarter of the energy use in the U.K. To reduce the emissions in the housing sector Net Zero Carbon is being introduced and by 2016 this type of housing will be mandatory for all new builds in England, Wales and Northern Ireland and most likely Scotland too. Even though the concept of Net Zero Carbon housing has been present for a long period of time there are only a small number of examples of this concept being taken into the built environment particularly in Scotland. It is because of this that has already been a prototype Net Zero Carbon home (formally known as Resource Efficient Home) built in Ravenscraig with the aims of testing the performance of Net Zero Carbon housing in Scotland and also to evaluate the current Post Occupancy Evaluation method for housing to determine if it is suitable for Net Zero Carbon housing.

The testing was carried out during the commission stage before the house was occupied and included; thermographic imaging, blower door tests, temperature/humidity testing and testing of the renewable energy technologies installed in the house. From the results of the testing recommendations were made to increase the performance of future Net Zero Carbon housing. Also as the testing of the prototype was carried out during the commissioning stage it allowed some of the problems found in the house (such as the low air tightness) to be rectified thus increasing the energy performance of the house. This lead to the conclusion that because of the complexity and high standards needed for Net Zero Carbon housing that instead of using the current Post Occupancy Evaluation the testing method should be a Pre-Occupancy and Continuous Evaluation (POCE) so that the performance can be as high as possible

Acknowledgements

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I would also like all the BRE staff members at Ravenscraig especially, John Reid, who made it possible for me to access the prototype Net Zero Carbon home whenever I needed. As well as the members of staff from BRE I would also like to thank the staff from Zero Waste Scotland who also made this project possible.

Finally I would like to thank my family and friends for their help and advice while carrying out my project.

Table of Contents

List of Figures

List of Tables

1. Aims and Objectives

There are two main aims of this project, the first is to carry out a series of tests to monitor the performance of a recently built prototype Net Zero Carbon home in Scotland. This monitoring can be used as an aid to the design team and builders as they will be able to use the results from the testing to determine if the house is operating as intended. As the house is a prototype the design team are aware that there may be some problems but by testing it is hoped that this project may lead to better performance of future Net Zero Carbon homes.

The second aim of this project is to used improve the current housing evaluation procedures so that they are modified to take into account the complexity and high standards needed for Net Zero Carbon housing.

To achieve the aims of this project requires the accomplishment of the following objectives:

1. Review current and future policy in the U.K with regards to Net Zero Carbon housing.
2. Review the concepts of Net Zero Carbon housing and any problems which may be associated with them.
3. Review current monitoring techniques and any reasons why they have to be update for use in the future.
4. Carry out tests on the case study home to determine if it is operating as it should be.
5. Make recommendations on how the performance of the base case Net Zero Carbon home and future homes may be increased.
6. Give an indication of a monitoring method for future Net Zero Carbon housing.

2. Literature review

2.1 Energy Use in the U.K

In 2011 the housing sector in the U.K accounted for more than a quarter (26.43%) of the total energy used throughout the country (Palmer and Cooper 2012). From figure 2.1 the total use of 452TWh is the second highest energy consumption by any sector with only road transport consuming more energy.

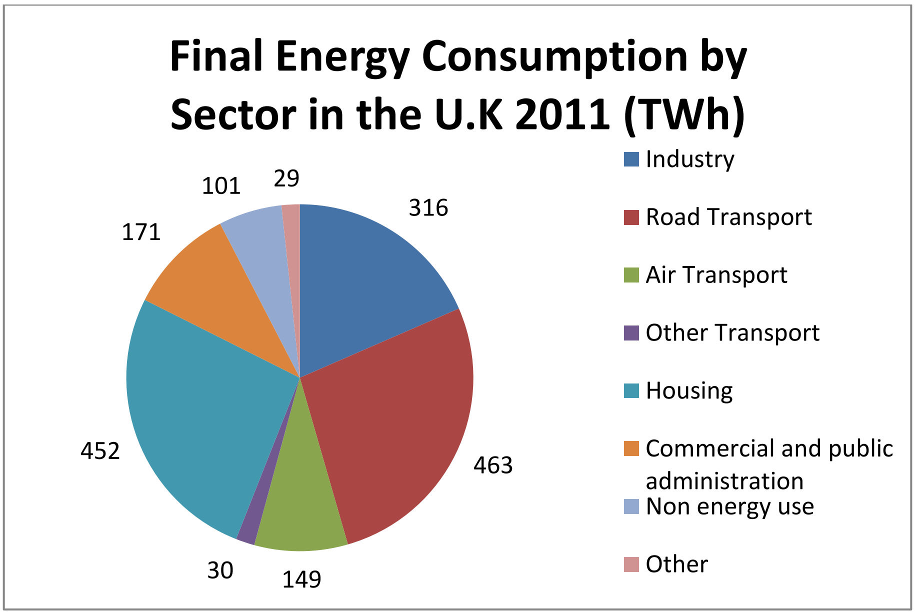

Figure 2.1 – Final Energy Consumption by Sector in the U.K 2011

As most of the energy consumed in the U.K is from traditional sources (coal, oil and gas) there are still huge CO_2 emissions and in the housing sector this accounted for around 150 million of CO_2 per year in 2011 (figure 2.2):

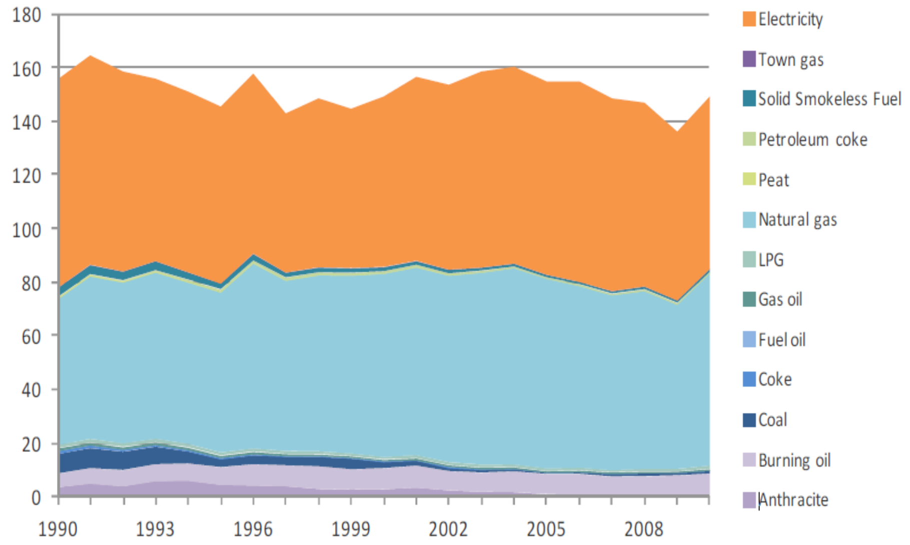

Figure 2.2 – Housing CO_2 emissions in the U.K for the last 20 years

From this figure it is seen that from 1990 – 2011 the CO_2 emissions in the U.K fell slightly even though the number of homes in the country increased by more than 3 million over the same period of time (Macrory, 2010). This reduction has been achieved by increasing building standards meaning new homes have a much less energy consumption compared to older homes. It is expected that in the U.K between 100,000 to 200,000 new homes will be constructed each year which could lead to dramatic CO_2 emission reductions not only the housing sector but from figure 2.1 the country as a whole. One method by which reduction of CO_2 emissions could be achieved would be by changing regulation and introducing the use of Net Zero Carbon housing.

2.2 Regulation

Both the U.K and Scottish governments have set targets to reduce the carbon emissions throughout the country. To fall in line with the Kyoto protocol (2008) the U.K government set a target of 20 % reduction on carbon emission (compared with 1990 levels) by 2020 and in 2008 the Climate Change Act was introduced which states that as a whole by 2050 the carbon emissions for the full of the U.K should be 80% less than 1990 levels. Even though the Scottish Government has set the same 80% target for 2050, there has been a more optimistic target set for 2020 of 42% reduction in carbon emissions compared with 1990 levels. Realistically, for these targets to be achieved there has to be changes made to the housing sector which accounts for more than a quarter of the country's energy use. In England and Wales there have been laws passed that require all new build homes to be level 6 in the code for sustainable homes by 2016. In Scotland the law currently states that all new homes must emit 70% less carbon dioxide compared with a similar building built in 1990. There is also the ambition to introduce regulation that requires all homes built in 2016/2017 to be Net Zero Carbon (Scottish Government, 2008). There have been indications that even though Net Zero Carbon housing is technically feasible throughout the UK, there are some obstacles which may hinder the likelihood of widespread Net Zero Carbon housing by 2016. Mainly these obstacles are legal issues, such as local planning permission, others are financial issues, owing to the high initial cost of construction (Osmani and O'Reilly 2009).

As well as regulations being introduced for new buildings, there have also been some regulations set out by the Governments to aid current home owners to cut their carbon emissions. The two main regulations are the Green Deal and the Feed in Tariff. These were introduced in 2010 in Parliament and passed in autumn 2012, the Green Deal allows home/business owners to upgrade their energy efficiency by the use of a loan up to the value of £10,000 which will be paid through their energy bills. This loan is against the property instead of the owner and so if the property is sold, it is the new owner's responsibility to keep up with payments.

Introduced in 2010, Feed in Tariffs are financial incentives that allow homeowners with integrated renewable technologies to be paid for each kWh of electricity generated, even if the electricity is used by the owner themselves. As most homes are located in urban areas, the majority of domestic Feed in Tariffs in the U.K are applied to PV installations, Figure 2.3 shows the relative capacity of each renewable energy system that qualified for the feed in tariff in 2012.

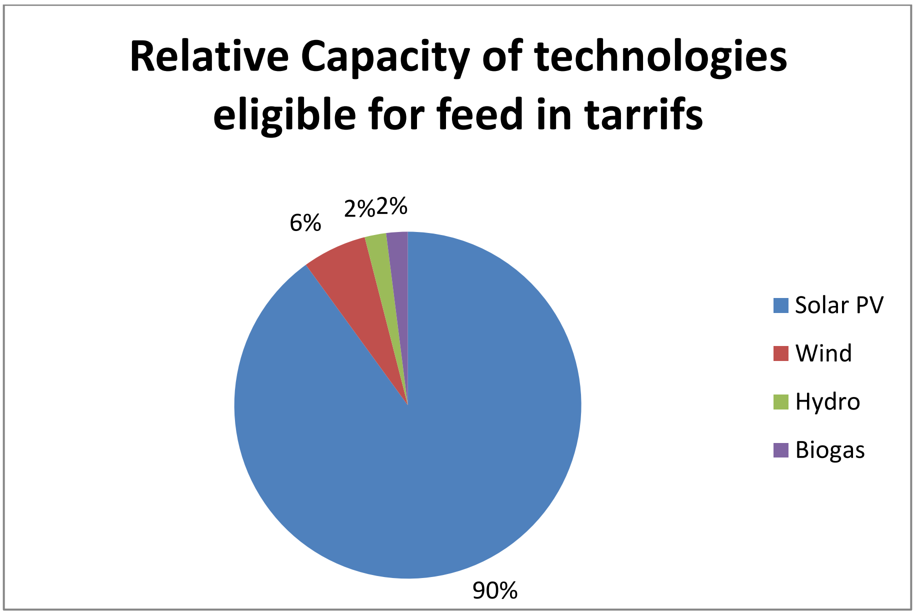

Figure 2.3 – The relative capacity of each renewable technology eligible for the feed in tariff in the U.K

The money is paid by the utility companies and the tariff per kWh is dependent on the size and type of renewable energy source used. Table 2.1 gives the feed in tariff prices for solar PV installations and Table 2.2 is the feed in tariff for other types of renewable technologies

Total Installed Capacity (kW)	Generation tariff with eligibility date 1/08/2012–31/10/2012(p/kWh)	Generation tariff with eligibility date 1/10/2012 – 30/06/201(p/kWh)	Lower Tariff if (EPC requirements not met eligibility 1/08/2012–0/06/2013(p/kWh)
< 4 (new build and retrofit)	16	15.44	7.1
> 4-10	14.5	13.99	7.1
>10-50	13.5	13.03	7.1
Stand alone	7.1	7.1	7.1

Table 2.1 – U.K Feed in Tariff prices for solar PV

Technology	Tariif band (kW capacity)	Tariffs from 1/12/2012 – 31/4/2013 (p/kWh)
Hydro	<15	21.65
	15-100	20.21
Wind	<1.5	21.65
	1.5-15	21.65
	15-100	21.65
Micro CHP	<2	12.89

Table 2.2 – U.K Feed in Tariff for Other newable technologies other an PV

One of the major flaws associated with the Feed in Tariff is that the owner of the renewable techology is paid by the utiliy company, and so other users on the network can find that they are subsidising the renewable technology as the cost of electricity to them has been increased. The work by Klien (2012) in Germany noticed this problem and indicated that the generosity of Feed-in Tariffs has to be carefully monitored and adjusted tightly in line with market developments, to avoid deadweight losses and excessive increases in electricity prices. This is seen in Table 2.1 which shows that as the market penatration of solar PV has increased, the feed in tariff price has decreased so that the cost of electricity for other users does not increase. These Feed in Tariffs can be very advantageous to Net Zero Carbon housing, as intergrated technologies are used extensively. However, by the time the Net Zero Carbon homes become the widespread it is expected that Feed in Tariffs will not be avaliable.

2.2.1 Code For Sustainable Homes

In England, Wales and Northern Ireland the Code for Sustainable Homes was introduced in 2007 as an assessment method to determine and certify the environmental performance of newly built homes. Unlike other standards throughout the world, the code for sustainable homes was set up to enhance the environment as a whole and not just to cut carbon emissions through energy efficiency/use techniques.

The assessment of the home is carried out in two stages, the first of which is the Design Stage Assessment. This is based on the final detailed design of the project which must include specifications/drawings and also instructions to the contractor and/or supplier. After this stage an interim code certificate is issued, then the second assessment stage known as the Post Construction Review is carried out. In this review it is determined if the construction of the home was carried out in accordance with the plans given in the detailed design of the project. Following this assessment stage, the final code certificate is issued. On the final certificate the home is given a rating level between 1 and 6 to determine its sustainability level, with level 1 being a very poor home with many problems and level 6 being an extremely sustainable home (such as a Net Zero Carbon home). Currently all new homes in England, Wales and Northern Ireland have to be at least level 3 and by 2016 the mandatory level will be 6. The level given to a home during assessment is determined by a credit weighted average of 9 environmental categories. Each category with their issues have been listed in Table 2.3 (BREEAM, 2010).

Category	Issue
Energy and CO2 Emissions	Dwelling emission rate (M) Fabric energy efficiency (M) Energy display devices Drying space Energy labelled white goods External lighting Low and zero carbon technologies Cycle storage Home office
Water	Indoor water use (M) External water use
Materials	Environmental impact of materials (M) Responsible sourcing of materials – basic building elements Responsible sourcing of materials – finishing elements
Surface Water Run-off	Management of surface water run-off from developments (M) Flood risk
Waste	Storage of non-recyclable waste and recyclable household Waste (M) Construction site waste management Composting
Pollution	Global warming potential (GWP) of insulates NOX emissions
Health and Well-being	Day lighting Sound insulation Private space Lifetime Homes (M)

Management	Home user guide Considerate Constructors Scheme Construction site impacts Security
Ecology	Ecological value of site Ecological enhancement Protection of ecological features Change in ecological value of site Building footprint

Table 2.3 – Categories and issues for the Code for Sustainable Homes

Some of the categories have a higher effect on the environment than others, thus they have a higher credit rating. The three highest credit weighed categories (Energy and CO_2 emission, materials, Health and Well-being) account for more than 72% of the total credits available in the assessment. In table 2.3 next to some of the issues there is an (M). This indicates that for any home wishing to be classified level 6, these issues will have to be addressed and the other issues are optional.

Similar to other standards such as the Passivhaus in Germany, there are specific building regulations (such as wall u-values and level of insulation) in the Code for Sustainable Homes which must be met. The minimum requirements for level 6 homes are listed below in Table 2.4

Building Element	Specification (to meet Code 6 HLP)
Floor U-value (W/m²K)	0.10
Roof U-value (W/m²K)	0.10
Wall U-value (W/m²K)	0.12
Window U-value (W/m²K)	0.80 (triple glazed)
Roof light U-value (W/m²K)	1.10 (triple glazed)
Door U-value (W/m²K)	0.88
Air Permeability @50PA ($m^3/[hr.m^2]$)	2 or less
Thermal bridging (y-value)	0.04
WHMV-HR heat recovery efficiency	92%
Heat Loss Parameter (HLP)	Varies between 0.60 & 0.80

Table 2.4 – Building regulations for a level 6 home (SSE,2010)

As well as specific building regulations there are also some other requirements needed for a home to be classified as level six in the codes for sustainable homes. These are listed below.

- Net Zero CO_2 Emissions
- Less than or equal to 80 litres of water used per person per day
- 80% of materials used must be sourced in an environmentally friendly way
- The run off of water is designed to happen at off peak times
- There must be 60l of space on the grounds to store recyclable waste
- Local authorities must be contacted to recycle as much material from construction as possible
- All materials used for insulation must have a global warming potential less than 5 for both in manufacturing and installation
- Kitchens must achieve a minimum *Average Daylight Factor* of at least 2%
- All living rooms, dining rooms and studies must achieve a minimum Average Daylight Factor of at least 1.5%
- 80% of the *working plane* in each kitchen, living room, dining room and study must receive direct light from the sky
- A Home user guide must be created
- The site must be of low ecological value

As the Scottish Government has not set out specific standards for housing in the future, it is assumed that it will follow a model similar to that of the Code for Sustainable homes set out in the rest of the U.K.

2.3 Net Zero Carbon Housing

A Net Zero Carbon home is a domestic building which over the period of one year will have a net zero energy consumption and net zero carbon emissions. A house is determined to be Net Zero by carrying out a series on the building's fabric as well as the on-site renewable energy systems

The work done by Sartori et al (2010) indicates that defining a Net Zero Carbon home can prove to be extremely difficult as there are many definitions and types of buildings. An example of different definitions is with regards to measuring the offset for zero net carbon emissions. Does the carbon neutral offset come from primary or secondary energy source? If the offset was from the primary energy source (coal, oil, gas etc.) then the carbon emissions would be nearly three times greater than that for the secondary source of electricity (Øvergaard, 2008) as the fossil fuel plants that generate electricity are about 30% efficient. Also primary energy/carbon calculations prove to be much more difficult than secondary energy/carbon calculations and there is one main reason for this (Marszala; Heiselberg; et al, 2011). The energy infrastructure for generating electricity is ever changing owing to the integration of renewable energy systems on to the grid and most of these sources are non-despatchable, meaning they will have to be taken full advantage of when available. Over the period of a week the sources used to generate the electricity may be ever changing due to the weather. For example, one day there may be high wind speeds on which wind farms are producing upwards of 30% of the electricity, and the other 70% is made up from conventional sources but the next day the wind speeds could drop and wind farms may only produce 10% of the need and the other 90% is conventional. Obviously the carbon emissions from the primary source would be much greater on the second day but for the energy/carbon offset calculations this difference in days is difficult to input so averages have to be used. Another problem with the calculation for primary energy is whether the carbon emissions and energy needed to transport the fuel to the plant should be included in the calculation. It is because of these difficulties in primary energy calculations that for the purpose of this project, the Net Zero Carbon and Energy offsets refer to the secondary (useable) source.

2.3.1 Principles of Net Zero Carbon Housing

There are two main principles found in Net Zero Carbon homes. These are energy efficiency and renewable energy generation.

2.3.1.1 Energy Efficiency

By using a variety of different design and construction techniques the energy use in a Net Zero Carbon home can be dramatically reduced when compared to a standard house; up to a 90% reduction in the heating need and up to a 40 % need in the electrical demand.

The most common method of reducing the heating demand in a home is by using passive solar building design which makes optimum use of the solar energy entering the home (Balcomb, 1984) which can be used as heating and/or lighting source. There are several strategies carried out in passive house solar building design (Stevanović, 2013):

- The building is orientated so that it will face the equator, in the U.K this means orientating Net Zero Carbon homes south
- The layout of the rooms and walls in the building is carefully designed so that the rooms most likely to be occupied during the day make use of the solar gains. In the U.K this typically means rooms such as the living room will be placed at the south of the building.
- Many large triple glazed windows are used facing the equator so that as much solar energy can enter the house during the day and is retained for a long period of time.
- Thermal mass is used to store solar energy gained throughout the day and release the energy as heat during the night when the temperature will have dropped. Also solar mass is used so that the solar energy gained in the equator facing part of the building can be transferred to other parts of the building.

As well as using passive solar building design when constructing Net Zero Carbon homes, the building is made as airtight as possible and there will be a high level of insulation installed. Both these techniques of high air tightness level, and insulation, are used to reduce the heat loss in the building thus reducing the heat demand of the building. This method of reducing heating demand through passive solar building design, increased air tightness and increased insulation level can lead to the problem of overheating in Net Zero Carbon homes during the summer months which is looked at in detail in section 3 of this report. To reduce the electrical demand in Net Zero Carbon homes all the appliances used are as energy efficient as possible and also all lights installed are LED.

Usually at the design stage, 3-D computer simulation packages are used to create a realistic model of the Net Zero Carbon home. Using such packages allows for different parameters (such as orientation and room layout) of the home to be changed and simulated. This allows the designer to create the most energy efficient home as possible through trial.

2.3.1.2 Renewable Energy Generation

As well as making the home as energy efficient as possible Net Zero Carbon homes usually have some capacity for on-site renewable generation, known as micro generation. There are several technologies which can be used for energy generation on site such as PV or micro-wind for electricity, biomass boiler for heat and solar thermal for water heating. Biomass CHP can also be used for cogeneration of heat and electricity but this is more suitable for larger buildings. Instead of using one technology in isolation there are usually different technologies integrated into the home and they are connected in a system known as a Hybrid System. An illustration of a wind-PV hybrid system is demonstrated in Figure 2.4.

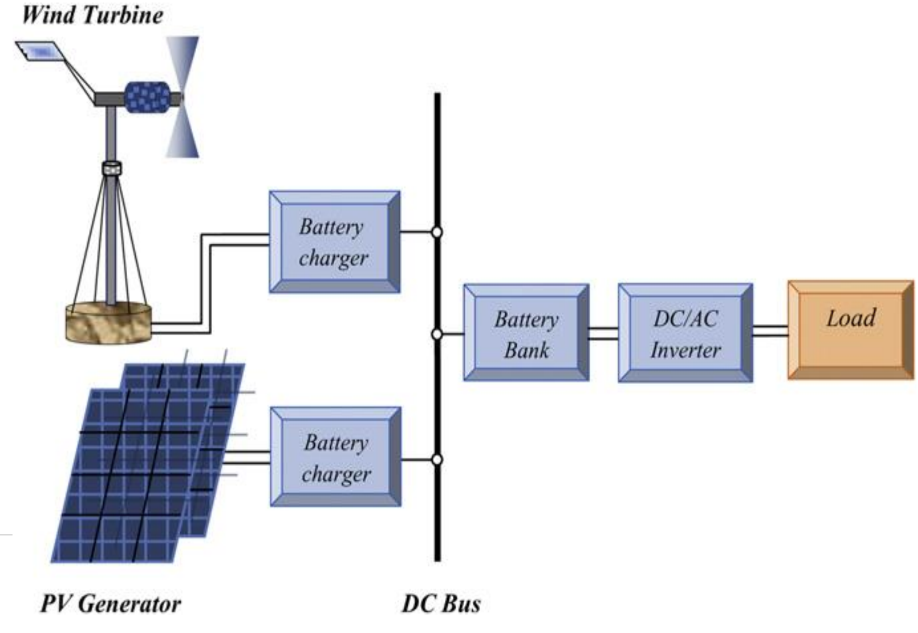

Figure 2.4 – Block diagram of a wind-PV hybrid system (Kaabeche et al, 2011)

For most Net Zero Carbon homes their location determines what type of hybrid system can be installed with the most common system being a PV/ solar thermal/ biomass boiler system (S. Antvorskov, 2008). The reason for this is that most Net Zero Carbon homes are located in urbanised area were space is limited, thus PV and solar thermal become the best options as they can be fitted on the roof of the building and do not need much space. On the other hand the use of micro-wind in urban areas can prove to be difficult. They not only take up space, but also due to the turbulence and the wind shadow effect in urban areas their yearly output can be reduced by up to 50% making them very inefficient (Bahaj et al. 2007). If two or more homes are connected in a Net Zero Carbon community then there can be other options of on-site renewables to use such as a Biomass District heating system.

2.3.2 Different types of Net Zero Carbon housing

There are three main types of Net Zero Carbon housing that are in operation today. All three of the types use the same principle of energy efficiency but it is on site renewable energy system which determines their classification, the three are:

- Autonomous Net Zero Carbon Home - The house is not connected to the grid and all energy demand has to be met from on-site generation meaning that there is a large amount of on-site renewable technologies and battery storage needed.
- Grid Connected Net Zero Carbon Home - Has on-site generation but is connected to the grid as a back-up. This can interact with the grid so when there is a surplus of on-site energy it can exported to the grid but also when needed energy can be imported. For this to be Net Zero Carbon the amount of energy exported has to be equal or greater than that imported so there is usually a large amount of on-site renewable technologies.
- Grid Reliable Net Zero Carbon Home – The house is connected to the grid and relies on it for most of the energy needs. However they have made an agreement to only be

supplied with energy from renewable technologies. In these homes there is usually a very small amount of on-site renewable present.

Autonomous Net Zero Carbon homes are by far the hardest to construct, especially in cooler climates, as the on-site renewable hybrid system has to meet the energy demand of the home at all times or there will be no energy available at all. To do this requires a lot of battery storage which currently is an expensive and inefficient technique. Grid reliable Net Zero Carbon homes are less expensive to construct than the others, but their reliability on the grid hinders their future potential as if they were built in mass, the grid would not have enough of a renewable energy supply to meet the demand. It is because these reasons that Grid Connected Net Zero Carbon homes are seen as the future of homes and are the focus of this project.

2.3.3 Advantages/Disadvantages of Net Zero Carbon homes

Net Zero Carbon homes have advantages and disadvantages to their owner when compared to traditional housing. The main advantage to the owner is that they have a significantly reduced running cost because the energy efficiency measures reduce demand (Logue 2013). Also, over time, as the cost of energy is set to rise, owners of Net Zero Carbon homes will not see as steady a rise in energy bills compared to owners of traditional housing. Another important fact for the owner of a Net Zero Carbon home is that they significantly reduce their personal carbon footprint.

Even though the owner of a Net Zero Carbon home will save money on energy bills each year, the initial cost of purchasing a Net Zero Carbon home is higher than for a traditional home of similar size. Another disadvantage of current Net Zero Carbon housing is that it is a relatively new idea and there are very few experts on the area currently, which can lead to poorly designed and constructed homes. The final disadvantage for current Net Zero Carbon home owners is that there is constant research and development being carried out on small scale renewable technologies, especially PV, which is leading to more efficient methods of on-site energy generation at reduced cost, making the current installed technologies out of date.

2.3.4 Case Stud of Previously Built Grid Connected Net Zero Carbon Homes

One of the first Net Zero Carbon projects in the U.K was the Beddington Zero Energy Development (BedZED) set up in Hackney, London in 2002. This was a project of 82 Grid Connected Net Zero Carbon homes which was developed to demonstrate how people can live sustainably in the future. The main aims of the project were:

- Reduce water consumption compared to the UK average by 33%.
- Reduce electricity consumption compared to the UK average by 33%.
- Reducing space heating needs compared to the UK average by 90%.
- Reduce private fossil fuel car mileage to 50% of UK average.
- Eliminate carbon emissions due to energy consumption.

To achieve these goals the homes followed the two main principles of Net Zero Carbon homes demonstrated in section 2.3.1; energy efficiency and on-site renewable energy generation. To reduce the energy demand, the homes had very high levels of air-tightness and insulation, also all the appliances in the homes were low energy. A unique point about these homes was that energy meters were on show in the house as it was hoped that doing this would change the occupant’s behaviour and thus reduce energy demand. As for the on-site renewable generation, there were two systems integrated into the community. The main renewable system for the community was a wood fuelled CHP which tested outputs were 120kW of electricity and 250kW of heat. The second system was that each home was fitted with PV panels for a total community capacity of 108kW. As with most Net Zero Carbon homes the BedZed community was connected to the grid as a back-up and also each individual home had electric heaters in case the heating from the CHP plant was not sufficient.

In 2007, 5 years after being developed the performance of the 82 homes in the community was monitored. From this monitoring there was found to be several problems which were highlighted within the community. The major problem for the community was with the wood fuelled CHP plant. At the time of monitoring the CHP plant was no longer in operation and even when it was operational, the plant was only ever able to produce a maximum of 80kw of heat (66% of the quoted value under test conditions). There were several technical reasons which caused the wood chip CHP to fail to reach maximum capacity and ultimately cease operation, which include:

- The technology was new and had never been tested in “real” conditions before.
- S0ome of the equipment was designed to run constantly to be reliably but this did not happen when integrated into the community.
- There was a build-up of tar at night from cooled wood chip which caused major damage to the plant.
- The operation cost of the plant was unsustainable as it was far greater than the cost of a conventional heating system.

As for the photovoltaic system installed, it was able to contribute 20% of the electricity need for the community but due to the failing CHP plant, the community relied heavily on the grid for electricity for both appliances and electric heating (Hodge and Haltrecht, 2007). Another problem found within the community was that the homes were prone to overheating in the summer months. When surveyed it was found that more than 55% of people living in the homes felt that they were too warm in the summer.

As well as finding the problems in the homes the monitoring was also able to determine if the community met the aims set out at the start. The findings are listed below:

- 25% reduction of electrical demand compared with other U.K homes built in 2002.
- 80% reduction in space heating demand compared with other U.K homes built in 2002.
- 64% reduction on private fossil fuel car mileage compared with U.K average.
- 40% reduction of water consumption compared to U.K average.

The carbon emission reduction could not be accurately determined as the CHP was not in operation. From the results it is evident that the only aim the community met was the reduction in private car miles, thus the community cannot be classified as a successful Net Zero Carbon housing project. However, there were some positives as the electrical demand; heating demand and water consumption were reduced dramatically which can help the designers of current Net Zero Carbon homes.

2.4 Current Energy Monitoring Procedure for Homes

Currently, the most common procedure for monitoring the energy performance of a home is a Post Occupancy Evaluation (POE). The definition of a POE is a performance evaluation of a building or buildings in use (MacLennan, 1991). Initially these POEs were carried out in the 1960s to determine if a building was fit for purpose but overtime, as reducing CO_2 emissions has become of more importance, POE's have been increasing used to determine the energy performance of buildings (Zimmerman and Martin, 2001). While conducting a POE the energy performance is determined by carrying out a series of test to determine the electrical and gas consumption of the building. Also during the POE the occupants are interviewed, with the results being used to determine if they are using the building as indented or if there is extra activity which is increasing the overall energy use. The results obtained from the POE can be as used a "design" aid; "management" aid and "benchmarking" aid for sustainable development (Cooper, 2001). As a "design" aid the results are used to aid in the design of future buildings of similar style to increase their energy performance. When used as "management" aid the results are used to determine if any changes can be made to the building structure or to the occupant's behaviour to increase energy performance. Finally when used as a "benchmarking" aid, the results are used for measuring progress in the transition towards sustainable production and consumption of the built environment.

2.5 Need for New Testing Technique for Net Zero Carbon homes

Even though POEs have been around for decades, there are some problems associated with them which may make them obsolete for future when Net Zero Homes become mandatory, these flaws are listed below:

- Being post occupancy – This can cause many problems when dealing with Net Zero Carbon homes due to their high standards. It is unlikely that the high standards will be met first time when the building is erected and if the flaws were found after the home was occupied it would be difficult, time consuming and costly to fix them. This was found in the BedZED community, where the CHP plant was found to have problems which could not be fixed as it was too expensive because the system had already been connected to furbished homes.
- There is no testing of the buildings fabric – As previously demonstrated a Net Zero Carbon home has very high standards with regards to air tightness and thermal losses but in a traditional POE these are not tested.
- They mostly deal with energy consumption – With the increased building standards for Net Zero Carbon homes there is the potential for some problems to arise in the thermal comfort (such as overheating) but this is not tested in a traditional POE.
- Renewable energy systems are not taking into account – One of the major principles of Net Zero Carbon homes is renewable energy generation but in traditional POEs these systems are not taking into account.

As demonstrated there are many flaws that can be associated when applying a POE to a Net Zero Carbon home and it is because of this that a new testing technique is needed, especially as the Net Zero Carbon housing stock will rise dramatically. The testing carried out in this report on a prototype Net Zero Caron home will a Pre-Occupancy and Continuous Evaluation (POCE). This POCE will be mainly experimental and the testing carried out will be for specific issues which can be problematic for Net Zero Carbon housing including: overheating, thermal losses, air leakiness and under/oversized renewable energy systems. By carrying out this POCE it is desired that the technique will be seen as more advantageous than a POE and can be used in the future when Net Zero Carbon housing is mandatory

2.6 Prototype Net Carbon home

The prototype Net Zero Carbon house itself is a joint venture by Zero Waste Scotland and BRE. The house is part of the BRE innovations park in Ravenscraig, Motherwell which is located 16 miles South East of Glasgow city centre shown in Figure 2.5.

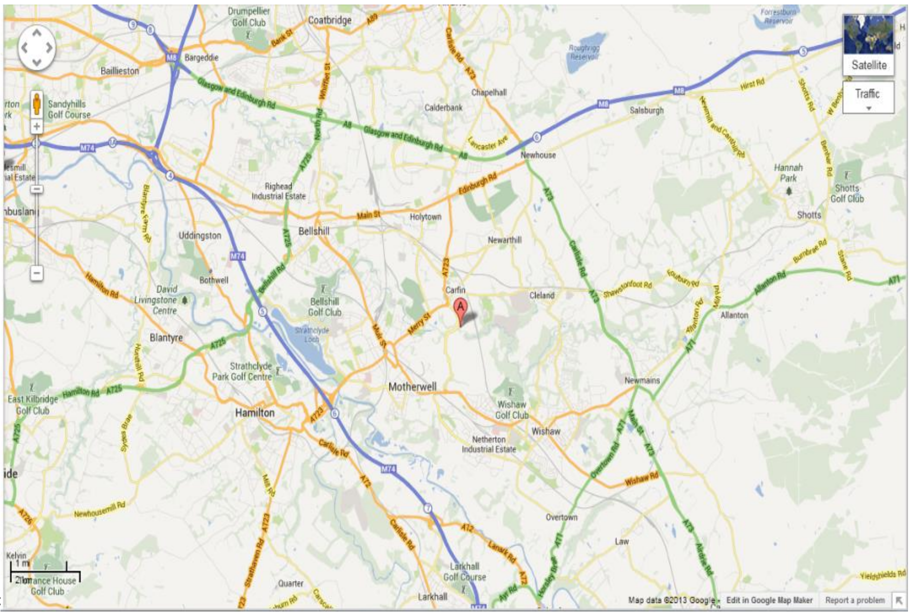

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Figure 2.5 – Location of protoype Net Zero cabon House (Google maps)

BRE started work on the Ravenscraig innovation park in 2012 with the aim of trialling and testing new ideas from architects, developers and manufacturers before they were applied to real communities. The park at Ravenscraig is the second of its kind set up by BRE in the U.K, with the first being a successful project in Watford which started in 2005 (BRE,2013). At Ravnescraig there are a total of ten plots and a visitor centre with nine plots already being allocated for a specific house type. Currently only the Net Zero Carbon and Volumetric houses have been constructed with the refurbished house underway. Once all the houses have been constructed they will have unqiue properties and objecives to each other but will all two confine to 2016 Scottish building standards similar to that for a level six home in the code for sustainable homes (table 2.4).

The Net Zero Carbon house is a two story detached house with two bedrooms, two bathrooms, a living room with open plan kitchen, office space and a small outside drying area up stairs. Figures 2.6 and 2.7 show some images of the house, the full plans of the house are only avaliable in cad format.

Figure 2.6 – Picture of the upstairs of the protype house

Figure 2.7 –Picture of the downstairs of the prototype house

As the house is Net Zero Carbon there are several renewable technologies intergraded into the building. On the south facing roof there are 9 flat PV panels which can produce a maximum of 2100W of electricity. The DC to AC converting equipment used for the PV panels is located in the cupboard of the master bedroom. Also, the house uses a 2.3kW biomass boiler located in the cupboard adjacent to the living room. As back up the house is connected to the grid and each of the bedrooms has an electric heater in them. Like all Net Zero Carbon houses, the prototype house has many large windows especially on the south facing wall and in the living area which are used to make use of as much solar gains as possible. The equipment in the home includes a cooker, hob, dishwasher, washing machine, chest fridge, chest freezer and two 39’’ LED televisions all of which are at least A rated. For lighting there are a total of 22 LED light bulbs used all of which were rated at 14W.

One of the main attractions of the ptrotoype Net Zero Carbon house is that it has been developed as a life cycle Net Zero Carbon house (it is known formally as the resource efficient house). Therefore even at the design stage there was great care taken to cut the carbon emission from the construction of the house. Instead of being constructed on site, the house was constructed at the manufacture’s warehouse in four separate pods then transported and assembled onsite. This step was taken as construction on site can lead to a lot of waste material being made; also as much waste as possible was recycled during assembly. The protoype house also makes as much use from recycled material as possible. Some of the glass material is made from recycling and even the grass used for outside used to be part of one of Glasgow’s professional football teams park.

3 Indoor Thermal Comfort/Overheating

Thermal comfort as defined by Nicol and Humphreys (2002) is the thermal state of the human body in terms of the thermal environment, which determines if a person feels too hot or too cold. It is not simply a measurement of air temperature, but is dependent on other factors such as humidity, air velocity, personal clothing and activity. Over the years there have been many standards set out my by national governments to try and regulate the indoor thermal comfort levels with one such example being the BS EN 15251-2007. This is a British standard developed in 2007 to given standards on the thermal conform in mechanically ventilated building, which Net Zero Carbon houses are. However most regulating documentations deal with thermal comfort levels in public places such as offices and schools, as in the home thermal comfort can be seen as a subjective matter. The work done by Parry and Irvine (1980) demonstrated that the ideal indoor air temperature was 22^0C and they found that in if the homes went above 24^oC or below 20^oC then the occupant would begin to feel discomfort.

As with the temperature there is a wealth of information on the humidity levels allowed for a satisfactory indoor thermal comfort. Wolkoff and Kjaergaard (2007) determined that for any building the relative humidity levels should be between 30-60% as levels out of this range can prove to be uncomfortable for the occupants.

With the building standards set to increase there is a real possibility that the indoor thermal comfort of the occupants will deteriorate. The increased high levels of air tightness and the amount of insulation needed in new buildings will mean that much less heat will be able to escape compared to older buildings. Obviously this is an ideal situation for the cooler seasons of the years (autumn, winter, spring) when some level of heating is needed, however in the summer months this heat retention may be a problem. Most energy efficient homes are designed in such a way that they make optimum use of passive solar gains. In the summer months the gains may be so large that without the correct ventilation and design a home may be subject to too much heat retention which consequently deteriorating the thermal comfort inside. This idea of summer overheating due to increased insulation and airtightness has already been seen in some passive houses (which have higher standards than the 2016 Net Zero Carbon buildings) throughout the world (Chiras, 2002)

As part of this project two different techniques are used to determine the thermal comfort of the protoype Net Zero Carbon house which are described in the sections below.

3.1. Determining Heat Variation throughout the Home

To determine if the prototype house was susceptible to overheating and determine how heat travelled throughout the house, the temperature and humidity of each room in the house, as well as outside which would give a comparison, were taken.

The measurements were done using the Bruel and Kjaer indoor climate analyser 1213 shown in Figure 3.1 below.

Figure 3.1 - Bruel and Kjaer indoor climate analyser 1213

This equipment can be used to measure a variety of different indoor climate parameters (such as air temperature, humidity, drew point temperature, etc) relatively quickly and several at the same time. To measure a parameter the user connects one of the five transducers (Figure 3.2) into the corresponding portal at the back of the machine. Once the transducer has been connected, the user then uses the buttons on the front of the machine to display the desired parameter on the screen. It should be noted that the user has the option of the instant value or the average over a period of time (1h, 6h or 24h). For this project the instant value was used.

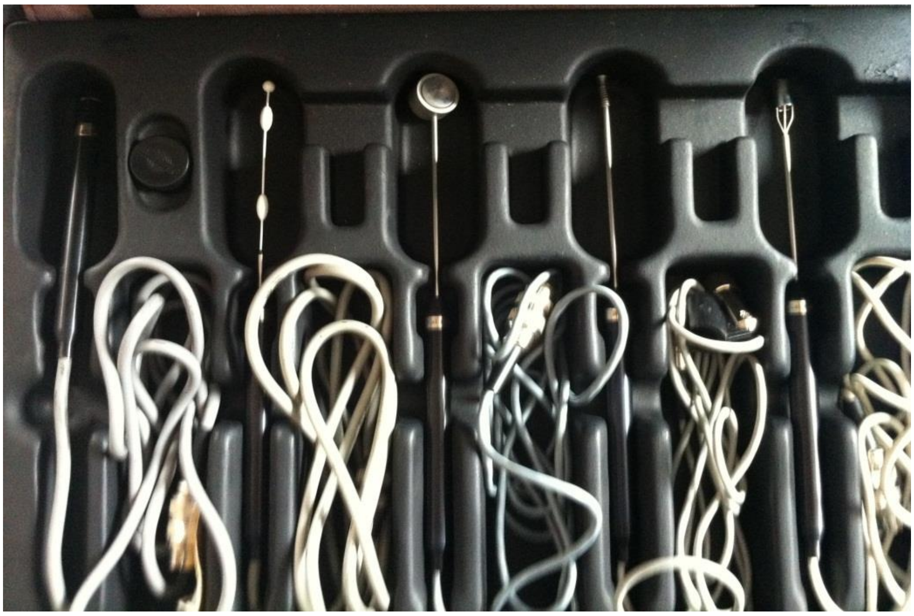


Figure 3.2 – The five transducers used for the indoor climate analysis. From Left to right: air temperature, surface temperature, air velocity, humidity, radiation

For validation reasons it was felt that the tests had to be carried out on more than one occasion. If the tests were only carried out on one day an accurate picture could not be built up as the day may have been unusually warm or cold for the summer. The tests were carried out between the 6th and 19th of June when the outside temperatures ranged from 16.7-22.7 ^{0}C which is similar to the average daily temperature for the summer in the surrounding area of between 18.1^{0}C and 19.7^{0}C (Met Office, 2013). All the tests were carried out between the hours of 11am and 4pm as this is viewed as peak sun hours when building temperatures will be their highest (Akbaria et al, 2005). Not only were the test carried on different days but also the tests were carried out while the house was under different conditions. These different scenarios are indicated in the section 3.1.2 of this report.

3.1.2 Test Results

On the 6th of June 2013 there were some workers in the house which meant including myself, there were five people in total in the house. On this day three different tests were run.

Scenario 1 was set up so that all the internal doors in the house were open and the room windows were left open. In Scenario 2 all the doors and windows in the house were shut and for the final scenario all the internal doors of the house were left open, windows were shut but during this trial the external front door of the house was open and shut several times as the workers were packing equipment into the van. The results from trials 1, 2 and 3 are shown in Table 3.1. The weather on this day was sunny but also overcast for long periods of time.

	Scenario 1		Scenario 2		Scenario 3	
	Temperature (Degrees)	Relative Humidity (%)	Temperature (Degrees)	Relative Humidity (%)	Temperature (Degrees)	Relative Humidity (%)
Outside	19.4	42	18.9	47	20	43
Living Room	21.2	44	21.6	62	21.6	41
Kitchen	21.5	60	21.5	64	20.6	44
Bedroom 1	22.1	54	22.6	58	21.7	46
Bedroom 2	21.7	55	22.2	57	21.5	44
Dining Room	21.7	52	21.8	61	21.1	44
Office Space	21.9	59	21.9	58	21	42
Bathroom 1	22	54	22.6	55	21.1	45
Bathroom 2	21.2	63	21.3	65	20.6	43

Table 3.1 – Temperature and humidity test results 6/6/2013

On the 19th of June another three trials were conducted on the house. This time the house was unoccupied. The first two scenarios are the same as scenarios 1 and 2 on the 6th of June.

Scenario 4 mirrors Scenario 1 and Scenario 5 is the same as Scenario 2. The difference is with Scenario 6. In this scenario all the internal doors and windows were shut but the patio door on the second floor beside the stairway and office space was left open. Again the results are shown below in table 3.2. On this day it was sunny with a relatively clear sky and only some cloud cover.

	Scenario 1		Scenario 2		Scenario 3	
	Temperature (Degrees)	Humidity (%)	Temperature (Degrees)	Humidity (%)	Temperature (Degrees)	Humidity (%)
Outside	18	54	16.5	56	20.7	41
Living Room	21.2	42	21.7	43	22	37
Kitchen	21.4	43	21.4	43	22.2	43
Bedroom 1	22.4	42	22.2	42	23	40
Bedroom 2	22	42	21.9	43	22.5	42
Dining Room	22	42	22.2	42	21.4	42
Office Space	21.7	43	21.8	44	22.7	42
Bathroom 1	21.4	46	21.2	45	22.2	43
Bathroom 2	20.9	44	21.5	45	21.1	43

Table 3.2– Temperature and humidity test results 19/6/2013

Between the 6th and 19th of June there were some other testing days however these are similar to the 19th as the temperatures were similar and the house was unoccupied, thus these have been left out of the report. Also, some tests were run on the solar radiation levels and air velocity in each room but again they do not give any value to this report so they were left out as the measured used for thermal comfort at this time were temperature and humidity.

3.1.3 *Discussion from manual testing*

Both Table 3.1 and 3.2 indicated that the house has been designed and built in such a way that overheating and poor indoor thermal comfort should not be a problem for the average summer days in the area. The highest temperature in the house at any given time was 23^0C and seen only once. Also almost always during the test the humidity in every room was within the comfortable range of between 30% - 60%.

From the tables, it is evident that the upstairs of the house (where both of the bedrooms, the upstairs bathrooms and office space are located) is warmer than the downstairs area with the master bedroom being the warmest room in the house. The reason behind this is relatively straightforward; over time, heat rises and with there being a lot of insulation on the roof of the building the heat will be "trapped" at the top floor of the house thus making the area slightly warmer than other parts of the house. Also, in the building design the master bedroom's window is directly facing south towards the sun during the afternoon, the time at which these tests were run. This means that the master bedroom has many solar gains and because it is a relatively small and highly insulated room, the heat will be retained for long periods of time. One advantage of designing the house in such a way is that the master bedroom is less likely to be used during the day compared with other rooms in the house such as the living room or kitchen so overheating is not as much a problem as it could be.

Comparing the data from both tables it is evident that on the first day of testing the relative humidity in the home is affected by human activity. On the first day of testing when the workers were present the humidity in some rooms of the home was in excess of 60% at times, whereas on the second day when there was no activity in the house the humidity was in the comfortable 40% range.

One final consideration to note from tables 3.1 and.3.2 is that even if the external doors are open, the thermal comfort of the house does not deteriorate. In Scenario 3 the front door of the house was opened many times and from table 3.1 it is seen that in most rooms of the house the temperature drops slightly but the drop is not significant as the temperature throughout the house is still in the comfortable range of between 20 and 24^0C. Also when the external door was opened in this test scenario, the relative humidity dropped to the 40%

region which is much more comfortable for the occupant than the two previous scenarios were the relative humidity was in excess of 60% in some rooms. In table 3.2 the effects of opening the patio door are slightly skewed and difficult to compare as the outside temperature in Scenario 6 was significantly greater than that for Scenarios 5 and 6. However the results show that the temperature and relative humidity of each room in the house were in the comfortable range.

3.2 Determining Thermal Comfort Using Software

As well as carrying out manual testing, the thermal comfort of the Net Zero Carbon house was also tested using the Eco-wand meter. Ecowand is a recently developed technology which can determine the thermal comfort of the user by the use of a monitor and specially designed software.

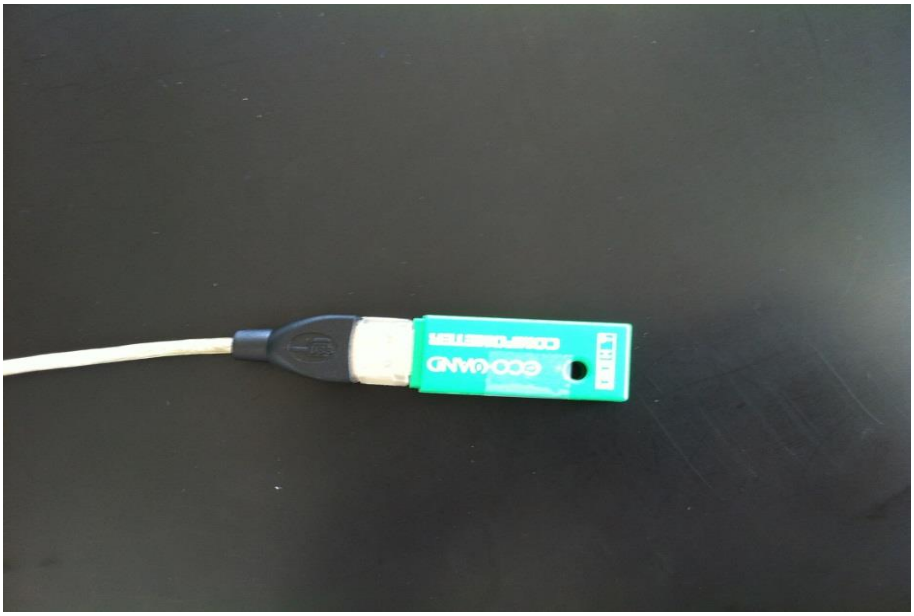


Figure 3.3 – The Ecowand USB monitor

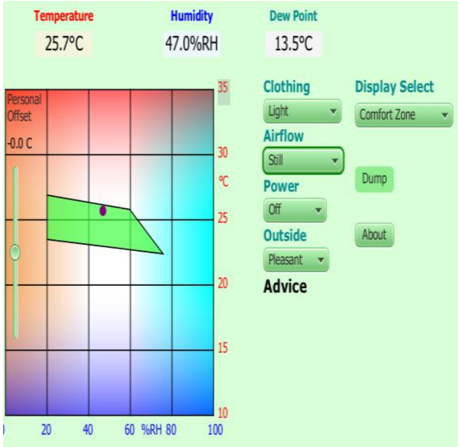
The monitor in Figure 3.3, which is used to measure the temperature and humidity of the surroundings, is plugged into the USB point of any computer and the data from the monitor is fed into the corresponding software installed on the computer. Unlike the manual testing, the Ecowand software also takes into account the airflow of the building (for example slight breeze) and the amount of clothing wore (i.e. light) which is input manually into the software by the user. Once these four parameters have been defined, the user will be given a graphic representation of their thermal comfort on screen and if it is out of the comfortable range suggestions are made on how to increase the comfort. An advantage of this software is that it gives the specific thermal comfort for the user instead of a generic thermal comfort which can be hard to define.

3.2.1 Results

As with the manual testing, this Ecowand technology was set up in the house on several different occasions and was used by a variety of people. The reason different people used the software was that the clothing of each individual differs thus the thermal comfort will vary. When using the software, several different areas of the home were tested but for the purpose of this report all results are from the results taken from the living area.

Test 1: 19/07/13

The weather on this day was sunny and the outside temperature while testing varied between 20 – 23^{o}C. On this day there was some cloud cover



Temperature 25.7°C

Humidity 47.0%RH

Dew Point 13.5°C

Personal Offset -0.0 C

Clothing Light

Airflow Still

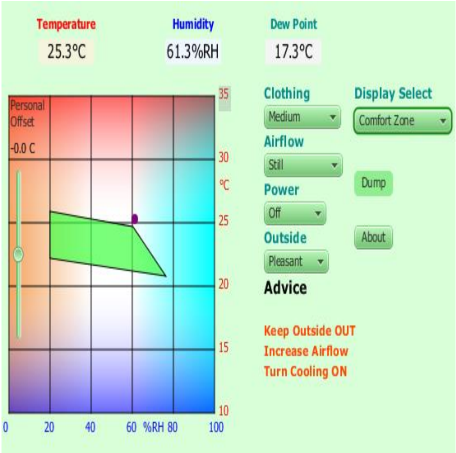
Power Off

Outside Pleasant

Display Select Comfort Zone

Advice

Figure 3.4 – Thermal comfort user 1 test 1



Temperature 25.3°C

Humidity 61.3%RH

Dew Point 17.3°C

Personal Offset -0.0 C

Clothing Medium

Airflow Still

Power Off

Outside Pleasant

Display Select Comfort Zone

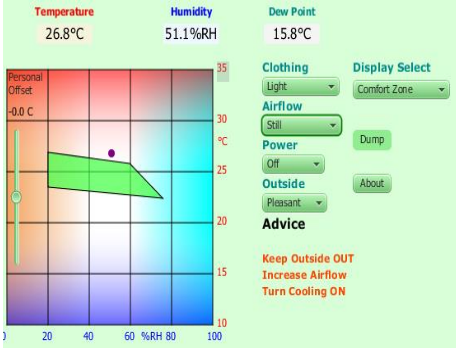
Advice

Keep Outside OUT
Increase Airflow
Turn Cooling ON

Figure 3.5 – Thermal Comfort user 2 test 1

Test 2: 26/07/13

The temperature on this day was similar to that of test 1 of around 23^{o}C however there was no cloud cover and much more solar radiation was reaching the home


Temperature
26.8°C
Humidity
51.1%RH
Dew Point
15.8°C
Personal Offset
-0.0 C
Clothing: Light
Airflow: Still
Power: Off
Outside: Pleasant
Display Select: Comfort Zone
Advice
Keep Outside OUT
Increase Airflow
Turn Cooling ON

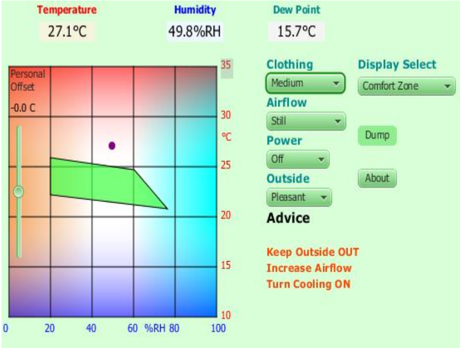
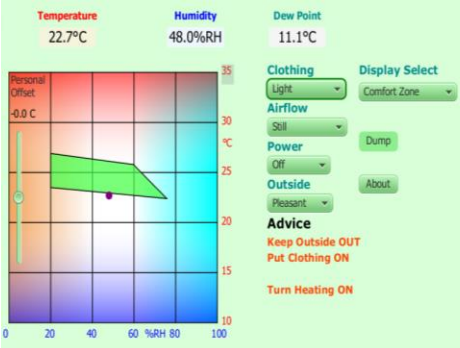

Temperature
27.1°C
Humidity
49.8%RH
Dew Point
15.7°C
Personal Offset
-0.0 C
Clothing: Medium
Airflow: Still
Power: Off
Outside: Pleasant
Display Select: Comfort Zone
Advice
Keep Outside OUT
Increase Airflow
Turn Cooling ON

Figure 3.6 – Thermal comfort user 1 test 2

Figure 3.7 – Thermal Comfort user 2 test 2

Test 3: 12/08/13

On this day the outside was cooler than the other two ecowand test days with the maximum outside temperature being 16^{0}C and also there was a large amount of cloud cover.


Temperature
22.7°C
Humidity
48.0%RH
Dew Point
11.1°C
Personal Offset
-0.0 C
Clothing: Light
Airflow: Still
Power: Off
Outside: Pleasant
Display Select: Comfort Zone
Advice
Keep Outside OUT
Put Clothing ON
Turn Heating ON


Temperature
22.8°C
Humidity
47.4%RH
Dew Point
11.0°C
Personal Offset
-0.0 C
Clothing: Medium
Airflow: Still
Power: Off
Outside: Pleasant
Display Select: Comfort Zone
Advice

Figure 3.8 – Thermal comfort user 1 test 1

Figure 3.9 – Thermal Comfort user 2 test 3

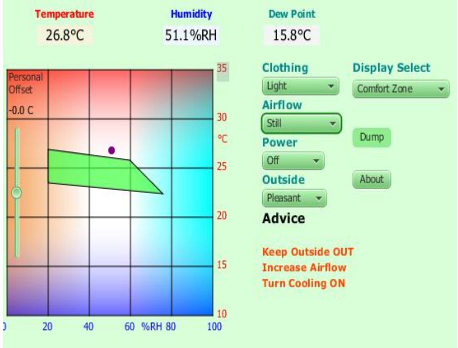
3.2.2 Discussion for Ecowand

From the Ecowand testing results it is evident that the protoype Net Zero Carbon home is vulnerable to overheating at points during the summer. At the time of tests 1 and 2 the country was experiencing the highest temperatures of the year. During these test the thermal comfort of the user was undesirable 75% of the time and even at times when the user was in the thermally comfortably zone they were at the upper limit (figure 3.4)

The testing also indicates that the clothing level of a person can be a significant factor to their thermal comfort. In the first test day when the outside temperature was an above average 23^{0}C user 1 had light clothing on (shorts and t-shirt) whereas user 2 had medium clothing on (jeans and t-shirt) but their thermal comforts were completely different. User 1 was in the thermal comfort zone but user 2 was not.

Comparing the results from tests 1 and 2, it is evident that the amount of solar radiation entering the home affects the thermal comfort of the occupant dramatically. At the time of testing the outside temperatures of the house were similar at around 23^{0}C but on the first test day there was some cloud cover, whereas on the second day there were clear blue skies meaning more solar radiation reaching the home. This higher level of solar radiation leads to a 1.8^{0}C increase in the indoor temperature. As previously discussed, this increase in temperature happens because the solar gains are trapped in the home owing to the high-level of home airtightness and insulation.

A final point to note from all three Ecowand tests is that during testing the airflow of the home was always still. The reason for this was that in the downstairs living room/kitchen there is only one window which can be opened which makes it difficult to create an air flow and also the high building standard means there are no natural airflows. If there were more air flows it would mean that the thermal comfort of the occupant may be increased by cool air from outside entering the home, thus cooling the occupant. An example of this is demonstrated below.

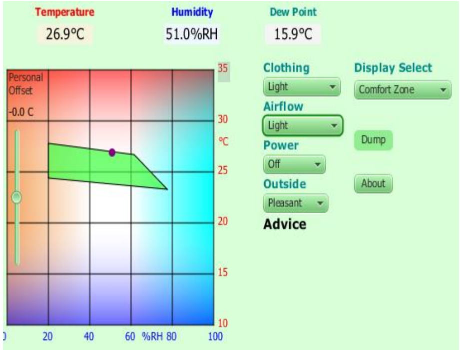


Temperature 26.8°C
Humidity 51.1%RH
Dew Point 15.8°C
Personal Offset -0.0 C
Clothing: Light
Display Select: Comfort Zone
Airflow: Still
Power: Off
Outside: Pleasant

Advice

Keep Outside OUT
Increase Airflow
Turn Cooling ON

Figure 3.10 – "Real" Rest results from test 2



Temperature 26.9°C
Humidity 51.0%RH
Dew Point 15.9°C
Personal Offset -0.0 C
Clothing: Light
Display Select: Comfort Zone
Airflow: Light
Power: Off
Outside: Pleasant

Advice

Figure 3.11 – Test 2 results if airflow was to be increased

Initially the user’s thermal comfort is out of the recommend range however by increasing the airflow slightly their thermal comfort level has increased.

3.3 Recommendations

Taking into consideration both the results from the manual and Ecowand testing there are some recommendations that can be made to increase the thermal comfort of the prototype Net Zero Carbon home during very high temperature days in the summer. Firstly as an increase in airflow can increase an occupant’s thermal comfort, it would be recommended that in future all Net Zero Carbon housing all the windows have the ability to be opened so that the occupant can allow as much as possible outside air to enter the home. Another recommendation for future Net Zero Carbon housing is that there should be some form of shading implemented in the summer months to reduce the amount of solar radiation entering the home with the effect of cooling it. As shading would not be used on regular occasions it would be recommended to use a simple easy to set up solution such as ‘black out’ blinds.

A final recommendation which requires research and development is integrating the Ecowand technology into the heating/cooling system for future Net Zero Carbon housing. If the technology was integrated it would mean that the thermal comfort of the occupants could automatically be controlled by monitoring then adjusting the heating/cooling.

4 Heat loss

With the new regulation on Net Zero Carbon housing coming into effect by 2016/2017 throughout the U.K, one of the main issues designers/builders will have to overcome during construction will be minimising the heat loss in the house. Heating in the average U.K home accounts for 66% of the total energy. In the home the majority of heat is lost through the building fabric by either thermal losses (through the conduction of heat through the building fabric) or by losses through ex-filtration (i.e. warm air leaving the building through ventilation and cracks in the façade). In designing and constructing more energy efficient homes ex-filtration, also known as air leakage, is the main issue as this can prove more difficult to tackle than reducing the thermal losses.

4.1 Air tightness

For air leakage to occur there usually has to be cracks or holes in the building fabric and also a pressure difference between the inside and outside of the building. There are four main driving forces in the U.K home which produce an air leakage (The Energy Conservatory, 2012):

1. Stack Effect – The heat in the home will rise to the top of the building and the cooler air will be at the base of the building. This will cause a slight pressure difference were the warm air will leak out of the holes and cracks at the top of the building which will be replaced by cooler air from outside coming through the holes and the cracks in the bottom of the building. The cooler air from outside is drawn into the base of the house because of the lower pressure. This stack affect is the most common type of air leakage in the home.

2. Wind Pressure – In windy locations the wind will cause outside air to enter the building through the holes/cracks facing the wind, whereas on the other side of the building the indoor heat will leak out.

3. Point Source Exhaust or Supply Devices – Combustion appliance chimneys and exhaust fans push air out of the building which creates a negative building pressure which therefore draws air from outside. With supply fans a positive air pressure is created, thus the inside air is forced outside by the holes and cracks in the building.

4. Leakage to the Outside: - Supply ducts work the same way as an exhaust fan (negative building pressure) whereas return ducts work in a similar way as a supply fan (positive building pressure).

If there are many air leakages in a home, the occupant's comfort thermal comfort level will start to deteriorate as they will start to feel cold. Not only will their thermal comfort deteriorate but there has also been some research (Chana; Nazaroff; et al, 2005) which suggests that the occupant's health may also suffer as pollutants from outside are also entering the home. Figure 4.1 gives a percentage breakdown for the average home where air leakage points are usually found.

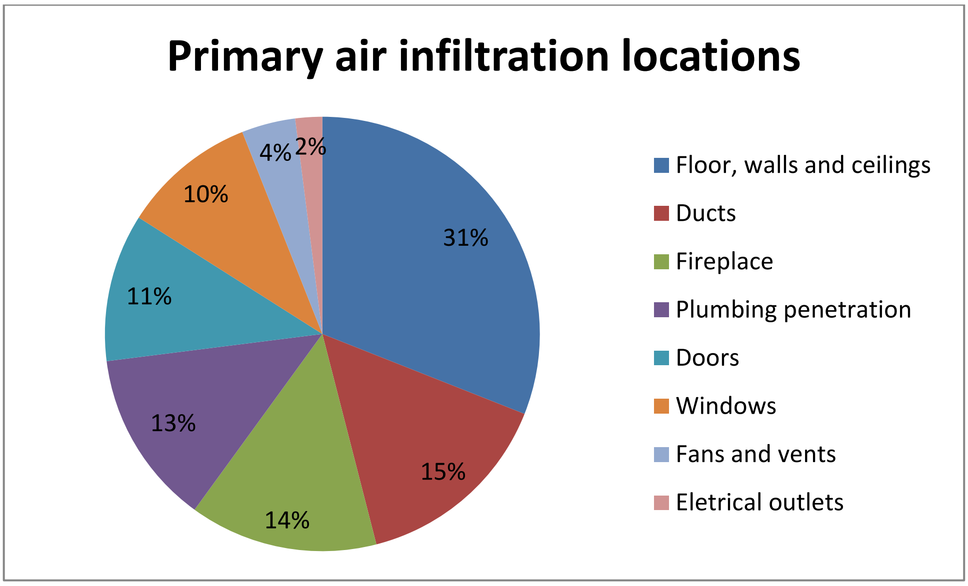


Figure 4.1 Percentage breakdowns of air leakage sites (California Energy Commission)

Here it is demonstrated that almost one third (31%) of the air leakage points in the average home are found within the walls, ceilings and floors. This is expected as the materials used for these constructions can be hard to seal and also there are many joints at these points which may not be as tight as possible. Figure 4.2 gives points in the average home where air leakage is likely to occur.

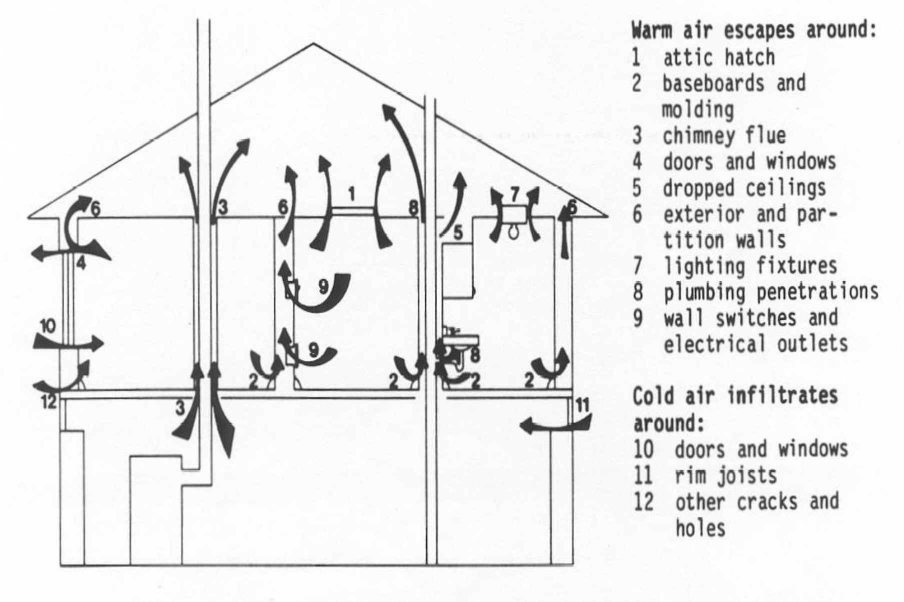


Figure 4.2 Air leakage points in the average home (Energy Conservatory, 2012)

In this figure some of the driving forces explained earlier can be seen. In between the top of the living space and roof there is much heat loss (points 1, 3,5,6,7 and 8). This is due to the stack effect. This stack effect can also been seen at the bottom of the home as air is entering the building through both the windows and the walls (10, 11and 12). These cold air infiltrates could also be cause by the wind if it was in the right direction. Points 2, 3, 4, 5, 8, 10,11 and 12 indicate that any surface that is connected to the exterior of the building is liable to air leakage. From this figure it is demonstrated that there can be many places in a home where air leakages occur which can make it difficult for designers and builders to create an airtight building.

4.1.1 Blower Door Test

In the previous section it was demonstrated that air leakage can be a cause of concern for the home owner as a high rate of heat loss will cost money. It is because of this that once a building has been constructed it will have to undergo testing to determine its airtightness. Usually detecting holes and cracks in a building by hand can prove very difficult (Gadsby; Linteris; et al, 1981) thus to determine the airtightness of a building, a pressure differential between the outside and inside of a building has to be created. The most common way of achieving this is by the use of a blower door.

First used in 1977 the blower door consists of a powerful, variable-speed fan with a speed controller mounted in an adjustable panel that is temporarily fitted into an open exterior doorway (Van der Meer, 2013). There are also manometers used which measure the pressure differential at both sides of the blower door (through the use of tubing) as well as the fans air flow, a standard blower door is shown in Figure 4.3

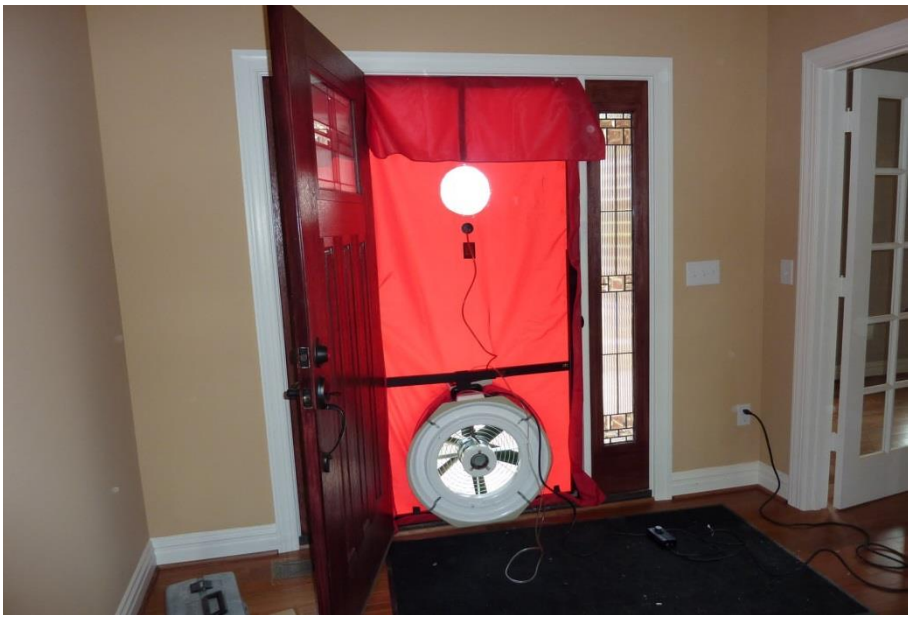


Figure 4.3 – A Standard Blower Door

Depending on the configuration of the blower door and fan, the house can be either pressurised or depressurised. In the set up the house is being depressurised and this is the most common method of testing. When the house is depressurised, air from the outside will be entering the building through holes as cracks were as in pressurising mode the air will be leaving the building thought the holes and cracks in the fabric.

Before installing the blower door for a test the building has to be prepared so that accurate results can be achieved. The guidelines for building preparation before testing are (ATTMA, 2010):

- All internal doors should be open for the duration of the test.
- All drainage traps should be filled with water.
- All areas of the dwelling to be tested should be connected by openings no smaller than a single leaf doorway (800 mm x2000mm). Any areas of the building where this is not achievable must be recorded and noted within the test report.
- All incoming service penetrations (e.g. power, telecoms) should be permanently sealed.
- All external doors and windows should be closed (but not additionally sealed). This includes door thresholds. The exception to this will be apertures to which test equipment is connected.
- Background trickle ventilators, passive ventilation systems and permanently open uncontrolled natural ventilation openings should be temporarily sealed.
- Mechanical ventilation and air conditioning systems should be turned off. These systems should be temporarily sealed to prevent air leakage through the systems during the test.
- Measure temperature and pressure both inside and outside of the building as well as the local wind speed.
- Calculation of building envelope and volume.

Once the building has been prepared a test can be carried out. The testing procedure for the air tightness test is relatively simple and can be carried out either manually using the manometers or automatically using computer software such as TECTITE. When carried out manually the operator can increase the pressure difference between the building and the outside by increasing the fan flow. They may need to change the fan’s rings to increase the pressure difference to the desired value. In a manual test either a single point or multipoint test will be run. In a single point test the operator will adjust the fan to achieve a pressure difference of 50 Pascal’s then will read the fan flow from the meter. For the multi-point test the fan flow will be measured at a range of different pressure differences, usually the range is between 20 – 60 Pa. this multipoint test is more accurate than a single point test. When using software the system will carry out a multipoint test automatically and will give instant results to the user. If the testing is being carried out under a depressurisation of the building then the operator will be able to detect locations of holes and cracks in the fabric by using either their hand or a by using a smoker.

The values for the air flow of the fan at different pressure differences and the building envelope values can be used to calculate different parameters for the airtightness of the building. The two most important parameters for the air tightness are the air permeability and air change rate both at a 50 Pa pressure difference. The air permeability at 50Pa (AP_{50}) measured in $m^3.h^{-1}.m^{-2}$ is calculated by

$$AP_{50} = \frac{C_l * 50^N}{A_E} \qquad (1)$$

Where C_l is the air leakage coefficient is the flow exponent and A_E is the building envelope. The air leakage coefficient and flow exponent are determined by the amount of data points and also the weather (temperature/air pressure) at standard values. The calculation for the air changes per hour ACH_{50} is:

$$AC_{50} = \frac{C_l * 50^N}{V} \qquad (2)$$

Were V is the volume of the building. When using the software the air permeability and air change rate per hour will be calculated automatically.

When comparing the air tightness of different buildings the air permeability is the characteristic which is used as the standard, Table 4.1 shows the current best practice for air permeability for different types of buildings.

Type	Air Permeability @ 50 Pa ($m^3h^{-1}m^{-2}$)		Air Change Rate @50 Pa (h^{-1})
	Best Practice	Normal	
Dwellings			
Naturally Ventilated	5.0	7.0	-
Mechanically Ventilated	1.0	5.0	-
Code for sustainable homes level 6 (Net Zero Carbon)	-	<=2	~1
PassivHaus Standard	-	<1.0	0.6

Table 4.1– Best practice for building air tightness (ATTMA, 2010)

As well as best practice there is also a requirement that for any new building in Scotland the air permeability must not exceed 10 $m^3h^{-1}m^{-2}$.Taking into account the information in the table above for Net Zero Carbon homes, the air permeability should be around 2 which is the requirement needed for a level 6 home in the Code for Sustainable Homes

4.1.2 Testing Method

From above, the test carried out to determine the airtightness of the prototype home was the standard blower door test. As the user had no experience of the equipment and software, several trials were done before taking the equipment to the prototype Net Zero Carbon home. The first trial was setting up the equipment and learning how it will be set up in the protoype house; this was done in the ESRU departmental office. For the second trial a mock test was carried out in the users own home. This was performed to make sure that the equipment and the corresponding TECTICE software were working as designed. Another advantage of doing these trials, other than increasing the understanding of the test, was that it would save time when doing the actual test on the Net Zero Carbon house.

Once both of the trials were successful the equipment was taken to the prototype Net Zero Carbon home for an airtightness test to be carried out, all the equipment used is shown in Figure 4.4

Figure 4.4 – The equipment used for the prototype home air tightness test

Before carrying out the test the house had to be prepared in accordance with the ATTMA guidelines, which are in section 4.1.1 of this report. In the home there were 7 fan openings which had to be closed over as far as possible and sealed, which was secured by using tape (figure 4.5) and all the internal doors in the home were opened (Figure 4.6). As the Net Zero Carbon home had never been occupied the plug holes for the sinks, baths and showers were filled with water to seal them up. The MVHR system was switched of and the air supply and extraction points for both this system and the air heat pump were taped off.

Figure 4.5 – Picture of a sealed fan point

Figure 4.6 – Picture of internal doors in the house open

Once the house was properly prepared, the equipment was assembled and fitted to the main external door way of the house on the north wall. The blower door once set up is demonstrated in the prototype house is seen in Figure 4.7.

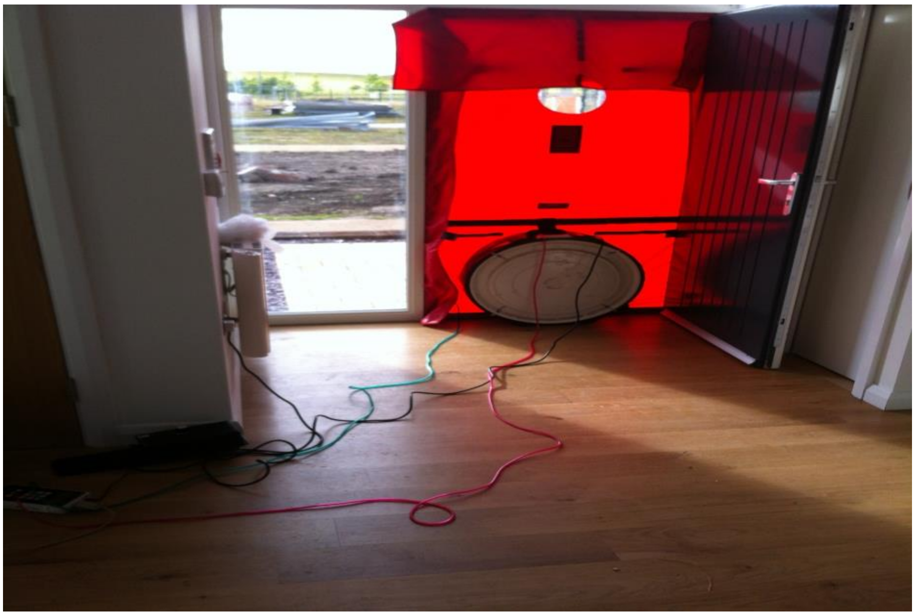


Figure 4.7 – Blower door set up in the prototype Net Zero Carbon house

The door was set up so that the house would be de pressurised. There were several reasons why this particular set up was chosen, with the main reasoning being that when the house was depressurised leakage points could be detected using the smoker. Also the weather and house set up would have made a pressurisation test rather difficult to undertake. With the set up in Figure 4.7 complete, the manometer was connected to a laptop with TECTICE software installed and an automatic test was done. When running the test the software took fan flow rates at regular intervals (every 5PA) of pressure difference between the maximum difference being 60PA and the minimum being 20PA.

4.1.3 Test Results

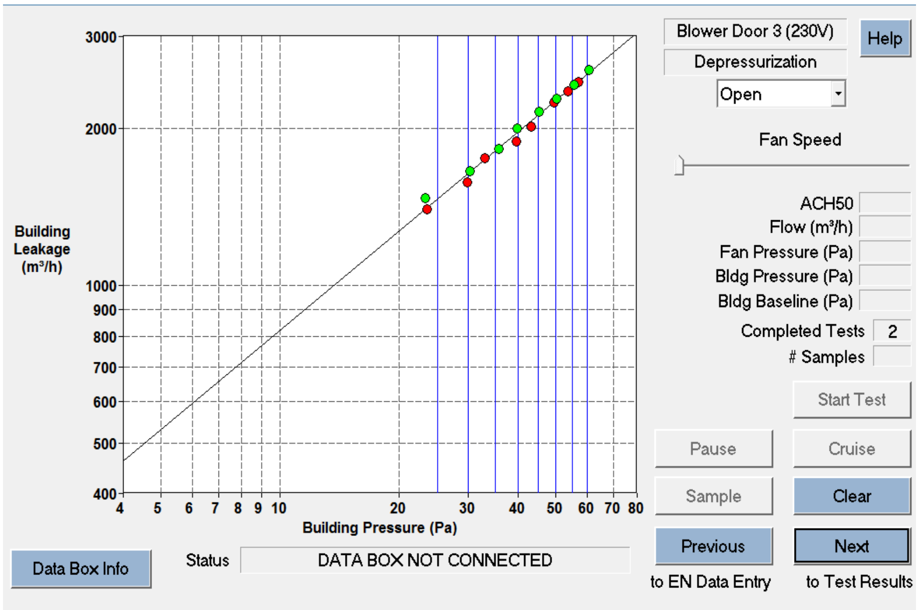
As the aim of this project was to test and aid the design team of a prototype Net Zero Carbon home, the blower door test previously described was carried out several times. Each time the test was carried out. The air permeability and air change rate at 50Pa was noted as well as locations of substantial air leakages in the house. These locations were sealed then the blower door test was carried out again to determine the effect the sealing made on the air tightness of the house. This process was repeated a number of times. Before the initial blower door test the surface area and volume of the building was calculated to be 347 m^2 and 511 m^3 respectively.

4.1.3.1 Initial Test

The weather conditions at the time of the initial test are in Table 5.3 and Figure 5.3 gives the graph for the fan flow rate at different pressure differentials.

Measurement	Value
Indoor Temperature	18.5 ^{0}C
Outside Temperature	14.2 ^{0}C
Barometric Pressure	$1x10^5$ PA (Standard)
Wind Class	Light Wind

Table 4.2 – Measurements of building dimensions and weather conditions before first test



Blower Door 3 (230V)

Depressurization

Open

Completed Tests 2

Status DATA BOX NOT CONNECTED

Figure 4.8– Fan flow rate v pressure difference first test

Using the information from Table 5.3 and Figure 5.3 the software was able to give the air permeability and air change rate at 50PA difference. The air permeability at 50PA is and 6.33m^{3}h^{-1}m^{-2} and the air change rate was 4.88 air changes per hour.

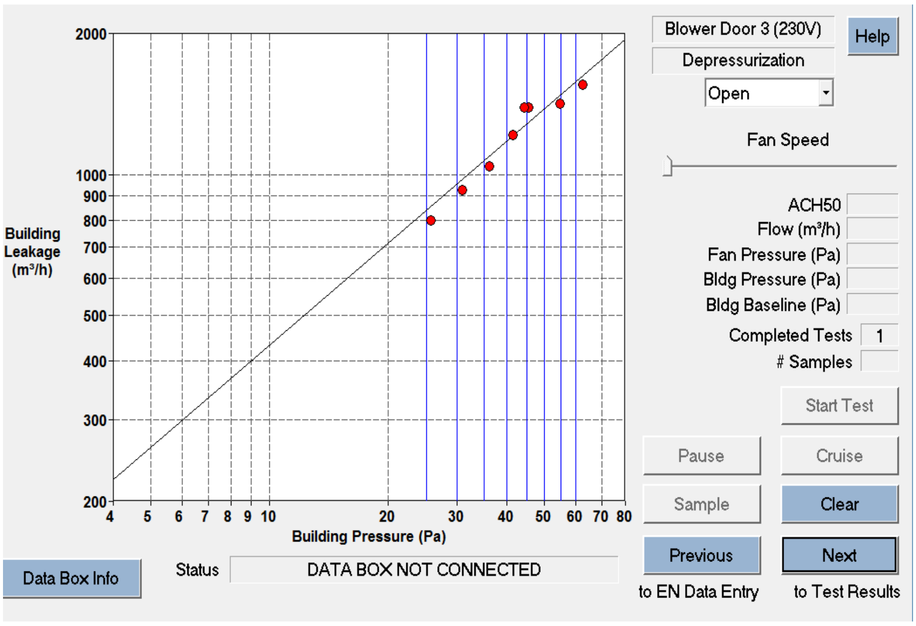
As well as finding the air permeability and air change rate of the home at 50PA, a smoker was used to find places of leakage in the house. The main sources of leakage in the house found were:

- At the bottom of the seating area in the living room
- The patios door beside the office space
- At drainage and service pipes for machines in the kitchen
- The floor in the small store cupboard
- Sockets
- At the connection points of the 4 construction pods

4.1.3.2 Second Test

Measurement	Value
Indoor Temperature	22.4 ^{0}C
Outside Temperature	21 ^{0}C
Barometric Pressure	1x10^5 PA (Standard)
Wind Class	Light Wind

Table 4.3 – Measurements of building dimensions and weather conditions before second test


Blower Door 3 (230V)

Depressurization

Open

Completed Tests 1

Status DATA BOX NOT CONNECTED

Figure 4.9 – Fan flow rate v pressure difference second test

From the results of the test it was calculated that the air permeability at 50Pa was 3.99 m^{3}h^{-1}m^{-2} with the air change rate being 2.71 changes per hour at 50Pa. Again the smoker was use to find leakage points and when used, it was found that there were several holes in the building walls (created by workers to use) which still had to be sealed.

4.1.3.3 Third test

Measurement	Value
Indoor Temperature	21.8 ^{0}C
Outside Temperature	17.3 ^{0}C
Barometric Pressure	1x10^{5} PA (Standard)
Wind Class	Light Wind

Table 4.4 – Measurements of building dimensions and weather conditions before third test

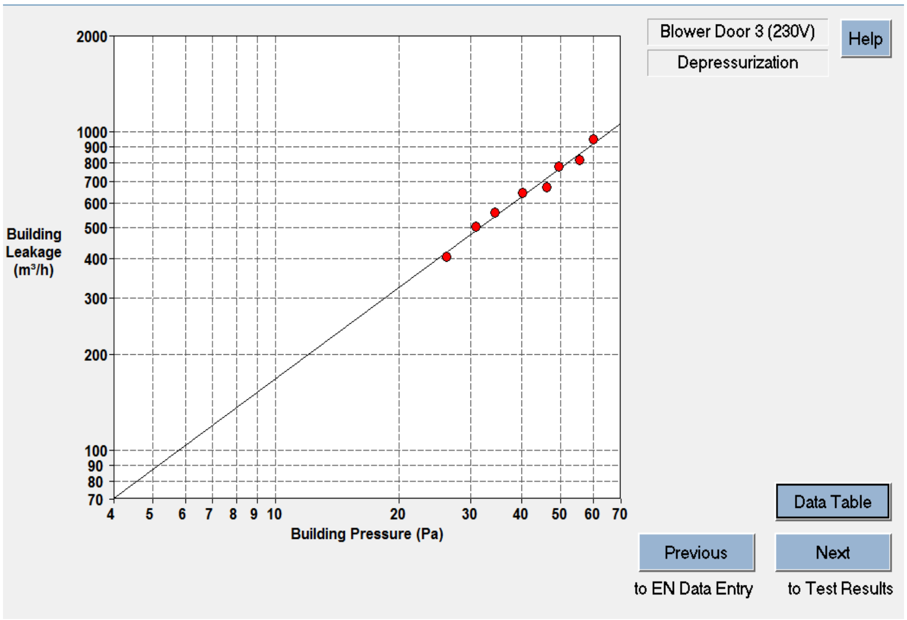


Figure 4.10 – Fan flow rate v pressure difference third test

By the time this final test had been carried out, all of the previously located points of leakage had been permanently sealed, which took a long period of time. This final test yielded an air permeability of 2.05m^{3}h^{-1}m^{-2} and air change rate of 1.4 changes per hour both at 50 Pa. When using the smoker at this point it was found that there were no real points of leakage in the interior of the building.

4.1.4 Discussion

From the results it is evident that the building standards set out for Net Zero Carbon housing (<= 2m^{3}h^{-1}m^{-2} air permeability at 50Pa) can be difficult to achieve. Even after carrying out the blower door test several times and sealing up all detected leakage points the protoype Net Zero Carbon home did not meet standard as the final air leakage was determined to be 2. $05m^3h^{-1}m^{-2}$.

When carrying out the first blower door test it was determined that the use of off-site construction caused some problems when erecting the home. The home was constructed as four separate pods which were connected on site to form the house. When the four pods were connected on site they were not fully sealed at the joints which created several large leakage points. These leakage points ran the full length of the house and sealing them proved to be difficult and time consuming. As the house had already been furbished before the test was carried out, several of the carpets had to be lifted before these joints could be properly sealed. Also when carrying out this first blower door test there were several other leakage points found which are listed in section 4.1.3.1, some of which (such as under the living room seating area) were easily detected by hand or eye. These easily visible large leakage points may have been again caused by the use of off-site construction. The set of builders who erected the building at the site in Ravenscraig was a different set of builders from those who constructed the four pods at the warehouse which was in Northern Ireland. As the builders on-site were not involved in the construction of the pods, they would not know which points would be cause of leakage when the building was erect.

In the second test human error again led to a relatively high (for a Net Zero Carbon home) air permeability of $3.99m^3h^{-1}m^{-2}$. The leakage locations in the initial test had been sealed but over that time some work had been carried out in the house, especially with the plumbing work in the downstairs bathroom. When this work had been carried out there were several holes created in the interior walls but once the work had been finished these holes were not fully covered and sealed, which caused them to be leakage points during the second blower door test.

In the final test after all the previously leakage points had been found the air permeability was still slightly more than the value needed for a Net Zero Carbon home. As all the internal leakage points had been sealed it has been determined that some leakage is occurring at the pod joints but it is very difficult to seal because the home has already been fully erected and furbished.

4.1.5 Recommendations for future buildings

From the results in the previous section there are two main recommendations made for future Net Zero Carbon housing to improve air tightness. Firstly the buildings should be constructed as one instead of as a series of pods as it was found when connecting the pods that there is the potential for large leakage points to develop at the joints. This may mean that off-site construction is not an option. The second recommendation is that there has to be regulation put in place for builders of Net Zero Carbon housing to be made aware of common leakage points in the home. This would stop the scenario seen in the prototype home were there were several visible leakage points left unattended after both construction and maintenance. It should be noted that as prototype Net Zero Carbon was a show home and thus other factors such as deconstruction had to be taken into account. Because the home would only be up for a limited amount of time the frame was made of steel which caused some air leakage points. However, if the home was to be mass produced steel frames would not be used and the houses would more than likely meet the standards for Net Zero Carbon housing of (<= $2m^3h^{-1}m^{-2}$ air permeability at 50Pa

4.2 Thermal Losses

There are several thermal losses which can occur in a building’s fabric which are caused by a variety of reasons, the most common of these reasons are explained below:

- Poor quality insulation – Thermal insulation is used to reduce the conductive heat transfer in a building’s fabric (walls, ceiling, etc) but if this is of poor quality then the heat can easily move from the inside of the building to the outside. This means that there is more energy needed to heat the building to a comfortable level as less can be “trapped” in the living area thus making the building less energy efficient.
- Insulation installed incorrectly – In many buildings it has been found that the insulation building is not evenly spread out which leads to some parts of the building being cooler/warmer than others. This leads to a poor thermal comfort as it is desirable for the occupant to experience the same temperature throughout each room in a building also more heating would be needed.
- Penetration of insulation by non-insulation material (thermal bridges) – When a non-insulating material penetrates an insulating material the heat will transfer through this non-insulation leading to a higher heat transfer rate thus more thermal losses. These thermal bridges are commonly found at joints, windows, etc and are very difficult to fix once the building is erect. It has been determined that if thermal bridges are eliminated in a building then the heating use can be reduced by up to 15% (Erhorn-Kluttig and Erhorn, 2009).

4.2.1 Thermographic camera

The most common way to detect thermal losses in a building is by use of a thermographic camera, which creates an imaging from infrared radiation instead of visible light. All objects emit a certain amount of radiation depending on their temperature, which is known as black body radiation. Figure 4.2 gives the black body radiation for objects at several different temperatures

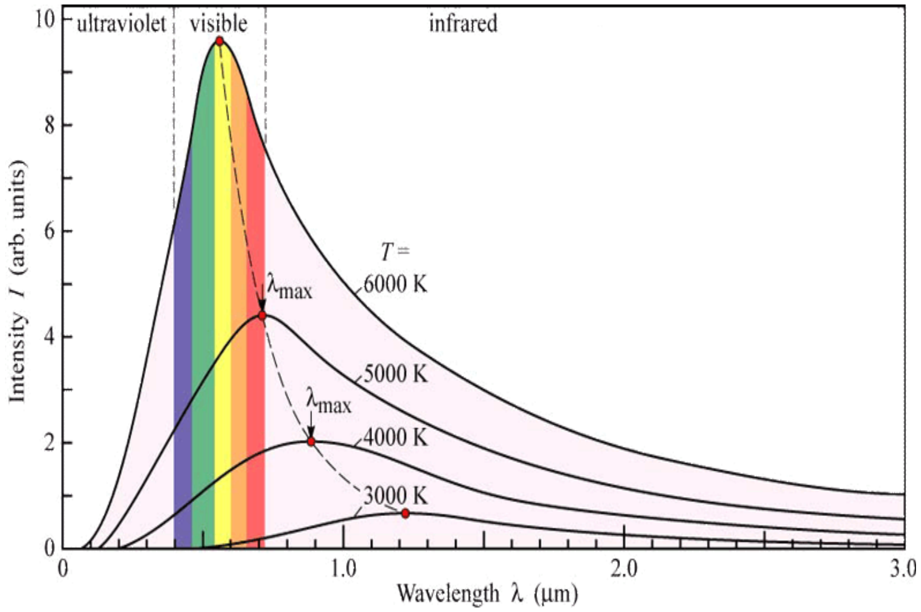


Figure 4.11 – Black Body radiation for object between 3000-6000K

This figure demonstrates that the higher the temperature the lower the peak wavelength is and also it indicates that for objects at room temperature (~295K) most of the radiation will be in the infrared. By measuring this infrared light instead of the visible light a thermographic camera can create a picture of the temperature variations of an object in a similar fashion to creating a normal photograph. The thermographic image is made up using one colour channel but often pseudo colour is used to display temperature differences as it is convenient for the users. When using a thermographic camera the user can find thermal losses by the temperature variations in the buildings fabric.

4.2.2 Testing method

A thermographic camera similar to that in figure 4.12 was used to test insulation in the prototype Net Zero Carbon and to find if there were any thermal losses.

Figure 4.12- The type of thermal imaging camera used to test the prototype Net Zero Carbon Home

The test was carried out at night and for 12 hours before the test the biomass boiler was set to run at a high level. This was done so that during test there was a significant temperature difference between the inside and outside of the house so that a high quality image could be made. When the test was carried out the outside temperature was 13^0C and the inside temperature was around 25^0C. At each side of the house several images were taken using the three different colour scales available on the camera, some of taken are demonstrated in the section below.

4.2.3 Results

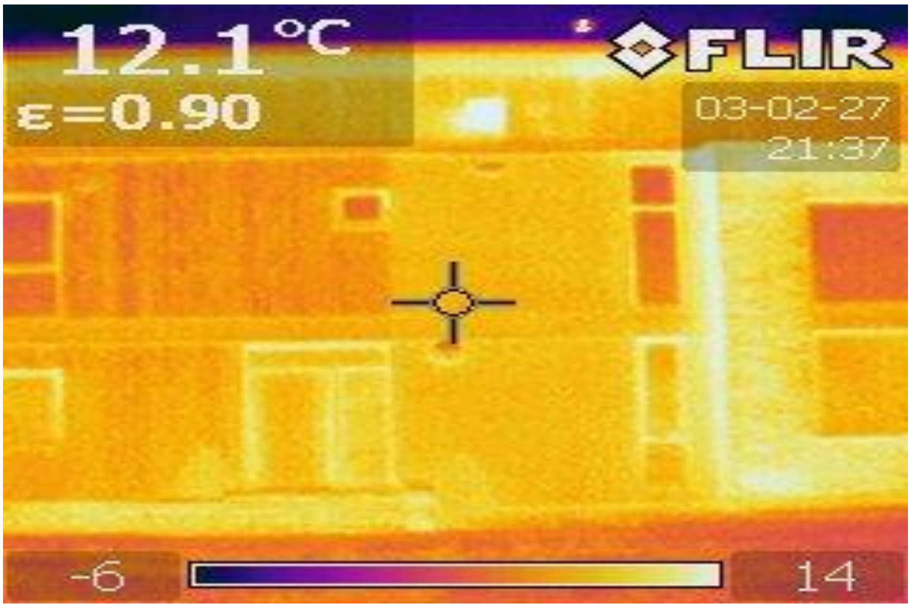


Figure 4.13 – Thermographic image of north facing wall

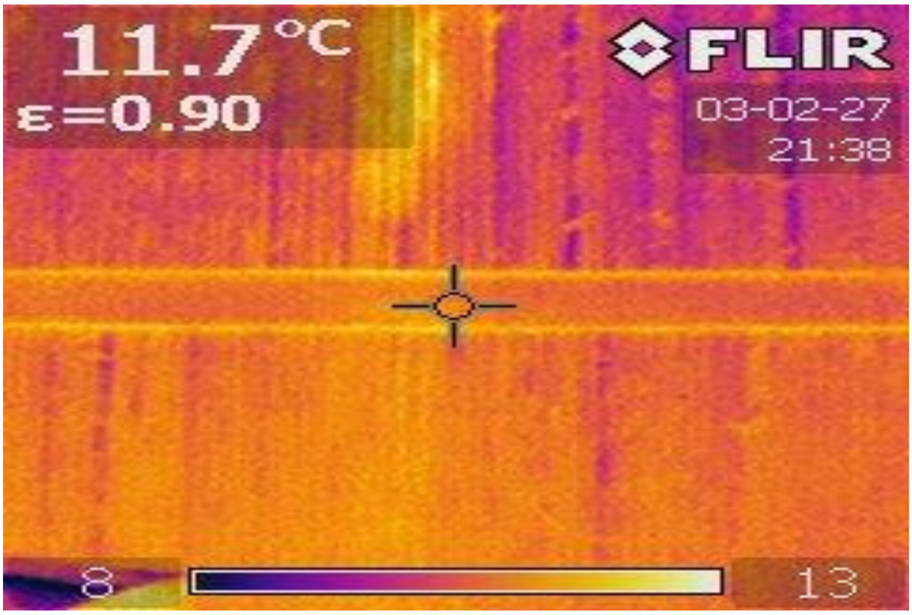


Figure 4.14 – Thermographic image of east facing wall

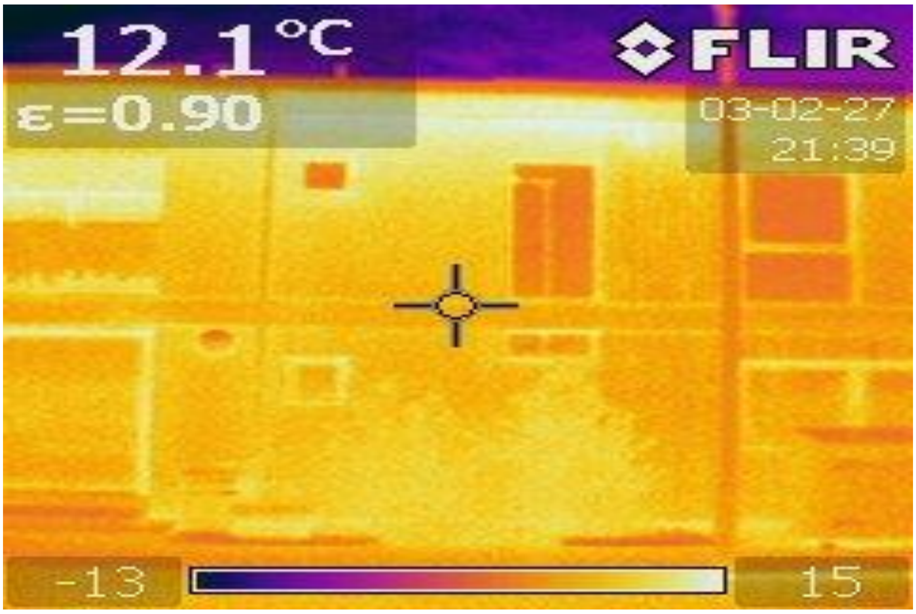


Figure 4.15 – Thermographic image of south facing wall

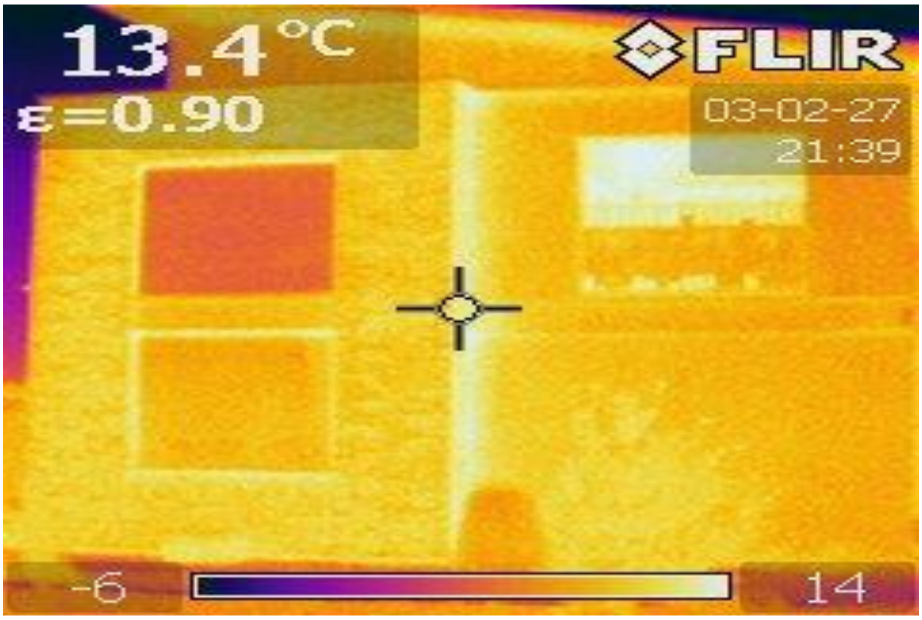


Figure 4.16 – Thermographic image of west facing wall

4.2.4 Discussion

Overall from the thermographic images it is evident that there are very little thermal losses as the thermal insulation is of a high quality and has been installed correctly. From all four of the pictures it can be seen that the fabric temperature is much higher than that of outside meaning as much as possible of the heat is being retained in the house. Figure 4.15

demonstrates the phenomenon that heat rises over time, at the top of the building there are white parts indicating that they are much warmer than the rest of the house.

The one cause of concern regarding thermal losses is in the east facing wall of the house where the outer layer is constructed from recycled wood instead of brick. In figure 4.14 the thermographic has found that in between the joints (especially at the upper half of the building) the temperature is significantly lower than the rest of the building which means that these joints are acting as thermal bridges were the heat from the house can escape. The problem with the wood outer laying can also be seen in 4.13 where the wood outer laying cannot retain as much heat as the rest of the house (the imaging is not as bright) meaning that the temperature throughout the building would have a slight variance and the occupants thermal comfort may be decreased.

4.2.5 Recommendations

The recommendation after carrying out the thermographic imaging testing is that the outer layer of future Net Zero Carbon homes should be made of the same material preferably brick. This would cut down on the chance of a thermal bridges occurring (which happened in the wood) and also it would made the heat retention in the building more homogenous thus the occupants thermal comfort would not decrease due to temperature variation.

5 Demand Profiles

Before testing of the renewable energy systems in the Net Zero Carbon home could be carried out yearly demand profiles for the house had to be determined. Both the heating and electrical yearly demand profiles of the house were needed and as throughout the duration of this project work the home was unoccupied, which made it impossible to obtain "real" demand profiles and instead the two yearly demand profiles were determined by computer simulations.

5.1 Yearly Electrical Demand Profile

The freely downloadable open source validated model developed by Richardson (et al, 2010) allowed for the creation of a yearly electrical model for the prototype Net Zero Carbon home. This model developed in excel uses Monte Carlo simulation techniques to create unique 1 day, 1 minute resolution electrical demand profiles for a home depending on the lighting, appliances, occupancy data and time of year. Monte Carlo simulations are used to simulate the variation of a house electrical demand on a day to day basis. The occupancy data patterns in the model are based on real occupancy use in U.K homes taken from the U.K time of use survey 2000 (Richardson et al, 2008). For the prototype Net Zero Carbon home 365 simulations were run (for each day of the year) and the appliance/lighting data was taken from the technologies currently installed in the home. It was simulated that there would be four occupants living in the home. The yearly output of the home in 1 hour time steps is demonstrated in Figure 5.1

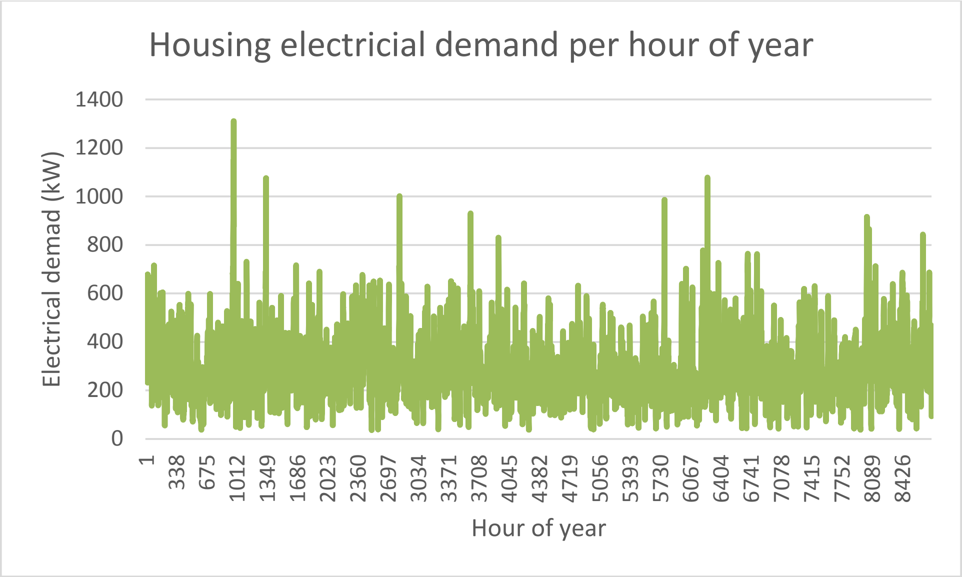


Figure 5.1 Yearly Electricity Demand

5.2 Yearly Heating Demand Profile

The model created by Grant (2013) for use in another MSc project (Figure 5.2) was used to generate a yearly heating demand profile for the home.

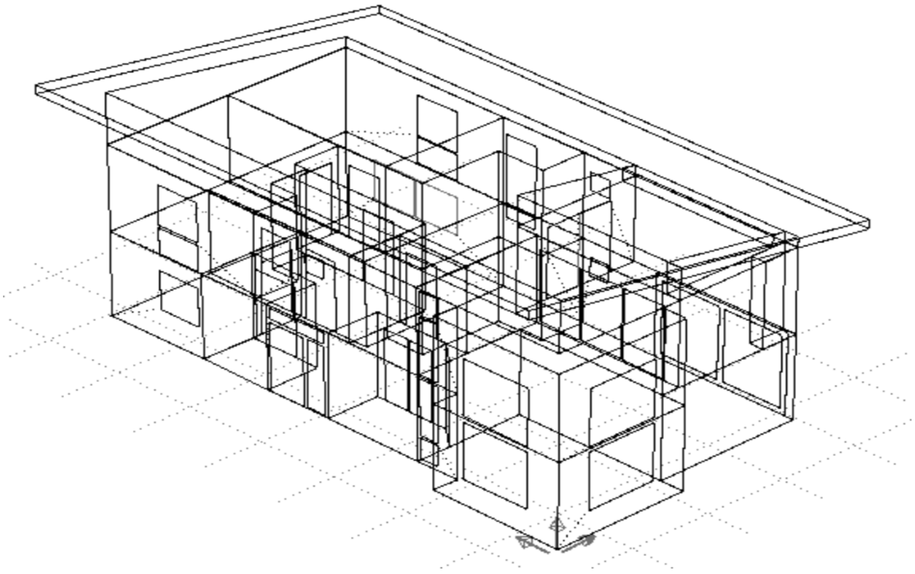


Figure 5.2 Model used to generate a heating demand for the prototype Net Zero Carbon Home.

This is a sophisticated esp-r model of the protoype Net Zero Carbon home and a graphic output of yearly heating demand from the profile is seen in Figure 5.3

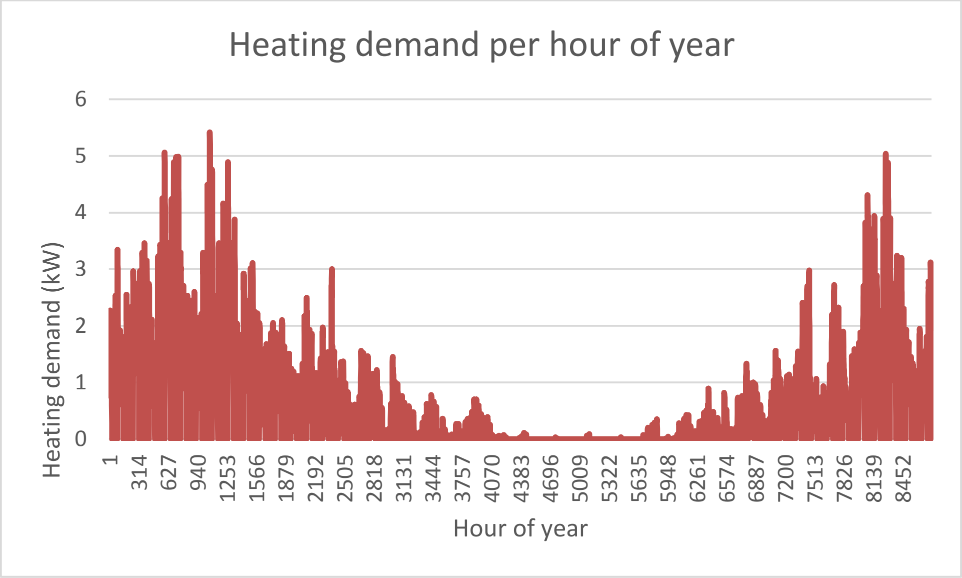


Figure 5.3 – Graphic output of the yearly heating demand profile taking from esp-r

6. Renewable Energy Systems

6.1 Photovoltaic Panels

The most common renewable energy technology that is integrated into Net Zero Carbon housing is photovoltaic panels; the main reason for this being that photovoltaic panels are relatively small and can be easily installed on the roof of a building. It is because of this usage potential in the home that there is the aim of a European photovoltaic installed capacity of 240,150 MW by 2020, (European Photovoltaic Industry Association, 2012).

In the prototype Net Zero Carbon home there are a 9 photovoltaic panel system installed on the south facing roof, with the convertor and monitoring equipment located in the cupboard of the master bedroom. These photovoltaic panels are the only source of on-site electricity generation in the house, thus they will be tested to determine if their output can cover the electricity needs of the home throughout the period of a year. To do this, monitoring is needed to determine the relationship between solar irradiance and system output. From this monitoring the output of the panels for a "typical" year can be calculated and this can be compared with the electrical need for the home.

6.1.1 Operational Details

Photovoltaic (PV) is the method of generating electricity directly from sunlight by means of the photovoltaic effect (similar to the photoelectric effect) which only occurs in some semiconducting materials , known as photovoltaic materials, due to the p-n junction. When photons (light) strike the photovoltaic material the energy is absorbed by the electrons which will increase their energy which allows the electron to "jump" across the p-n junction. This flow of electron across the p-n junction creates a direct current (DC). These photovoltaic materials are used in solar cells for the generation of electricity and the most common materials used are monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride or copper indium gallium selenide/sulphide (Jacobson, 2009). Several of these solar cells can be connected together and packaged to form a photovoltaic (solar) panel, a single solar panel is illustrated in Figure 6.1.

Figure 6.1 – Illustration of a single solar panel

The output from a single solar panel can only typically range between 100W and 400W, which would only be enough electricity to power very small appliances such as a kitchen blender. It is because of this low output from a single photovoltaic panel, that usually many panels are connected together to form a photovoltaic array which is the main component in a photovoltaic system. These systems will also include an inverter to convert the DC output into AC (which has much more useful application) and the system will include monitoring and metering equipment. In some systems a sun tracker and movable array may be attached to optimize output. By installing a system in the domestic sector several kW of electricity can be generated which may be capable of supplying a home’s electrical needs at several periods during the year reducing the running cost.

6.1.2 Limits/ Efficiency

As with many renewable energy sources the output of photovoltaic panels is intermittent and is near impossible to predict over an extended period of time. A photovoltaic panel relies on sunlight to produce electricity so none can be generated at night and on overcast days the output will be reduced significantly. This can cause a problem when integrating photovoltaic panels into the home. The panels usually have peak output at mid-afternoon, the time when a home is the least likely to be occupied thus most of the electricity generated will either be wasted or exported to the grid. To overcome this, battery storage may be used but currently this is an inefficient technique for extended periods of time. Also the further away from the equator a photovoltaic panel is situated, the less effect it has because of the decreased sunlight hours there are during the winter/autumn months of the year and also the solar radiation throughout the year is not as intense. Figure 6.2 gives a graphic representation this for Europe.

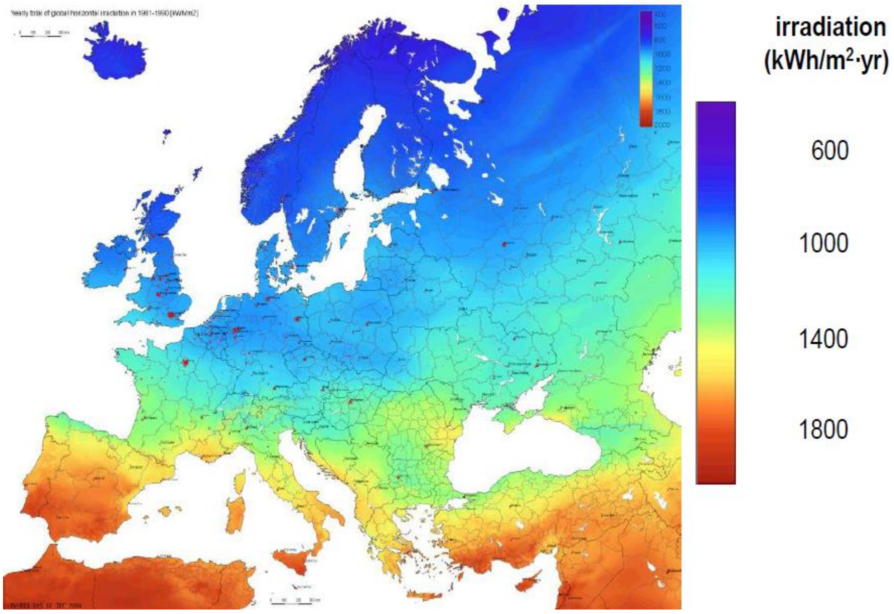


Figure 6.2 – European solar irradiation (Joint Research Centre, 2009)

Here it is evident that over the period of a year the output of a photovoltaic system will have a greater effect the closer it is situated towards the equator. The solar irradiance is about three times higher in the south of Spain and Italy (1700 kWh/m^2.yr) than it is in Scotland (600 kWh/m^2.yr). This factor should be taken into account when building/designing and designing Net Zero Carbon homes in more northern climates. Solar panels are unlikely to cover the full electricity needs for the home and other technologies such as micro-wind may also have to be integrated into the renewable technology system.

The capacity power of a photovoltaic panel is given by the maximum output under standardised test conditions (STCs). In practice it is extremely difficult for a solar panel to generate the same maximum as that under STCs thus the capacity of the solar panel can be reduced significantly. It has been determined that the capacity of current solar panels in operation in current standard housing can vary between 8% -25% (Green; Emery: et al 2012) which is much lower than conventional power sources as well as current operational renewable technologies. The capacity of a specific solar panel will be determined by its location and also the photovoltaic material used (some materials are more efficient at producing a current but are usually more expensive). As the research and development of semiconductors is developing at a rapid pace, it is expected that sometime in the future that solar panels may be able to have capacities over 50%. Again as the capacity of solar panels is low for Net Zero Carbon homes, there needs to be more than one way of generating a renewable electricity supply.

6.1.3 Testing method

The output compared with solar irradiance testing was carried out manually by using a light meter (Figure 6.3) and the output screen from the installed monitoring equipment from the photovoltaic system.

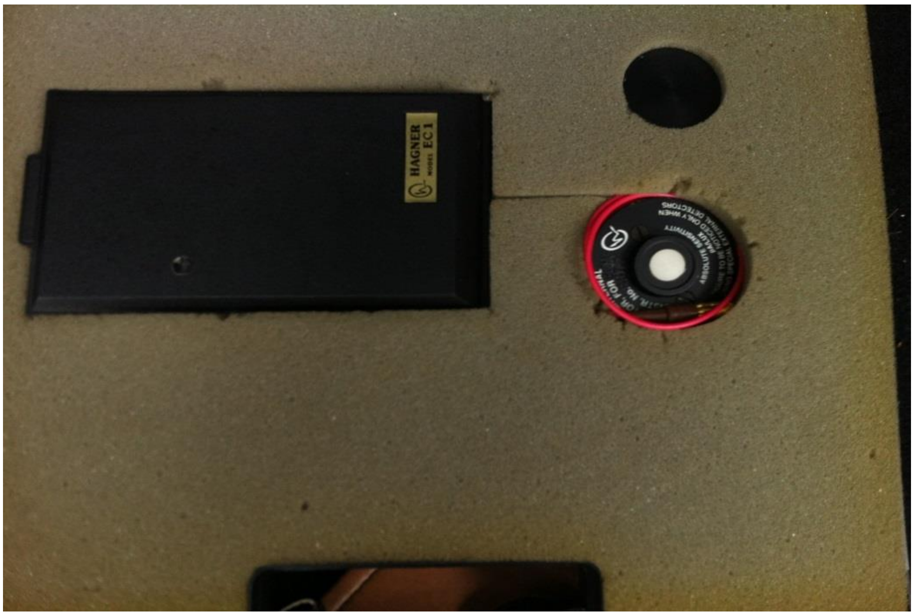


Figure 6.3 Light meter used for photovoltaic testing

The light meter was placed at the south end of the house in the same direction as the photovoltaic panels. This was as close as the meter could be placed to the solar panels as there was no way to reach the panels on the roof. Using the meter and some conversion the irradiance in (W/m^2) could be calculated and from the monitoring system in the master bedroom the photovoltaic systems output could be determined. This manual testing method was performed on several different occasions and under different weather conditions (bright sunny day, overcast day, rainy day etc). This was done to decipher how the system's output differs depending on the weather conditions.

Once the data had been gathered, a relationship between the solar irradiance and photovoltaic system was found and this relationship was used to find the output of the photovoltaic system over the period of a year. For the output to be determined, the solar irradiance data for a "typical" year would be needed. This data was taken from the ME927 resource and policy Assignment 1 spread sheet which gives "typical" solar irradiance at each hour of the year for Glasgow. As the prototype is located only 16 miles from Glasgow city centre the solar irradiance would be similar throughout the year. Using this yearly output and the electrical demand profile created in section 5.1, the effectiveness of the PV system was could be determined.

6.1.4 Results

Result	Value
Total PV output	2889.45 kWh
Total Electrical Need	2479.94 kWh
Electrical Surplus	1943.98 kWh
Electrical Deficit	1534.02 kWh
Number of hours PV covers the full electrical need of the home	2802

Table 6.1 – Results from PV testing

Cost of importing Electrical deficit	Gain of exporting surplus PV and current tariff	Overall profit
1534.02 kWh * 15.979 p per kWh	1943.98 * 15.44p per kWh	£300.15 – £245.12
£245.12	£300.15	£55.03

Table 6.2 – Economic analysis of the PV system

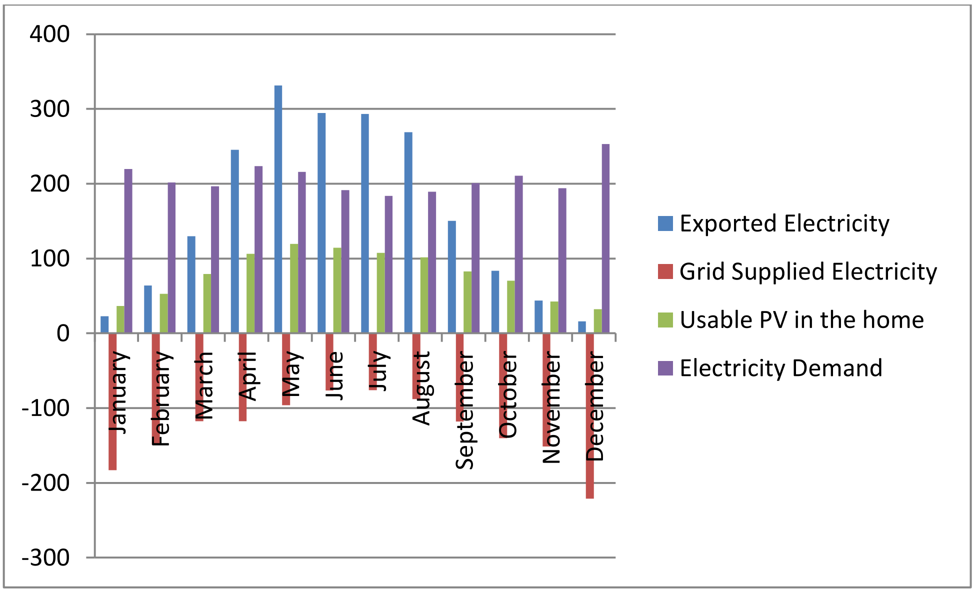


Figure 6.4 – Monthly output of PV

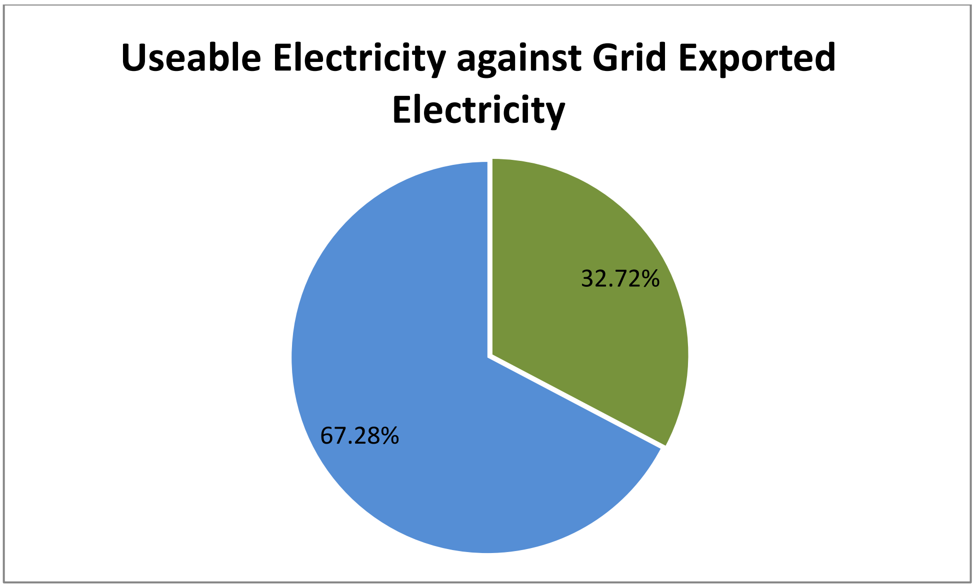


Figure 6.5- Proportion of useable PV against exported electricity

6.1.5 Discussion

From Table 6.1 the PV system in the prototype Net Zero Carbon home has achieved its main goal of generating more electricity than is needed in the home. Overall the PV system generates over 400kWh hours of electricity than is actually needed for the home to operate for a full year, meaning the carbon offset will be negative if the secondary source calculation is used.

Even though the protoype home has achieved the goal of generation Net Zero Carbon electricity, it is evident through the results that there are some problems about when the PV system is actually generating electricity. From Figure 6.5 it is seen that less than a third of the total electricity generated from the PV system is actually used in the home and from Figure 6.4 it is demonstrated that the amount of useable PV changes dramatically changes throughout the year. In the winter (January/December) the electricity demand is at its peak but the PV systems output is at its lowest meaning the system is generating less than 10% of the electricity needed in these months which would be similar to a current standard home. This leads to large amounts of electricity being imported from the grid, thus higher carbon emissions. However in the summer months the PV can cover in excess of 50% of the electricity needs of the home, which is much higher than the optimum capacity of 25% seen in current building standard housing with integrated PV. The increased capacity in the summer months is due to the fact that the efficiency of the technologies used in the Net Zero Carbon home is much greater than that used in standard housing today thus the demand has been decreased.

Another problem with the installed PV system is the amount of electricity that is being exported to the grid. Overall the amount of electricity exported to the grid is more than twice the amount of that which is being used in the home and in every month apart from December the amount of exported electricity was more than the usable. Also in the summer months, the amount of exported electricity was actually more than that needed to operate the home. The reason that there is such a high amount of exported electricity is because the time of day that the PV system is generating electricity is completely different to when it is needed in the home. From the simulations, usually the house has a low occupancy during the afternoon, the time when the PV system is generating the most electricity. Currently, this amount of exported electricity would not be seen as a problem to the home owner as through the feed in tariffs the owner would be set to make money off the PV system each year (Table 6.2). However in the future where Net Zero Carbon homes will be the norm and feed in tariffs are no longer available, this large amount of exported electricity will be a problem.

6.1.6 Recommendations

Through the results achieved in the testing and analysis of the PV system installed in the prototype Net Zero Carbon house, there follows some recommendations. Instead of only one technology being used for on-site electricity generation, the system should be made up of a variety of technologies which could include micro wind or biomass CHP. This would allow for the generation of renewable electricity in different types of weather conditions. For a single Net Zero Carbon home such as the prototype home this would prove difficult because of the price and location. However in the future when there will be Net Zero Carbon communities the use of wind power and CHP should become more viable.

For a single build Net Zero Carbon home it is recommended that there should be some form of battery storage installed. This would allow for the electricity being generated throughout the afternoon to be used later in the night when the home is being occupied, thus reducing the amount of exported electricity and increasing the percentage of useable electricity. Another advantage which may be found if battery storage was to be installed, would be that less solar panels would need to be in the photovoltaic array to cover the electrical demand of the house thus reducing initial cost.

A final general recommendation to be made for Photovoltaic systems is that the PV converting equipment should be located in an unoccupied room of a house, such as a loft or basement. The reason for this is that in the prototype home it was found that the converting equipment made a lot of noise while in operation and if the house was occupied this would be distracting and bring displeasure to anyone living there.

6.2 Biomass Boiler

By Far the most common form of renewable energy fuel used is bioenergy, which accounted for 73.7% of the total renewable energy used in the U.K in 2012 (Figure 6.6).

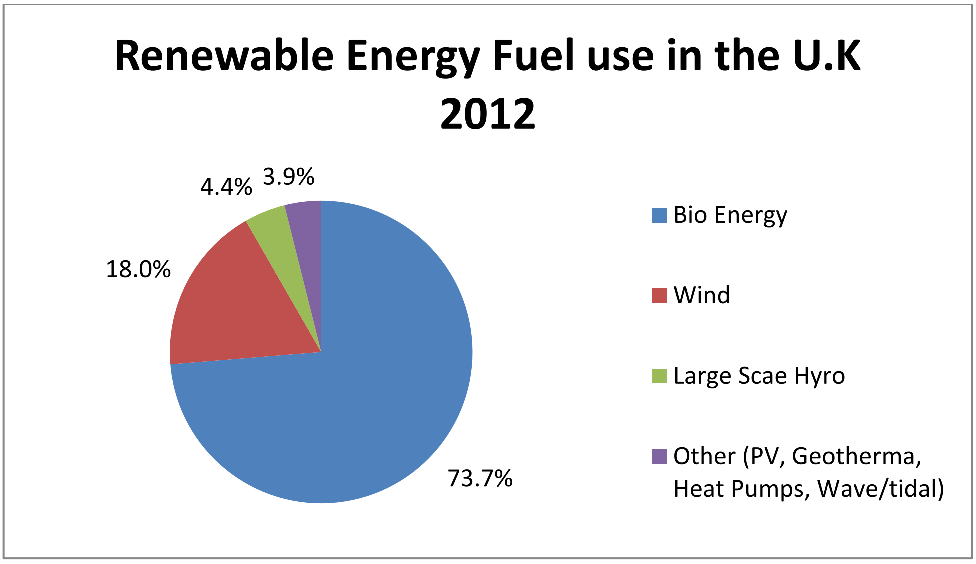


Figure 6.6 – Renewable Energy fuel use in the U.K in 2012 (Macleary et al, 2013)

For centuries this bioenergy in the form of biomass has been used for domestic heating, ranging from simple wood fires to the advanced wood pellet boilers which are in operation today. The biomass being used for domestic heating is a renewable fuel, as long as the reserves are not being used as fast as can be grown, and is being extensively used in Net Zero Carbon homes.

6.2.2 Fuel types

There are two main types of fuel which are used in advanced biomass boilers; wood chip and wood pellets. Wood chips are created by reducing a large piece of wood, such as a log, into smaller easier to handle pieces which increase the total surface meaning a higher burning efficiency than larger pieces. These wood chips can be easily created from recycled material which would otherwise go to waste. As for wood pellets these are constructed by compressing large amounts of wood by-products (like saw dust) and are more of a dense solid structure than wood chips. This solid dense structure allows the wood pellets to have moisture content of around 10% which is much lowe than the 20-30% usually found in wood chips. This lower moisture content allows wood pellets to burn more efficiently than wood chips, demonstrated in Table 6.3 by the higher calorific value.

Fuel Type	Net Calorific Value (kj/kg)
Wood Chip (30% Moisture)	3.55
Wood Chip (20% Moisture)	4.2
Wood pellets (10% Moisture)	4.8

Table 6.3 – Net calorific value of wood chips and wood pellets (Verojporn, 2012)

6.2.3 Types of advanced heating systems

Currently there are three main types of advanced biomass heating systems in operation, all of which generate heat through direct combustion occurring in the boiler: fully automatic, semi-automatic and pellet fired.

In fully automatic systems deliver trucks are used to deposit large quantities of wood chip into a storage tank then from these storage tanks the wood chips are transported to the boiler by the use of conveyor belts. A computer system is used to control when the boiler is operating and also how much wood chip is being transported from the storage tank to the boiler. These fully automatic systems are usually too complicated and expensive for a single house thus they are mostly used on large builders such as sports centres.

For smaller buildings semi-automatic systems are more common, these systems are of a similar style to the fully automatic systems but require some level of manual operation. In semi-automatic systems the storage tanks are much smaller and are usually filled manually with wood chip and also the conveyor belts are smaller as the storage tanks are closer to the boilers. In these systems instead of a complicated computer control system being used the boiler is controlled manually and the conveyor belt only transports the wood chip when the boiler is running. Also for smaller buildings pellet fired systems are common, in these systems the storage tanks are placed above the boiler and filled with wood pellets and like semi-automatic systems the boilers are controlled manually. As previous explained wood pellets are much denser and have a higher calorific value when compared with wood chips meaning the storage tank for these systems can be much smaller than semi-automatic systems. In these pellet fired systems instead of a conveyor belt being used the pellets are enter the boiler through the force of gravity.

6.2.4 Prototype Biomass system

The biomass system found in the prototype Net Zero Carbon home is a relatively simple… system. The boiler (pictured in Figure 6.7) is located in the main living area of the home and has a rated output of 2.3kW.

Figure 6.7 - The prototype biomass boiler

To determine if the boiler system installed in the prototype Net Zero Carbon home was suitable to heat the output of 2.3kW was compared to the heating demand for the full year taken from the esp-r of the home. The results from this are in the section below.

6.2.5 Results

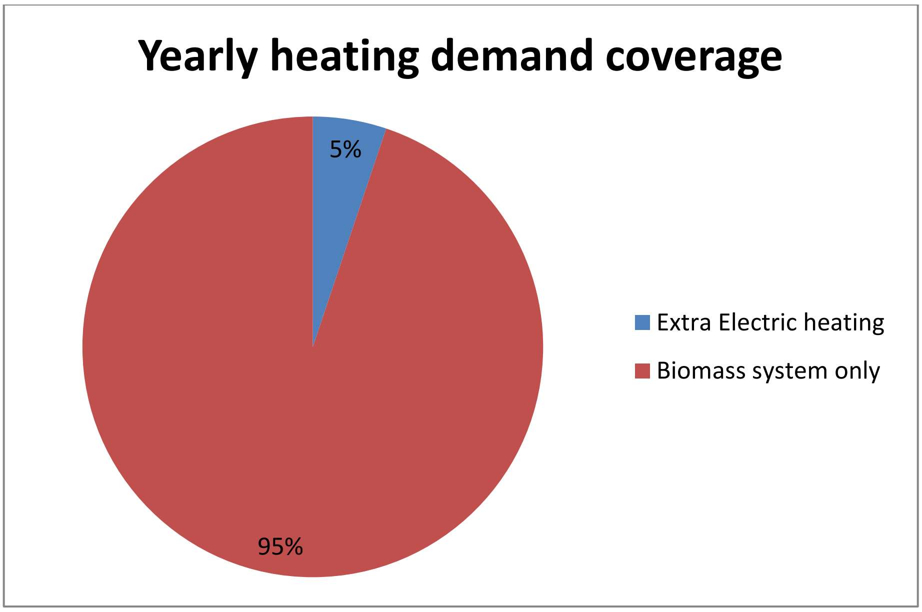


Figure 6.8 – Yearly heating demand coverage

6.2.6 Discussion

From Figure 6.8 it is demonstrated that throughout the period of a year the biomass system installed is able to cover 95% of the heating demand in the Net Zero Carbon house without the use of the installed electrical heaters. This is a very high percentage of the heating that the biomass system is able to cover and during the period of a year only 341.39kWh of electricity is needed for the heaters. From Table 6.1 it is determined that overall the PV system installed in the home generates and extra 409.51kWh of electricity than is actually used by the appliance etc so the extra heating demand can be added to this network and the home can still be determined to be Net Zero Carbon . Again the problem with this is that at the time when the majority of extra electrical heating is needed (in the winter and at night) is the time when the PV systems is not generation. Indicating that even more storage would be needed.

It has also been determined that the biomass system has been optimally sized for the prototype house. Several different sizes were trialled at it was determined that any biomass system under 2.3kW would mean that more than 409.5kWh of extra electricity would be needed to heat the home thus the house would not be able to be defined as Net Zero Carbon . Also there is no need for a larger biomass system as the 2.3Kw system is adequate as it covers 95% of the need and a larger system would only increase the cost to construct the house.

As the biomass boiler in the prototype Net Zero Carbon house has been correctly sized there is only one recommendation which can be made for future Net Zero Carbon housing. Which is to make use of simulation packages in the design stage to determine the heating load of a building before it has been constructed. This allows the biomass to be corrected size so that it is not over or undersized which could lead to problems in the future.

7. Pre-Occupancy and Continuous Evaluation (PCE)

The POCE testing method carried out in this report has been determined to be more advantageous when evaluation a Net Zero Carbon home when compared with the traditional POE. By testing at the pre-occupancy and pre-commissioning stage allowed for changes to be made to the building fabric to increase energy performance. This is especially evident with the building airtightness where the airtightness of the building was originally very poor for a Net Zero Carbon home, however by making several changes and testing the house several times the airtightness was increased dramatically to a high standard. If these tests were carried out post occupancy then the changes would be very difficult to make and the airtightness may not have been able to be increased to such a high standard. Also using this test method allowed it to be found that the house was prone to overheating at certain times in the summer. The tests for overheating were carried out over a period of several months and were continuous which allowed for different testing conditions, in a POE the time frame for testing may not have been as long thus the overheating may have been missed.

Another advantage of the testing method carried out was that it was not just the energy consumption which was measured to determine how good the energy performance of the building was. The airtightness, thermal losses and renewable energy systems were all measured which would not be part of a POE. Also, the use of computer simulations allowed for the energy demands of the home to be predicated which was very useful when testing the renewable energy systems. These computer simulations could also be used to determine how the home is operating in the real environment compared with the ideal environment but this is out the scope of this project.

It is because of these advantages that it is recommended that the evaluation method used for Net Zero Carbon homes should be a Pre-Commissioning and Continuous evaluation (POCE). As the project was only 3 months long a full continuous assessment could not be carried out but a layout test is demonstrated in Table 7.1 below:

Construction Stage	
Design stage	Modelling of home to predict the operating conditions and energy use
Pre-Commissioning	Test the Renewable systems of the home and predict there yearly output.
	Test the fabric of the house (airtightness/ thermal losses)
	Test the conditions of the house such as thermal comfort.
	Implement any changes needed and retest to demonstrate if they have increase the performance of the home.
Post Occupancy (Continuous Assessment) – These tests would ideally happen every year as that is the time scale for a the home to be carbon neutral	Assess if the homes energy consumptions and conditions are similar to the predicted values from the model
	Retest the renewable energy systems to demonstrate if they are operating as predicated
	Determine whether full time occupants have deteriorated the living conditions (thermal comfort/ moisture etc)
	Find if the airtightness/ thermal losses have been effected in anyway over time.
	Again make any necessary changes to the building to increase energy performance

Table 7.1- Test layout for a POCE

It is important to note that the test results from a POCE will have to be weighed in some way to give the overall picture of how the home is operating. The weighing will be unique for each property as they all have different needs and uses and the weighting should be determined before testing is carried out.

8. Conclusions and Further Work

The two main objects of this project were to test the performance of a prototype Net Zero Carbon home in Scotland and also to evaluate and improve current housing evaluation procedures so that they are more relevant to Net Zero Carbon housing.

It was determined through research that the current building evaluation technique of POE was not suitable for Net Zero Carbon housing and instead the idea of a Pre-Occupancy and Continuous Evaluation (POCE) was introduced. A POCE was then carried out on a prototype Net Zero Carbon house in Scotland were the thermal comfort, thermal losses, air tightness and renewable energy technologies were tested. It was found that during certain periods during the summer that the prototype house was prone to overheating, some recommendations so that this would not happen in future Net Zero Carbon housing but could not be implemented due to privacy reasons. As for the thermal losses there was found to be a small problem with the material used in construction as the wood on the exterior of the building was creating thermal bridges. Again like the thermal comfort recommendations were made for the future for improvements but could not be implemented on the prototype house. The air tightness was tested using a blower door and initially it was found that the air tightness of the home was $6.33m^3h^{-1}m^{-2}$ which is very low for a Net Zero Carbon building. But unlike for thermal comfort and thermal losses the recommendations made were implemented in the building and the air tightness was increased to $2.05m^3h^{-1}m^{-2}$ which is at the upper limit for a Net Zero Carbon building. As for the renewable energy systems these were tested and there output was determined which was compared with the housing electrical and heating demand generated by the use of different simulation packages (as real data could not be obtained). From this it was found that the prototype house can be classified as Net Zero Carbon because the net energy consumption, thus net carbon emissions, is zero over the period of a year.

By carrying out this evaluation method it was determined that it was more advantageous to use a POCE than a POE. The main reason for this being that as Net Zero Carbon houses are of very high standard they can be hard to construct and may have problems associated with them. But by testing before the house is occupied would allow for any problems to be fixed easier than they would be as at time when occupied some problems (i.e. insulation) would be very difficult to fix. As the period of this project was only 3 month a method for a full POCE was demonstrated to give an idea of how it would work in future.

The future work for this project would be to carry out a full POCE on the prototype Net Zero Carbon home which would require it to be occupied for a period of time. This would give full result and give information on whether or not the performance of the house deteriorates over time also, it would also demonstrated if the actual heating and electrical demand was similar to that determined by the simulation packages. Another part of the future work of this project would be implementing the recommendations made in this project and find if they increase the performance of the prototype Net Zero Carbon home.

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