Department of Mechanical and Aerospace Engineering

An investigation into potential of passive solar features to realise net zero carbon housing

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Abstract

The legislation is driving us towards the low carbon future, and the governments around the world are striving to achieve quite the targets. Scotland having the most ambitious targets is trying to explore all the available techniques to reduce the carbon emissions. One of the important technique to reduce the carbon emissions and to achieve the green building targets is to make the use of passive solar.

Passive solar techniques making the use of the solar energy can prove a boon for reducing the carbon emissions as there is no maintenance required and less investment. There are various passive solar techniques available, however it is important to use the appropriate technique depending on the conditions at the place, combination of the appropriate techniques may have enhanced savings in the energy.

This thesis tries to look into the potential of these techniques to achieve carbon savings and tries to explore the feasibility of these passive solar techniques to contribute towards achieving the goal of zero carbon housing.

To analyse the potential of these techniques, a model of a house representing a standard house in Scotland was created and its performance on the parameters of energy, CO_2 emissions and overheating was obtained. The standard house was the added with various passive solar techniques one by one and its performance was obtained based on the same parameters. The results obtained were then compared with those of a standard house.

Conclusion was made based on the results about the potential of these techniques to contribute towards achieving zero carbon housing.

Acknowledgements

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1. Introduction

The world is trying to reduce the carbon emissions which is driven by the legislation. Among all the countries of the world UK has the most ambitious targets. Of all the energy consumed in the world, domestic housing contributes to 30% – 40% of energy use and 1/3rd of carbon emissions. With the governments round the world looking forward to become sustainable and reduce the carbon emissions it is paramount importance to reduce the domestic energy use and promote low carbon housing. (council, n.d.)

With the aim to achieve low carbon targets there are various ways opted by the legislation like promotion of renewable energy on various scales, introduction of code for sustainable housing. But as energy for heating and cooling is one of the major part of domestic energy use and reduction of that energy can lead to significant reduction in carbon emission. Thus, increasing the energy efficiency of the building is very important. There is a potential to reduce the carbon emissions and energy use to a great extent using passive solar techniques which are quite simple and not much expensive compared to others. Although it is not known to what extent passive solar techniques will prove beneficial in achieving the targets looking at their overall performance, this thesis investigates the impact of various passive solar techniques in realizing zero carbon housing with the help of simulation.

2. Literature Review

2.1. Green Buildings

The U.S Environmental Protection Agency describes green building as “Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building.”

With increasing awareness about sustainability around the world, green buildings are seeing a rapid growth in the recent years. Green buildings are designed with the aim to reduce the impact on the environment, human health with maintaining the comfort level of built environment. (Agency, n.d.)

The various impacts on various aspects caused by the buildings on Environment can be categorised into,

- Utilisation of natural resources such as Land, Water, Wood etc.
- Utilisation of energy and carbon emissions
- Effect on the ecosystem.

2.2. Net zero carbon housing

Net Zero carbon house can be defined as the house which over a period of a year has net zero carbon emissions and net zero energy consumption. This is achieved by various methods like onsite renewable energy generation to increasing the energy efficiency of the house.

1. Grid Connected

These houses import energy from the grid at times of year when the energy generation from its sources is not able to sustain itself and export energy to the grid during the period when the energy produced by the onsite sources exceeds the demand.

2. Autonomous

These are the houses which are completely self-sufficient for their fulfilling their own energy demands form onsite renewable sources of energy. They are not connected to the grid and cannot import or export energy from grid in any circumstances. These kind of houses are best suites in the areas which lack grid infrastructure.

2.3. Legislation

The severe changes of climate change can be seen in all the places of the world and Scotland is not an exception to it. It is evident from the data that there is a rice of 0.5°C in Scotland since 1914 (Scotland, n.d.). Foreseeing the severe impacts due to climate change the world is strongly committed to reduce the carbon and slow down climate change.

Scotland has emerged as a leader with having the most ambitious goals to reduce the carbon levels by 80% till 2050 as compared to 1990 carbon levels also to have 100% of its net electricity through renewable sources (Legislation, n.d.). With all the factors such as legislation, politics and social awareness pushing towards reducing the carbon emissions various steps are taken by the government to achieve the same. The ways to put a step further to achieve these targets is to promote renewable energy production and to improve the energy efficiency.

The legislation is promoting renewable energy production on a large scale on various levels, on shore, domestic and off shore. With renewable energy not sufficient to attain the energy consumption needs and government striving to increase the energy production from them, increasing the energy efficiency can prove very helpful.

2.4. Current energy consumption

Almost 40% of UK carbon dioxide emissions come from buildings, and so reducing the building emissions and promoting Green buildings is an integral part of building regulations (Government, 2013). UK total energy consumption by sector statistics show that Buildings energy consumption accounts more than quarter of the total energy consumption in UK.

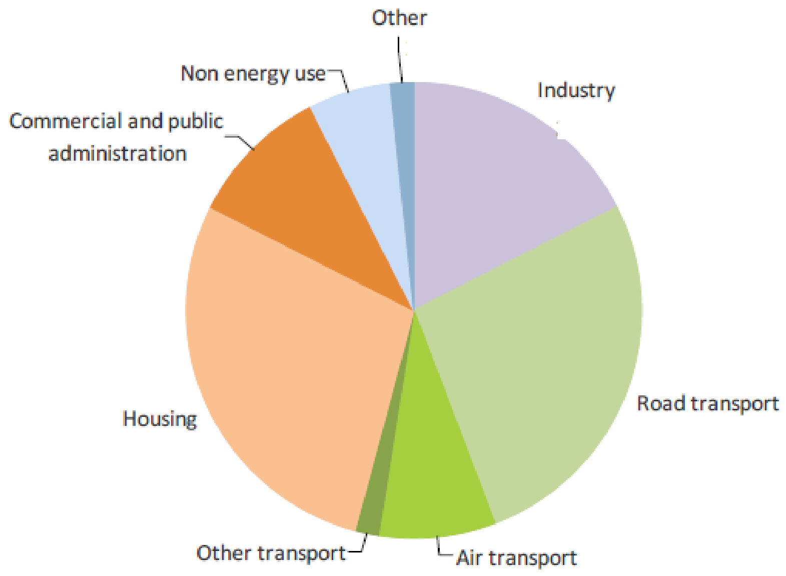

Figure 1 - Total Energy consumption by sector

The graph in the figure 1 shows the total energy consumption in UK according to sector. It can be seen from the graph that housing sector is one major energy consuming sector. It accounts to about more than a quarter the total energy consumption in UK. As the sector being one of the largest contributor to carbon emissions, there is a need to address the issue in the sector. *(Scotland, n.d.)*

2.5. Achievements in targets

The world working towards the transition to a low carbon environment, it can be still said that we are in the initial stages of the long journey. Scotland having the most ambitious targets in the world, is planning to have 50% renewable electricity by 2015 and 100% renewable electricity by 2020. The DECC (Department of energy and climate change shows that Scotland was successful in achieving 36.3% of its electricity demand using renewables by 2011 which has increased to 39% in 2012. This makes Scotland close enough to achieve its target of 50% renewable till 2015 and 100% till 2020.

Though achieving the target is not impossible, but it is a difficult job to achieve with increasing electricity demand. In order to achieve the targets it is necessary to work towards the goal collectively with all the efforts not only to increase the renewable energy production but also to improve the efficiency of the current systems and reducing the energy demand to an extent possible. With the building sector consuming the maximum electricity of the total electricity consumption. In order to achieve the goal Scotland has been working towards increasing energy efficiency of the building by improving the building regulations standards.

Policies such as Green Deal were introduced to promote energy efficiency. According to the deal the cost of retrofit the house in order to improve its efficiency was given upfront and was to be paid in instalments in the future which didn't exceed the savings. Also, two-thirds of cavity walls have already been insulated and annual loft insulation rates more than doubled between 2008-09 and 2011-12. (Government, 2013)

2.6. Code for sustainable housing

Code for sustainable housing was developed by the UK government with the aim to reduce the carbon emissions. This gave directives to achieve low carbon housing which was based on 9 measures for sustainable design. The 9 measures of sustainable housing are;

1. energy/CO_2
2. water
3. materials
4. surface water runoff (flooding and flood prevention)
5. waste
6. pollution
7. health and well-being
8. management
9. ecology

A rating of points ranging 1-6 is given to a building based on the above aspects. The buildings are required to have a minimum rating of the building as specified by the local government. A building standard of 3 rating is incorporated in the building regulations and the builders are required to maintain the minimum standard. (government, n.d.)

2.7. Passive solar techniques

Passive solar makes use of solar energy without any use of mechanical systems for the purpose of heating, cooling and ventilation. Passive solar design is nothing but making use of direct heat from the sun. This technique lets the heat from the sun into the house during the winter days and blocks the heat during the summer. The solar gain of the house can be increased by making simple changes to the housing design like changing the size of the windows, changing the thermal mass of the walls, or introduction of windows on the roof. It can also be done by introduction of some passive solar techniques like trombe wall or introduction of water wall to increase the thermal mass.

All the passive solar techniques will have a different behaviour depending on the geographic location and depending on the weather conditions. It is very crucial to implement the right one at the right place and determining the right one is very important. With proper use of these techniques, the issues of heating, cooling, ventilation and lighting can be addressed.

Some of the factors in building design and construction that affect the energy consumption of the building to great extent are;

1. Glazing
2. Window size and location
3. Thermal mass of the house
4. Air infiltration rate
5. Heat recovery
6. Movable insulation
7. Shading
8. Phase change materials
9. Trombe wall

10. Water wall
11. Solar chimney

These mentioned passive solar techniques and their significance is described in the following part of the thesis,

Glazing

Efficient glazing allows the solar radiation into the space but restricts the heat loss through it. There are various types of glazing which do the same work but with different efficiency, for example single glazing, double glazing, and triple glazing.

With the U-value of the glass decreasing with more glazing or low-e coating etc. the solar losses are decreased. The table below shows general U-values of the glasses,

Table 1 - U-values of Glass

Type	U-value W/m^2K
Single glazing	5.0
Double glazing	3.0
Triple glazing	2.2
Double glazing with low-e coating	1.7
Double glazing with low-e coating and Argon filled	1.3
Triple–glazing with multiple low–e coatings and Xenon filled	0.4

Window size and location

Altering the size of window has a significant impact on the solar gains as well as on the heat loss. The location of the window is very important and should be positioned in the right direction to maximize the solar gain. In places like Scotland a south facing window will prove a lot more beneficial than a north facing one, on contrary in Australia the opposite will be a better thing to do.

Thermal mass of the house

Thermal mass is a vital component in passive solar design. A house with more thermal mass absorbs and stores the incident solar energy and emits it later when the temperature in the building drops. This also helps stabilise the indoor temperature of the building as it does not react to the change in temperature instantaneously. (Bruce Haglund, 1996)

.This proves beneficial mostly in cold climates where the solar heat is absorbed by the material during the day and the absorbed heat is released during the night making the ambiance more comfortable. (Merthyr Tydfil County Borough Council, 2006)

Air infiltration rate

Maintaining a balance in the air infiltration to promote the required ventilation and reduce the heat losses is a very important task. An infiltration rate of about 0.35 – 0.50 ACH is generally considered good. Higher infiltration rates may prove beneficial in warm climates to reduce the temperature but is subject to dependence on various other factors. Increasing the air tightness proves quite beneficial for energy conservation but above certain level it may deteriorate the quality of the air. Also in passive solar houses, if a proper ventilation is not maintained the possibility of overheating of the house rises. (Passive Solar Industrtes Council, n.d.)

Sunspace

Sunspace is a room or an area in a house having glass roof and walls which promote the flow of solar gain into the building. It is generally built on the south side of the house to promote maximum intake of solar gain. It not only promotes solar gains but also increases the light gains into the building. The space can be a good option to grow some plants and vegetables as it has access to light and air.

With proper utilisation of sunspace made to harvest solar energy, a large amount of heating energy demands of the house can be minimised with maintaining good comfort levels for the user.

Water wall

Thermal mass plays an important role in temperature distribution in a building. It can be seen that the houses with the buildings high thermal mass absorb the incident heat during the day and help keep the dwelling cool and release the absorbed heat during the night maintaining a pleasant temperature and good comfort levels for living in. The issue arising in constructing buildings with high thermal mass is the huge amount of cost involved and large quantity of material required for building them.

The issue can be solved by using materials with high density providing a good thermal mass. Using water is one of the best way to do that.

Water wall is a passive solar technique used while building energy efficient house with the aim to increase the thermal mass of the walls. This technique proves beneficial to store the incident solar energy. These walls prove an advantage as they not only do the work of collection but also of storage of the incident solar energy. They have a long life and can be made of energy in-expensive materials. They also prove relatively less expensive than using phase change materials.

Trombe wall

Trombe wall is a passive solar technique which makes use of the solar heat gains to heat the zone beside it. These are built generally on the south direction a few inches away from the wall. Two openings are provided to the wall one on the lower side and the other on the upper side of the wall. The air between the glazing and the wall gets heated up due to induced solar radiation on the glazing, the hot air then rises and enters the zone beside through the opening available, on the other hand the relatively cold air from the zone is forced in the trombe wall which is then heated and a flow of air is set up.

The trombe wall gets heated slowly over a period of time during the day and cools down slowly at night keeping the room warm and also maintaining airflow. The picture in the figure 2 shows a trombe wall and the flow of air.

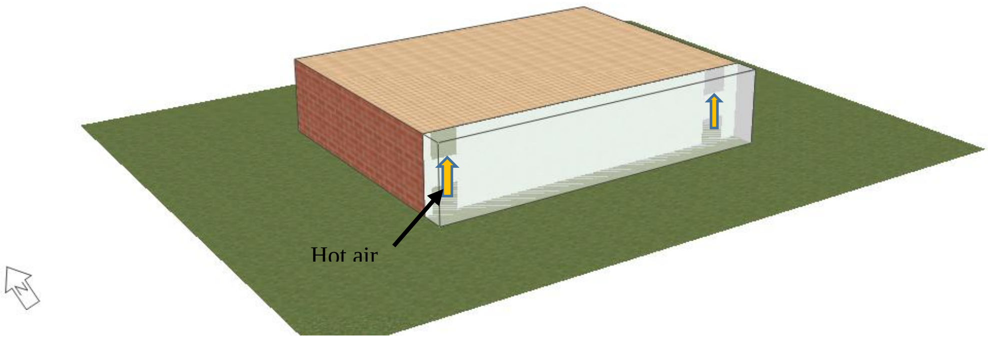

Figure 2 - Trombe wall

Shading

Shading devices block the direct solar gains to prevent over heating of the houses. They prove beneficial to avoid over heating of the houses due to excessive solar gains. Without the shading devices there might be a problem of excessive heat transfer through the windows during winter nights and summer days. Though the windows and glazing is smartly designed, with variation in the weather conditions there might arise the necessity of allowing or blocking the inflow or outflow of the gains which can easily be done using shading.

3. Methodology

3.1. Introduction

With increasing awareness to reduce the carbon emissions find the extent of the effect of various passive solar techniques on the energy consumption of the house, a house model representing a typical house in Scotland was modelled and simulated with various passive solar techniques. The result of which were analysed to find the extent of their impact. The model represents a house built with par to 2013 building regulations as the base case. Further changes were made to it with introduction of various passive solar techniques individually and with combination to get the results to reach some conclusion.

3.2. Modelling

The housing in Scotland is widely diversified and the houses are of different types. There are 2,488,496 houses in Scotland considering 2010 national statistics. All the flats in Scotland can be divided in four different types,

- Flats
- Terraced
- Semi-detached
- Detached

Considering the number of dwellings, Flats and Detached houses are becoming more popular recently with flats popular in the urban areas and detached houses in the other areas (NATIONAL RECORDS , 2011). Flats being compact have less external wall area as compared to the floor area, and it is significant as the heating energy is directly proportional to the area of external wall and that of the windows. Thus, the loss or gain of heat form and to the external sources is minimal and the flat are highly dependent on mechanical systems.

This is completely opposite in case of detached houses, there is a potential of huge energy gain because of large external wall area and the windows, although there can be great loss of energy through the same. Thus, the design and architecture plays a very important role in detached house, and has a significant effect on the energy consumption of the house (Jason Palmer, 2011).

Considering the sensitivity of detached houses to energy and they being the most popular in Scotland in the recent times, the model will be a detached house with 2 bedrooms, living room and kitchen. The model will be simulated with various passive solar techniques to assess their impacts on the energy consumption of the housing.

The population distribution in the houses across Scotland was quite diverse with some houses occupied by retired couples, some by working professionals while others by young families. The data showed though the distribution was diverse but it showed most number working professionals preferred for flats while old couple preferred house in remote rural areas, the families occupied most of the detached houses .It was also found that most of the families in Scotland had on an average 4 members in the family consisting 2 adults and 2 kids. Thus, it was found that a detached house for a family of 4 represents a typical house in Scotland also this was the one which had the most impact on the energy usage. So, this house was selected as the base model.

Considering the literature review and defining the important parameters for the house a house model representing a house with two bedrooms, living room and kitchen was modelled using IES. Constructing a model was the most important part of the thesis as the effect of various changes had to be simulated on the model.

3.3. Assumptions

During the research for the project the following assumptions were made;

- The house had all electric heating and no gas was used for the purpose of heating.
- Only heating loads are considered in this thesis.
- The house was built using 2013 building standards and the construction material used satisfied the standards.
- The house consisted a family of 4 with 2 adults and 2 kids.
- Both the bedrooms in the house had same zone conditions.

3.4. Software

The thesis had to analyse the effects of various passive solar techniques and the heat transfer, Energy consumption and carbon emissions involved commercial code IES was used. The software lets the user design a model to the requirements and allows to test various design options and helps to compare aspects like passive solar design, carbon emissions involved, energy consumption, occupant comfort etc.

The use of this software was made to obtain results for various scenarios and compare them in the thesis.

3.5. Analysis

A model was built with the required specifications of the geometry in IES software. Construction materials were assigned as per the requirements and other systems were specified. The house had some internal gains from light, humans and other activities occurring in the house, these gains were considered.

The heating and cooling systems in the house were defined. Also the as it is not practical and energy efficient as well to keep the heating continuously on, various habits of users on heating controls were looked at and the most energy efficient of all was chosen for the analysis as the thesis is looking at additional energy savings towards zero carbon if coupled with current best practices.

The results were analysed to find the reduction in the energy use for heating purposes and the amount of reduction in CO_2 was calculated. The results of the base case were compared with the other results to find the percentage savings in the energy consumption and carbon savings.

4. Simulation

For analysing the effects of the passive solar techniques on the house and to analyse the extent to which energy savings can be achieved, the thesis considerers a standard house made with the 2013 building regulations and various passive solar techniques were applied to the house in individually and in combination to look at the energy savings that can be achieved by making appropriate use of the passive solar techniques.

It was quite important part of the thesis to select a house which would represent a typical house in Scotland built with the most recent building regulations. A model which represents the house was created in IES. Simulation was carried on the model based on the weather data of Test Reference Year (TRY) and the results were obtained.

4.1. Model geometry

The standard model was constructed based on the statistical data to represent a typical house built in 2013, with occupancy of a family of four with two adults and two kids. The construction material used was according to the 2013. The widows were made of double glazing and the house had a pitched roof. The house had internal height of 3m. The house had a floor area of 197.25 m^2 and external wall area of 140.2173 m^2. The house consisted of a living room, a kitchen and two bedrooms. With the kitchen and the bedrooms in the south and living room in the north side. Windows were provided as standards for each room to allow sufficient light and air flow when necessary.

Base model which was built using the 2013 building standards was modelled, the specifications of which are described in section 4 of the thesis. The model will be used as a standard current scenario of the house and will be used to compare the results of the models with installed passive solar techniques to find the energy savings and the resultant carbon savings. The model was then simulated dynamically and results of various parameters were obtained.

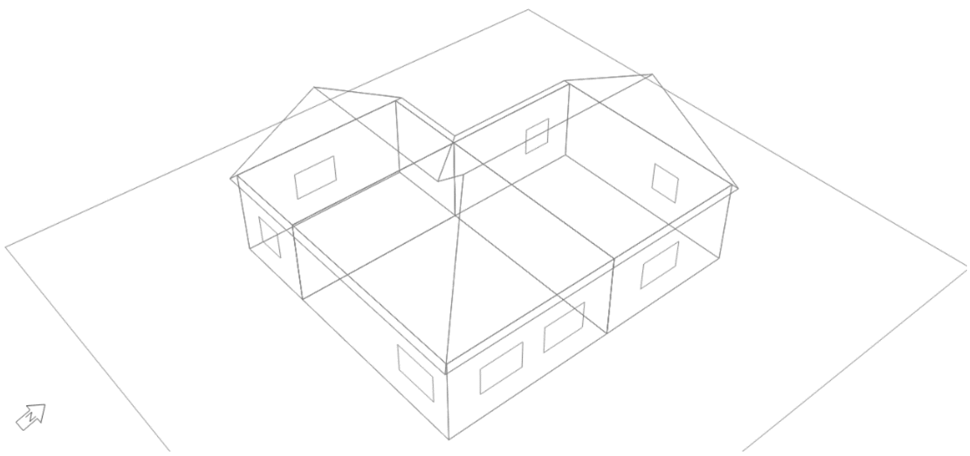

Figure 3 - Wire frame of model house

4.2. Model Constructions

The construction materials play an important role in altering the thermal behaviour of the house. As the thesis tries to look at the extent to which zero carbon can be achieved using the buildings built using 2013 standards. The construction materials used in the building was at par with 2013 building standards.

The characteristics of the standard model created are given in the table below,

Table 2 - Building material properties

Category	**Description**	**U value ($W/m^2 \cdot K$)**	**Thickness (mm)**
Internal Ceiling/Floor	2013 Internal Ceiling/Floor	1.0477	282.5
Door	2013 Door	2.1659	37
External Window	2013 External Window	1.5652	24
Ground/Exposed Floor	2013 Exposed Floor	0.2226	268.2
Internal Window	2013 Internal Window	4.1409	0
Internal Partition	2013 Internal Partition	1.8754	75
Roof	2013 Roof	0.1794	317
External Wall	2013 External Wall	0.2594	208.9

The U-values of the above mentioned materials satisfied the current building standards. The windows were double glazed. The external walls had a thermal mass of 21.9500 kJ/ (m^2.K).

The house is had natural ventilation and with windows closed had the air infiltration rate of 0.25 ACH.

4.3. Control System

A control system was introduced for heating and cooling which had a heating pattern from 6am to 10 am and 5pm to 10 pm which was designed for moderate use of energy. The heating system is powered completely using electricity and no gas is considered in the model. The heating and cooling set points are set at 19°C and 23°C respectively. A control system was also designed for opening and closing windows which was used as per the need.

4.4. Solar shading

Solar shading was one of the most important aspect of the project. It was important to calculate the angle of the sun over a period of year with respect to the location of the house. Designing the windows to increase solar gains during winter and reduce during summer is one of the key criteria to build a self-sufficient passive solar house. Looking at the solar calculations for Glasgow, the solar window was identified to be between 9am to 4pm. This is the time between sun shine is incident on the house throughout the year.

4.5. Weather Data

Weather data was the most important input for simulation. The data was derived from ASHRAE climate data base. The data used was for the UK Test Reference Year 1964, which represents the average weather over years. As the location selected was in Glasgow, the test weather data was selected for Glasgow.

The figure 3 shows the temperature distribution of the selected location over a period of one test year.

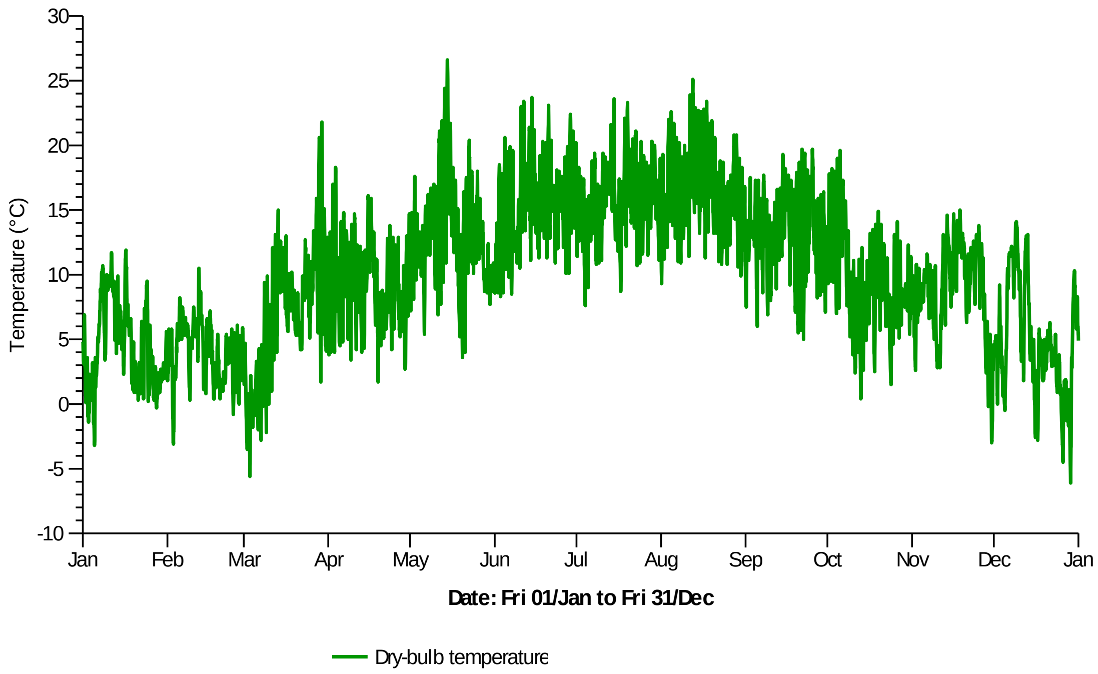

Figure 4 – Graph of annual weather temperature

5. Results

5.1. Standard house

The simulation results of the standard house were obtained after simulation of the model. The results of the considered parameters like temperature distribution, solar gains, energy consumption and CO_2 are discussed below.

Temperature distribution

With the house simulated with the above mentioned specifications the temperature distribution of different rooms is analysed to look at the maximum and minimum temperatures reached in the respective rooms.

The graph below shows the temperature distribution over a period of one test year for the bedroom,

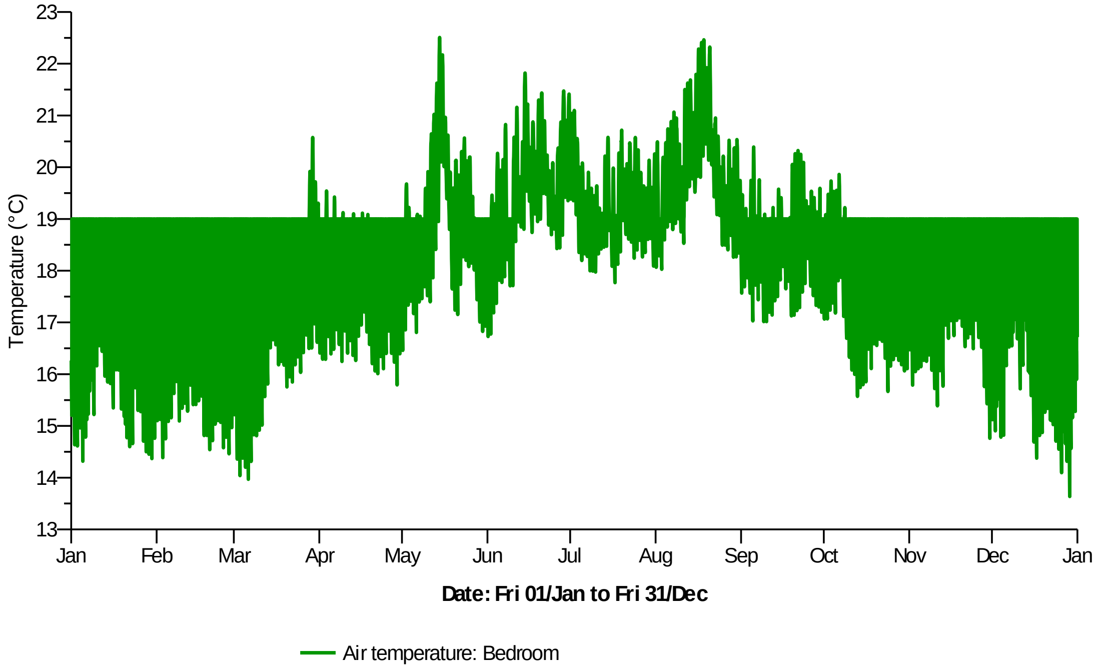

Figure 5 - Temperature distribution in bedroom in a standard house

It can be seen in the graph in figure 5 that the temperatures in the house are in the range of 14°C to 23°C, which is in a comfort zone. There is no overheating seen in the room. The room air temperatures for the living room and the kitchen are analysed as well, the temperature distribution graph of the kitchen and the living room are shown in the figure 6 below,

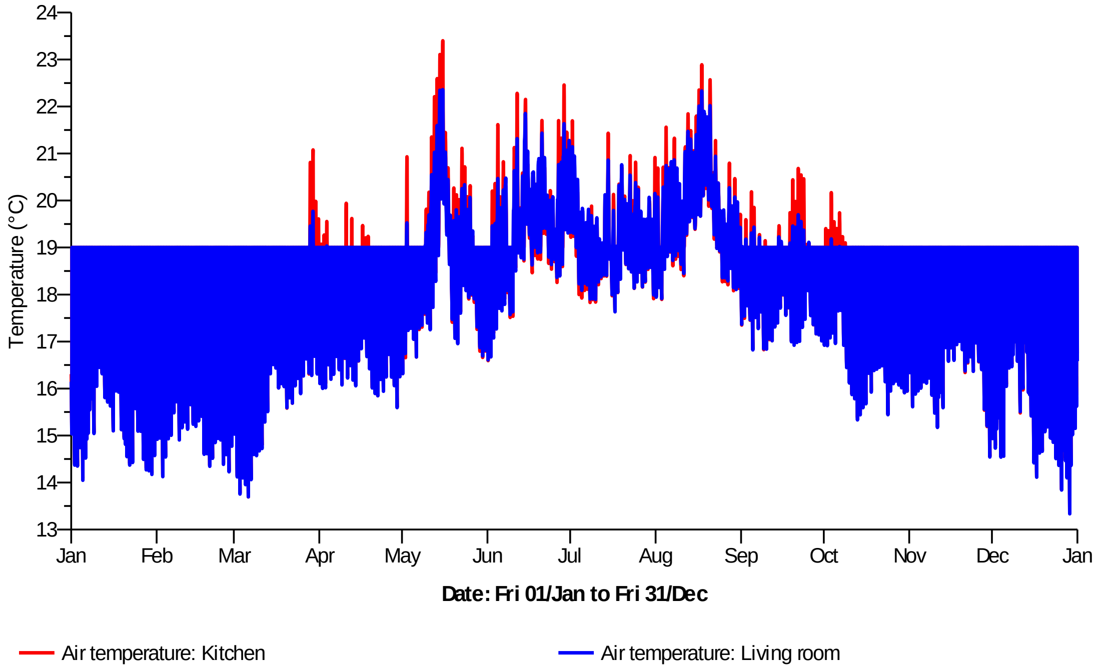

Figure 6 - Temperature distribution in kitchen and living room in a standard house

It can be seen that the temperature distribution is similar in pattern, however the temperatures in the living room are slightly lower than the other rooms. This is due to low solar as the living room is situated on the north side of the building.

Solar gains

The solar gains of the house over a period of year were also analysed. It can be seen that the profile of solar gains over a period of year is not constant and shows a lot of non-uniformities. This is because of the weather conditions at the selected location which shows a lot of variation. Although the solar gains vary a lot over time, it can be seen that there is a noticeable increase in the solar gains during the months of April to September. Although peaks can be seen distributed all-round the year the density of solar gains is more during the period of April to September.

The distribution of solar gains can be seen in the figure 7 below,

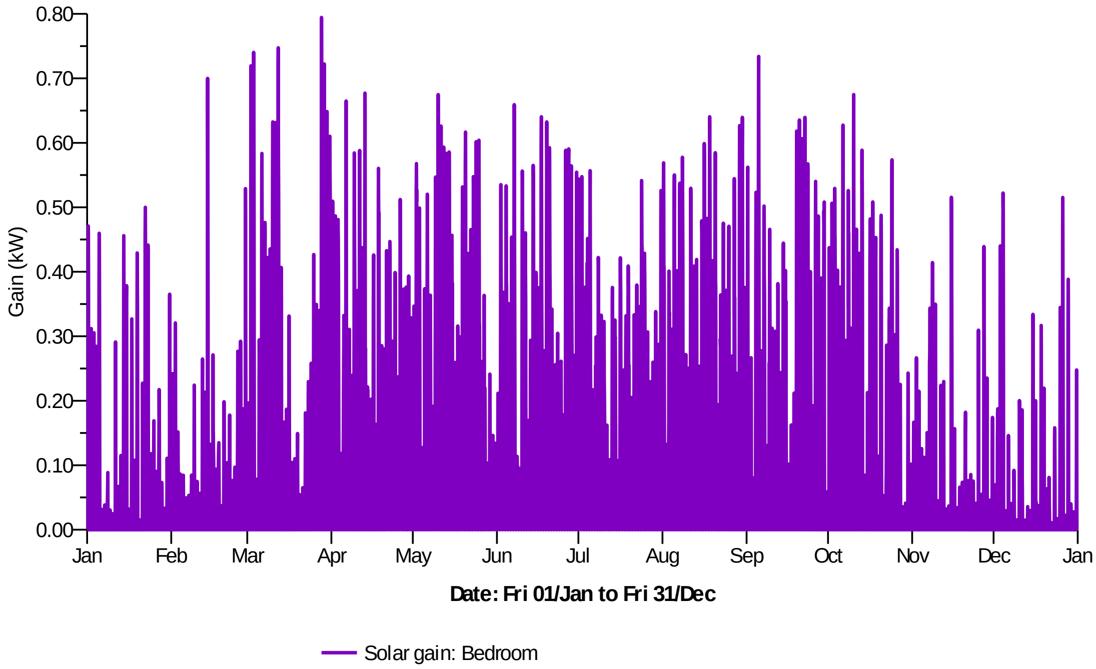

Figure 7 - Solar gains in south facing bedroom in a standard house

The monthly summation of the incident solar gains can be seen in the above graph with maximum and minimum amount of solar gains at different times in a year.

Table 3 - Solar gains in different zones in a standard house

Months	**Kitchen Solar gain (MWh)**	**Living room Solar gain (MWh)**	**Bedroom Solar gain (MWh)**	
Jan	0.0056	0.011	0.0297	
Feb	0.0068	0.0158	0.0258	
Mar	0.0223	0.0427	0.0761	
Apr	0.0309	0.0575	0.0809	
May	0.0394	0.0845	0.105	
Jun	0.037	0.0824	0.0995	
Jul	0.0302	0.0687	0.0834	
Aug	0.0313	0.0726	0.0978	
Sep	0.0231	0.0477	0.0756	
Oct	0.0184	0.0299	0.0622	
Nov	0.0066	0.011	0.0246	
Dec	0.0042	0.0075	0.0225	
Summed total	**0.2558**	**0.5314**	**0.7831**	**1.5703**

Energy Consumption

The energy consumption of the house for a year is obtained by dynamic simulation of the model, the graph shows the distribution of energy use.

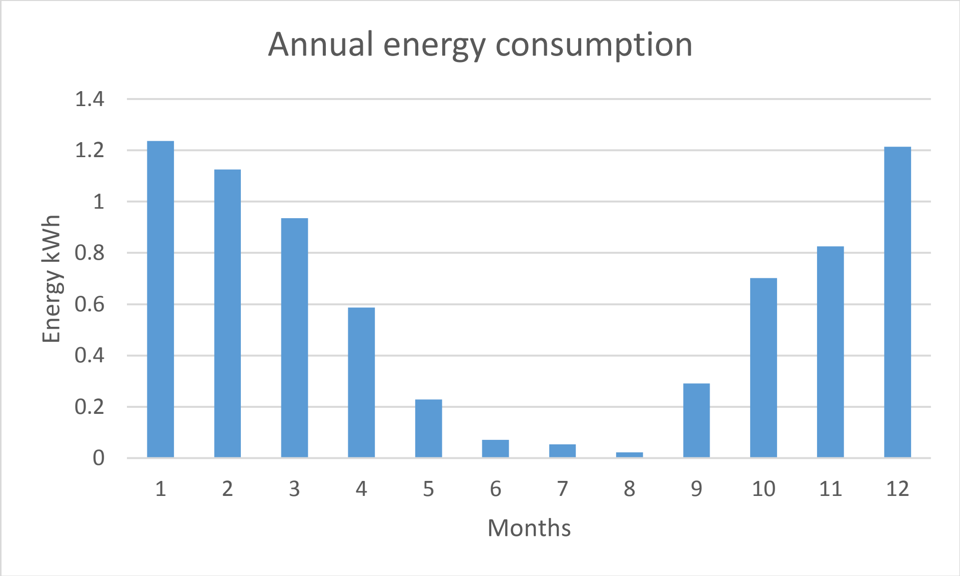

Figure 8 - Annual energy consumption in a standard house

The above graph shows the distribution of energy consumption over a period of a year. It can be seen as the weather in the location has a cold climate most of the loads are the heating loads and the consumption increases in the winter as compared to summer. The annual summation of energy consumption by the house for heating is 7.29MWh.

It was kept in consideration that the comfort level of the user is not compromised while setting the controls. The temperatures in the house are always in between a range of 14°C to 25°C. A heating and cooling set points set at 19°C and 23°C.

Carbon Emissions

The above values thus represent consumption of a typical house with annual energy consumption of 7.29 MWh. With this energy consumption the house contributed to 7568 kgCO_2 emissions in a year. The graph below shows the distribution of carbon emissions for a period of year.

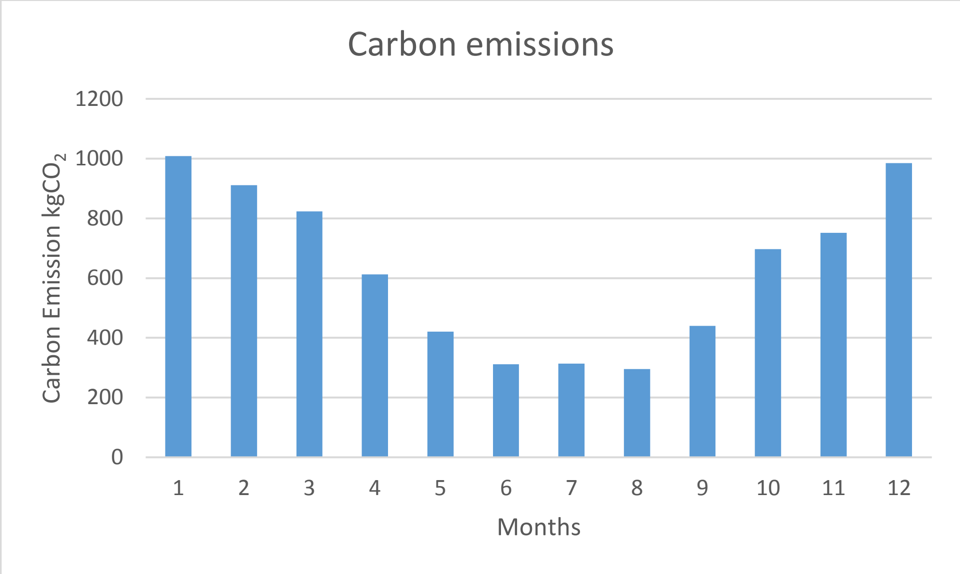

Figure 9 - Carbon emissions of a standard house

To attain the targets of 100% zero carbon it is necessary to reduce the carbon emissions to the maximum possible level. With no changes made to the standard building and no special features applied the house had 1.83 MWh solar gains which had a potential to reduce the energy consumption of the house and contribute to reduce the carbon emissions. Though the amount of solar gain is not sufficient for making the house zero carbon, the solar gain can be increased by introducing passive solar techniques. Carbon emissions in a year are found to be 7568 $kgCO_2$

The effect on the solar gain by introducing passive solar techniques and its effects on various other aspects like room temperature, energy consumption and comfort level are discussed in the later part of the thesis.

5.2. House with Sun Space

To analyse the impacts of introduction of various passive solar techniques, the base model was modified and a sunspace was added to it on the south side. The construction of the external wall was kept the same. Sunspace of width 1m and height 3m was built across the bedrooms and the kitchen. The volume of air in sunspace is $30m^3$. The sun space was made with a standard glass with a U-value of 1.565 W/m^2K .The model was then simulated using the same weather data and the same control system to find the increase in utilisation of the solar gains.

The below model shows the wire frame diagram of the house with an attached sun space in the south side.

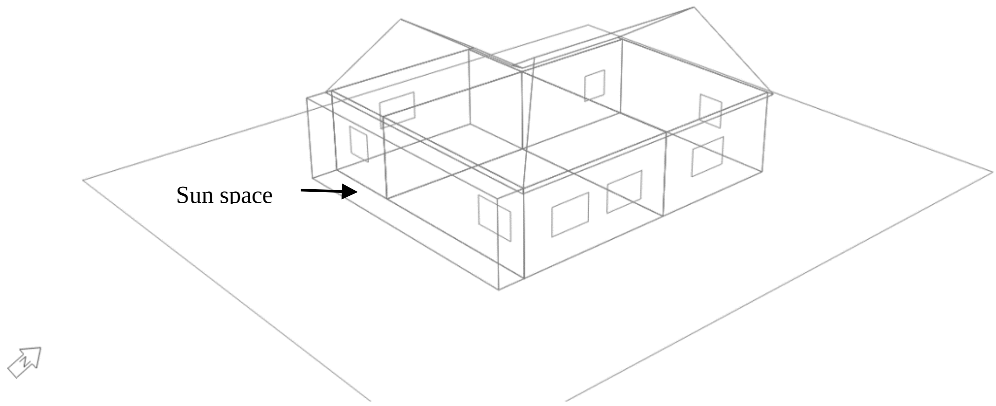

Figure 10 - Wireframe of house with sunspace

Temperature distribution

To assess the temperature distribution of the house after adding a sunspace to it on the south side and to look at the effect of increase temperature due to the increase in the gains.

There was a potential problem of overheating after the addition of sunspace to the house which could degrade the comfort levels of the house or would increase the cooling load. Thus, to analyse the issue of overheating, the results were analysed to find out the number of hours the temperature in the house was above 25°C. It was seen in the base model that the temperatures in all the rooms were in the range of 14°C to 25°C.

The temperature profile of the bedroom shows the distribution of temperature for a period of year,

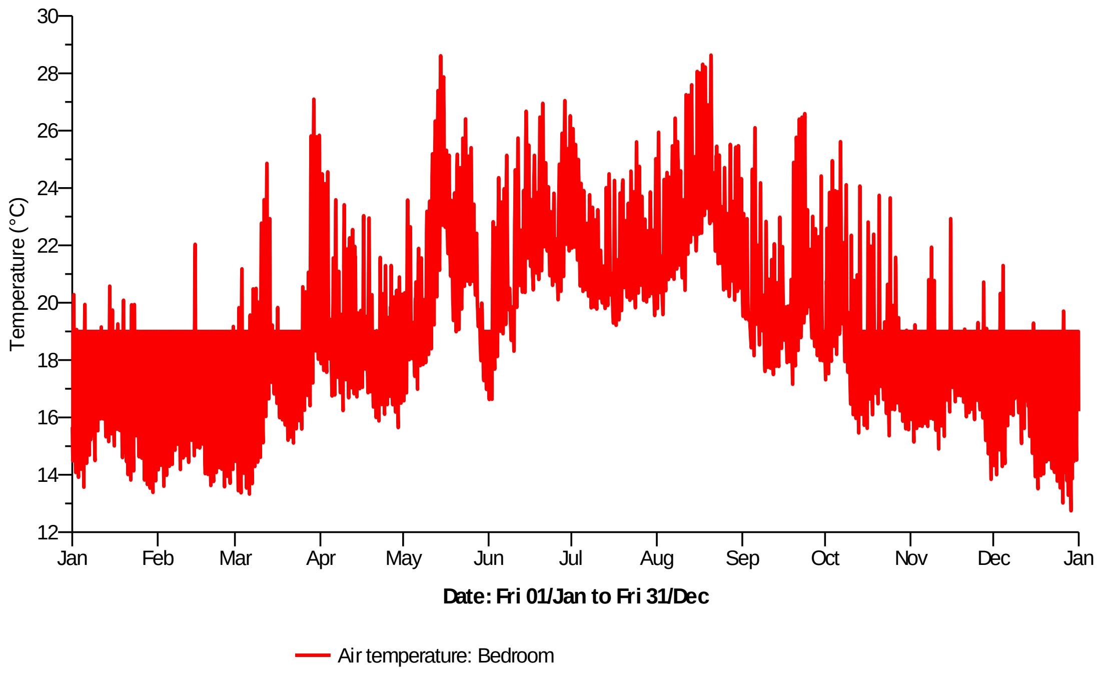

Figure 11 - Air temperature in bedroom of a house with sunspace

It can be seen in the graph that the temperature in the bedroom has reached above 28°C and the total time the room air temperature was above 25°C is 326 hours. The temperature in the kitchen and the living room are analysed as well to see the effect of sunspace on them. The temperature distribution of kitchen and living room is plotted in the graph of the temperature distribution can be seen in the figure 12 below,

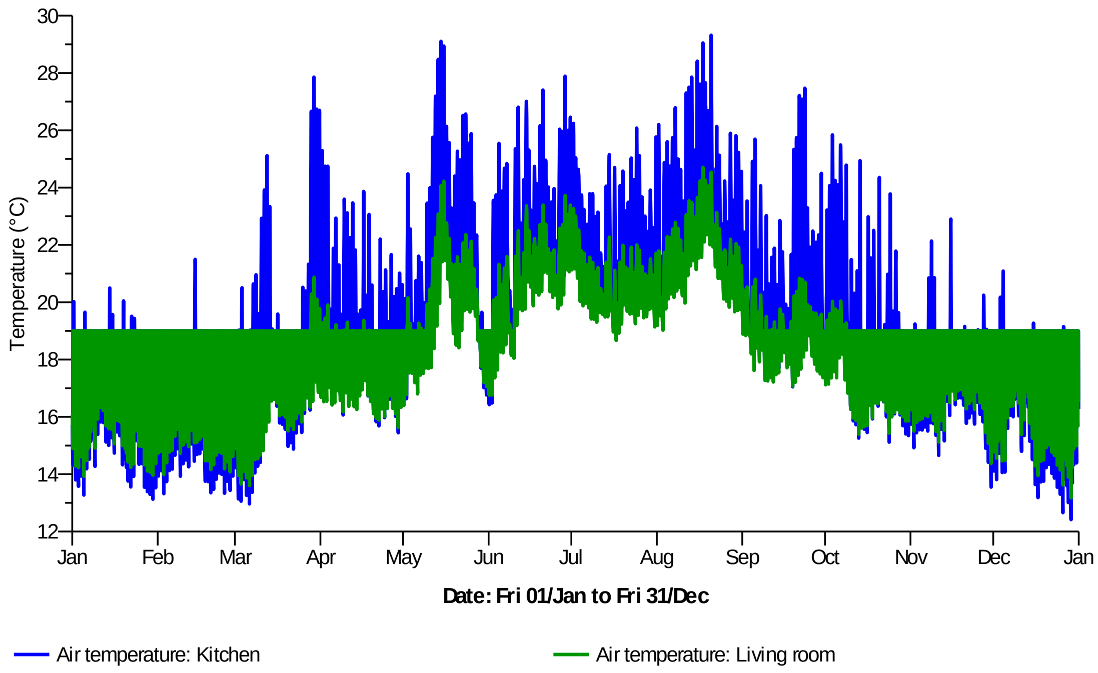

Figure 12 - Air temperature in kitchen and living room of a house with sunspace

It can be seen in the figure above that the temperature in the kitchen is similar as that in the bedrooms, however the temperature in the living room is less with respect to the bedrooms and the kitchen. The temperature in the kitchen show that the temperatures are above period of 25°C for time period of 371 hours. Which shows that there is problem of overheating of the bedroom and kitchen with 326 hours and 371 hours respectively.

Within the sunspace, the temperature increase much higher level due to inflow of large amount of solar energy. The graph in the figure 13 below shows the temperature distribution profile of the sunspace.

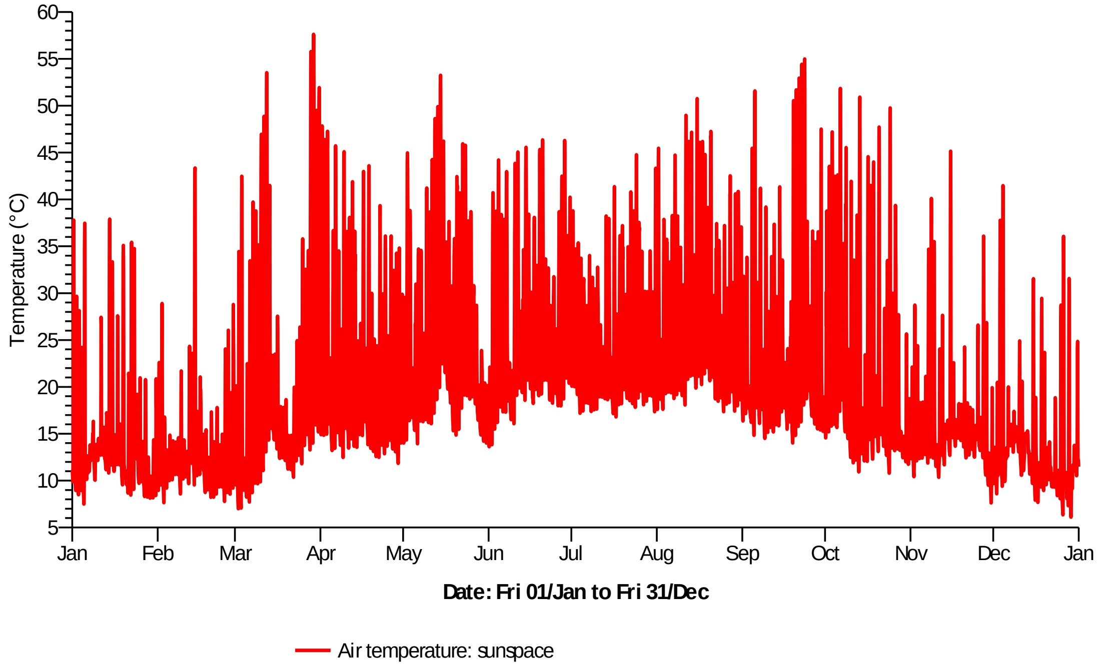

Figure 13 - Air temperature in sunspace

It is seen that the temperatures in the sunspace reach as high as 58°C during the times of high solar gains. The temperatures are higher than 25°C for 1880 hours in a year

Solar gains

The results obtained from the model show the increase in solar gain which was transmitted through walls into the house. Rise in the temperatures of the bedroom and kitchen is also seen. The solar gains for the kitchen, bedroom and the living room are shown in the table 4 below,

Table 4 - Solar gains for different zones

Month	Kitchen Solar gain (MWh)	Living room Solar gain (MWh)	Bedroom Solar gain (MWh)	
Jan	0.0112	0.011	0.0204	
Feb	0.0104	0.0158	0.0213	
Mar	0.0348	0.0427	0.0616	
Apr	0.042	0.0575	0.0702	
May	0.0489	0.0845	0.1016	
Jun	0.0448	0.0824	0.097	
Jul	0.0376	0.0687	0.0793	
Aug	0.0413	0.0726	0.094	
Sep	0.0341	0.0477	0.0646	
Oct	0.0299	0.0299	0.0449	
Nov	0.0111	0.011	0.0171	
Dec	0.0087	0.0075	0.0148	
Summed total	**0.3548**	**0.5314**	**0.687**	**1.5732**

It can be seen in the table 4 that the maximum amount of solar gain is received by the living room and the kitchen. Thus receiving the most amount of solar gain and having an attached sun space both the kitchen and the living room face the problem of overheating.

Energy Consumption

The addition of sunspace on the south side has an effect on the energy consumption of the room as a large amount of solar energy is been harvested using the sunspace and transmitted to the dwelling. The result of which the energy required for heating is decreased, and the annual energy consumption of the dwelling is reduced to

6.68 MWh. The graph showing the annual energy consumption can be seen in the figure 14 below,

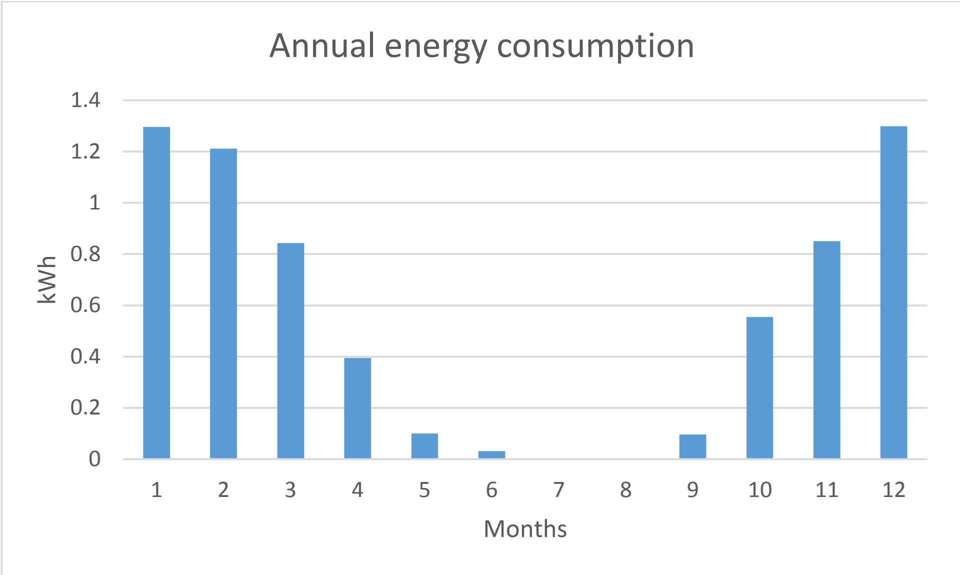

Figure 14 - Annual energy consumption for a house with sunspace

Carbon emissions

The house is the same model as the base model but has an additional sun space. Which results in reduction of the energy consumption to 6.68 MWh and reduce the carbon emission to 7210 $kgCO_2$. The reduction of carbon emissions is relative to the energy consumption and can be seen in the graph in the figure 15 below

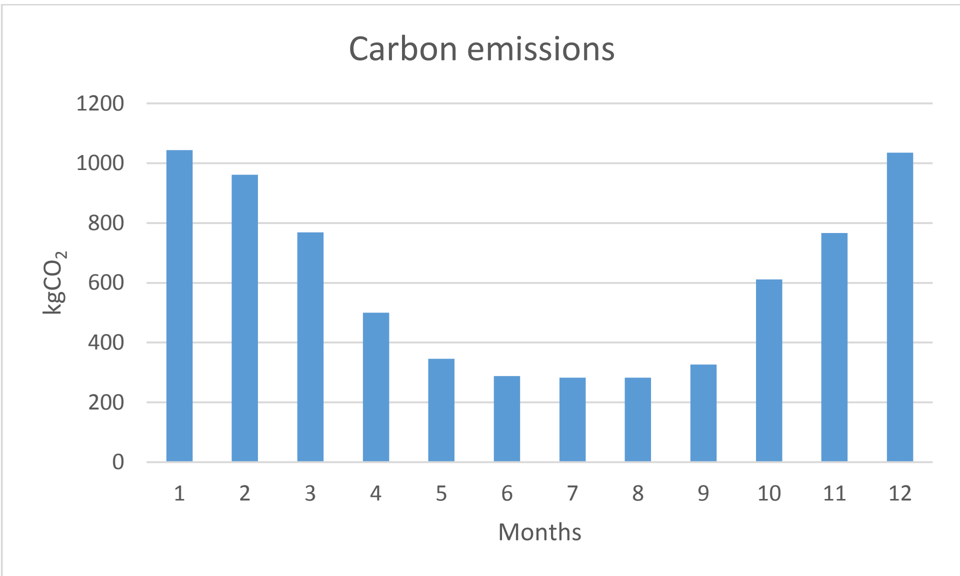

Figure 15 - Carbon emissions in house with sunspace

The amount of CO_2 saved accounts to 4.74% saving in carbon over a period of year from one house.

5.3. House with a Water wall

One of the passive solar technique as discussed in the previously in the thesis is building a water wall to increase the thermal mass of the building. A water wall of width 300 mm was built across the external wall of the house. Simulation was of the house with the water wall was done using the same weather and same system controls. The heating and cooling profiles were kept same as in the base case, also the heating set point was set to 19°C as in the base case. The weather data selected for the house was at Glasgow with weather data used was for the test year.

The results were obtained after simulating the model which are discussed in detail below,

Temperature distribution

The model being modified and water wall being added to it, there was a considerable change in the temperature distribution profile. It is seen that the difference between the maximum and the minimum temperatures around the period of year is smaller as compared to the previous models. This change can be seen due to the increase of thermal mass of the dwelling, which promotes the storage of the incident solar energy into itself and release the energy during night when it is relatively cold. The temperatures are found to be in the range of 15.5°C to 21.3°C. A graph of temperature distribution profile of the south facing bedroom shows this,

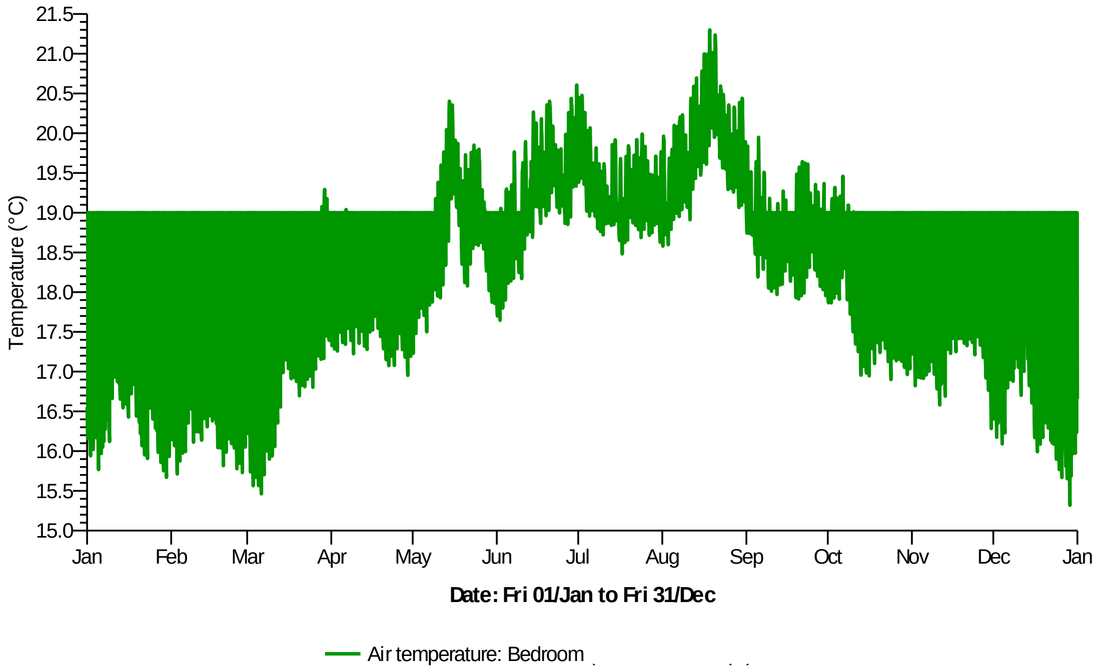

Figure 16 - Bedroom temperature distribution with water wall

Also, when the temperatures of the living room and the kitchen were looked at, it was seen that the variation of temperature was decreased in them as well. Not only the difference in the maximum and the minimum temperatures was decreased but also the temperature difference in both the rooms was decreased and there was more stable distribution on temperature in the whole dwelling. The graph showing the temperature distribution in the living room and the kitchen is shown in the figure 17 below,

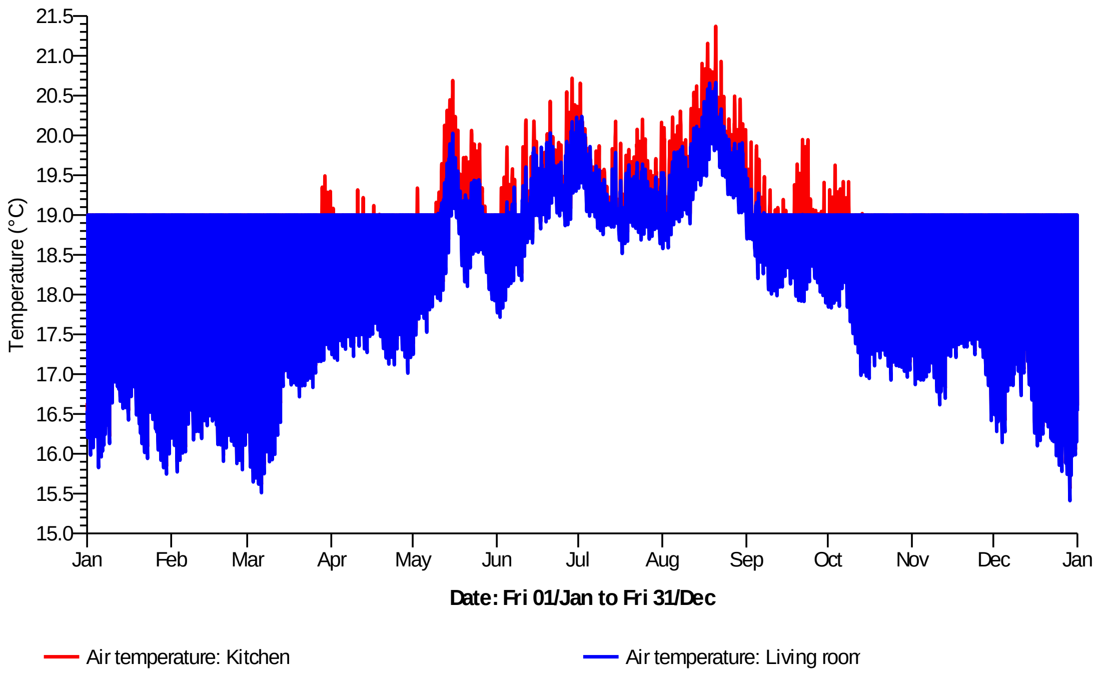

Figure 17 - Air temperature profile in living room and kitchen with water wall

Thus, it can be seen that increasing the thermal mass stabilises the temperature in the dwelling. Also the storage of the solar gains increases the temperature to comfort level. There is no overheating seen in the dwelling as the inside air temperature never rises above 25°C.

Solar gains

As the structure of the dwelling was not altered than the original base case the solar gains of the dwelling are not altered. Although the structure was not altered, the increase in thermal mass has helped to harvest the solar gains and distribute them evenly in the dwelling. This had a very significant effect on the temperature distribution of the dwelling.

Energy Consumption

The increase in thermal mass of the dwelling also had effects on the energy consumption of the dwelling. The data for energy use of the dwelling with water wall is obtained from the model. It is seen that the total annual energy consumption is 6.98

MWh which is lower than the base model however it is a little more than the model with sunspace.

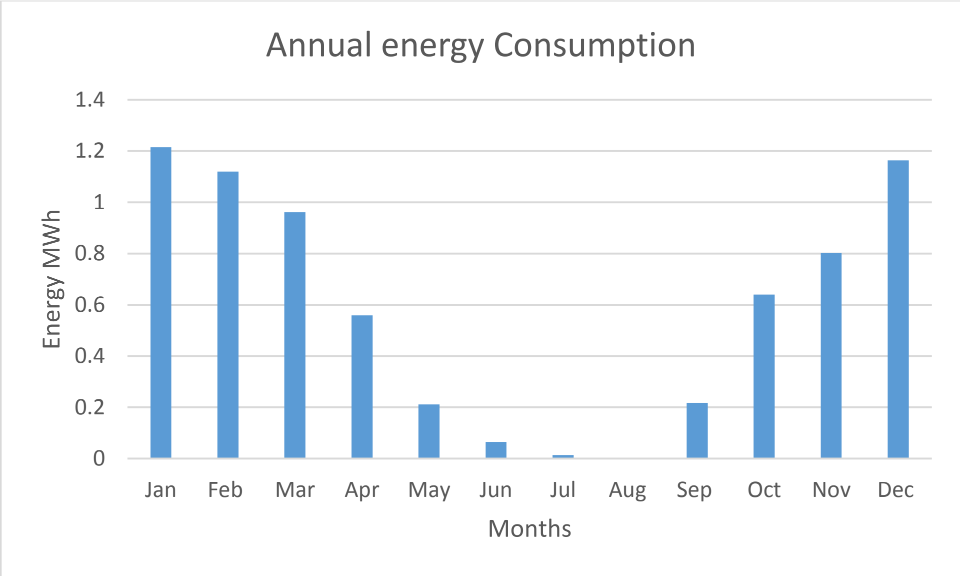

Figure 18 - Annual energy consumption with water wall

Due to the increase in thermal mass of the dwelling the energy required by the dwelling is increased but the inside temperatures show a less variation.

Carbon emissions

The carbon emissions are directly proportional to the energy consumption of the dwelling, with the energy consumption of 6.98 MWh the carbon emissions for a year account to 7383 kgCO_2.

A graph showing annual distribution of carbon emissions over a period of year can be seen in the figure 19 below,

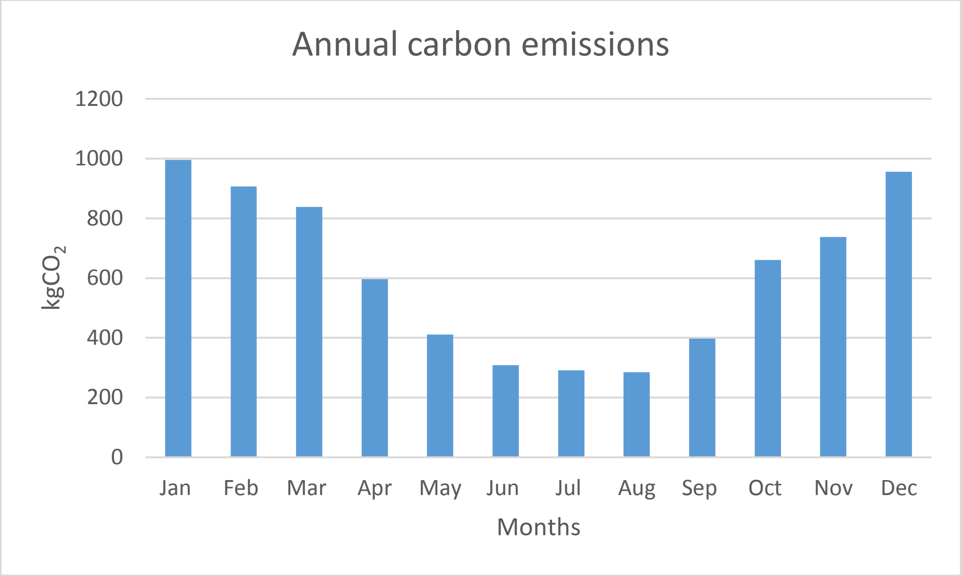

Figure 19 - Annual carbon emissions for house with water wall

Again as the carbon emission is directly proportional to the energy consumption the graph shows the decrease in the emission of CO_2 in summer when the heating loads are comparatively less.

5.4. House with large South facing windows

Increasing direct solar gain is one of the simplest way to make use of the abundant available solar energy. This can be done by increasing the size of the windows to let more solar gains into the house.

With the aim to increase the direct solar gains the size of the windows was increased. The angle of the sun was taken into consideration and the windows facing the south side were increased in length and width. The windows covered the area double to the original. As the angle of the sun during winter is low most of the time the large windows in the south as well as the other direction prove beneficial to harvest the incident solar gains, on the other hand small windows on the other sides of the house restrict the low angled solar gains during summer as this may lead to overheating.

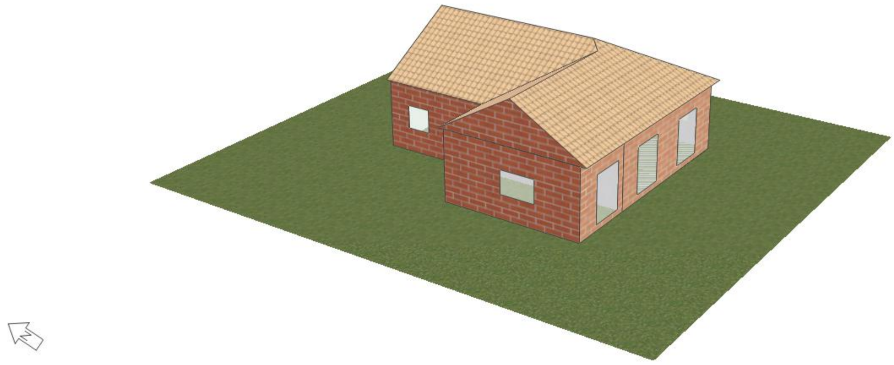

Figure 20 - House with large south facing windows

The results obtained from simulating the model are,

Temperature distribution

With the increase in the area covered by the windows the solar gains in the south facing room has increased directly in relation to it. There is a noticeable temperature rise seen in the rooms. As the direct solar gains have increased there is increase in variation seen in the temperature seen as it is directly proportional to the weather conditions. A total of 52 hours of overheating is seen in the south facing rooms of the dwelling, however no overheating is seen in the living room which is in the north facing part of the dwelling.

Solar gains

With the increase in the size of the south facing windows the solar gains of the house have seen a significant increase as the direct gains have increased. The total incident solar gain incident on the dwelling over a period of year is 3.03MWh.

Table 5 - Solar gains of house with large south facing windows

Months	Kitchen Solar gain (MWh)	Living room Solar gain (MWh)	Bedroom Solar gain (MWh)
Jan	0.0375	0.011	0.0728

Feb	0.0293	0.0158	0.0559	
Mar	0.0926	0.0427	0.1696	
Apr	0.0975	0.0575	0.1697	
May	0.1089	0.0845	0.1973	
Jun	0.1006	0.0824	0.1841	
Jul	0.0865	0.0687	0.1583	
Aug	0.0984	0.0726	0.1869	
Sep	0.0874	0.0477	0.1613	
Oct	0.0833	0.0299	0.1487	
Nov	0.0328	0.011	0.0597	
Dec	0.0295	0.0075	0.0565	
Summed total	**0.8842**	**0.5314**	**1.6207**	**3.0363**

It can be seen from the figures that the solar gains have increased to a great extent with the increase in size of the south facing windows.

Energy Consumption

The changes in the size of the windows have an effect on the solar gains of the dwelling. There is an increase in the amount of gains seen during warm sunny days, however there is increased heat loss as well during cold nights due to the increase in the size of the windows. The results of the energy consumption were obtained and the energy consumption of the dwelling was analysed,

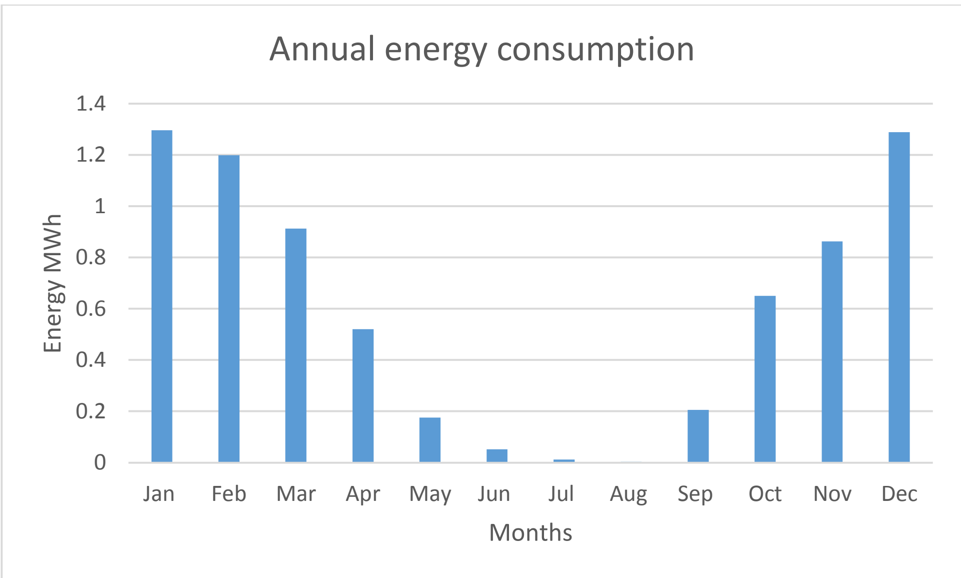

Figure 21 - Annual energy consumption for a house with big windows

It was found that the total annual energy consumption was 7.18 MWh. The monthly distribution of which can be seen in the graph in the figure 21 above.

Carbon emissions

Although there was a lot of incident solar energy captured with bigger windows there were losses involved as well due to the same. Collectively both the gains and the losses had an impact on the energy consumption of the building. The carbon emissions which are directly proportional to the energy consumption are looked upon, it is seen that over a period of year 7477 $kgCO_2$ is emitted.

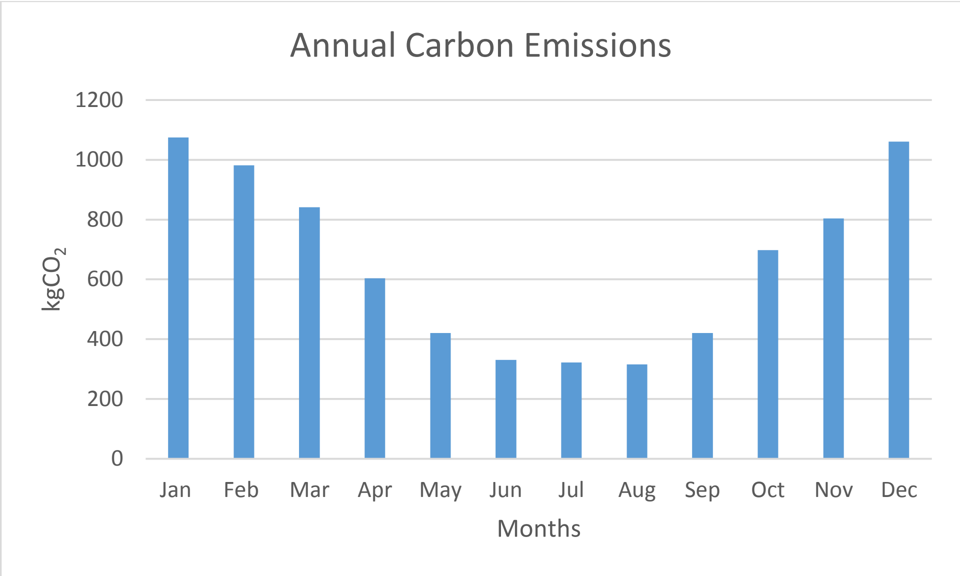

Figure 22 - Annual carbon emission in a house with large south facing windows

The above graph in the figure 22 shows the variation of carbon emissions over a period of a year.

5.5. House with Trombe wall

To have a look at the impact on the energy consumption of the house with different techniques, a trombe wall was designed and modelled in the software and it was simulated for the same weather conditions and same location.

A trombe wall was created with four opening of 0.125 m^2 at the lower and the upper side of the wall connected with the room. A control system was designed for the opening and closing of the openings. The openings were linked to a control system, which were open during the day and closed during the night to reduce the loss of heat. The results were obtained from the simulation are discussed below,

Temperature distribution

The temperatures in the trombe wall are seen to have reached as high as above 59°C, however the temperatures during night reach quite low. This cause the temperatures to go down in the room adjacent. Although the designing of the control system for the vents avoids this cooling of the room. The temperatures in the room with a trombe wall have reached about more than 29°C. The time of overheating of the room throughout the year was seen to be 553 hours in a year. The temperature distribution of air temperatures in the bedroom can be seen in the graph in the figure 23 below

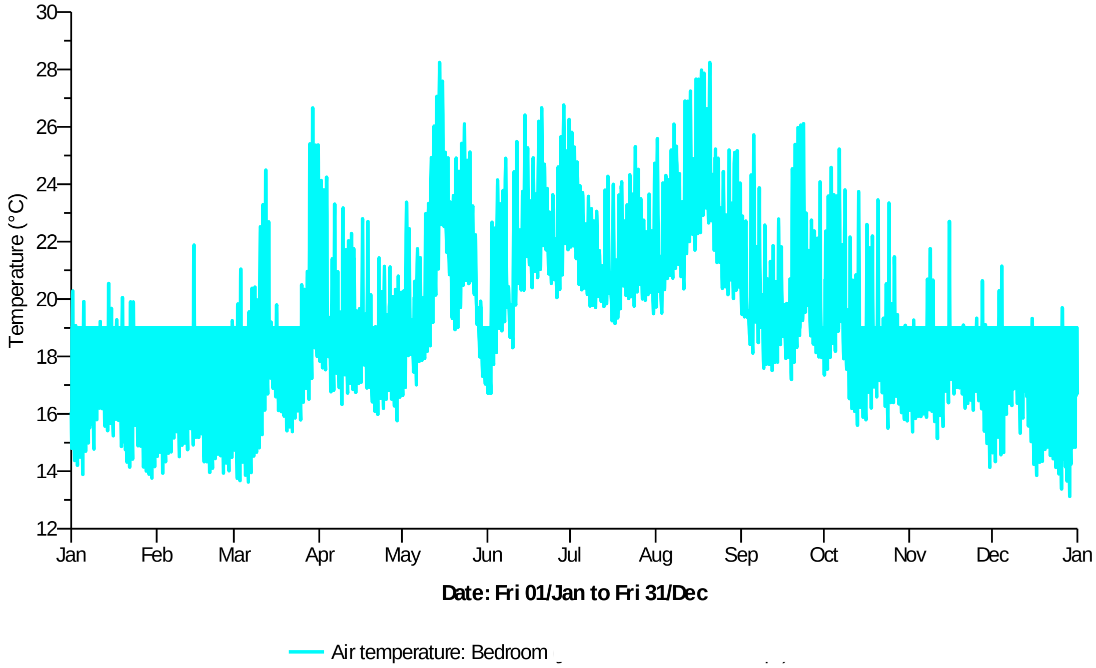

Figure 23 - Temperature of bedroom in a house with trombe wall

The bedroom and the kitchen are connected to the trombe wall and the temperatures in the both can be seen to be similar. The temperatures in the kitchen and the living room can be seen in the graph shown in the figure 24 below, the temperature in the kitchen is quite high as compared to the living room.

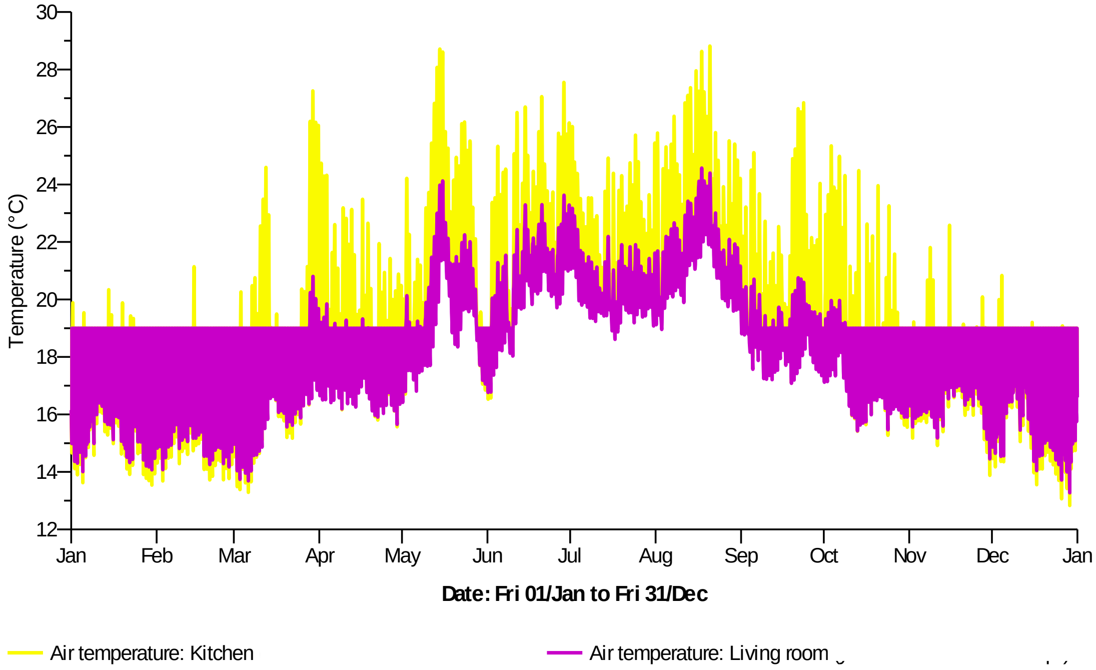

Figure 24 - Air temperatures in kitchen and living room of a house with a trombe wall

Solar gains

The solar gains have increased substantially due to the addition of a trombe wall. Although there is not much increase in the solar gains in the bedroom, kitchen and the living room, but the trombe wall has been successful in capturing a substantial amount of solar gains. The zone wise distribution of the solar gains can be seen in the figure below.

Table 6 - Solar gains in a house with trombe wall

Months	Kitchen Solar gain (MWh)	Living room Solar gain (MWh)	Bedroom Solar gain (MWh)	sunspace Solar gain (MWh)
Jan	0.0066	0.011	0.0129	0.3054
Feb	0.0074	0.0158	0.0165	0.2215
Mar	0.0245	0.0427	0.0453	0.6913
Apr	0.033	0.0575	0.0559	0.6795
May	0.0417	0.0845	0.0895	0.741
Jun	0.0391	0.0824	0.0871	0.6846
Jul	0.0321	0.0687	0.0701	0.5925
Aug	0.0335	0.0726	0.081	0.7016
Sep	0.0251	0.0477	0.0504	0.6433
Oct	0.0204	0.0299	0.03	0.6284

Nov	0.0074	0.011	0.0111	0.2523	
Dec	0.0051	0.0075	0.0088	0.24	
Summed total	0.2759	0.5314	0.5587	6.3813	7.7473

It can be seen from the table that the maximum amount of solar gains are during the months of summer and decreases during winter which also relates with the amount of energy consumption and the carbon emissions.

Energy Consumption

The energy consumption has not seen a substantial decrease overall in a year. However it can be seen that the energy consumption has decreased to almost zero in the months of July and August but have increased sharply in the months of December and January. The distribution of annual energy consumption according to the months can be seen in the graph in the figure 25 below,

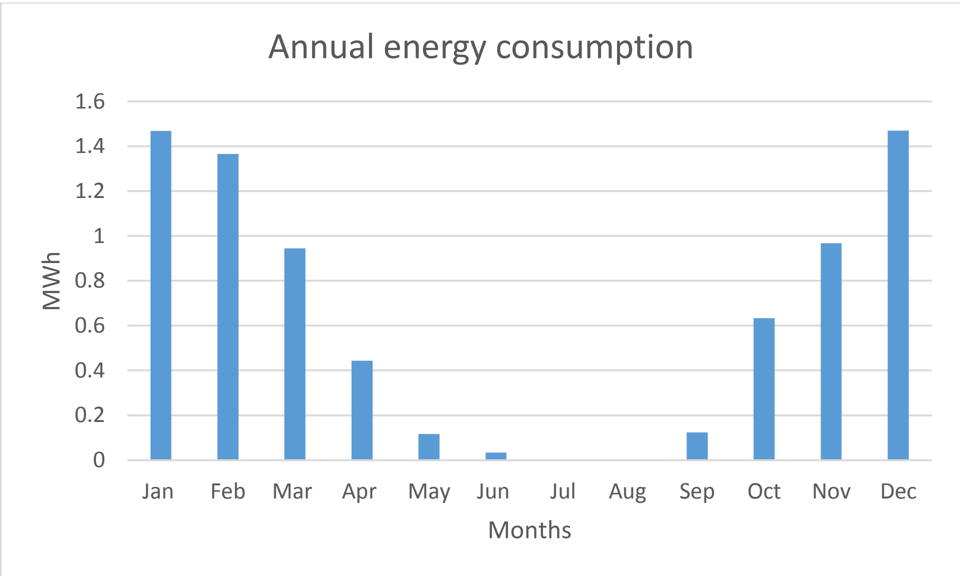

Figure 25 - Annual energy consumption of house with trombe wall

The total energy consumption of the house with a trombe wall was found to be 7.57 MWh over a period of year.

Carbon emissions

The carbon emission is found to be 7897 $kgCO_2$ overall in a year which was proportional to the 7.57 MWh energy consumed by the house. The distribution of energy consumed can be seen in the figure 26 below,

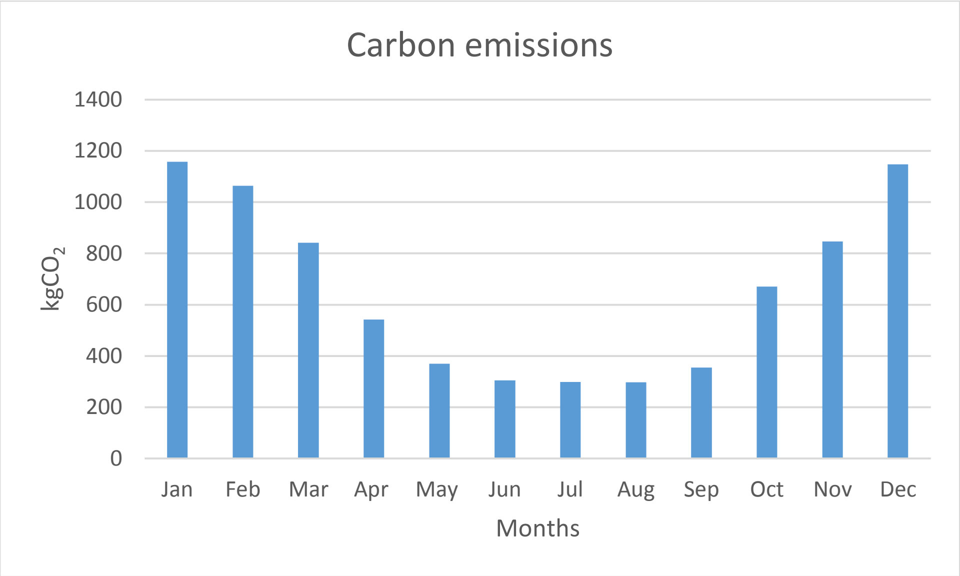

Figure 26 - Carbon emissions of a house with a trombe wall

A pattern of gradual decrease of the emissions is seen with the increase in the sunlight timings which affect the solar gains. However the emissions are not near to zero in any month of the year.

5.6. House with sunspace and water wall

The house model with big south facing windows is modified to have the external wall made of water wall, to analyse the effect of increased direct gains in addition to increased storage because of increase in thermal mass by addition of water wall. The results obtained after simulation of the model are discussed in the following section,

Temperature distribution

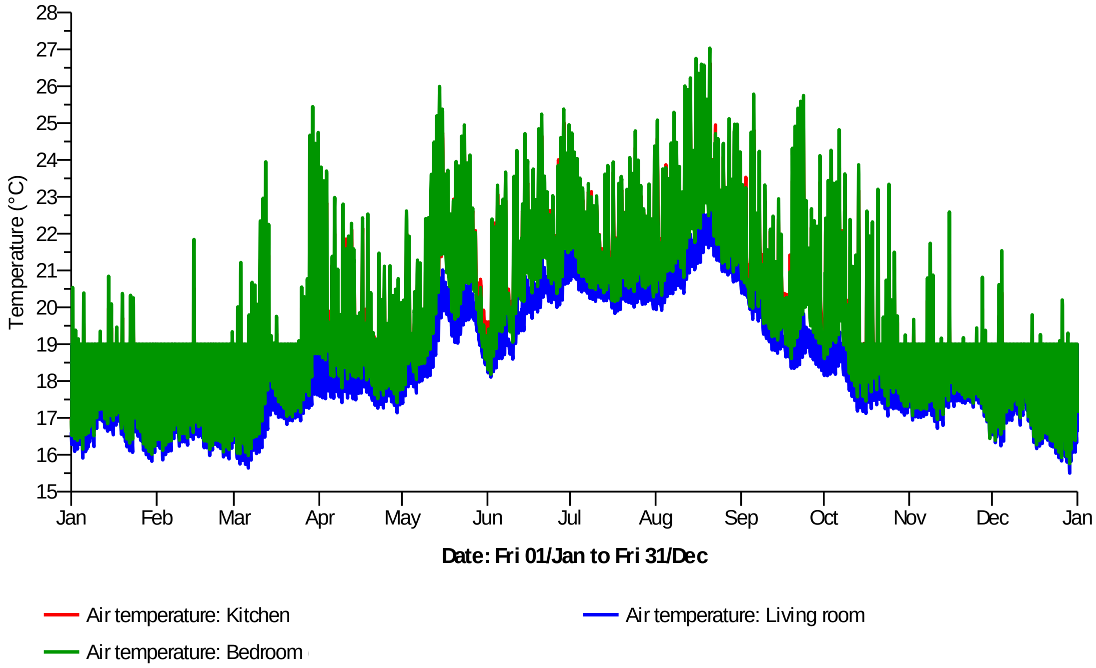

Figure 27 - Temperature distribution of different rooms in a house with sunspace and water wall

In the figure 27, showing a graph of the temperature distribution in different rooms. With the increase of thermal mass of the dwelling and increase in the solar gains, it can be seen that the temperatures of the dwelling has not only increased but also well distributed. Even with the increased capture of solar gains, not more than 130 hours of overheating is seen in the dwelling.

Solar gains

The solar gains of the house with a sunspace and a water wall show not much change than the one with sunspace. However the staring capacity of the solar gains is altered due to the addition of a water wall to the design.

Table 7 - Solar gains of different rooms of a house with sunspace and water wall

Months	Kitchen Solar gain (MWh)	Living room Solar gain (MWh)	Bedroom Solar gain (MWh)
Jan	0.0112	0.011	0.0195
Feb	0.0104	0.0158	0.0179
Mar	0.0348	0.0427	0.0535

Apr	0.042	0.0575	0.0577	
May	0.0489	0.0845	0.0767	
Jun	0.0448	0.0824	0.072	
Jul	0.0375	0.0687	0.06	
Aug	0.0413	0.0726	0.0723	
Sep	0.0341	0.0477	0.054	
Oct	0.0299	0.0299	0.0414	
Nov	0.0111	0.011	0.016	
Dec	0.0087	0.0075	0.0145	
Summed total	0.3546	0.5314	0.5555	1.4415

The total solar gain for the rooms is found to be 1.44 MWh in addition to that of the sunspace. The increase in amount of solar gain has contributed to almost zero energy usage during summer.

Energy Consumption

The model with sunspace and water wall was simulated under the same conditions as the others with the same weather data used, it was seen that the overall energy consumption has increased substantially. However the energy consumption has decreased to zero in the months of July and August.

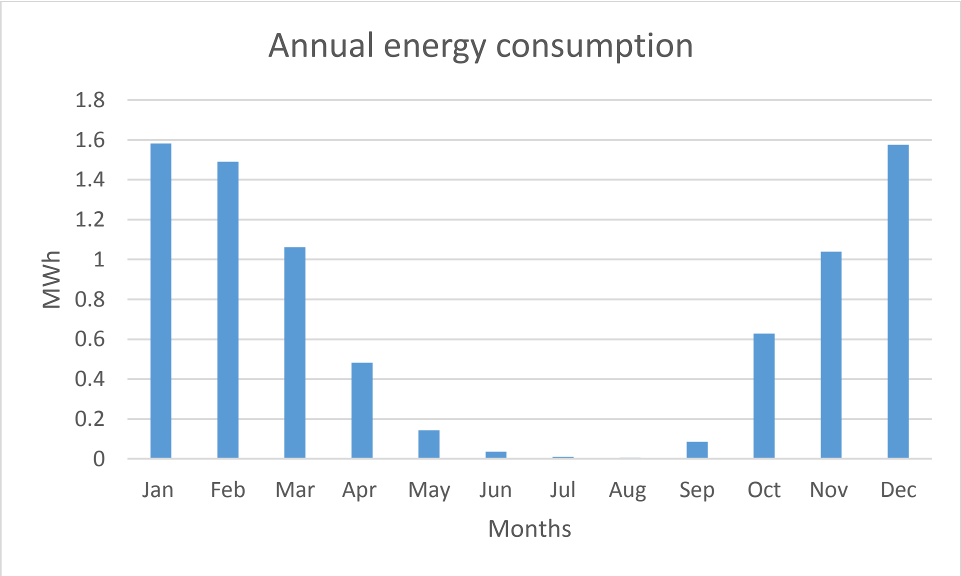

Figure 28 - Energy consumption of a house with Sunspace and water wall

The annual energy consumption is found to be 8.14 MWh. The graph in the figure 28 shows a steep rise in energy consumption during summer in a house model with sunspace and water wall. This can be seen due to very low solar gains and high thermal mass which requires more energy to get heated.

Carbon emissions

The carbon emissions of obtained for the simulation of the model show that there is an increase in the carbon emissions from the model. The results of the carbon emissions in a graphical form can be seen in the figure 29 below,

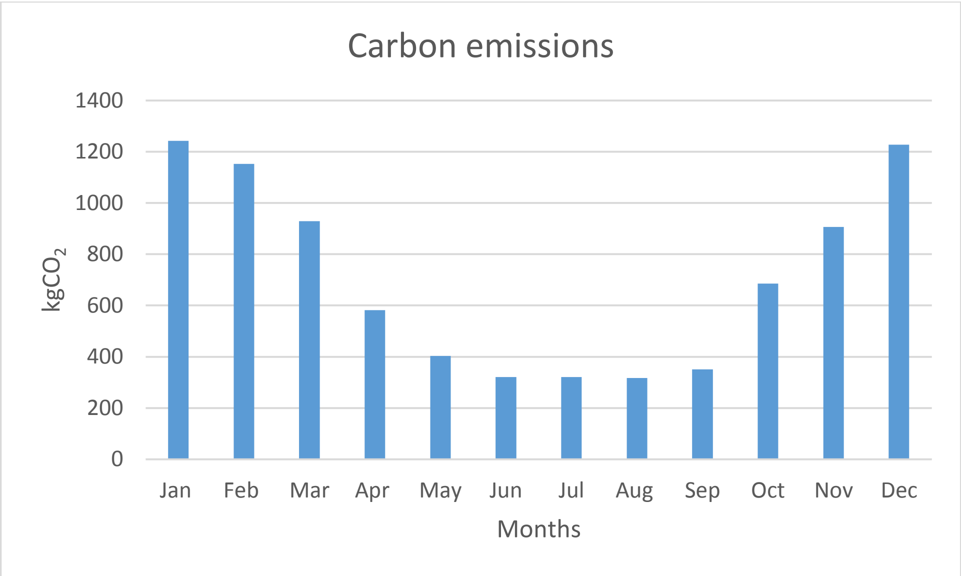

Figure 29 - Carbon emissions of a house with a sunspace and water wall

Although the pattern of the graph is similar to that of the others, an increase in the carbon emissions can be noticed in the graph. A total of 8439 kgCO_2 is emitted by the dwelling in a period of one year.

6. Chapter 6: Discussion

To assess the effect of various passive solar techniques on the energy consumption and various techniques were compared to the standard house constructed with the current building standards individually to assess the change in energy consumption and the carbon emissions over a period of a year. To compare them, bar graph of houses with passive solar techniques was compared with the graph of the standard house.

The table below shows the statistics of the results,

Table 8 - Combined Results

Model	Energy Consumption MWh	Carbon Emissions $KgCO_2$	Number of Hours of overheating
Base Case	7.29	7568	0
Base case + Sunspace	6.68	7210	371
Base case with big south facing windows	7.18	7477	52
Base case + Water wall	6.98	7383	0
Base case + Trombe wall	7.57	7897	553
Base case + sunspace + water wall	8.14	8439	130

Analysing the above results, as it can be seen that the energy consumption and carbon emissions are proportional directly to each other. However the overheating factor is independent of both of them. Therefore, there is a need not only to consider about energy conservation but also to take care the comfort levels. It can be seen in the table 8 above that there is an increase in the energy consumption over a period of year with installation of passive solar techniques, however looking at the monthly energy consumption it can be seen that the techniques prove beneficial during some weather conditions and not overall. To understand the behaviour of passive solar techniques and their effectiveness over times in a year and to assess their effectiveness they are compared with the performance of the standard house.

6.1. Sunspace

Annually sunspace proves beneficial over a period of year with 0.61 MWh savings in energy reducing the carbon emissions by 358 $kgCO_2$. The comparison of annual energy consumption of a standard house with a house with sunspace is seen in the figure 30 below,

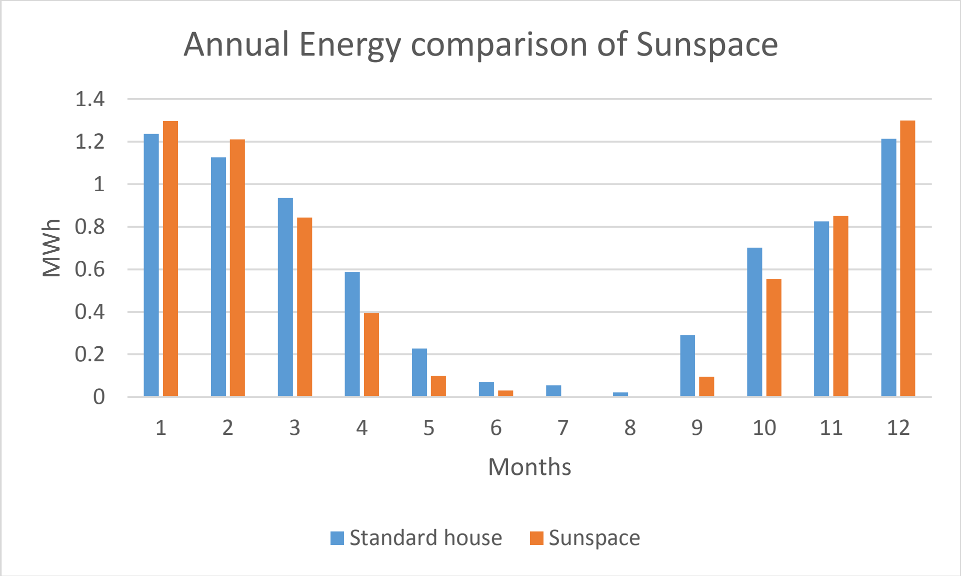

Figure 30 - Comparison of energy of standard house and house with sunspace

Sunspace increases the solar gain and the energy consumption is seen to have reduced substantially during most of the months the months. A steep decrease in the energy consumption is seen during April to September, however the energy consumptions are higher than in a standard house during the months of November to February.

Looking at the yearly carbon emissions a trend similar as the energy consumption is seen in the figure 31 below. However the carbon emissions are never seen that the carbon emissions are never zero.

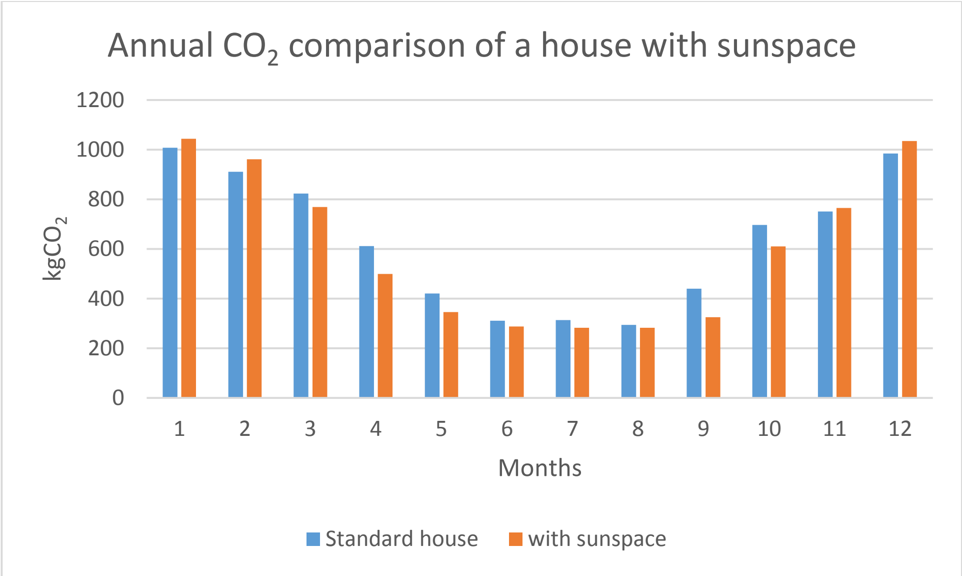

Figure 31 - Comparison of carbon emissions of standard house and house with sunspace

There is a saving of 4.8% in CO_2 emissions with the introduction of sunspace. It can be said that the sunspace has a great potential to reduce the energy consumption of the dwelling, however sunlight plays an important part in it. So, in the absence of proper sunlight this can be a one of the major source of heat loss through the dwelling and can lead to higher energy consumption, thereby increasing the carbon emissions. Another issue involved in installation of sunspace is overheating. In a year 371 hours of overheating is seen in the house with a sunspace.

With provisions made to reduce the heat losses during the winter and control the gains during the summer this can help reduce the carbon emissions maintaining the comfort level.

6.2. Water wall

Introduction of water wall increases the thermal mass of the dwelling allowing it to absorb and store a large amount of heat. This stored energy was used to keep the house warm enough in at night. Due to this not only energy efficiency is increased but also as there is thermal mass there is stability in the temperature of the dwelling, no frequent overheating of the house is seen. Looking at the annual energy consumption, 0.31 MWh of energy is saved.

The comparison of the energy consumption and the carbon emissions is done with the statistics of the standard house and the statistics of the house with water wall, which can be seen in the figure 32 and 33 respectively.

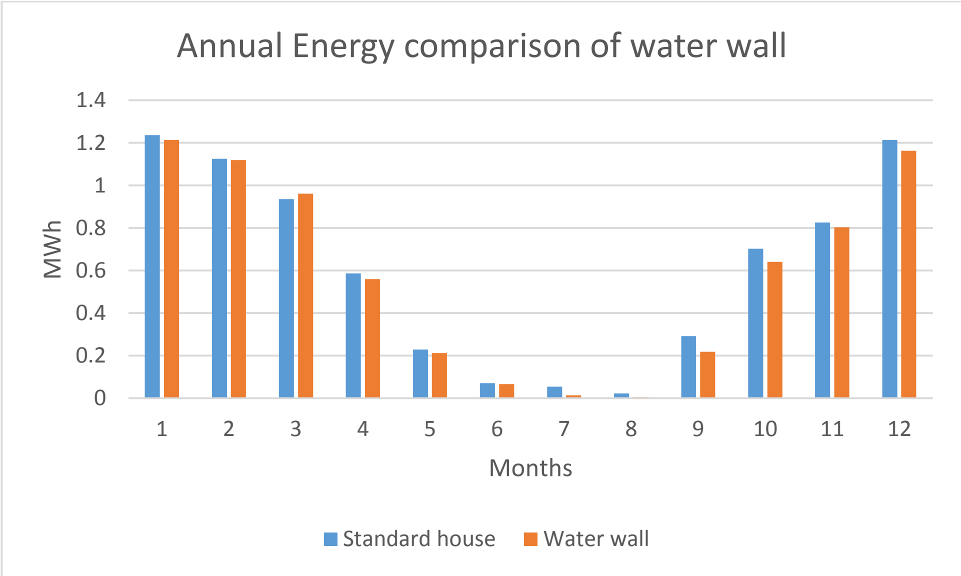

Figure 32 - Comparison of energy of standard house and house with water wall

In the figure 32 showing the comparison of annual energy consumption of a standard house with a house having a water wall, it can be noticed that the energy consumption in each month as compared to that of the standard house is less in most of the months. However, there is a very little difference in the energy consumption of the both.

Although the savings in the energy consumption are not that substantial, there is a continual energy savings throughout the year. This can prove one of the good technique to save energy as there is stable energy savings seen annually.

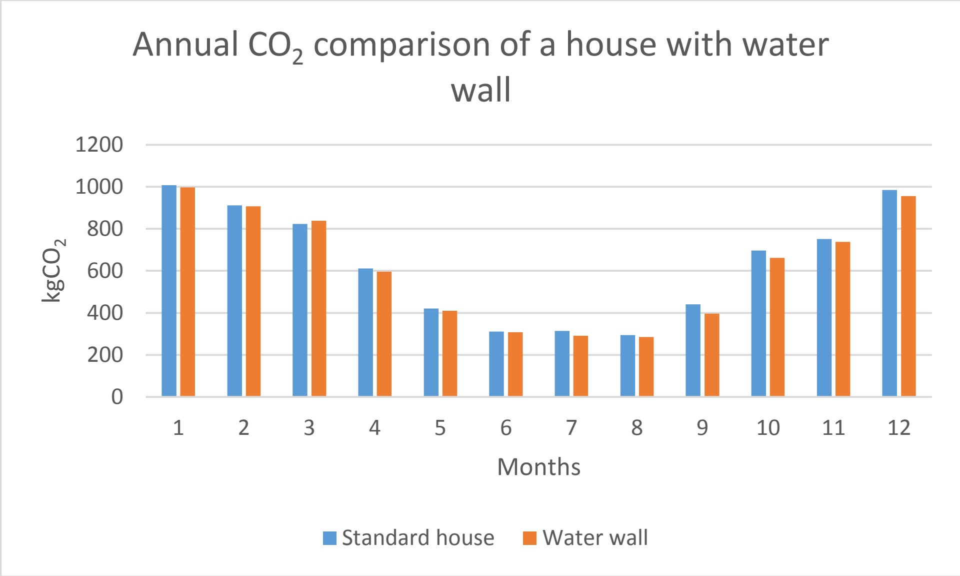

Figure 33 - Comparison of carbon emissions of standard house and house with water wall

A trend not much different than that of the energy consumption is seen in the case of carbon emissions. A little but continuous saving in the carbon emissions can be seen in the house with a water wall, apart from the month of March which shows more emissions as compared to the standard house. Annually 185 $kgCO_2$ was saved in a single house, which accounts to 2.4% savings. Overall, constructing a water wall is a steady way of saving energy.

6.3. Large south facing windows

To assess the performance of the dwelling with increase in the direct gains the performance of the house with large south facing windows was compared with the performance of the standard house. To compare the results a bar graph was plotted with the results of both the houses which can be seen in the figure 34 and figure 35 below.

The comparison of the energy consumption of the house with large windows was done with the standard house, it was seen that there was not energy savings seen when the annual results were analysed. Annual saving of 91 MWh was seen when the energy consumption was compared to the standard house.

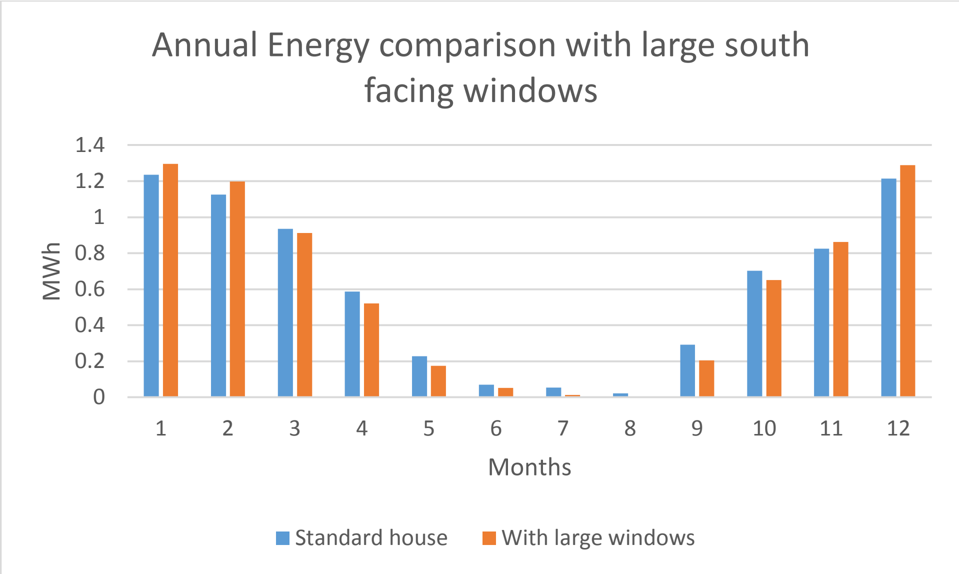

Figure 34 - Comparison of energy of standard house and house with large windows

Comparing the carbon emissions of the dwelling with the standard house it was seen that very little as 0.11 $kgCO_2$ was saved annually. The amount carbon saved is directly proportional to the energy saved and was not able to contribute much to the carbon savings as not much of the energy was saved.

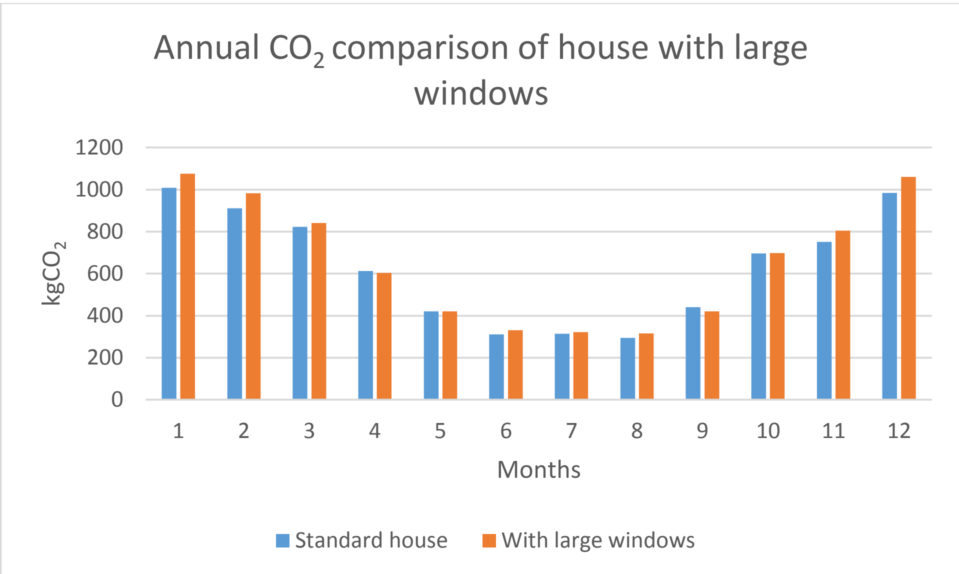

Figure 35 - Comparison of carbon emissions of standard house and house with large windows

Apart from very little savings there were 52 hours of overheating seen during the year. Also, there are peaks in temperature seen during the times of high solar gain. As there is no storage available any extra solar gains lead to sudden rise in the room temperature.

6.4. Trombe wall

A trombe wall which is one of the passive solar technique was analysed for its energy and carbon emission performance over a period of a year. Comparing the results of the house with a trombe wall graphs were prepared which can be seen in the figure 36 and figure 37 below.

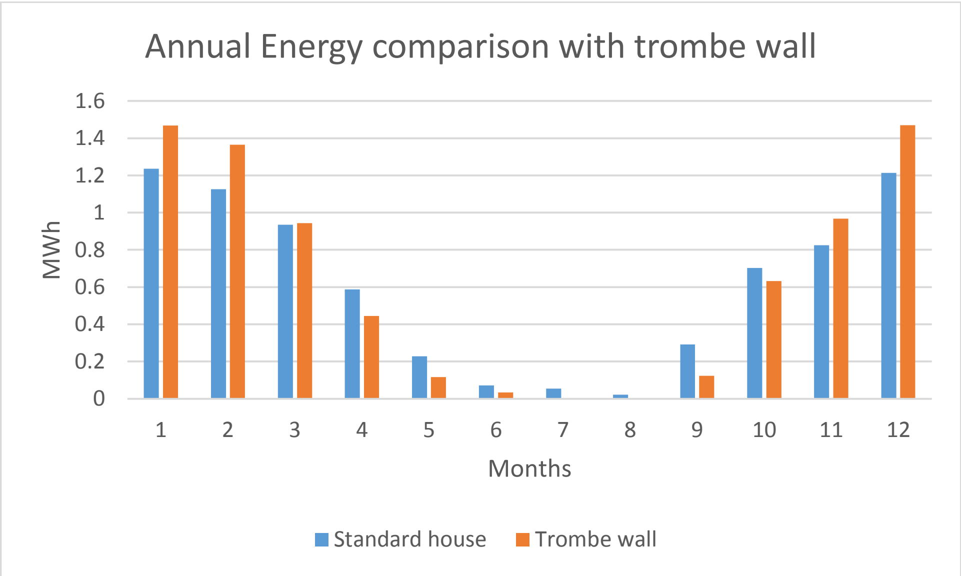

Figure 36 - Comparison of energy of standard house and house with trombe wall

The energy performance of a house with a trombe wall was analysed for a year and it was seen that the trombe wall performs well during summer but contributes in increased energy consumption. However over the period of the year the net energy saving are -329MWh for energy and -0.28 $kgCO_2$ for carbon emissions. As there are more losses during the winter than the savings in summer there is a net loss.

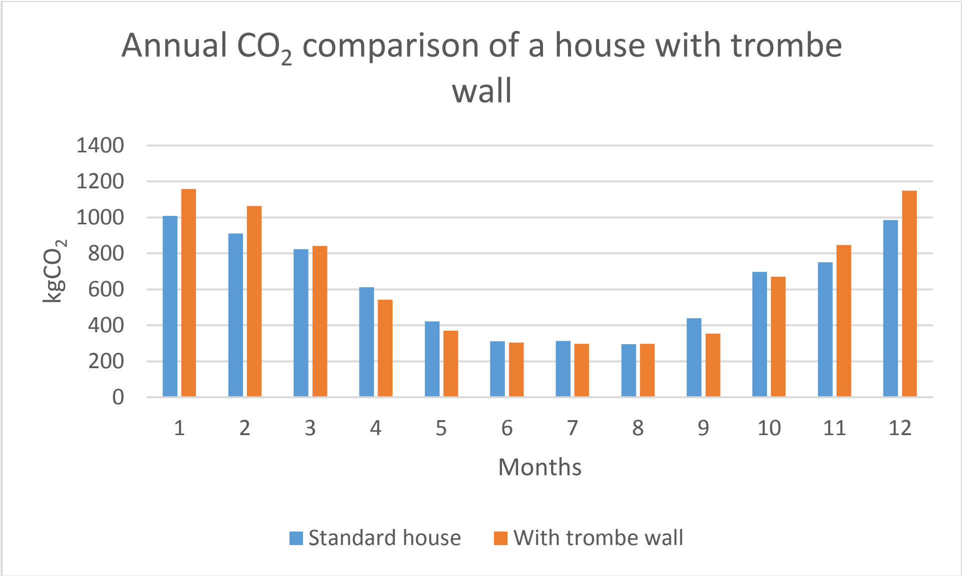

Figure 37 - Comparison of carbon emissions of standard house and house with trombe wall

Trombe wall is seen to be quite effective during the summer but contributes to a lot more losses during the winter. It is a good technique which can help energy savings only during the times of abundant solar gains.

6.5. <u>Sunspace and water wall</u>

Finally to see the effect of the combination of two passive solar techniques the house was added with a sunspace and a water wall. The model was then simulated under the same conditions and the results were obtained which were compared to see its impact on energy consumption and carbon emissions, the graphs comparing the statistics can be seen in the figure 38 and figure 39 below.

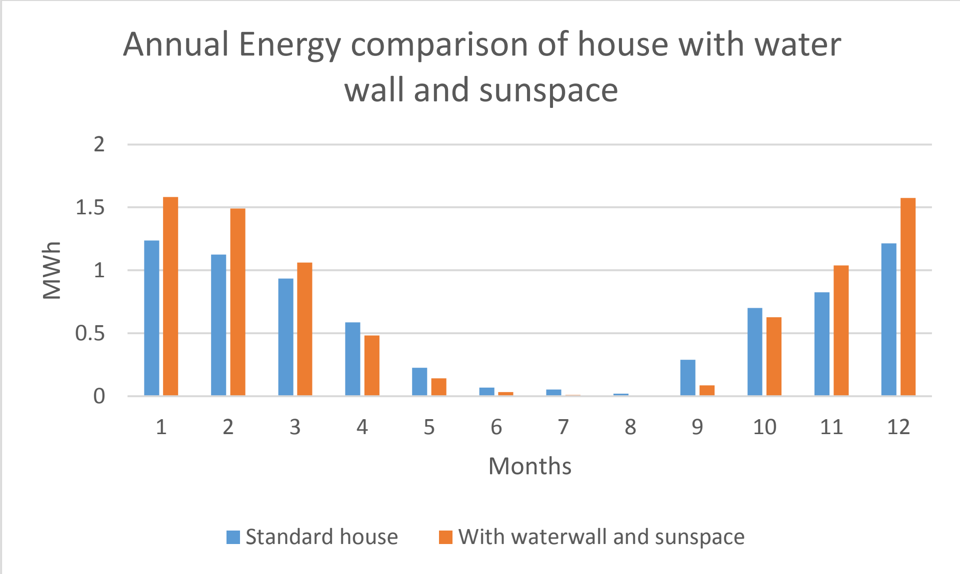

Figure 38 - Comparison of energy of standard house and house with water wall and sunspace

The results of the annual energy consumption comparison of the house with a water wall and a sunspace show that there is actually an increase of 0.84 MWh in a year. The net rise in energy consumption can be seen in spite of the savings in the energy during the period of summer. This can be noted due to the increased energy consumption in the winter.

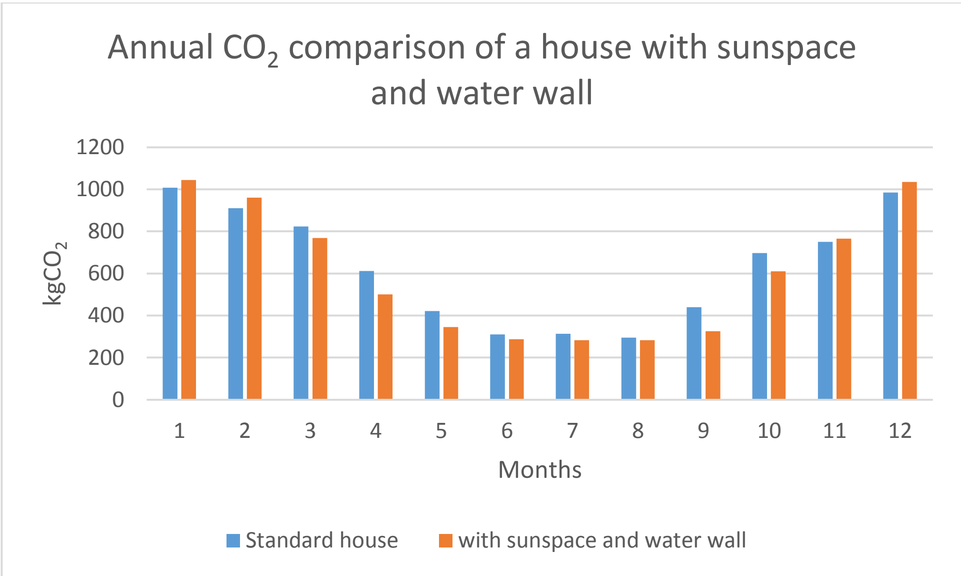

Figure 39 - Comparison of carbon emissions of standard house and house with sunspace and water wall

Also in terms of carbon emission, there is a net increase of 871 kgCO_2 in a period of a year. The combination of these two techniques has reduced the overheating time in the house to 130 hours in a year as compared to that only with a sunspace. However, the overheating time is increased in the as compared to that of the house with a water wall.

7. Conclusion

In this thesis various passive solar techniques were analysed for their performance and energy savings if added to the current standard buildings. It was seen from the results that these techniques are dependent largely on the availability of solar gains and can give extraordinary results if there is abundant sunlight available. However there is a need to use shading devices or blinds to avoid the solar gains to avoid overheating. Also a lot of these techniques lead to increase in energy consumptions during the times of winter due to increased losses and overheating during summer.

None of the passive solar technique is found to perform to achieve energy savings throughout the year. However all the technique cause savings in the summer when there is abundant solar gains. And these same techniques lead to more losses or consume more energy to get heated during summer as the solar gains are very less also there are losses involved in some of the techniques or changes like increase in thermal mass consume more energy to heat.

To make the best use of the passive solar techniques can be to use them to reduce the energy consumption only in the months of summer when there is abundant availability of solar gains. These techniques like sunspace can be closed during the winter to avoid losses. The large windows can be fitted with blinds to reduce the loss during winter. Techniques like increase of thermal mass cannot be altered, however the performance of the dwelling with increased thermal mass was seen to be good.

The net carbon savings annually are seen to be in the range of 3-5% for all the techniques. Although these savings are quite high considering their performance only in summer the losses in wither are much higher causing the net savings to be low.

Looking at the results it can be said that it is quite difficult with the use of only passive solar techniques to achieve the zero carbon targets. These techniques can surely help reduce the carbon emissions and can contribute toward achieving the zero carbon targets.

8. Future Work

The field of passive solar is vast and there is a need for extreme precision in design to attain the desired results. Future work in this takes into consideration practices to reduce the loss of energy during winter and reduce the net energy consumption even further.

There can be further analysis made to find the various ways there is loss of energy and efforts can be made to reduce these losses. The model can be analysed further to test their performance with better with use of more advanced control system and the use of blinds or movable shading devices to reduce the losses during winter.

Although overheating is one of the main problem and a lot of research is going to reduce it, it can be seen from the analysis of various models during this thesis that one of the other major problem is the excessive use of energy due the installation of these passive solar techniques caused during the times of non-availability of solar gains. Trying to figure out a way to isolate the passive solar techniques to reduce the winter losses can be an area for further work in this field.

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