Domestic buildings thermal demand from Renewable Energy Sources-A case study of UK

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Abstract

There is a huge potential for energy production demands in homes to be met by renewable energy technologies at a lower and cheaper rate. This paper focuses on Nottingham, a city of United Kingdom. The Government policies of making every home zero carbon by the year 2016 and uses a simulation-based optimisation approach, in order to find the hourly energy break down in a typical UK , semi-detached home and how the energy demand can be covered by different combinations of renewable energy technologies system. The system comprising PV/Wind Turbine/Battery/Converter has got the cheapest cost of energy which was found to be 0.06 £/kWh and cover more than 80% of the total energy production among all the different available systems. The feasibility of this solution is discussed from economic and environmental perspectives, alternative solutions are considered.

Keywords

Greenhouse gas emissions; Integer environmental solutions; Homer; renewable energy technology systems.

Introduction

During the period of 1970-2004 an increase of 70% in global greenhouse gas emissions (GHG) has been found (IPCC, 2008) and a 0.7% increase in the average global temperature of the world since the beginning of the last century. Energy Usage in buildings around the globe accounts above 24% of greenhouse gas emissions and 40% of primary energy use(Riley M et al., 2008).Carbon dioxide gas is the main contributor in GHG and is contributing 77% out of which 27% comes from domestic buildings (HM Government, 2006). Energy resources shortfall and climate changes on a very rapid scale resulted in Net Zero Energy Buildings being no longer considered as buildings of remote future, but solution for the reduction of energy use and mitigation of CO_2 emission in the building sector (Marszal et al., 2011). The German Federal Government goals in its fifth energy research program held in 2005 was to reduce their primary energy demand by half compared to their current use, their main long goal term was zero-emission buildings (M. Heinze et al., 2009).

The infrared radiation from the sun is absorbed by GHG therefore the radiation cannot escape into the space, this effect is called the green house effect and is thought to be the cause of global warming, and Government wants to reduce CO_2 level to 60% by 2050 (DCLG, 2006). The goal of zero carbon buildings is not only to reduce the energy demands of a building, but also design low carbon techniques and energy balance for the renewable energy systems (Biaou et al., 2006). In UK every year it is approximated that around 160000 new homes are built and Government wants to increase this number to 240000 by 2016 (Catto, 2008) but at the same time it wants to reduce CO_2 emissions therefore the Government is planning to construct more sustainable homes. The Government is planning to build zero carbon homes so that the homes should have a net zero carbon emission throughout the whole year. The Government's aim is to reduce overall emissions of carbon (the major cause of climate change) by 80% in 2050 from the level during 1990 (Jie Zhu, 2014).In order to meet these objectives renewable energy technologies (RETs) needs to be used, this paper will investigate which combinations of RETs will be feasible to meet the Primary (Thermal and Electrical) energy demands in home (Semi detached). The reason for selecting semidetached houses in this paper is that the percentage of it being used in UK is 30.8% and in Midlands this figure rise to 37 % as compared to other houses detached (22.6%) and terrace (25.5%) in the UK.(Housing Statistics, 2002). PV and solar thermal panels are the most commonly used renewable technology to meet zero-energy target for onsite system. (Marszal et al, 2011).Buildings with existing energy infrastructure and minimized demands of cooling/heating should be considered ideal should be covered by non local sources to avoid over-sizing of onsite systems, e.g. Solar thermal systems (Voss et al., 2007).

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2. Software Packages

The software programs which are used in this research are;

Integrated environmental solutions (IES)

Under a common user interface IES (Integrated environmental solutions) brings together a number of different simulation modules; simulations can be done on an hourly basis and the total energy (Primary and thermal) break down for each hour of a calendar year. The following sections of software were used in this paper.

- Model Builder
  ModelIT

- Thermal
  Apache: Thermal calculation and simulation.
  Vista: Results analysis.

- Solar

Sun cast: Solar shading analysis.
ModelIT is used for building construction, Thermal section profiles for various tasks were assigned to each space followed by solar shading analysis in Solar, simulations were run, and Vista was used to check the analysis and results.

HOMER

HOMER (Hybrid Optimization Model for Electric Renewable) is an optimization software package which simulates varied Renewable energy technology system configurations and scales them on the basis of net present cost.It firstly assesses the technical feasibility of the Renewable energy technology systems system (i.e. whether the system can adequately serve the thermal and electrical loads and constraints imposed by the user). Secondly, it estimates the net present cost of the system, which is the total cost of installing and operating the system over its lifetime. The components considered in this paper were photovoltaic, wind turbine and a storage system comprising a battery and a converter. A number of inputs were required to run simulation for example inputs for primary and thermal load, components and resources (solar, wind and natural gas).

3. Methodology

3.1 Program flow and procedure

The building is drawn in ModelIT IES followed by the simulation which performs cooling, heating, artificial lighting, day lighting, solar and internal gains calculations throughout a year for the city of Nottingham, UK. It gives the total energy (electricity and natural gas) and total electricity energy consumption break down values for each hour of the year, These files are saved as .dmd files in Notepad, which are then imported in HOMER as annual average hourly data files to provide Primary load and Thermal load inputs respectively.

Inputs which are provided to HOMER includes the cost, capital, quantity and size values for all the components including the renewable energy technology systems that are considered in the model system, HOMER in return do the cost analysis of the whole system and show the total energy production for all the renewable energy technologies system combinations that were considered in the model.

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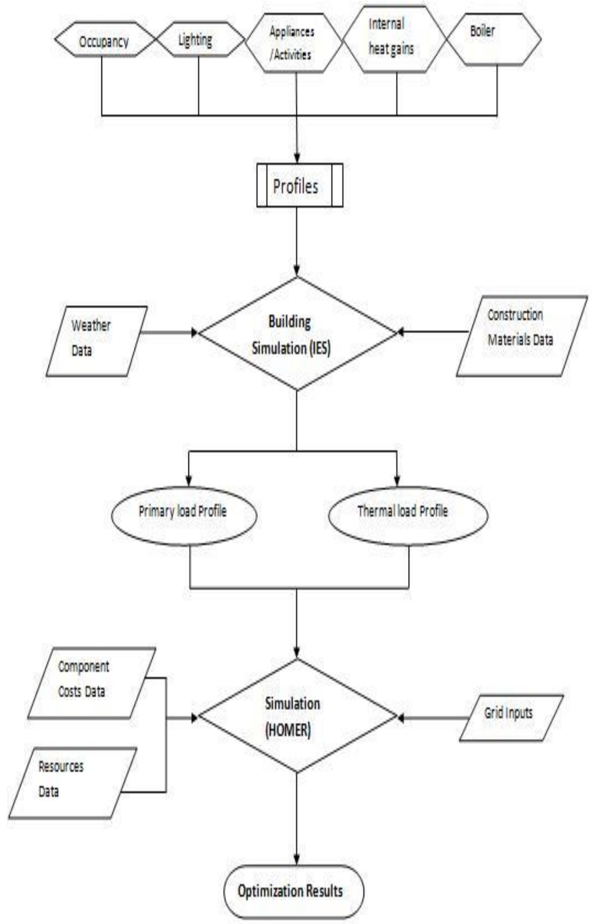


Figure 1: Program flow and procedure flow chart

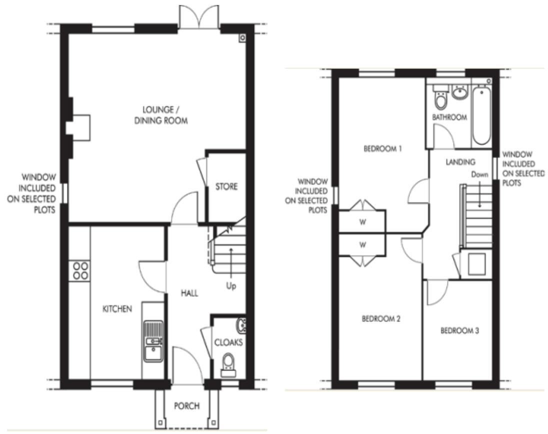
3.2 Case study building

3.2.1 Building description

The building modeled for the purpose of this study is a pair of semi detached houses separated by a party wall in between. It is located in Grange Park which is on the south side of Loughborough, Leicestershire; the data for the building was taken from William Davis Company which has been building new homes in midlands, UK since 1935. The summer and winter design day temperatures are 29.29ºC and -4.65ºC respectively.

3.2.1.1 Layout

The layout of both the houses is identical as ground floor comprises a kitchen, a living/dining room, a store and a small bathroom where as three bedrooms, a hall and another bathroom is present on the first floor. The total floor area of the building is 261.51m^2 and the total volume is 584.091m^3.



Plan of ground floor (left) and first floor (right), (William Davis, 2009)

Figure 2. Plan of the building.

3.2.1.2 Number of occupants in the building

When area of the total floor is less than 450 m^2 then the number of occupants is calculated by the following equation. (R. Burzynski, 2010)

N= 0.0365 TFA - 0.00004145 TFA^2…1
TFA stands for total floor area of the dwelling (m^2), (Anderson et al, 2001).
The total numbers of occupants were found to be 4.1 for each floor so the total numbers of occupants were taken as 8 in the model.

3.2.1.3 Construction materials

In this model 2002 building regulations has been used with external wall consisting of brick and block work followed by layers of insulating materials, concrete and plaster, the floor starts with a layer of aggregates followed by layers of brick and block, concrete, insulating materials, timber and carpet. In internal partition walls there are insulating materials between layers of plaster, the doors are of timber; in external glazing air is filled between Pilkington K 6mm and clear float 6mm. In ceiling gypsum plastering is used and have layers of board sheets, cavity and concrete while in roof tiles are used and have two layers of cavity with a layer of asphalt between them, the roof has also got a layers of insulating materials and plaster.

Table.1 U values for the Building envelope.

Construction	U value (W/m^2K)
External Wall	0.3495
Floor	0.2499
Ceiling	0.785
Internal partition	1.994
Door	3.295
External Glazing	1.977
Roof	0.1589

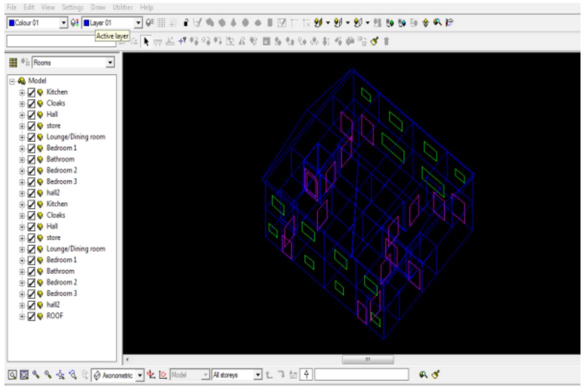


Figure 3: Illustration of the Modeled semi detached house in ModelIT (IES)

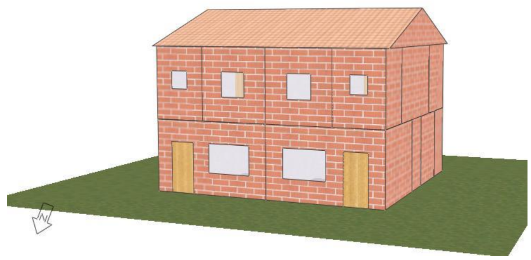


Figure 4: Illustration of the Modeled semi detached house in Model viewer (IES)

3.3 Profiles

Various profiles have been assigned to IES to obtain simulation results.

3.3.1 Heating Profile

The boiler selected in this model runs on natural gas having a seasonal efficiency of 89 %. The heating pattern on weekday for a typical UK home is that the heating should be on from 0700 hrs to 0900 hrs and then from 1600 hrs to 2300 hrs while on weekends and on holiday from 0700 hrs till 2300hrs. (Anderson et al, 2001).
The heating profile drawn for weekday and weekend are shown in Figure 5 .

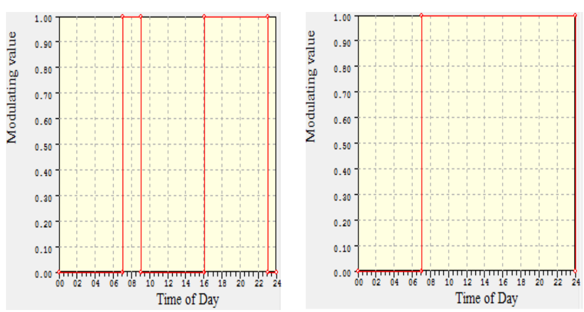


Figure 5: Heating profile for weekday (left) and weekend (right)

3.3.2 Occupancy

The occupancy pattern of rooms/spaces in this model is based on the UK time use survey, 2000 which was conducted on a large number of people in UK in year 2000 which showed the various form of activities performed by individuals at certain time of the day. Each room has got its own occupancy pattern depending on the number of occupants, profiles for all the rooms/spaces have been set up and assigned to them but as an example the profiles for Bedroom 1 are shown here. In Figure. 6 the modulating value of 0.5 represents one occupant and similarly a value of 1 represents two occupants but in case of Lounge/Dining room the modulating value of 0.2 will represent one occupant as the total number of occupants are taken as five.

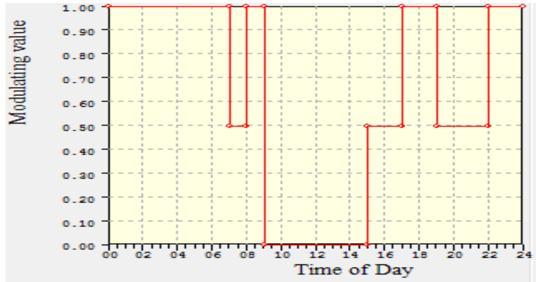


Figure 6: Occupancy profile for Bedroom1

3.3.3 Lighting

The profile of lighting for a room depends upon the occupancy pattern of that particular room and a modulating value of 1 represent that lights are on where as 0 represents they are off. The lighting profiles for bedroom1 on weekdays and weekends are shown in Figure 7.

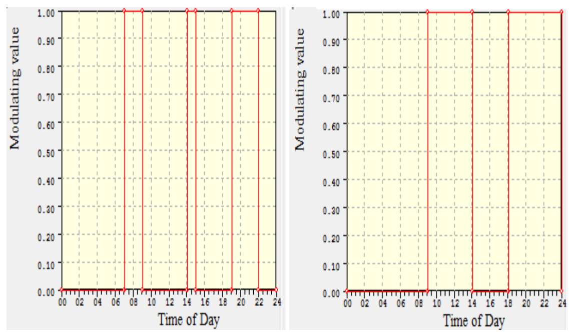


Figure 7: Lighting profile for Bedroom1 on weekday (left) and weekend (right)

3.3.4 Electrical appliances/activities

Different electrical appliances/equipments are considered in this model like stand by and continuous, the profiles drawn for electrical appliances are based on the study conducted by Firth et al (2008), the profiles shows that between midnight and 6 am the energy consumption is always low as after 6 am the occupants starts using the appliances actively, as an example the profile of TV is shown in Figure. 8, the profiles for all the other appliances/activities have also been assigned (not shown here).

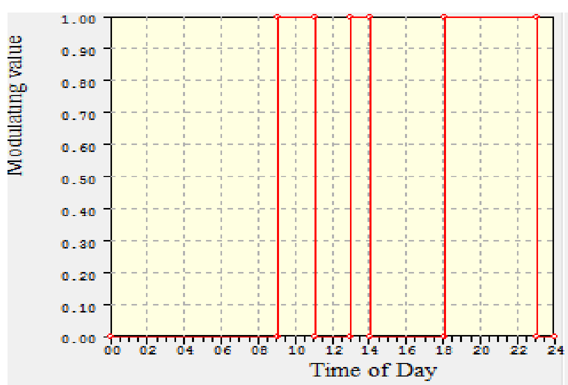


Figure 8: Profile for TV

3.4 Building Templates

IES requires assigning thermal templates to rooms to run the simulation; these templates were made in building template manager in which a number of different template types are present the most varying template type is the thermal conditions template in which template for each room was described by tagging the appropriate profile (drawn in Apache: Thermal calculation and simulation) to each category and inputting the standard values for

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various internal heat gains. Templates for all rooms/spaces were described in the building template manager and each template was assigned to its specific room. All the heat gains assigned have its own profile as described before. The internal heat gain values for all the appliances/equipments and activities are taken from CIBSE guide A. Table 2 shows the heat gains from various appliances/activities.

Table: 2 Heat gain values for appliances/activities.

Appliance/Activity	Power (W)
TV	100
Computer	100
Toaster	1310
Microwave	700
Cooking	1500
Ironing	1000
Cleaning	1000
Washing	490
Cell phone	20

3.5 Solar shading analysis and Simulation

solar shading analysis were applied on the model generating the table of solar altitudes for fifteenth day of each month after assigning the templates then Apache simulation was run for the whole year to obtain the total energy break down for each hour of the year.

3.6 Data collection for HOMER

Data was required for all the components that were considered in this study, this data was collected through telephonic interviews and emails from various vendors, manufacturers and suppliers of renewable energy technologies namely Energy Saving Trust, New and Renewable Energy Centre Ltd (NaREC), Battery Mega store website, Centre for Alternative Technology (CAT), British Gas, Energy and environmental website, Windfinder website, and Atmospheric Science data centre sponsored by NASA. Figure. 9 shows the components which were selected in this model and for whom data was collected.

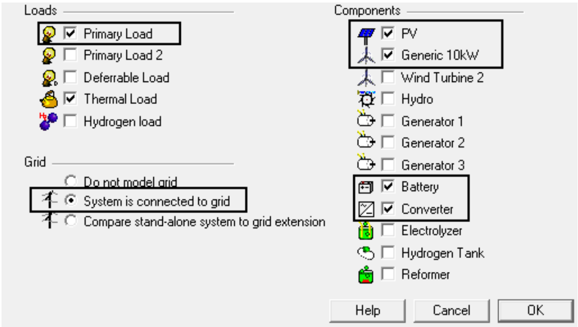

Figure 9: Illustration of the equipments considered in this study

3.6.1 Primary and Thermal Load Profile

Primary and Thermal load profiles requires energy load for each hour of the day in kW. These hourly load values were obtained from IES and then imported to HOMER.

3.6.2 Costs Inputs

The details of the cost inputs of the components which were considered in this case are shown in Table 2. There are an other cost inputs of RETs which were applied to fulfill the energy production demand but here an example is shown.

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Table 3: Cost inputs of various components.

COMPONENT	SIZE(kW)	CAPITAL(£)	REPLACEMENT(£)
PV(Photovoltaic)	5	7500	7000
Wind turbine	3	2400	2200
Battery	2	1500	1500
Converter	5	2641	2500

3.6.3 Grid Inputs

Grid inputs requires price rates at which the electricity is sold and sent back to the grid, the price at which electricity is sold back to the grid is usually lower than the price which is paid for electricity from the grid, Figure 10. Shows the price of electricity chosen for this study.

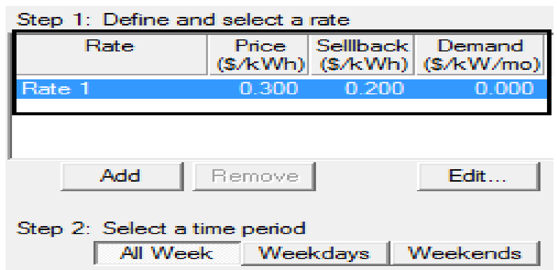

Figure 10: Grid inputs showing rate of electricity considered in this study

3.6.4 Resources Inputs

3.6.4.1 Solar Resource

HOMER needs the meteorological data of the area that is under analysis for complete simulation. This data is then used as input for simulation and describes the renewable resource (J.R. Hall, 2014) .Solar resource input data was obtained from atmospheric science data centre website which is sponsored by NASA's Earth Science Enterprise Program, this data is important because it is used to calculate the PV array power for each hour of the year. If solar resource radiation is provided to HOMER then it calculates the clearness index by using

$$K_T = \frac{Have}{Ho,ave}$$

Where; $H_{o,ave}$ is the monthly average radiation on the surface of the Earth, and $H_{o,ave}$ is the monthly average extraterrestrial horizontal radiation on a horizontal surface in kWh/m^2 and can be calculated by using equation 2;

$$H_{o,ave} = \frac{\sum_{n=1}^{N} Ho}{N} \quad (2)$$

Where; H_o is the total daily extraterrestrial radiation per square meter which HOMER calculates using a series of other equations (not shown here).

3.6.4.2 Wind Resource

The data for wind resource was taken from wind finder website this data is used to calculate the wind turbine power for each hour of the year.

3.6.4.3 Natural gas Inputs

This data was obtained from British gas and the price (£/m^3) was taken as 0.5£/m^3.

4. Results and Analysis

IES gave the total energy break down for each hour of the year and the results obtained from HOMER showed the most efficient system in terms of cost of energy (COE) and renewable fraction and also showed the relationships between the levelized annual cost of energy, net present cost (NPC) and primary load. The IES simulation-based monthly energy consumption values for the Semi detached house are shown in Figure 11.

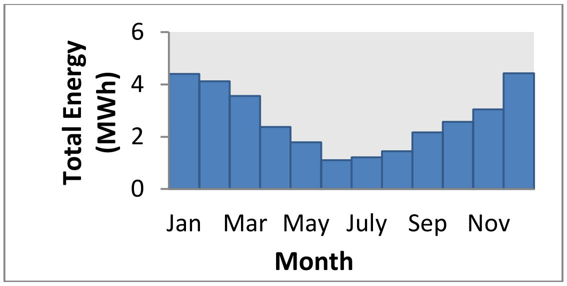

Figure 11: Monthly values of total power consumed in the Semi detached house

The results show that the highest amount of energy is consumed in the month of December and the total energy consumed for the whole year was found to be 32818kWh/year, whereas the energy consumption per square meter was found to be 125.49kWh/m^2/year and the total carbon dioxide emissions per square meter were 44.63kg/m^2/year. According to Letcher & Chambers,(2005) the predicted value of energy usage in kWh/m^2/year for a three bedroom semidetached home built on 2002 building regulations is 132kWh/m^2/year and the carbon dioxide emissions are 38kg/ m^2/year it means that the energy consumption value has fallen within the limits, where as there is a difference of 6.63kg/ m^2 in carbon dioxide emission rates which could be due to a slight increased floor area of the semidetached house and the various profiles assigned to it in IES.

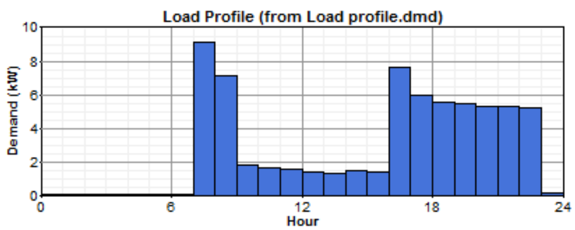

Figure 12: Annual average Primary Load profile for 24 hours

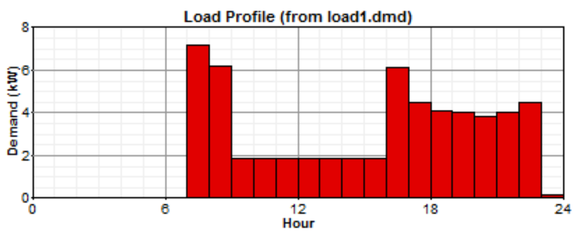

Figure 13: Annual average Thermal Load profile for 24 hours

Figure 12 and Figure 13 shows the annual average Primary and Thermal loads profiles respectively for 24 hours, these profile was obtained from IES and were stored as .dmd file and imported in HOMER, the thermal load profile means the profile excluding the electricity load it shows that the peak energy is consumed between 0700hrs and 0800hrs, where as very little energy is consumed during the day time when most of the occupants are not at home and boiler is off, the rate of energy consumption is high, continuous and almost uniform from 1600hrs onwards till 2300hrs.

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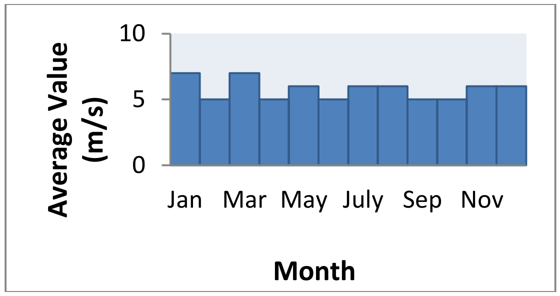

Figure 14: Wind speed monthly average for year 2008

The annual average wind speed in Nottingham is 5.76m/s (wind finder). Figure.14 shows a monthly average wind speed for the year 2008. A quick comparison of Figure.14 with Figure.11 shows that when the wind speed is high then the energy consumption is also high and more space heating is needed. Monthly wind speed average data for the year 2008 was obtained from wind finder website.

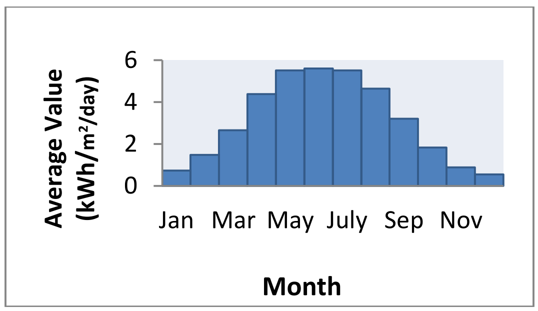

Figure 15: Monthly average solar radiations in Nottingham, UK

Figure. 15 shows monthly average daily radiation in kWh/m^2. It is highest in June with a value of 5.6kW/m^2. Daily Solar radiation is negligible during the winter months when energy is most needed. Annual average solar resource in Nottingham in 2008 was 3.074kWh/m^2/day. The simulation run on HOMER gave a number of results about the Cost of energy**,** Net present cost, levelized cost of energy and renewable fractions of the various combinations of renewable energy technologies that were considered during this research. The case which is described here involves four combinations of Renewable energy technology systems namely Grid/PV/Wind Turbine/Battery/Converter, Grid/ Wind Turbine/Battery, Grid/ PV/ Battery/ Converter and Grid/ Wind Turbine/ Battery/ Converter.

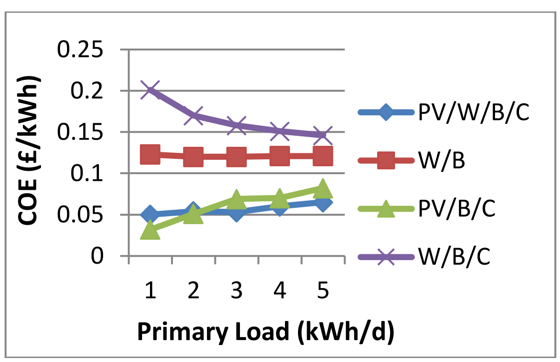

Figure 16: Cost of energy, (COE) for different system types over increasing Primary load

Figure. 16 shows the results for systems with 100% reliability, the value of COE for W/B/C decreases as the primary load increases but the value of W/B system remains almost constant at 0.13£/kWh . The PV/W/B/C system has a constant rate of Cost of energy up to a primary load of 3kWh but after that it increases as the load increases and PV/B/C system graph shows that it has the most cheapest cost of energy value at a primary load of 1kWh, it

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intersects PV/W/B/C system at 1.5kWh point and after that it increases up to 3kWh but between 3 and 4kWh it remains constant and its price reaches to 0.08£ at 5kWh.

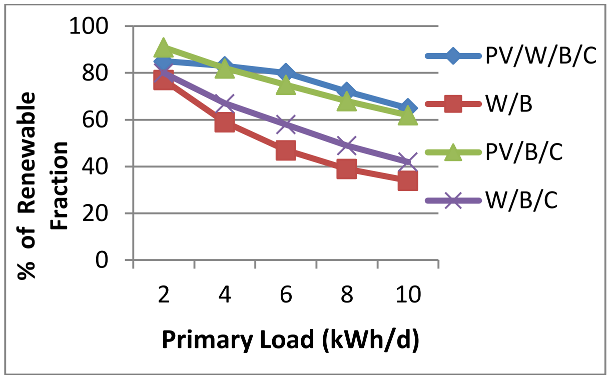

Figure 17: Renewable fraction for different system types over increasing Primary load

Figure. 19 shows the relationship between percentages of renewable fractions and the total primary load, renewable fraction is the portion of the system's total energy production originating from renewable power sources. Figure.17 shows that when the primary load is smaller than most of the energy production is covered by the RETs but when the primary load increases then renewable fraction value decreases, the most efficient system is PV/W/B/C as it can cover more than 80 % of energy production though its graph move downwards as the primary load increases but still it can manage to cover most of the energy for the day as at 6kWh/d it covers 82 percent of the energy production and according to Figure.12 more often than not the average primary load for an hour is less than 6kWh. The most inefficient system is the W/B system as it can cover only 47 % of the energy production when the load is 6kWhday (it is the hourly load mostly after 1600 hrs). Levelized cost of energy is the average cost per kWh of useful electrical energy produced by the system, Figure 18 shows that the cost of levelized energy remains between 0.1 and 0.12£ for the all the primary load values.

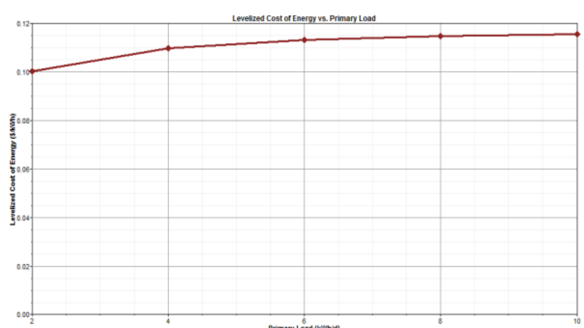

Figure 18: Levelized cost of energy over Primary load

HOMER also calculates net present value of the cost of installing and operating the system over the lifetime of the project (Sam Koohi Kamali, 2009) and Figure.19 shows that there is a linear relationship between NPC and primary load as the Primary load increases net present cost also increases.

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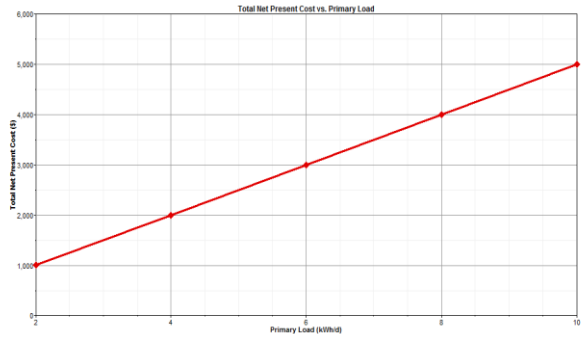

Figure 19: NPC over Primary load

Conclusions

The first part of the results obtained from IES showed that the highest energy consumption occurs in winter months and the energy consumption in summer months is about 2.5 to 3Mwh less than winter months, the main reason for it is the space heating. Study of the primary and thermal load profiles showed that the annual electricity load is very less as compared to annual natural gas load; the main reason for it is the presence of the gas boiler providing space heating in a high percentage of semi detached homes. The annual average primary load profile also showed that the peak energy consumption occurs between 0700hrs and 0900hrs when occupants are doing most of their activities.

The results obtained from Homer showed that the wind speed is higher in winter season and so is the energy consumption, when the wind speed decreases the energy consumption also decreases. The monthly average solar radiation is almost negligible in winter months and reaches its peak in June when it is 5.8kWh/m^2/day. The optimal Renewable energy technology system is the PV/Wind Turbine/Battery/ Converter system as it has the cheapest COE(£/kWh) value compared with the other systems which were considered in this paper because it costs only 0.06£ for a primary load of 5kWh/day and it is also the most efficient system because it can cover more than 80% of the energy production for a primary load up to 6kWh/day, the COE for a wind turbine/ battery system remains constant for all the primary load values as it is between a range of 0.1 and 0.15£/kWh but it the most inefficient system as it can cover only 48% of the energy production when the primary load is 6kWh/day.

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