Assessment of a residential property for improvements in energy efficiency & renewable energy production

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Abstract

The Energy demand and its supply in recent world have too many consequences associated with it. Numerous green energy options are being explored in the interest of the saving the world environment. Improvement in efficiency of the residential properties is the one of the best and essential solutions of the energy crises. The domestic sector in UK and EU contribute almost half of the total energy consumption, out of which nearly half of the energy is utilised for the heating purposes. The efficiency of energy consumption of the residential property can be improved by introducing the energy efficient appliances, proper insulation and water and central heating advancement. This research incorporates the study of thermal property of existing dwelling in terms of the insulation, air-tightening and ventilation. The research involved the investigation of the selected property for the improvements in its energy demand both thermal and electrical. Inspection of electrical appliances and their energy demand and the suitability of the chosen property for installation of renewable energy system were also focused in detail. After a thorough study of the property it was found that the no element of the house was up to the standards. The energy performance of the dwelling was found to be band E and had opportunities to improve the performance up to band B. Heat loss calculations of the elements of the house suggested that there were possibilities to reduce the heat loss by almost 680 W/K if refurbished to meet the standard minimum requirements. It was also found that in terms of economics the house had potential to save up to almost £500 per year in running cost by making the improvements in thermal property. Most of the appliances of the house were found to have fairly good efficiency except the electrical shower and microwave oven. However none of the appliances were found energy performance certified. The chosen property was also examined for the compatibility with renewable energy sources. The power predictor was mounted on the site to record the real time readings of wind strength, wind direction and solar intensity to verify the suitability of the site. The power predictor found that the site was not suitable for the wind turbine installation which was also verified using Energy Saving Trust's online service. However the site was found appropriate for the solar energy system installation and the economics of the system showed that the payback period for the particular system should be 22 years, which was reasonable in this case.The research was done aiming the ultimate solution for the domestic energy crisis for particular dwelling and the results have shown very promising future if the suggestions are met.

Keywords: Energy Efficient Buildings, Solar Energy, Wind Energy, Energy conservation.

I. INTRODUCTION

Our society has become extensively dependant on fossil fuels for years. They are very finite sources now and continue to be depleted as a result of very high energy demand. The major consequence associated with the use of fossil fuels is the emission of pollutants. These pollutants have damaged the environment significantly and they still continue it. Greenhouse effect, ozone layer depletion and acid rain are well identified results of many of pollutants. Most of the governments in world have started taking greenhouse gases, especially CO_2 production issues very seriously.

The United Kingdom government aim to meet 80% reduction in CO_2 level by 2050 compared to that of 1990. CO_2 emission form the housing was accounted for 165 million tonnes per year in 1990 in UK, and new houses under construction add on in that number. At present there are about one in five houses in UK had been built before or during 1920s. (EST, 2010a)

II. BACKGROUND

The issues with energy demand of the dwellings have taken a very serious shape in recent years. Chwieduk (2003) stated that domestic sector accounts for 40% of total energy consumption in European Union out of which 57% energy is acquired for space heating, 25% for water heating and 11% for electricity. It is required to introduce innovative environmental-friendly energy technologies in the domestic sector other than the general conventional believe for the better results.

The government of UK has declared that any new building constructed after October 2008 need to be Energy Performance Certified (EPC). Any section of a building or a whole building undergoes any refurbishment or alteration need to have EPC as well. (DCLG, 2011) EPC is a performance certificate for the house (similarly for appliances) determined using thermal characteristics of the house (Energy consumption and efficiency in case of appliances). The thermal characteristic of the house can be determined using the features of the material of construction, air-tightness, ventilation and glazing properties of the house. The government has declared the minimum required thermal characteristic (in terms of U-vale) of individual elements of the dwelling. An example of typical EPC is shown in figure 1 below.

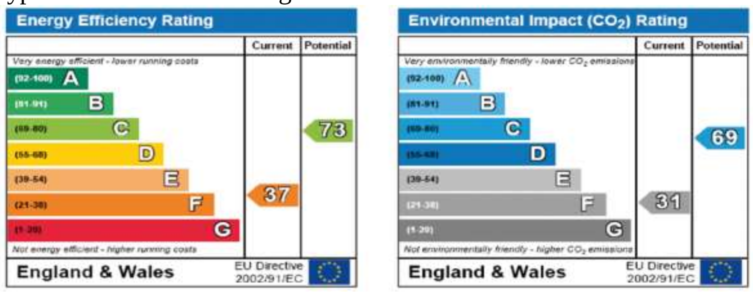

Figure 1 A sample Energy performance Certificate (Source: DCLG, 2011)

The EPC is classified in 7 bands, Band A to Band G, where Band A being the highest and Band G being worst. This is true for the domestic appliances as well. Most common practice to determine the thermal performance of the house is with the help of U-values of the components. The definition of U-value is explained below. Although in some cased R-values are also used which is an inverse of the U-value.

U–Value: It is also known as thermal transmission and it can be defined as "Heat flow rate per unit area in steady state per temperature difference between surroundings on each sides of the system. The unit of this quantity is W/m^2K. Lower the U-value higher the greater the insulation effect. (Van Dıjk and Arkesteıjn, 1987)

R-value is the capacity to resist the flow of heat and can be measured in terms of m^2K/W. Higher the R-value better the insulation effect.

The performance of windows can be explained using the G-value as mentioned below.

G–value: "It is a measure of total solar energy entering the room through windows out of total available solar radiation incident on the window." This quantity is unit less and specifically applied to windows. (Van Dıjk and Arkesteıjn, 1987)

Thermal property of the house is not the only parameter that makes difference in the energy performance of the dwelling but also electrical energy demand of the appliances possessed by the dwelling play a major role in determination of energy performance of the house.

There have been many studies on different topics to test the nature of the energy consumption of appliances and the effect of the occupants' behavioural changes. The test on appliances and their energy consumption pattern can be the best solution to identify the loops in the electrical energy consumption possessed by the house. The standard method to represent the energy requirements of the appliances is by the means of their wattage. Some appliances have their rated energy consumption shown in terms of ampere (A) and voltage (V) while others give them directly in wattage (W). In fact the wattage is simply the product of ampere and voltage. The energy consumed by any appliances can be represented in kWh which is basically the watts (kW = watts/1000) consumed by a particular appliance when run for an hour. It is very important to use EPCertified (energy performance certified) appliances to ensure minimum waste of electricity.

After taking all the measures to reduce energy requirement it is a practicable solution to think about the renewable energy. The renewable technologies are not all about solar or wind energies only. However it cannot be denied that these technologies are most popular because of their high efficiency and compatibility compared to others. Use of solar energy can be done to heat up the space as a passive solar application or water heating and electricity production as active applications. The use of micro combined heat and power (CHP) system is very promising technology and is likely to contribute in renewable energies in future. Use of Ground Source Heat Pump (GSHP) is also very effective way to replace or distribute the heat load on the conventional heating systems. Air source heat pump can be used when it is difficult to install GSHP.

III. ENERGY DEMAND OF THE HOUSE

The energy demand of any building can mainly be classified in two categories as shown in a chart below. Figure 2 explains that the thermal (heating/cooling) demand of the house is generally met either passive solar (natural gains) or by active input. The mechanical heating by means of boilers or heat pumps are common examples in this category. The electricity demand of the house is being met by the means of conventional power station such as coal-fired power plants, or nuclear power plants. The demand of the solar and micro wind turbines is gradually increasing with time.

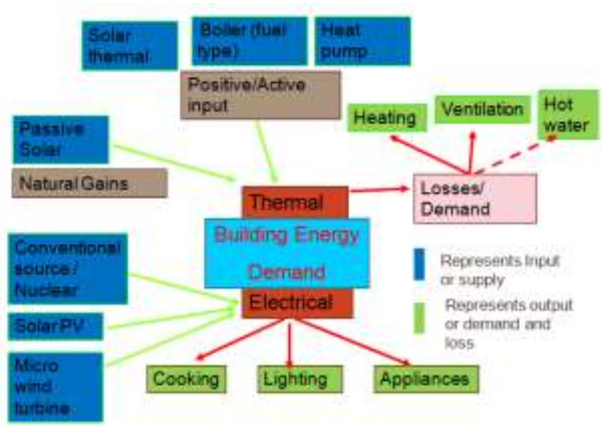

Figure 2 Classification of energy Demand of the house

(1) Thermal demand (It could be heating or cooling both, but here heating is taken as major thermal energy demand of the house)
(2) Electrical demand

There are various physical and behavioural factors to determine the energy demand load profile for particular building and they often vary for each building. Physical and behavioural factors have a direct relation with the composition of the building, occupancy pattern, number of occupants and other variables. Several authors believe that it is possible to reduce annual energy demand of the house by 10-20% by modifying end-users behaviour.

IV. EXPERIMENTAL METHOD – ENERGY CONSUMPTION AND ENERGY UTILISATION PATTERN

A. Characteristics of chosen existing property

The property chosen to be examined and propose improvements to make it energy efficient was mid terrace house and believed to be built in Victorian time (1837 – 1900). It was not built with high standards of thermal characteristics. Due to the age and lack of effective thermal properties the chosen dwelling was having potential retrofitting opportunities to meet current building regulations. The property was having no or very little insulation in different parts/elements. Experts believe that if this property can be retrofitted to meet standards than any dwellings in the UK can be modified to be energy efficient and that was the key characteristic of the chosen dwelling.

The electricity consumption by the appliances and the energy behaviour and approach of the occupants were also inspected for the same dwelling and is discussed further in chapter 2.4.

The property was considered as hard to be retrofitted without destroying due to its solid walled fundamental construction. The chosen property was in the same lane of the SHEFFIELD ECO-TERRACE property, which was retrofitted by Sheffield city council and Energy Saving Trust (UK) as a motivational illustration for the community. Mr. Thompson and SYEC confirmed that the chosen property has very similar characteristics as the SHEFFIELD ECO-TERRACE building before its transformation.

Taking Measurements of the house elements was first step towards making the dwelling energy efficient. Schematic diagram of the dwelling was made using Autodeck Ecotect software to understand the heat loss behaviour in detail. U-values and the areas of different elements of the house e.g. wall, roof, floor were decided to calculate heat loss. Heat loss calculation is very effective way to understand the dwelling's thermal properties for each element. These calculations for different components of the house help to decide if that particular component needs any thermal treatment. The schematic diagrams of the chosen property are shown in figures 19 and 20 below.

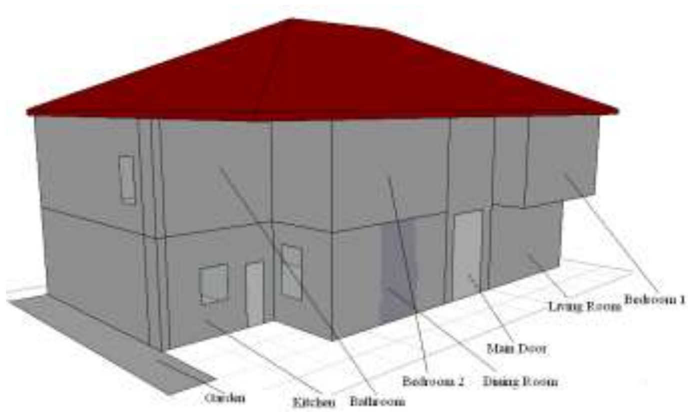

Figure 3 Front view of the chosen property to be inspected

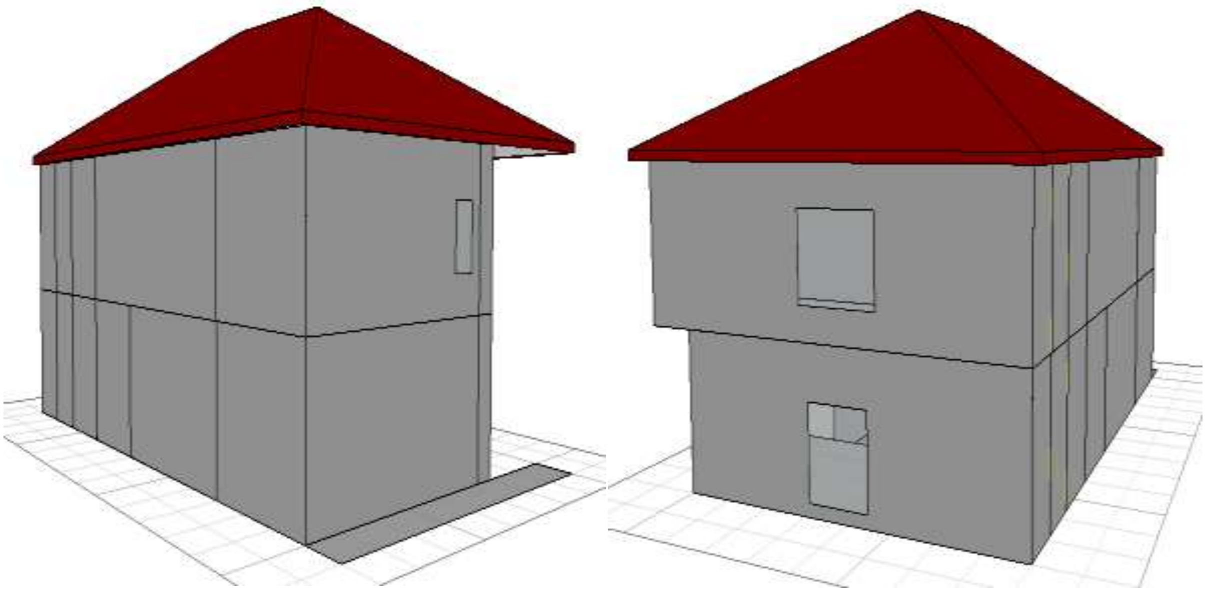

Figure 4 Side views of the chosen property

The wall thickness was measured to be 240 mm, including 20 mm of interior plaster layer and no other insulation. The dwelling was having carpeted timber floor with unknown thickness and no insulation or special treatments. It was having pitch roof without access to loft. Most of glazing in house was double-glazed with aluminium frame and no low e-coating. The windows were believed to have air-filled gap between the layers. The dwelling was believed to be very poor in air tightening and not having any mechanical fans or other type of ventilation systems except natural drafts. Main form of house heating was by means of mains gas combustion in a combi boiler supplying heat to radiators. The boiler was believed to be installed during or after 1998 and the efficiency was assumed no more than 70%. The boiler was having time controller but no thermostatic control of room temperature. Hot water was being delivered by the same boiler, while the shower was electricity operated. The property was having cellar as well but the access to it was sealed and hence it was not possible to examine it.

The detailed specification of the house used for heat loss calculation and other quality check are shown in table 3 below.

Height of eves (m)	*6 (taken a rounded up figure)*
Length of South/North Wall (m)	*4.05*
Length of East/West Wall (m)	*17.4*
Angle of roof pitch	*45^o (0.785 radians) (Assumed)*
Thermal Element	***U – value (W/ m^2K)***
Roof void / Attic	*2.30 (un-insulated loft)*
Solid bricks	*2.10*
Ground Floor	*0.62*
Openings	***U – value (W/ m^2K)***
Solid timber door	*3.00*
Existing double glazing	*2.70*
Thermal Bridging Analysis	*-*
Total Floor area	*71.47 m^2*
Ventilation	*Natural (No extract fans)*
Air tightness	*Very Poor*
Heating	*(Combi) Boiler (< 70 % Efficiency)*
Hot water	*Boiler*
Low energy lights	*8 bulbs out of 11*

Table 1 Specification of the chosen existing property

(EST, 2010a) (Thomson, 2011) (Ref 40 all SYEC)

The thermal performance of the property is explained with the help heat loss calculations as shown in table 4.

Table 2 Thermal performance and heat loss calculations of the property

ELEMENTS		***U-Value***	***Total Area (m^2)***	***Specific Loss (W/K)***
Walls (Block and Plaster)	*-*	*-*	*Height of eves x Length of solid wall*	*U-value x (total area – Glazing area)*
	South	*2.10*	*24.3*	*42.25*
	East	*2.10*	*104.4*	*219.24*

	North	*2.10*	*24.3*	*39.96*
	West	*2.10*	*104.4*	*217.22*
Glazing (Double)	-	-	-	*U-value x glazing area*
	South	*2.70*	*(2.41 + 1.77) = 4.18*	*11.29*
	East	*2.70*	*0*	*0*
	North	*2.70*	*5.27*	*14.23*
	West	*2.70*	*0.96*	*2.59*
Floor		*0.62*	*71.47*	*44.31*
Roof		*2.30*	*99.7 [(Length of south wall x Length of east wall)/cos (0.785)]*	*201.6*
Total Heat Loss (W/K)				*792.69*

Heat loss calculations show that the maximum heat is being lost by non-insulated walls, which accounts for 518.67 W/K, almost 65% of total. The results of heat loss calculations indicate that the requirement of insulation on different elements of the house was very necessary. The varieties of suitable insulation options for individual components are discussed in chapter 3.1.

Energy Saving Trust's online “Home Energy Check” service was accessed to get an energy report for the current condition of the house (See Appendix), which was taken in consideration while suggesting best practice improvements.

IV. RENEWABLE ENERGY PRODUCTION ASSESSMENT FOR THE HOUSE

B. Wind Turbine Compatibility

Figure 26 shows the wind speed data read by the instrument. The instrument measured 0.7 m/s wind speed at 3m hub height from the ground at site. The instrument recorded highest wind speed in early April, which was roughly 1.6 m/s. There has been a significant decrease in wind speed from early October to early December. One significant observation can be done from the graph that in almost every month, wind speed has been higher in starting than the end of that respective month except December 2010 and January 2011.

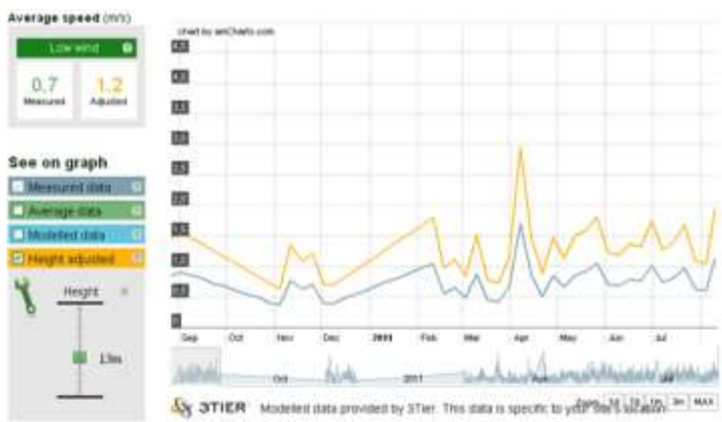

Figure 5 Wind speed data recorded by the power predictor on the site

The above figure also shows the estimated wind speed at adjusted height of 13m, but was not able to show the average wind speed at that height and hence it was calculated manually to observe the effect on power production. Paul Gipe (2004) has shown how to calculate wind speed at adjusted height in his book.

The instrument has recorded maximum wind distribution in north-east direction, which is 36.3%. It clear that the wind turbine should be set up in this direction if possible, or somewhere in between north and east with optimum angle to the incoming wind.

4	GaiaWind 133 - 11kW	Financial report	£50,600	-419.7kWh	-£50.37	-0.7%	-228.8kg	-14.2%
5	Skystream 3.7	Financial report	£9,908	-94.3kWh	-£11.31	-0.7%	-50.9kg	-3.2%
6	Westwind 20kW	Financial report	£60,000	1.3kWh	£0.16	0.0%	0.7kg	0.0%
7	Westwind 10kW	Financial report	£40,300	0.6kWh	£0.07	0.0%	0.3kg	0.0%
8	Eoltec Scirocco 6kW	Financial report	£23,000	0.5kWh	£0.07	0.0%	0.3kg	0.0%
9	Evance Iskra R9000	Financial report	£24,150	0.1kWh	£0.01	0.0%	0.0kg	0.0%
10	Proven 7	Financial report	£16,000	0.1kWh	£0.01	0.0%	0.0kg	0.0%
11	Westwind 5.5kW	Financial report	£24,200	0.1kWh	£0.01	0.0%	0.1kg	0.0%
12	Airquiet 6kW	Financial report	£15,000	0.0kWh	£0.00	0.0%	0.0kg	0.0%
13	Endurance E-3120 50kW	Financial report	£240,000	0.0kWh	£0.00	0.0%	0.0kg	0.0%
14	FuturEnergy 1kW	Financial report	£5,000	0.0kWh	£0.00	0.0%	0.0kg	0.0%
15	Proven 11	Financial report	£25,000	0.0kWh	£0.00	0.0%	0.0kg	0.0%
16	Proven 35	Financial report	£50,000	0.0kWh	£0.00	0.0%	0.0kg	0.0%
17	GR5	Financial report	£25,000	0.0kWh	£0.00	0.0%	0.0kg	0.0%

Figure 6 Power report predicted by power predictor for wind turbine installation on site

The power predictor considers the site poor for the wind turbine installation. Figure 28 shows some of the suitable wind turbines to choose if very keen to install wind power at the site. Column 3 explains the capital cost for the installation of particular turbine. Column 4 shows potential kWh production for respective turbine. Column 5 and 6 show the basic value and capacity factor for the corresponding turbines respectively. Column 7 shows the $kgCO_2$ saved by using renewable energy, and column 8 shows carbon footprint of the turbine.

Although the first two wind turbines cannot produce any energy at the site, Westwind 20kW turbine can produce 2.1kWh energy, which meets almost 0.1% of the annual demand (~3500 kWh) when installed at 3m height from the ground. To estimate the power production at 13m height using power equation 2 shown above, actual efficiency of the turbine and real value of air density were missing hence it was decided to employ equation 3 shown below.

$\frac{P}{P_o} = (\frac{H}{H_o})^{3\alpha}$ Where P = Power produced at uplifted height (kWh), P_o = Power produced at original height (kWh), H = Uplifted height (m), H_o = Original height (m) and α = wind shear exponent or Hellman exponent.

Equation 3 (Paul Gipe, 2004)

And hence

$\frac{P}{2.1} = (\frac{13}{3})^{(3)(0.34)}$ Thus $P_{@\ 13m}$ = 9.37 kWh

The power produced at 13m height meets almost 0.26% of the annual demand. This production even does not appear satisfactory to convince the governmental or non-governmental organisation (NGO) to approve planning for the site.

A. *Solar PV System Compatibility*

Figure 30 gives an idea about the solar intensity at the site over a period of 10 months. The average solar availability was measured in terms of W/m^2. The solar energy has not relation with the height but it depends upon the angle between sun and the device called azimuth angle. In the northern hemisphere the solar PV systems are recommended to obtain optimum power production.

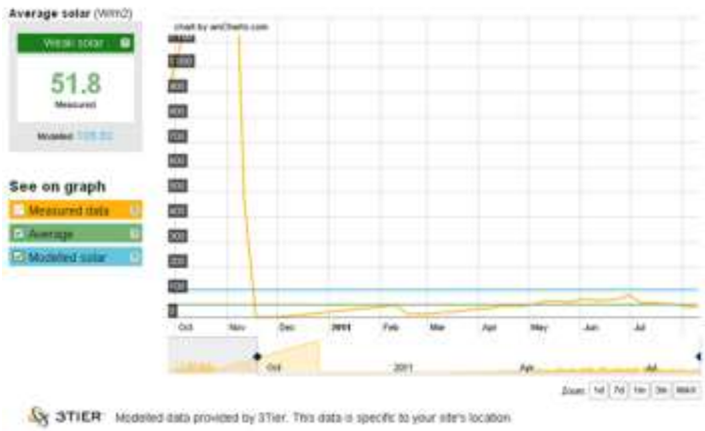

Figure 7 Solar intensity data recorded by power predictor on site

The instrument had measured average solar intensity 51.8 W/m^2. Three solar PV systems were found suitable for the application on site as shown in figure 31.

	Sort by kWh		Capital cost	kWh	Basic value	Capacity factor	kgCO$_2$ saved	Carbon footprint
1	Kyocera KD 2.7kWp array	Financial report	£14,559	764.7kWh	£91.77	5.3%	412.9kg	25.8%
2	Suntech STP 2.8kWp array	Financial report	£15,700	669.1kWh	£80.30	4.5%	361.3kg	22.6%
3	Sharp ND 2.5kWp array	Financial report	£14,763	621.3kWh	£74.56	4.7%	335.5kg	21.0%

Figure 8 Power report for the installation of the solar PV system on site

Kyocera KD 2.7 was estimated to payback in 22 years, while Suntech STP and Sharp ND systems were expected to payback in 30 and 29 years respectively.

V. DISCUSSION

A. Retrofitting the existing house

The house chosen to inspect the retrofitting potential was more than a century old. There were no signs of having it retrofitted before except few unavoidable repair works. There were no any governmental regulations or standards that could be followed while designing and building dwellings at the time of built of this house and hence construction was poor in terms of its thermal properties. The heat loss calculations of the house were a key to identify the thermal property of the house. Although there were not a precise indication of the heat load of the house since it was not possible to conduct an draught proofing and air tightness test which accounts for almost 12% of heat loss. Heat loss calculations were conducted using four elements wall, windows (or glazing), roof and floor. The solid walls with only a layer of wallpaper and plaster were found major culprits of heat loss. Heat loss calculations shows that they contribute almost 65.43% heat loss among those four elements. Insulating solid walls to meet the standard U-value of walls can bring the heat loss down up to 61.75W/K from 518.67W/K.

Energy Saving Trust estimates to save £75 a year if the solid walls were insulated. The CO_2 production of the house can be brought down by 0.75 tonnes per year by insulating these solid walls. It was also estimated that the investment on retrofitting of walls can payback in less than 2 years. The estimation of loft insulation provided by EST shows that it can cost £325 to insulate the loft if it has absolutely no insulation while topping up the insulation may cost up to £265. Considering the assumption made earlier, insulating a loft completely can save up to £85 to £295 in heating bill. It is the best option to insulate the rafters of the roof of the chosen house (2 bed mid terrace) with sprayed polyurethane foam. It could cost up to £1500 (excluding VAT) and save heating cost up to £455. (EST, 2009d). EST estimates that refitting of the windows could cost up to £2000 to £4000 while replacing them with low-e (low emissivity) coated windows. The low-e windows can save up to £35 to £125 per year and deliver best results for 15 to 20 years (EST, 2009b). Replacing the windows to meet minimum required U-value can save up to 14 to 15W/K heat loss and this number can be improved using higher quality windows. EST estimations for timber floor treatment states that the installation cost could be up to £100 for the material plus labour cost. The insulating timber floor can save up to £40 to £50 per year and can payback the investment in less than 3 year. The 15 year old heater was not expected to operate as efficient as 75%. It was estimated that replacement of heater can save running cost up to £113 a year. Solar water heater as a secondary system can save more money up to £21 a year. The advanced heating controls like room temperature thermostat or programmable controllers can save £103, which recovers the investment on heating systems in less than 3 years.

B. *Generating Renewable Energy*

EST suggests that use of the solar energy for a particular site can help save £21 a year in heating bills. These systems are recommended to mount on roof and need a small storage tank. This would help to share the heating load on the boiler for the daily hot water consumption. (See Appendix) The installation cost of such systems was estimated to be £4000 to £6000 depending up on the size. The large area of the solar collectors can generate more energy if enough roof space provided and the savings in heating bills can be lifted up to £50 a year. (EST, 2011d) The solar PV system was viable option for the site as well. The power predictor estimates that the site has a potential to produce 1248 kWh electricity every year when fixed with Kyocera KD 2.7 panels. Installation of this panels can payback the investment in less than 22 year. The power predictor had used only some of the manufactures' data who were register in the software so it is advisable to have a thorough market research before taking any decision. The EST mentions that if $5m^2$ to $10m^2$ unshaded roof area is available than it is possible to generate enough electricity to save £190 each year. Such systems cost £8000 to £16000 for the installation and hence the payback period cloud be reduce to 14 years. (EST, 2011d) Other than a solar energy, this site is also compatible for installation of air source heat pump to meet the heating demand of the house. As the property has enough space outside of the house to install the unit it can save up to £60 a year using this technology. Usually the installation cost of such units is between £6000 and £10000. (EST, 2011d).

VI. CONCLUSION

There is a possibility to save up to nearly £500 in energy bills and reduction in CO_2 production by 45% by bringing down it to 3.3 tonnes per year from current 6.2 tonnes year. It is certain that if a whole refurbishment of the house is not possible than, insulating the walls can be a short solution as walls area is the weakest element of the house. The investment on the wall insulation can be recovered in a short period of time. The roof area needs to be inspected by a professional to make precious comments and that should be the second choice for the insulation. It is very cheap option to insulate the roof without any attic room and hence should not be avoided. Roof insulation material and labour cost are very nominal and tend to have very short payback period.

The house has very poor ventilation arrangement as only natural ventilation is possible.

A comprehensive examination of the selected site suggests that the site is not appropriate for installation of the wind energy while it could be a good solution to install solar energy system. The results were confirmed using two sources, one the power predictor and second the Energy Saving Trust's online service. The site is also appropriate selection for air source heat pump installation to distribute the heat load of the dwelling.

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