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Affordability and Energy Consumption: A Study on Zero Carbon New Built Homes in the United Kingdom

Abstract

The need for sustainable development, the near zero tolerance to carbon emissions and rise in global house prices, have necessitated the provision of affordable and energy efficient housing projects by governments in most developed countries. In the United Kingdom, the same is true as almost half the total amount of carbon dioxide emissions is building-related, with housing contributing about 27% of the overall emissions. This paper demonstrates the role early building performance and cost evaluation could play in delivering affordable and energy efficient homes through evaluation of housing typologies against the UK policy set benchmark for assessing new built and zero carbon housing. Extensive reviews of various methods and techniques have been followed for pre-design evaluation, building performance simulation and cost estimation. The paper concludes by recommending guidelines for future studies on delivering affordable and reducing energy consumption in the new built homes.

Key words

Zero Carbon Home, Sustainable Housing, Energy Efficiency, Affordable Housing, Cost Analysis

1. Introduction

Over the past two decades, issues of climate change—as it relates to impacts of natural resource developments—has formed the overarching themes of academic and international discourse. As a result, international agencies and national governments have led the advocacy for sustainable development, as a key component to transforming the built environment. So far, many solutions to the challenges of global energy crises have been proposed and applied in recent years, including the provision of energy efficient housing projects by governments in most developed countries. In the *United Kingdom* (UK) the same is true as over 65% of *Global Greenhouse Gas* (GHG) emissions are energy generated (WILLIAMS, J. 2012), with about 64% of annual energy consumption by the building sector generated in houses (NICHOLLS, R. 2002). This assertion was buttressed by the INNOVATION UK (2009), who maintained that almost half the total amount of carbon-dioxide (CO_2) emissions, is building-related with housing contributing approximately 27% of CO_2 emissions.

COMMUNITIES AND LOCAL GOVERNMENT (CLG, 2006) report shows an average UK household emission of about 1.54 tonnes of carbon per annum. This has prompted government-led campaign on decarbonising the housing sector through the ambitious set target of affordable, zero carbon new-built housing delivery by 2016. In this regard, the housing industry is tasked with the erection of 120,000 private homes and 26,000 social homes per year to meet the housing supply of 200,000 units per year in England by 2016, which will account for about 30% of the housing stock by 2050 (BANFILL, P. – PEACOCK, A. 2007; RYDIN, Y. 2007; OSMANI, M. – O'REILLY, A. 2009; MCMANUS, A. 2010). This shows the proposed and expected contribution of the housing industry to the overall carbon emissions reduction by 2050 from the 1990 levels.

Surprisingly, the housing sector that seems to emit considerable amount of CO_2 among other sectors in the UK has been identified by the government as a solution to tackle energy crises and climate change at large. Back in 2004, UK government’s affordable new built homes programme set at sixty thousand pounds (£60,000) target, challenged the home builders to device measures aimed at building high standard energy efficient homes irrespective of the 'still-developing' renewable energy technologies which are supposed to be integrated in the building design (for example OSMANI, M. – O'REILLY, A. 2009). Following this, the housing developers are enjoined to deliver homes with set of standards that will consequently lead to a significant increase in cost of housing delivery (MCMANUS, A. 2010). Therefore, urgent need arises for the house building industry to align themselves with government plans by welcoming, implementing and proffering solutions to building energy efficient homes with low carbon emissions.

According to ENERGY EFFICIENCY NEWS (2010), the UK government proposed that 15% of its energy demand would be sourced from renewables by 2020, with interim targets of 4% from 2008 to 2012, and 7.5% from 2015 to 2016. However, based on the third quarter of the 2011 statistical report of the Department of Energy and Climate Change (DECC, 2011), renewable energy currently accounts for 9% of total electricity production. Although the utilisation of energy efficient heating and renewable system can lead to low energy homes (WANG, L. – GWILLIAM, J. – JONES, P. 2009), lack of financial data analysis, together with excessive energy efficiency policies linked with the construction of zero carbon homes may hinder the accomplishment of the carbon reduction target through the housing sector (OSMANI, M. – O'REILLY, A. 2009).

2. Aims of the study

The study aims to investigate the possibility of achieving an affordable and zero carbon home, through early design evaluations using demonstration houses that are currently being built at *Barnsley College*, *Honeywell* site in *South Yorkshire*, UK. The researcher questions whether zero carbon truly means zero energy? There are two major objectives in carrying out this study: one is to discover the impact integration of renewable energy sources and energy efficient design measures could make in overall building cost and energy consumption in housing; and the other is to investigate the annual energy consumption and the exact CO_2 emission savings the newly built homes are expected to deliver. In so doing, it is intended that these could help understand the benefits of pre-design evaluation for the *Barnsley College*, and the society at large. The study adopted both analytical case study approach using the *Dynamic Simulation Modelling* (DSM) for energy performance analysis and the *Building Cost Information Services* (BCIS) for cost analysis. Despite evidence of limited studies on pre-design evaluation with regard to energy performance and base build cost of the proposed new dwelling, the new built homes were assessed using code for sustainable homes and building regulations standards. The code for sustainable homes is the national standard for the sustainable design and construction of new homes, which aims to reduce carbon emissions and promote higher standards of sustainable design above the current minimum standards set out by the building regulations (CLG, 2006). Also, this will further produce cost effective and more energy efficient designs.

3. Case study

The case study project, *Barnsley College Demonstration Houses*, proposed to be on site at *Barnsley College* in *Barnsley Metropolitan Borough* at the north of the city of *Sheffield* in *South Yorkshire* (UK). According to *Jefferson Sheard Architects* (JSA, 2011), it comprises of 10 demonstration houses to be sited close to the *Barnsley College Sustainable Construction and Renewable Energy Centre* north of the Honeywell site which is well connected by public transport as shown in *Figure 1*. It is also of walking distance from the main campus at *Old Mill Lane*, the town centre and shopping areas.

The proposed *Barnsley College Demonstration Houses* have been selected as a case study for this paper for the following reasons:

- The proposal is in line with the UK government's proposed zero carbon homes by 2016.
- The design proposal is at stage D approval and appears to be the best time for early design evaluation for energy consumption check and base build cost.
- The proposed building units are intended to be sold as private houses, which make it paramount for affordability check.

- This study outcome may lead to cost and carbon savings of the proposed project.

Figure 1 – Artist Perspective view of The Barnsley College Demonstration Houses
Source: JSA (2011)

These sustainable homes are intended to serve as a tool for practical knowledge, in addition to the theoretical background of environmental technologies the *Sustainable Construction and Renewable Energy Centre* is expected to deliver. In the same way, they are expected to benefit the housing sector at large that is currently challenged with the delivery of affordable and energy efficient homes. The demonstration houses were constructed with various techniques of housing development eras ranging from the Pre 1900 Victoria end terrace *(Plot 1)* to 2016 Code level 6 house *(Plot 10)*. For the researcher to remain focused on the goal of achieving zero carbon homes through early design evaluations, the following plots were selected for evaluation and comparative study:

- *Plot 6* of 1970s Modern timber frame house
- *Plot 7* of 1990s Building regulations standard baseline house

- *Plot 8* of Code level 4 house
- *Plot 9* of Code level 5 house
- *Plot 10* of Code level 6 house.

This is to draw a comparative study of the cost and energy performance of the proposed 1970s and 1990s houses, representing the typical UK homes and the recent code level houses designed to meet criteria set out by the code for sustainable homes (CLG, 2010). On the next pages, *Table 1a–1b* detail the design requirements and specifications for both the typical UK houses and the code level houses.

Table 1a – Design specifications for the typical UK houses and the code level houses

*Source: JEFFERSON SHEARD ARCHITECTS (JSA, 2011) *see units below Table 1b*

	Typical UK houses	
Code level Target/ BREEAM Aspiration	**Plot 6 1970s Timber frame**	**Plot 7 1990s Building regs.**
Improvement in CO_2 emissions	60% Improvement	40% Improvement
GIA (m^2)	85	75
Floor to Floor Height	2,600	2,660
External Walls	0.18 W/m^2K	0.1 W/m^2K
Wall Thickness	265 mm	315 mm
Internal Walls	Timber stud	Timber stud
Windows	Double glazed	Double glazed
Doors	Double glazed	Double glazed
Ground Floor	0.18 W/m^2K	0.18 W/m^2K
Upper Floors	Suspended timber joists system	Suspended timber joists system
Roof	0.18 W/m^2K	0.1 W/m^2K
Renewable energy sources	2 kW PV (photovoltaic) Panels	4 m^2 Solar Thermal

Units: kW: Kilowatt; kWh: Kilowatt-hour and W/m^2K: Watts per square metre per degree Kelvin (U Value).

Abbreviations: GIA: Gross internal area; DER: Dwelling Emission Rate and TER: Target Emission Rate.

Table 1b – Design specifications for the typical UK houses and the code level houses.

Source: JEFFERSON SHEARD ARCHITECTS *(JSA, 2011).*

	Code level houses		
Code level Target/ BREEAM Aspiration	**Plot 8 Code level 4**	**Plot 9 Code level 5**	**Plot 10 Code level 6**
Improvement in CO_2 emissions	≥ 25% Improvement 2010 DER/TER	≥ 100% Improvement 2010 DER/TER	Zero Net CO_2 Emissions
GIA (m^2)	76	138	138
Floor to Floor Height	2,600	2,550	2,550
External Walls	0.18 W/m^2K	0.1 W/m^2K	0.1 W/m^2K
Wall Thickness	335 mm	330 mm	225 mm
Internal Walls	Timber frame Partitions	Timber frame Partitions	Timber frame Partitions
Windows	1.0 W/m^2K	0.7 W/m^2K	0.7 W/m^2K
Doors	1.0 W/m^2K	0.7 W/m^2K	0.7 W/m^2K
Ground Floor	0.18 W/m^2K	0.18 W/m^2K	0.18 W/m^2K
Upper Floors	Suspended timber Joists system	Suspended timber Joists system	Suspended timber Joists system
Roof	0.18 W/m^2K	0.1 W/m^2K	0.1 W/m^2K
Renewable energy sources	Mechanical Ventilation and Heat Recovery (MVHR), 3 kW PV Panels	Biomass Boiler, MVHR, 4 kW PV Panels, Rainwater Harvesting	Biomass Boiler, MVHR, 7.5 kW PV Panels, Rainwater Harvesting

Units: kW: Kilowatt; kWh: Kilowatt-hour and W/m^2K: Watts per square metre per degree Kelvin (U Value).

Abbreviations: GIA: Gross internal area; DER: Dwelling Emission Rate and TER: Target Emission Rate.

3.1. Typical UK houses (Plot 6 and 7)

This is a semi-detached building consisting of two bedrooms each. *Plot 6*, a typical 1970s house designed, utilising timber frame construction with a combination of brickwork and timber boarding. However, this was upgraded with insulation added to cavity, plasterboard and skim paint finish. While *Plot 7* was proposed following the 1990s building regulation standards for fabric heat loss, insulation levels and U-values for building elements. Designed as a late 20th century building using cavity wall construction with brick or stone outer leaf, cavity insulation and a lightweight concrete block inner leaf.

3.2. Code level houses (Plot 8, 9 and 10)

The brief for *Plot 8*, *9* and *10* is to provide new-built houses that meet future targets for reduced carbon emissions and the demand for higher environmental standards as detailed in the code for sustainable homes. The proposed building designs appear to be influenced by the *Building Research Establishment (BRE)* consultants that recommended lightweight construction designs using *Structural Insulated Panels (SIP)* construction for Code levels 5 and 6 in order to achieve the desired airtightness. Furthermore, the college desired a 'volumetric' design (prefabricated modular construction) for Code level 6. The Code levels 4 and 5 is a semi-detached two and three bedrooms house respectively, while the Code level 6 is a three bedroom detached house.

4. Methodology

The study adopted both fieldwork approach of primary data collection using analytical case study methodology to capture complexity of a single case and desktop study approach of secondary data in form of stage D report obtained from *Jefferson Sheard Architects*. For early design evaluation and analysis of the case study buildings, the *DesignBuilder* software has been used for building energy modelling and per formance analysis (DESIGNBUILDER, 2012).

The *DesignBuilder* software with its built-in *EnergyPlus* thermal engine and simplified *Building Energy Modelling (SBEM)* of result output as well as its recognition of Part L 2006, building regulations on fuel and energy consumption, was selected as a DSM option. Furthermore, to check affordability of the case study design, BCIS (2012) online, early design cost estimator has been used instead of manual calculations. This is believed to be more reliable and a preferred standard for building cost assessment in the UK.

4.1. Building modelling and simulation

The *EnergyPlus* simulation engine was chosen in the modelling options within the *DesignBuilder* software. The *Sheffield* weather file was used as the closest to the *Barnsley* location. The buildings were modelled observing the orientation and precisely following the architectural drawings and specifications provided by *Jefferson Sheard Architects*. The plots were modelled and zoned as separate plots although they are semi-detached buildings, as shown in *Figure 2*.

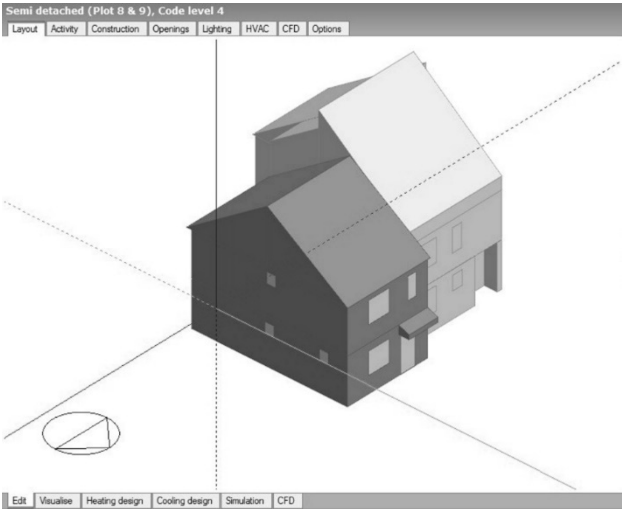

Figure 2 – Building simulation modelling using DesignBuilder software.
Designed by Dara, C. (2015)

This is to enable easy simulation of individual plots and simplified data analysis of the annual energy consumption, and CO_2 emissions produced. The various activities, construction, openings, lighting and HVAC system were carefully entered. The model was then simulated. This process was followed for all different plots.

4.2. Building cost analysis

Similarly, the BCIS online building base cost was used to calculate the cost of the houses (Plots). Firstly, the study type which is cost per square metre (£/m^2) was chosen. Newly built, residential and semi-detached estate housing was selected. This was then rebased to the *Barnsley* location, index 94 from *Yorkshire* and *Humberside* counties. It was further calculated and the result of various semi-detached houses, designed in different years with *Barnsley* rebased cost displayed. The building type and storey height were considered during the selection to enable a relatively close amount for the study buildings. The affordable homes at *Station road* appear to be most suitable when checked against other currently matching analysis. Therefore, this was chosen for all semi-detached houses both typical *(Plots 6 and 7)* and the Code levels 4 and 5 homes to promote quality research outcome. Moreover, the typical homes were designed to be energy efficient. The exact base cost of the housing type was used as a benchmark for calculating the cost per square metre of semi-detached houses and the cost of renewable technologies provided by approved suppliers. Again, this was carried out for the *Plot 10*—Code level 6 detached house, following the aforementioned procedure for the semi-detached house. In the same way, a close match project was chosen and the cost per square metre used to estimate the base build cost for Code level 6.

5. Analysis and results

The author believes that an early design evaluation will help building design professionals in the UK understand the cost implications and actual energy performance of the newly built dwellings which were rated using the 'code for sustainable homes' and 'building regulations' standards. The base build cost and annual energy consumptions of *Barnsley College* demonstration houses have been analysed to prove affordability and energy efficiency of newly built houses through a comparative study of the 1970s modern timber frame house to Code Level 6 (zero carbon) house. The findings were evaluated as a case study, which utilised different software for precise modelling and critical analysis. For the building energy performance simulation results, the computer models were simulated from 1st January to 31st December to generate annual energy consumption and CO_2 emissions rate. Finally, a comparative study of research outcomes were discussed. The inferential method of analysis that engages the comparison of results were used to further orchestrate some points.

5.1. Analysis of typical UK houses (Plots 6 and 7)

In the simulation modelling of the 1970s (Plot 6) typical house, the overall building energy demand from heating, lighting and hot water system were evaluated. However, the heating were calculated using gas, as the integrated PV panels output cannot cover for the heating system required in winter season. Following the analysis, the annual fuel breakdown gives an electricity of 2,108.67 kW, 5,283.30 kWh of gas and a total energy consumption of 7,391.97 kWh. In addition, the energy demand of heating, lighting and other activities were calculated with heat generation contributing about 71.47% of the total energy consumption. Recall, that the building is expected to meet 60% improvement in CO_2 emissions, in this regards the CO_2 emission produced was calculated and this amounts to 2,474.68 kg. The 1990s (Plot 7) typical house, energy performance simulation considered a 4 m^2 solar thermal system integrated for hot water generation. The system output in kilowatt hour will be deducted from the annual energy consumption. In addition, the plot was designed to meet 40% improvement in CO_2 emissions. The result of the analysis gives the annual fuel breakdown with electricity consumption of 2,095.58 kWh and a gas contribution of 6,993.12 kWh. Thus, the total energy consumed amounts to 9,088.70 kWh. Again, heat generation contributed about 76.94% of the total energy consumption. Furthermore, CO_2 emissions produced amount to 2,756.99 kg.

The 1970s and 1990s base cost calculation for a 2 storey semi-detached affordable home rebased to Barnsley location is about £605.31/m^2 (BCIS, 2012). However, 2% was added to the building cost to accommodate inflation as the sample building was designed in 2010. Further, the cost of installing the renewable energy features are considered (ENVIKO, 2012; EST, 2012). The building base cost for *Plot 6* (1970s) amounts to £57,613.71, and *Plot 7* (1990s) calculated to be £49,768.22.

5.2. Code Level Houses Analysis (Plots 8, 9 and 10)

For Code level 4 house *(Plot 8)*, energy performance simulation considered a design with thin bed masonry construction fitted with MVHR and 3 kW PV panels. In addition, to meet the environmental factor improvement set in 2010 Part L1A building regulations, it is estimated to perform ≥25% improvement of the *Dwelling Emissions Rate* (DER) over *Target Emissions Rate* (TER). For the Code level 4 house, the result of the building simulation displays electricity consumption of 2,917.25 kWh and 7,779.17 kWh of gas respectively per annum; therefore, the total energy consumed amounts to 10,696.42 kWh. For Code level 5 house *(Plot 9)*, energy performance simulation considered a design using SIP panel construction, fitted with MVHR, 4 kW PV panels and biomass boiler for heating. Rainwater harvester was used to recycle grey water. In addition, it is estimated to perform 100% improvement of DER over TER. The result of the analysis gives the annual fuel breakdown of 9,568.65 kWh for electricity consumption and the remaining 5,331.44 kWh from renewable source. Thus, total energy consumption stood at 9,568.65 kWh.

For Code level 6 house *(Plot 10)*, energy performance simulation considered a design using volumetric construction, fitted with MVHR, 7.5 kW PV panels and biomass boiler for heating. Rainwater harvester was also used to recycle grey water. Recall that plot 10 is estimated to have zero net CO_2 emissions. Following the analysis for the annual fuel breakdown, electricity consumption accounts for 9,652.28 kWh and the remaining 6,544.32 kWh from renewable source. Given this, the total energy consumption is 9,652.28 kWh. Heating contributes about 72.73% of the total energy consumption for code level 4 house. For code level 5 system misc. contributes 45.01% followed by 35.78% from heating. In addition, system misc. contributes 41.41% followed by 40.41% from heating for code level 6. Similarly, the CO_2 emissions output was calculated to be 3,515.26 kg, 10,220.26 kg, 11,094.60 kg for code level 4, 5 and 6 respectively. It is believed that heating with biomass boiler for code level 5 and 6 increased the CO_2 emissions output.

For Code level houses building base cost analysis (*Plots 8*, *9* and *10*), the same building cost estimation for the typical UK houses have been applied for the code level 4 and 5 as semi-detached houses. However, a sample project, detached 2 storey newly built house together with external works were used to calculate the cost per square metre for *Plot 10* (code level 6 house). This sample project was designed in 2010 at *St. Peter*, *Jersey*, and also rebased to *Barnsley* location (index 94). The cost of installing a compact loft mounted MVHR unit with super-efficient DC motors for extremely quiet running, maximum product life with minimal running costs (SOLARCREST, 2011), cost of installing biomass boiler inclusive of 5% VAT (EST, 2012), and the cost of rainwater harvesting system including installation cost (ENVIKO, 2012) were added to the respective plots to calculate the building base cost (see *Table 1a–1b* for details). Subsequent to that, the following were deduced:

1) The building base cost for *Plot 8*—Code Level 4 estimated to be £55,481.63
2) The building base cost for *Plot 9*—Code level 5 calculated to be £111,988.11
3) The building base cost for *Plot 10*—Code level 6 costs £137,685.67.

6. Discussion and comparison

Through the findings above, achieving affordable and energy efficient new builds in the UK might depend on the integration of renewable technologies. It clearly shows that zero carbon homes might not be zero energy homes with the *Plot 10* (Code level 6 house). To report the actual annual energy consumption, the electricity output produced by the renewable sources will be deducted from the modelled energy consumed as this was not calculated in the computer simulation.

The *European Commission* (JRC, 2010) website on estimating the performance of PV panels based on their geographical locations was used to calculate the solar electricity generated by the PV panels. A 2 kW crystalline silicon photovoltaic panel adjusted to the *Barnsley* location will produce about 1580 kWh electricity per annum. This excludes estimated percentage losses due to temperature, cables, angle of reflectance effects and others. Again, the 3 kWh, 4 kWh and 7.5 kWh PV panels used for code levels 4, 5 and 6 respectively were calculated using the same estimation method. The solar electricity outputs include: 2,380 kWh, 3,170 kWh and 5,940 kWh respectively. In addition, the usable free energy yield per annum, generated by using 4 m^2 evacuated tube solar thermal collector system, (ENVIKO, 2012) was also calculated. Similarly, the energy consumption generated due to the use of biomass boiler in code levels 5 and 6 were further deducted as it is considered as non-fossil fuel. Thus, the actual annual energy consumption for various plots calculated and tabulated in *Table 2*. In addition, the dwellings fabric energy efficiency were calculated.

The results on energy consumption figures are positive as all plots performed above the benchmarked annual energy demands of the typical UK household of 3,300 kWh of electricity and 16,500 kWh of gas (OFGEM, 2011). Furthermore, the code level 5 almost met the estimated dwelling *Fabric Energy Efficiency Standards (FEES)* with a difference in 0.37 $kWh/m^2/yr$.

Table 2 – Comparative assessment of the plots' energy consumption.
Source: Author's synthesis

	Plot 6 1970s Timber Frame	**Plot 7 1990s Building Regs.**	**Plot 8 Code Level 4**	**Plot 9 Code Level 5**	**Plot 10 Code Level 6**
GIA (m^2)	85	75	76	138	138
Modelled Electricity (kWh)	2,108.67	2,095.58	2,917.25	9,568.65	9,652.28
PV Panel (kWh/yr)	*1,580*	-	*2,380*	*3,170*	*5,940*
Solar Thermal (kWh/yr)	-	*1,800*	-	-	-
Electricity Consumption(kWh)	528.67	295.58	537.25	6,398.65	3,712.28
Gas consumption (kWh)	5,283.30	6,993.12	7,779.17	-	-
Annual Energy Consumption (kWh)	**5,811.97**	**7,288.70**	**8,316.42**	**6,398.65**	**3,712.28**
Dwelling FEE= kWh/m^2/yr	**68.38**	**97.18**	**109.43**	**46.37**	**26.90**

*FEE: Fabric Energy Efficiency

The code level 6 house dwelling Fabric Energy Efficiency (FEE)was below the estimated performance standard of 46 kWh/m^2/yr for zero carbon homes, as stipulated by the *National House-Building Council (NHBC, 2009)* and the *Zero Carbon Hub* (ZCH, 2010). This can be attributed to the lightweight construction using the SIP suggested by BRE consultants to ensure fabric airtightness. Moreover, the use of biomass boiler for space heating reduced the annual energy demands as space heating accounts for about 53% of a typical UK home (CLG, 2006). The contrast is seen with the code level 4 house that used gas for heating which contributed about 72.73% of total annual energy consumption. Thus, giving the highest dwelling FEE of about 109.43 kWh/m^2/yr.

To achieve the aim of the study, which is whether zero carbon homes can be actualised in the UK, the modelled CO_2 emissions rates as well as the *Dwelling Emission Rate* (DER) and the *Target Emission Rate* (TER) of all plots were calculated. The kWh generated using PV panels, was converted to kgCO_2 to determine the actual CO_2 savings. To convert kWh to kg of carbon saved based on the current guidelines provided by the *Department of Energy and Climate Change* (DECC, 2011). The conversion factor adopted was 0.542 kg CO_2 saved for each kWh produced from a carbon free source. The factor is based on the carbon emissions generated by the current UK power stations per kWh generated. A 4 m^2 evacuated tube solar thermal collector will save about 350 kg of CO_2 emissions per annum (ENVIKO, 2012). In addition, wood pellet biomass boiler is expected to save about 7,500 kg of CO_2 emissions per annum (EST, 2012). Following the same method, used to calculate for annual energy consumption, the carbon savings made from the use of renewable sources was deducted from the modelled CO_2 emissions output as illustrated in *Table 3*. Thus, determining the actual CO_2 emissions in kg CO_2/yr.

Result of *Table 3* shows that code level 6 house emits only 0.38 tonnes of CO_2, while code level 5 emits approximately 1.00 tonnes. These are below the 1.54 tonnes average UK household emissions rate per annum (CLG, 2006). From all indications, although the modelled CO_2 generated shows more emission for code levels 5 and 6, when the biomass carbon savings were deducted, it dropped leaving the code level 4 with the highest emissions rate of all plots. This could be attributed to the Mechanical Ventilation and Heat Recovery (MVHR) system used. In addition, when this was compared to the 1970s timber frame house which emits about 1.62 tonnes, slightly higher than average UK household emissions, it shows that the typical UK house *(Plot 6)* emits less than the code level 4 house *(Plot 8)*.

The results of the *Building Cost Information Service* (BCIS) online analysis on build base cost to prove the project affordability, the 1970s timber frame, the 1990s building regulations standard and the Code level 4 houses cost were below the UK set target of £60,000 for newly built homes.

Table 3 – Comparative assessment of the plots' CO_2 emissions rate
Source: Author's synthesis

	Plot 6 1970s Timber Frame	**Plot 7 1990s Building Regs.**	**Plot 8 Code Level 4**	**Plot 9 Code Level 5**	**Plot 10 Code Level 6**
GIA (m^2)	85	75	76	138	138
Modelled CO_2 Emissions ($kgCO_2/yr$)	2,474.68	2,756.99	3,515.26	10,220.26	11,094.60
PV kWh to kg = kWh x 0.542	856.36	-	1,289.96	1,718.14	3,219.48
Solar Thermal (kg)	-	350	-	-	-
Biomass (kg)	-	-	-	7,500	7,500
Actual kg CO_2/yr	**1,618.32**	**2,406.99**	**2,225.30**	**1,002.12**	**375.12**
CO_2 Emissions in Tonnes ~	1.62	2.41	2.23	1.00	0.38
DER (kgCO2/m2/yr)	**19.04**	**32.09**	**29.28**	**7.26**	**2.72**
TER= DER x 0.75	**14.28**	**24.07**	**21.96**	**5.45**	**2.04**

To calculate the DER, which is measured in $kgCO_2/m^2/yr$. we have

$$\text{DER} = \frac{\text{Modelled } CO_2 \text{ emissions}}{\text{given Gross Internal Area}}$$

The annual fuel running cost *(Table 4)* for the households was calculated with the typical British, 1970s timber frame building *(Plot 6)* showing lowest running cost, and the code level 5 home as the highest in cost. This was done following the typical prices for bulk purchase of fuels at domestic or small commercial scale; 14.5 p/kWh for electricity and 4.8 p/kWh for natural gas (BIOMASS ENERGY CENTRE, 2012).

Table 4 – Comparative assessment of the plots' cost analysis

Source: Author's synthesis

	Plot 6	**Plot 7**	**Plot 8**	**Plot 9**	**Plot 10**
Type of cost (in GBP)	**1970s Timber Frame**	**1990s Building Regs.**	**Code Level 4**	**Code Level 5**	**Code Level 6**
Build Base	**57,613.71**	**49,768.23**	**55,48.63**	**111,988.11**	**137, 685.67**
Electricity	76.66	42.86	77.90	927.80	538.28
Cost of gas	253.60	335.67	373.40	-	-
Annual Fuel Running	**330.26**	**378.53**	**451.30**	**927.80**	**538.28**

7. Conclusions

The paper describes the standards and procedures for evaluation that should be adopted for most reliable results to architects, building professionals, impact assessors, clients and established government bodies in the UK. The study followed an extensive review of various methods and techniques for pre-design evaluation, building performance simulation and cost estimation with the intention to draw a comparative study of the cost and energy performance of the proposed 1970s and 1990s houses and the recent code level houses designed to meet criteria set out by the 'Code for Sustainable Homes'. However, this was achieved by evaluating a case study of housing typologies project against the UK policy set benchmark for assessing new built and zero carbon housing. The findings do not only show the annual energy performance and base build cost of the plots, but also present a clearer picture of the exact cost of energy efficient measures and their impact on achieving the zero carbon homes, which would enable government and housing sector at large to get more focused on achieving the set target. Moreover, this would be of immense help to the *Barnsley College* that intends to use the project as a case study project to be monitored all through its life cycle.

Following the findings, achieving fabric energy efficiency of newly built homes depends significantly on walling, insulation and other construction materials used which further improve airtightness. The set energy efficiency standard of 46 kWh/m^2/yr for both semi-detached and detached homes was used to evaluate the result findings. The performance of the 1970s timber frame house of 68.58 kWh/m^2/yr could be attributed to the upgrading made on the cavity insulation. It is important to note that from the study, although the 'Code for Sustainable Homes' appears to be the most efficient tool in assessing the environmental performance of newly built homes, it cannot in all ascertain the actual energy performance and emissions rate of the investigated projects. This is seen with the code level 4 house with dwelling fabric energy efficiency of about 109.43 kWh/m^2/yr. On the other hand, the code level 5 met the set standard while code level 6 was over 40% better in fabric energy efficiency. It is suggested to the lightweight construction method adopted in design. Also, the utilisation of biomass boiler for space heating played an important role as heating contributes over 58% of average UK household energy demand Communities and Local Government (CLG, 2006).

The results of the study turned positive for code level 5 *(Plot 9)*, code level 6 *(Plot 10)* and the 1970s *(Plot 6)* timber frame houses based on energy efficiency. While the code level 4 *(Plot 8)* and the 1990s *(Plot 7)* building regulation baseline house seems to have performed below standard. The results of analysis of plots when compared with a typical UK household emissions rate of 1.54 tonnes per annum, the code levels 5 and 6 also met their set target of CO_2 emissions rate. Moreover, the 1970s house was slightly higher than the typical British household leaving the 1990s with the highest emissions rate of 2.41 tonnes per annum. On the other hand, this study has proved that zero carbon homes do not in all mean zero energy. Furthermore, the analysis of the plots cost to prove their affordability, showed that three out of five studied beat the UK set target of £60,000, with fuel running cost of below £500 per annum. It can be concluded that the study was positive as most project proved affordable and energy efficient with controllable emissions rate;

although, there were some differences in meeting set standards. The study results further show that achieving zero carbon homes does not totally depend either on meeting the criteria of energy and CO_2 emissions in the *Code for Sustainable Homes* or the SAP building assessments using the Part L Building Regulations as the case may be. However, the actual performance can vary in real times and this has proved that pre-design evaluation is pertinent in delivering the zero carbon houses by 2016. This will further benefit to *Barnsley College*, housing sector professionals, academics, government and public agencies involved in achieving affordable and energy efficient homes in the UK and globally.

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