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Reduce household energy consumption using passive methods

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Abstract

Recent researches and studies demonstrate that the need for sustainable buildings which do less impact on the environment is rising in the worldwide [1, 2]. Not only the energy generator from energy supply side needs to be considered to build a sustainable building, but also the novel construction methods and materials from demand side will contribute to the energy saving. The aim of this study is to carry out an investigation of a property's energy consumption from the view of passive energy saving, and then use the results to determine the best energy saving plan. A field audit and the Design Builder software simulation of a detached house were carried out during this study. The results indicate that the simulation energy consumption (9.66MWh) is matching well with the actual energy usage (9.76MWh) and the property consumes less energy than national average (16.90MWh). From the study, it is found that the annual total household energy consumption reduced for about 33% than traditional construction materials and technology by using passive energy saving methods.

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Keywords: Sustainable building; Passive methods; Energy consumption; Design Builder; Energy saving.

1. Introduction

Energy has become an important part of our life and it plays an essential role in human advancement. It is not only for solving the environmental problems by constructing sustainable buildings, but also satisfying the energy demands to the global warming and climate change [3]. Recently, the World Business Council for Sustainable Development published a study that asserts that a 60% reduction in energy use in buildings is possible by 2050 [4]. Improvement of energy efficiency does not just mean to turn off the lights or air conditioners. It is about utilizing energy more efficiently using novel energy systems and energy saving methods. Moreover, the improvements of energy efficiency could make a

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large majority of people live in a more comfortable environment. So the sustainable buildings mean supplied by the most effective method to reduce energy consumption and greenhouse gas emissions.

The objective of this study is to investigate the effect of construction methods and materials from demand side to the energy consumption of a house. The well-organized energy consumption plan could solve the problems of carbon dioxide emission and provide a basis for zero energy building.

2. Methodology

A residential building selected for this case study is a two-story detached house located in Newcastle upon Tyne, United Kingdom. It was built about 40 years ago in 1974. This residential property comprises entrance hall, living room, dining room, kitchen, toilet, four bedrooms and bathroom. The house benefits from cavity wall with insulation, double glazing, gas central heating, detached single garage and gardens to three sides. This house is without cooling and mechanical ventilation systems.

A field study of the selected detached house carried on in late April 2014. The house information (including the approximate usable areas of each room) and annual electricity and gas bills were gathered during the field study. Monthly weather and temperature data are also a factor to affect the energy consumption of each month. Base on the electricity and gas bills, energy consumptions per month could be summarized in Figure 1. The weather data below was obtained from NASA Surface meteorology and Solar Energy: RETScreen database [5] by inputting the latitude and longitude of Newcastle upon Tyne.

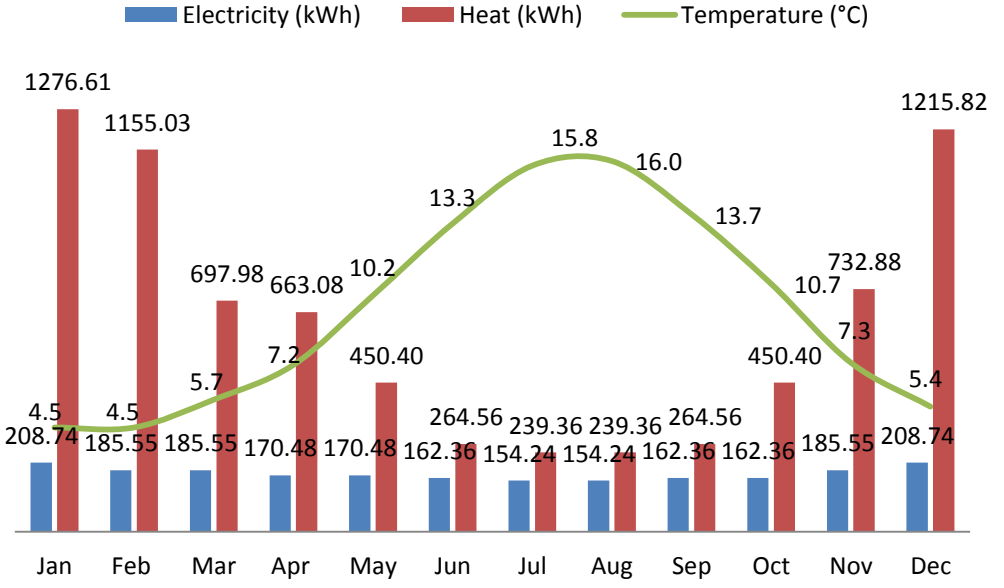

Figure 1. relationship between electricity and gas consumption and temperature

The property's dimension is 6.75m × 8.95m and the building area of the house is about 120.80mm^2. Story heights of ground floor and first floor are both 2.55m. Thicknesses of external and internal walls are 300mm and 100mm, respectively. The room dimensions of the property have been measured and shown in Figure 2.

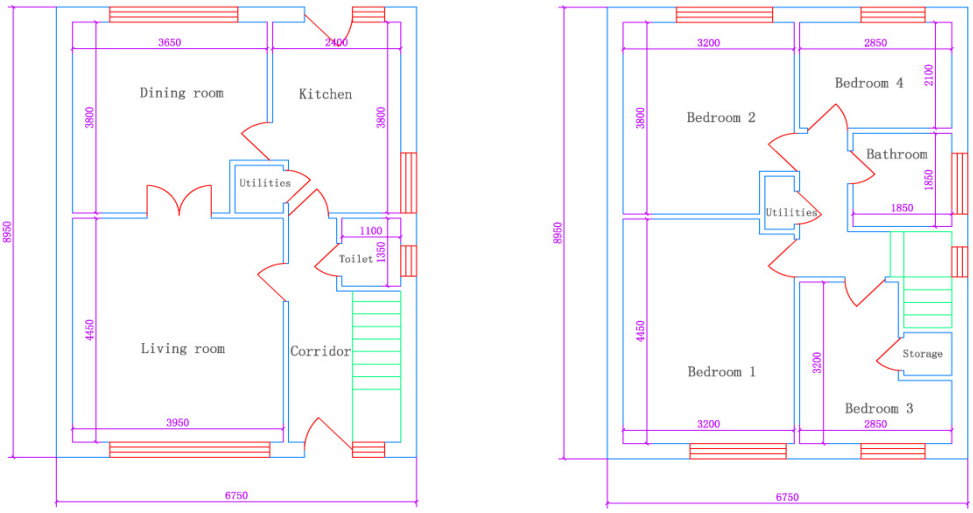

Figure 2. (a) ground floor plan of the house (b) first floor plan of the house

Design Builder simulation is used in the study. The software is the first comprehensive user interface to the Energy Plus dynamic thermal simulation engine [6, 7 and 8]. Accurate environmental performance data and stunning rendered images or movies could be generated at any stage in the design process. In this work, a Design Builder model for the detached house was set up to help decide the accurate energy demand and the size of CHP system for this selected house. The following Figure 3. shows the external facade of the detached house modelled by Design Builder.

Figure 3. (a) southwest facade of the house; (b) northeast facade of the house

3. Results and discussion

External walls of a house play an important role in the household energy saving. In the United Kingdom, properties are likely to be built with solid external wall before 1920. However, after that, solid wall was replaced by cavity insulation wall because of better performance. The detached house for this case study is benefits from cavity wall with polyurethane foam insulation.

Therefore, the energy consumptions in a calendar year simulated by the Design Builder are as follows. Electricity consumption is 2979.85kWh (2.98MWh), gas consumption is 6684.47kWh (6.68MWh) and the total energy consumption is 9664.32kWh (9.66MWh). According to the energy bills collected from the house owner, the actual usage of electricity and gas are 2110.64 kWh (2.11MWh) and 7650.04 kWh (7.65MWh), respectively. So the total energy consumption of the selected house could be calculated as 9760.68kWh (9.76MWh). Household energy consumption could be divided by the proportion of electricity and gas consumed. Base on the data from National Statistics in 2011[9], in North East, the average household energy consumption consisted of 20.9% electricity and 79.1% gas consumption. Thus, the electricity and gas usages are about 3.53MWh and 13.37MWh, respectively. Based on the energy bills, the realistic proportion of the electricity and gas usage are about 21.6% and 78.4%. The comparisons of the energy consumption in three different cases are summarized in Table 1.

Table 1. Comparison of the energy consumption in different cases

	Electricity consumption (MWh)		Gas consumption (MWh)		Total energy consumption (MWh)	
Simulation results	2.98	30.8%	6.68	69.2%	9.66	100%
Actual consumption	2.11	21.6%	7.65	78.4%	9.76	100%
Statistics data	3.53	20.9%	13.37	79.1%	16.90	100%

The recorded actual energy consumption indicates that the components of electricity and gas consumption for the house, comparing with the national statistics, match the statistic data. The differences are only 3.35% for electricity consumption and 0.88% for gas consumption. For the house, the energy consumptions are lower than those regional averages. The electricity consumption is 40.23% lower and gas is 42.78% lower. Totally, the energy consumption is 42.25% lower. The deviations could be seen from Table 2.

Table 2. Deviations between actual consumption and statistics data

	Energy consumption		Gas consumption		Total energy consumption	
	(MWh)	(%)	(MWh)	(%)	(MWh)	(%)
Actual consumption	2.11	21.6	7.65	78.4	9.76	100
Statistics data	3.53	20.9	13.37	79.1	16.9	100
Deviation	40.23%	3.35%	42.78%	0.88%	42.25%	-

The simulation results and actual consumption demonstrated that the model is matching the actual consumption well typically in the total energy consumption. They are nearly the same (9.66MWh and 9.76MWh). But electricity consumption in simulation is higher than actual usage and leads the proportion of electricity and gas consumption not matching well to the statistics data. The differences are 29.87% and 13.29%. The detailed comparison can be seen in Table 4 below. The reason should be the lighting and human activities in the simulation haven't been set accurately enough in the Design Builder model.

Table 3. Deviations between actual consumption and statistics data

	Electricity consumption		Gas consumption		Total energy consumption	
	(MWh)	(%)	(MWh)	(%)	(MWh)	(%)
Actual consumption	2.11	21.6	7.65	78.4	9.76	100
Simulation result	2.98	30.8	6.68	69.2	9.66	100
Deviation	29.19%	29.87%	14.52%	13.29%	1.04%	-

From the view of passive ways of building energy saving, the house consumes less energy than the national average and it can be seen as a good example of effective energy saving. It is found that, the

house has taken measures to save energy, e.g. between the external walls (outer and inner surface), an insulation material was filled in (see Figure 4); and energy saving electrical lights are used since 6 years ago.

Figure 4. (a) polyurethane insulation of cavity wall (b) air insulation of cavity wall

Different insulating materials of cavity wall have own heat preservation capacity. In this case study, polyurethane foam and air were chosen for insulation materials of the cavity wall to compare the different heat preservation capacity. The structures of different cavity walls are shown in Figure 4.

Table 4. Energy consumption of different external wall from simulation

	Insulation materials	Electricity consumption (MWh)	Gas consumption (MWh)	Total energy consumption (MWh)
Cavity wall	Polyurethane	2.98	6.68	9.66
	Air	2.98	10.63	13.61
Brick solid wall		2.98	11.52	14.50

Table 5. Comparison of capacity of heat preservation between cavity wall and solid wall

	Gas consumption (MWh)		Total energy consumption (MWh)	
Cavity wall	Polyurethane	Air	Polyurethane	Air
	6.68	10.63	9.66	13.61
Brick solid wall	11.52		14.50	
Saving percentage (%)	42.01	7.90	33.38	6.28

Table 4 shows that, different external walls did not affect the electricity consumption of the house. But cavity walls could save more energy than traditional brick solid wall. Thus, the household gas consumption could be reduced. As a result, the total energy consumption would vary with the gas consumption. From Table 4 and Table 5, it can be seen that for this property, the cavity wall insulated with polyurethane consumes the least energy (9.66MWh). Air insulation cavity wall's energy consumption is about 13.61MWh. If brick solid wall was used in the house, it needs the most energy (14.50MWh) during a year. That is because it has the worst heat preservation capacity so it consumes the most gas for keeping the property warm in winter.

For the insulation materials analysis, the performance of polyurethane is better than air did. As Table 5 demonstrates, compare to traditional brick solid wall, cavity wall insulated with polyurethane could save 42.01% more gas. And the reduction in total energy consumption is about 33.38%.

4. Cost analysis

For detached house in England, the cavity wall installation cost is £720; gas bill saving per year is £250; the payback time is 2-3 years. These data are obtained from the UK Energy Saving Trust (EST) and based on a typical gas-heated home with an 81% efficient gas boiler and gas tariff of 4.21p/kWh [10, 11].

According to the simulated results and gas tariff (4.171p/kWh) of this selected detached house, the gas saving is about £202 per year. The local cavity wall installation cost is lower than £720 so the payback time will still be about 3 years. Compare to the data from Energy Saving Trust, the simulation results are similar with it. Thus, from the view of cost analysis on different external walls (cavity wall insulated with polyurethane and solid wall), it is feasible to choose cavity wall for energy saving purpose.

5. Conclusion

The simulation results indicate that the energy demand is matching with the actual consumption well typically in the total energy consumption (9.66MWh and 9.76MWh). Household energy consumption could be reduced by passive energy saving methods, i.e. different construction methods and insulation materials. Cavity walls could save more energy than traditional brick solid wall. For the insulation materials analysis, the performance of polyurethane is better than air did. Cavity wall insulated with polyurethane could save 42.01% more gas than traditional solid wall, and the cavity wall with air insulation just save 7.90%. And the reduction in total energy consumption of the former is about 33.38%.

The results from this study show this is a good example of effective energy saving and this methodology can be used for other similar research on reducing the energy consumption by using passive methods.

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