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Investigating the impact of building's facade on the building's energy performance – a case study

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Abstract

This study investigated the thermal and indoor environmental performance of an office building in the northeast of England. The building was built using natural stone and glass; internally the large floor plates are bordered and penetrated by open voids that ventilate the building and provide exceptional day lighting. A computational model for this building was set up using Design Builder software. The model is validated using on-site monitoring data and then it is used to predict and evaluate the performance of the building. It is found that the U-value of glass and natural stone is relatively high that caused high energy consumption. To achieve the performance recommended by passive house standard, two scenarios are proposed and simulated. It is found that when the window size is reduced and low U-value wall materials used, the energy consumption for heating can be reduced by 33.9% for Scenario 1 and 45.7% for Scenario 2 in a year.

Keywords: Office building; Energy performance; Energy consumption; Sustainable Building; DesignBuilder

1. Introduction

The increasing energy use worldwide has been considered a main challenge in this century, which results in both the shortage of energy resources and the impact of environmental deterioration, i.e. climate change and global warming. To solve this urgent issue, countries all over the world are collaborating together to reduce their carbon emissions in compliance with Kyoto Protocol. United Kingdom has established its carbon-reduction target of 60%

Nomenclature			
building monitoring system (BMS)		**WWR**	**windows to wall ratio**

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carbon dioxide emissions by 2050 [1]. Out of the total final energy use, building sector is one of the largest energy consumer [2]. It has been reported that 40% of total primary energy requirement and 30% of carbon emissions were attributed to buildings worldwide [3]. Specifically in the UK, 19% of the carbon emission is emitted by the building stock. Yu (2011) [4] identified the factors affecting energy use in buildings and grouped them into 7 categories, which are outdoor climate; building physical characteristics; building services; occupants' behaviors; indoor environment quality; social and economic factors; user-based features. Among these factors, building physical characteristics and building service systems are the key influencing ones which can be significantly improved by optimized design and materials i.e. the insulation of building envelopes and building energy management systems. For instance, Cheung (2005) [5] observed 31.4% of energy saving potential by improving insulation of building envelopes while a reduction in energy consumption was found by Yang (2012) [6] when applying an optimal control strategy in building energy management. Particularly, retrofitting existing buildings plays an important role in achieving national's energy-saving target due to the numbers of existing buildings that are not complies with the energy efficient standards. This study is to investigate the current performance of an office building in the northeast of England and then to find the most optimum façade design in the UK climate and its impact on the building's thermal and total energy performance.

2. Methods

Methods for the study include: (1) **Data collection and analysis:** Data were collected by on-site monitoring, interviews with the energy and building manager, and data collection from building monitoring system (BMS). The gas was metered every30 minutes in kWh and electric is also measured every 30 minutes in kWh and the BMS include all the energy consumption data for king's gate during 2016 to 2017.; (2) Modelling: the building is modelled in Design Builder software to analysis the building's energy and thermal performance. ASHRAE Guide 14 were used to validate the model built [7]:

$$CV(RMSE) = \frac{\sqrt{\sum_{i=1}^{N_i} [(M_i - S_i)^2 / N_i]}}{\frac{1}{N_i} \sum_{i=1}^{N_i} M_i} \quad (1)$$

$$MBE = \frac{\sum_{i=1}^{N_i} (M_i - S_i)}{\sum_{i=1}^{N_i} M_i} \quad (2)$$

Where: CV (RMSE) is coefficient of variation of the root mean square; MBE is Mean bias error; M is the actual monthly energy consumption; S is simulated monthly energy consumption; N is Number of months.

(3) Further calibration was made to the building to investigate the impact of building's envelope on the thermal and energy performance. Three scenarios were chosen for this study (see Table 1):

Table 1 Three studied cases and the U-Value used

Scenario	WWR (front)	Glazing type
Base	85%	U-Value: 1.761
Scenario 1	35%	U-Value: 1.761
Scenario 2	Same as base	Lower thermal conductivity and high visible light transmission

2.1 Energy performance evaluation

Equations below [7] were used to carry out technical analysis in modeling and to study the impact on energy performance, and the potential economic viability. In terms of carbon emission they are different, but in terms of total energy, it is valid to total them up since they both were metered in kWh. But add the comparison gas to gas and electricity to electricity. For comparison of carbon emission and cost it has to be based on gas/electricity price and gas/electricity carbon factor individually. Such as scenario X, the gas maintains and electricity reduces. In terms of carbon emission it is better since CO2e conversion factor for electricity is higher than gas, and for cost, it is also better since cost for electricity is also higher than gas. [9]

$$\text{Annual cooling load reduction} = \text{Cooling load}_i - \text{Cooling load}_n \quad (3)$$
$$\text{Energy reduction} = \text{Energy}_i - \text{Energy}_n \quad (4)$$
$$\Sigma\text{Energy reduction (kWh)} = \text{Annual energy reduction} \times \text{lifetime} \quad (5)$$

2.2 Target building

An office building is located in the northeast of England and it is a multifunctional building. So the specification for five stores of workspace had to be robust and elegant. A four-story atrium unites the interactive working environments and provides a sky-lit social place, maximizing daylight and acting as a thermal and acoustic buffer between the offices and a bridge carriageway.

Figure 1 Target Building

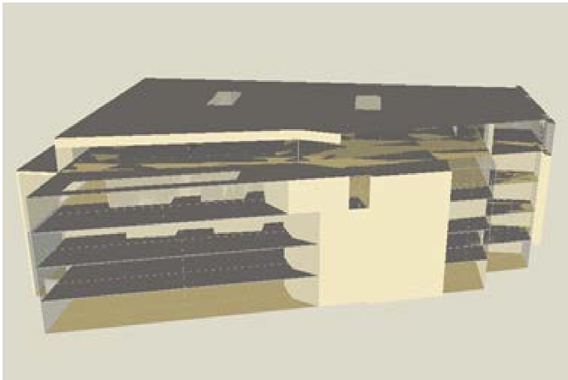

Figure2 King's Gate Building Modeling

Thermal imaging

One of the most powerful tools for inspecting a building's energy efficiency is by using thermal imaging analysis. Through the images, the building can be monitored, diagnosed and remedies sought that are aimed at ensuring the building uses energy efficiently. Advanced technologies in thermal imaging have become one of the most vital tools used to inspect existing buildings. The images visualize various sources of energy loss, figure out defections in insulation, the sources of air leaks, insulation moisture both in walls and roofs and detection of thermal bridges. All these can be documented and corrections sought timely before it becomes very expensive to repair and renovate the buildings.

Thermal imaging analysis has proven to be a very vital tool in the identification of energy-related flaws in a building because of its visual aid. Once the image has been interpreted the engineers or energy assessors are able to obtain accurate temperature data, they are then able to draft ways of improving energy efficiency by checking on insulation, moisture perforations thermal bridges and the heating, ventilation and air condition systems.

The building was constructed with a high thermal mass using thick concrete flooring and high glazing. For England low, the windows to wall ratio (WWR) of 29% is suggested for energy saving. However, the design for King's gate has a high glass cover. At north, east, south and west orientations solar control glazing cover 54%, 29%, 87% and 42% of the facades respectively (hence overall the building's external facade is 53% glazed). (Royapoor and Roskilly, 2015)This study investigates the impact of such high glazing on the buildings thermal and energy performance, and further investigation is made to find the most optimum façade design for the commercial building in the UK climate considering the WWR and type of glazing in terms of its thermal conductivity, visible light transmission, and heat gain coefficient. From this information, it can be seen from the thermal images that the inside is relatively warm, an indication that the triple glazing works within acceptable standards.

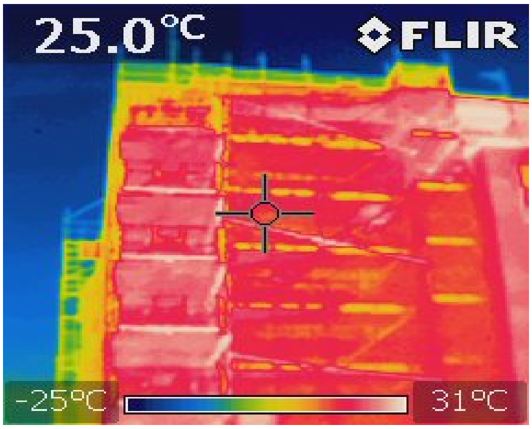

Figure 3 Thermal picture of King's Gate building's side.

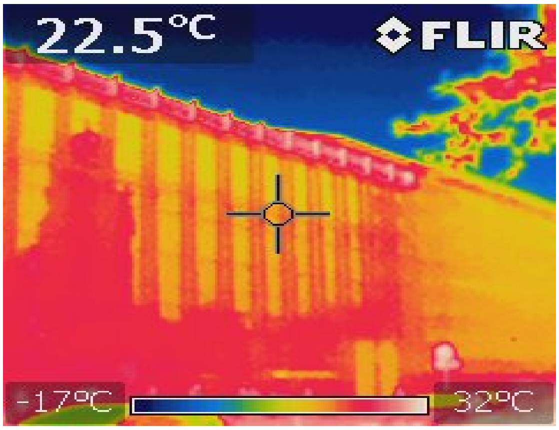

Figure 4 Thermal picture of King's Gate building's front.

According to the thermal images of both images indicate that the interior of the building is relatively warmer than the outside, with a temperature of less than 10 °C. The values are within the acceptable limit given by ASHRAE Guide. However, the indoor air temperature was maintained at 18°C to 24°C using building monitoring system (BMS), the large area of glass turned into the thermal bridge. It can be concluded that the images show that the King's Gate have a poor insulation effect.

2.3 Modelling

The building model was set up and validated compared with the actual monthly energy data to get the MBE and CV(RMSE) values. The model and data of the building is shown in Figure 2 and Table 2.

Table 2 Building data

Component	Description
Climate	Temperate maritime climate.
Floor Area	8,000 square metres.
Occupants	8 hours for work days.
Major zones	Open offices, small offices, training rooms and student service area (reception).
External wall	Nature stone.
Glazing	53% glazed with local shades.
Lighting	Mainly provided by T5 fluorescent lamps and has an automatic daylight control system
Floor	0.3 meter
HVAC	Under floor heating with AHU system and heat recovery system, and gas boiler. Cooling system was used in summertime. The indoor air temperature was maintained at 18°C to 24°C using building monitoring system (BMS).

The building was constructed with a high thermal mass using thick concrete flooring and high glazing. For England low, the windows to wall ratio (WWR) of 29% is suggested for energy saving. However, the design for the building has a high glass cover. At north, east, south and west orientations solar control glazing cover 54%, 29%, 87% and 42% of the facades respectively hence overall the building's external facade is 53% glazed [8].

3. Results and discussion

3.1 Building model and validation

The MBE value for electricity, gas and total energy (electricity and gas) consumption are -1%, -3% and -2% respectively, and the CV (RMSE) for the total energy is 7%. The values are within the acceptable limit given by ASHRAE Guide 14. Figure 5 shows a comparison between the actual and simulated gas and electricity and Figure 6 shows the actual and simulation data for total energy consumption. From Figure 5 the gas simulation data in January, October and December has 10% error. The reason is in January more than 3000 new students will come to Newcastle University and they will go to the building to register. The door will be opened very often so the actual data is higher than simulation. Then, for October because the temperature in softer ware database is a little lowers than real temperature, so the heating load is high in simulation system. The last month December is holiday season. That is why simulation data is high than actual data. However, as shown in Figure 6, it can find that total energy consumption's error is very low between 1%-8% .That means the model is precise enough and it can used as the base model. So all the retrofitting for simulation will based on this model.

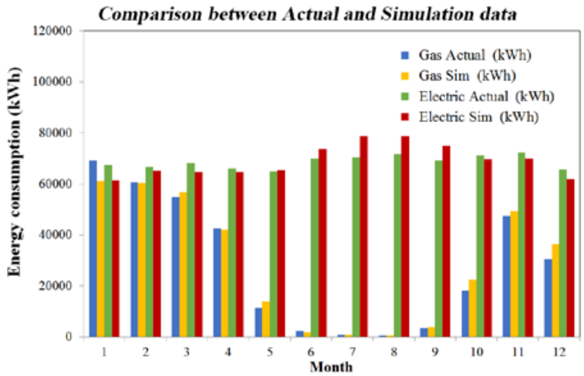

Figure 5 Comparison between Actual and Simulation

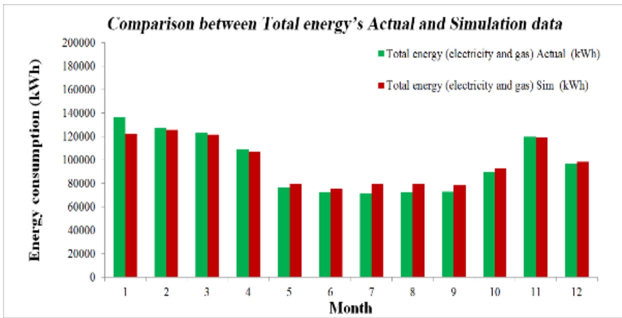

Figure 6 Comparison between Total energy's Actual and Simulation

3.2 Energy performance analysis

The building's total energy consumption in 2016 was 1,167,131 kWh where 29% of it was gas and 71% was the electricity. The electricity consumption maintained stable all year round while the gas consumption is dependent on the outdoor air temperature. The end-use energy consumption based on the simulation results for every scenarios are shown in Table 3:

Table 3 End-use energy consumption based on the simulation results

Type		Lighting (kWh)	Heating (kWh)	Cooling (kWh)	Equipment and other (kWh)	Total energy
Base		249,569	342,918	161,884	425,288	1179,659
Scenario 1		252,133	256,055	159,722	425,288	1093,198
Scenario 2		245,740	185,868	224,624	425,288	1,081,520

From Table 1, it can be seen that the u-value (1.761) for window glass is very high. Even the building use two layers glass as the facade and have a palisade arrangement metal covered it, the thermal loss from the glass windows cannot be ignored. The windows cover 53% areas of all facades and it is found that this is the main reason for the high heating (gas) consumption.

In order to reduce the energy consumption for heating, the first scenario is to reduce the window area to 20% and it is assumed that the same material (nature stone) is used to replace the glass. Build the wall in side can reduce the WWR. The specific implementation step is add the wall in side of the window and keep the regular window as it was. The U-value of the nature stone is 0.29. The simulation results are showed in Figure 7, 8 and 9. From Figure 7, it can be seen that the gas consumption is reduced from 342918 kWh to 256055 kWh and totally saved 33.9%

(86863 kWh) in a year. This is because the low u-value stone can keep the heat in building and prevents heat losses. Therefore reduce the glass area can make the whole building have a great thermal performance. But the electric consumption did not get lower because the need for lighting and equipment is still the same. Combined gas and electric consumption is total energy use in actual is 1167131 kWh per year. To use the nature stone instead of two layers glass the total energy consumption is 1093198 kWh and 86461 kWh energy is saved, which is 7.4% savings.

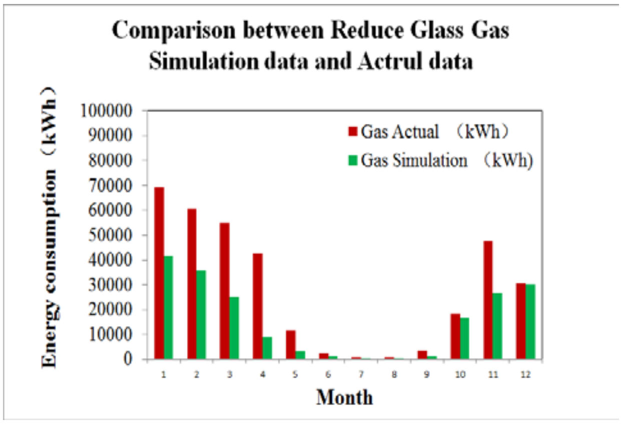

Figure 7 Gas consumption: reduced WWR and actual

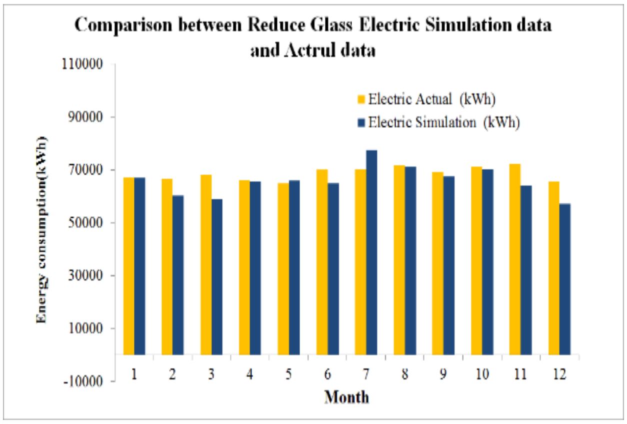

Figure8 Electricity consumption: reduced WWR and actual

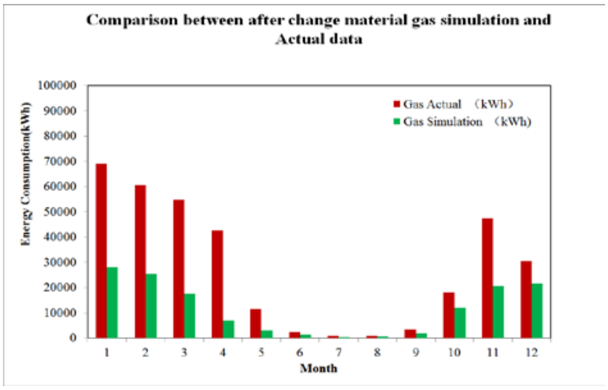

Figure9 Total energy consumption: reduced WWR and actual

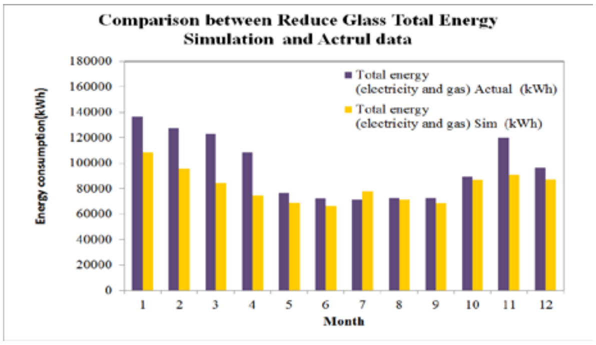

Figure10 Change wall material: gas consumption

Reduce the glass area can have an obvious effect on heating savings but it will damage the building appearance. To keep the original building design, the second scenario is proposed and it keeps the original glass area as it was and makes a change for the facade walls. The thickness of the nature stone is 580mm and it is assumed to be replaced by low U–Value bricks with the thickness 600mm. The building structure is not changed. The original wall is natural stone and the U-value is 0.29. In scenario 2, it is changed by the low U-value bricks and the U-value is 0.09. The simulation results are showed in Figures 10, 11 and 12. From Figure 10, it can be seen that the gas consumption for heating is reduced. The total gas consumption for Scenario 2 is 185868 kWh. Compared with the actual data 342918 kWh it decreases by 45.7% which is 157050 kWh in one year. Similar as Scenario 1, the electricity consumption does not changed too much as can be seen in Figure 11. Total energy usage is 1081522 kWh per year and it reduces by 8.4% (98137 kWh), as can be seen in Figure 12.

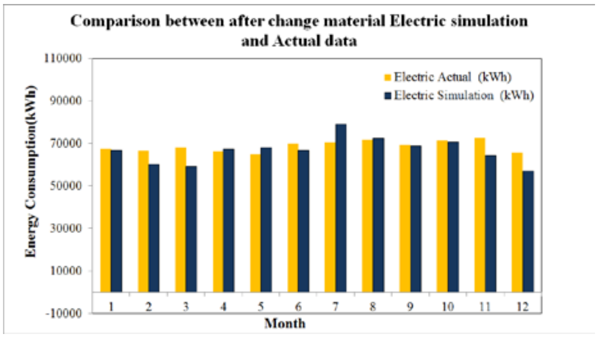

Figure11 Change wall material: electricity consumption

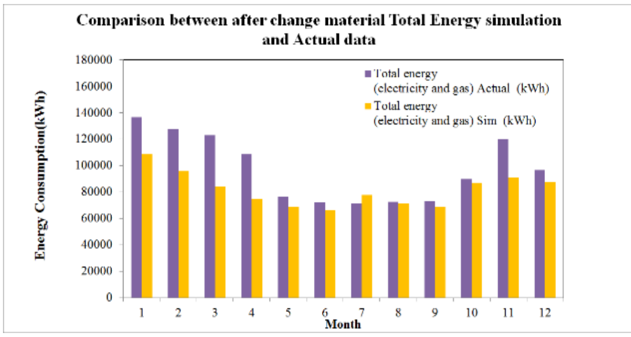

Figure12 Change wall material: total energy consumption

4. Conclusion

From these two scenarios studies, it can be seen that WWR has high impact on heating consumption of the office building in the Northeast England. Changing WWR value will get a good result to reduce gas consumption. Secondly, using low U-value materials for walls can also save the energy for heating. Further study is needed to investigate how to reduce electricity consumption. This project revolves around transforming existing buildings to conform to sustainable development goals by integrating the building's energy management, retrofitting them and sourcing other renewable energies. All this should be done at the backdrop of ensuring that the model and the results from its simulation are economically feasible.

Acknowledgements

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