TOARDS A LOW CARBON DESIGN: A CASE STUDY OF AN INDUSTRIAL BUILDING

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Abstract

In construction industry a large amount of carbon dioxide is emitted due to embodied and operational energy. In order to reduce the carbon emission from buildings during the operation stage to mitigate the climate change impact, some low carbon and clean technologies should be considered. This study analyses the relationship between different carbon-generating activities and the carbon footprint for an industrial case study in the UK using Carbon Neutral Protocol. The research included data collection through networking and visual inspection in order to identify which activities produce the most carbon emissions and allow investigation for solutions to aspire to a future sustainable building and to achieve carbon neutrality. Results from this study showed that operational carbon, especially from electricity and gas are the largest contributor. Results also showed that CO_2e from fossil fuel exceeded the standard benchmark for that type of building. Some clean technologies (solar, ground source heat pump) and energy efficient measures (fabric insulation) were suggested in order to minimise the emissions. The impact of these technologies have been modelled with IES-VE software in order to investigate each system size and potential saving. To achieve the carbon neutrality in the case study, the remaining carbon emission has been offset using an international renewable scheme, this requires the industrial building to pay a certain amount of money for each tonne they produced towards installation of any sustainable measure around the world.

Keywords:

Carbon Neutrality; Emissions; Energy; Greenhouse; Sustainability

INTRODUCTION AND THEORETICAL FRAMEWORK

In recent years, climate change has become the focus of global attention (O'Connor et al., 1999; Hotchkiss et al., 2015). Emissions of greenhouse gases (especially carbon dioxide (CO_2) emissions) generated by the burning of fossil fuels, is the primary cause of climate change (Hansen and Sato, 2016; Wang, and Li, 2016). It is widely recognized that, unless drastic actions are taken to reduce global warming, the world could be heading not only towards reduced growth but also, and more importantly, towards a major environmental disaster (Menyah and Wolde-Rufael, 2010; Reddy and Assenza; 2009). Climate change is one of the most pressing challenges in energy policy due to the increasing risks to human and natural systems predicted by climate science combined with the uncertainty in the magnitude and pace of the overall impacts (IPCC, 2014). The role of energy technology innovation in reducing emissions is becoming increasingly recognized in the transition to more sustainable, lower carbon energy (Anadon et al., 2011; Gallagher et al., 2006). IPCC indicates that the clean alternative source for energy such as nuclear power, wind, solar and hydroelectricity, are suitable technologies for achieving zero carbon target.

Wang and Chen (2015) have analysed the importance of renewable energy on reducing carbon emissions in China and elaborated upon the energy environment now facing China (Wang, 2013). Some studies, taken the US as an example, have explored and Quantified the carbon emissions from different sources, such as land-use change (Hertel, et al., 2010; and Fargione et al., 2008), farm operations (Lal, 2004), agriculture and forestry (McCarl and Schneider, 2001), and international trade (Weber and Matthews, 2007). Other studies have analysed the impact of energy consumption and income on carbon emissions (Soytas et al., 2007).

Implementing renewable energies and energy efficient measures have contributed to achieve the carbon reduction which lead to Carbon neutrality, especially for businesses and organizations that have large-scale activities. The Carbon Neutral Protocol is an internationally recognised accreditation that guarantees the carbon neutrality of an entity, product or activity. The benefits of accreditation include international recognition of Carbon awareness, enhanced marketability, and the promotion of health and wellbeing for employees [1], all of which are now promoted within political party governmental policies, where increased pressure for businesses to respond appropriately to climate change is expected to be demonstrated [2].

PURPOSE

The purpose of this paper is to define the principles of the Carbon Footprint Standard to estimate the operational carbon from gas, electricity and water and apply these to an industrial case study in the UK to provide guidance on available technologies and various strategies to reduce the environmental impacts of the organisation to achieve the Carbon Neutrality. The results obtained could be used by policy makers to evaluate effectiveness of different policy tools and the effects of interactions between these policies.

SCOPE

The investigation carried in this study was focused on finding an effective way for assessing the power generated by renewable energy sources, fabric improving, and market regulations on the mitigation of climate change in the UK. It also included calculation of the elasticity of carbon emissions for each activity in the case study for purpose of achieving neutrality using international offsetting schemes. For a business to become carbon neutral, it is important to understand that it is not about achieving a net zero in carbon emissions. It is about balancing the amount of CO_2 produced with a way that will pull the carbon back out of the atmosphere. This is called carbon offsetting [3]. The client will need to gain recognition and meet the specific requirements with The Carbon Neutral protocol.

The study does not include the other sources of carbon emission embodied in building in assessing the total Carbon footprint.

METHOD

The case study is three stories office building of 3,797m^2 (Figure 1) and was constructed in 1950s. Due to the age of the building, it is currently suffering high levels of energy loss through fabric due to lack of insulation, habits, rotting window frames and inefficient systems. These have contributed to increase in the company's carbon footprint. The building has external brick walls and concrete roof with no insulation on. Internal walls are mix between plasterboard and concrete-plasterboard/woodchip. Windows are single glazing with some manual double-glazing in one part of the building. In order to cut the emission and improve the energy performance of the building and move towards the carbon neutrality, the following methodology was considered:

Carrying out Carbon Assessment and Neutrality:

The procedure to achieve organisational carbon neutral accreditations adopted in the following steps:
1. Define the subject: give clear description of different activities in the building.
2. Measure the subject emissions: Carbon emissions are calculated using DEFRA (2019), Environmental Reporting Guidelines under three scopes.

- Scope 1: Direct emissions associated with activities within organisation, such as the combustion of fossil fuels for heating.
- Scope 2: Emissions caused from external source indirectly from the purchase of energy related to organisational activities, examples of such are the purchase of electricity where the source of the emissions is the generation of electricity.
- Scope 3: Indirect impacts associated as a consequence of organisation activities such as travel, electricity transmission losses, the supply of potable water, and uncontrolled waste removal'.

[1] https://assets.naturalcapitalpartners.com/downloads/The_CarbonNeutral_Protocol_Jan_2018.pdf.

[2] https://www.carbonfootprit.com/docs/2017_1_cfs_qualification_requirements_11.pdf

[3] https://doi.org/10.1016/j.habitatint.2011.10.010

The formula used to calculate CO_2e emission:

GHG emissions = activity data x emission conversion factor

3. Set target: A time frame for achieving net-zero greenhouse and a commitment is made.
4. Reduce emissions: achieve the target through a combination of Internal/external reduction methods.
5. Communicate: provide accurate and transparent information on how carbon neutral certification is achieved. Carbon footprint (CFP) certification presents an opportunity for an organisation to capitalize by developing a green image. There is a general misconception that environmental sustain ability and profitability are mutually exclusive. In reality, developing efficient sustainable system can be economical. Accreditation will also help enhance compliance with current and future environmental requirements.

Thermal modelling:

The thermal modelling has been achieved for purpose of simulation the low carbon and renewable technologies to achieve step 4 above, using Virtual Environment (VE) software called "Integrated Environmental Solutions" (IES-VE), it is a commercial software, and regularly use within the building services industry. The software consists of a suite of integrated analysis tools, which can be used to investigate the performance of a building either retrospectively or during the design stages of a construction project. The main data required for BIM model are geometry of the building, construction, thermal, and solar shading information (Figure 2). The later includes location and weather data of the studied site.

Figure 1: A computer model for the case study in Liverpool-UK

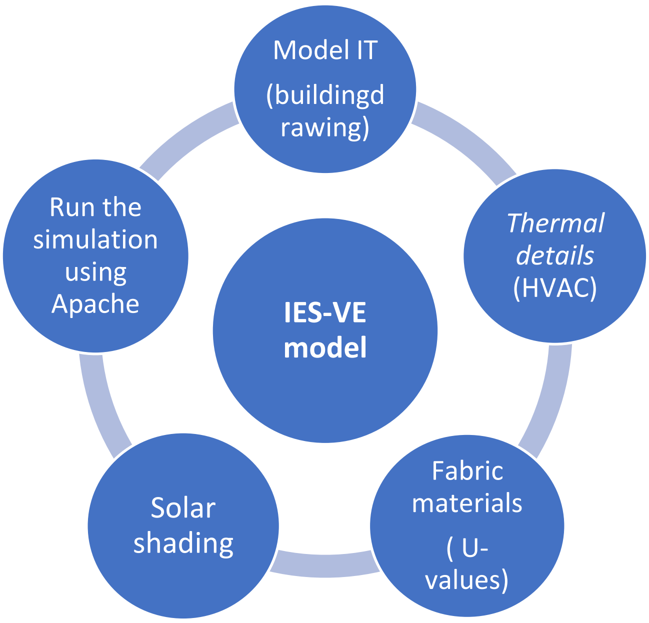

Figure 2: Steps for thermal modelling used for the case study using IES-VE

FINDINGS

CARBON ASSESMNET

The main activities that generate carbon in the building are gas, electricity and water. Results for carbon assessment (using three years data) showed that electricity consumptions and CO_2 are less than the standard benchmarks to the building so the consumption is well maintained (Table 1). However, Gas energy consumption is continuously increasing significantly over the three years but still slightly less than the standard benchmarks (CIBSE, 2008) to the building while CO_2e is over the benchmark. Gas consumption should be monitored and managed to reduce the consumption so urgent attention should be given to gas.

Carbon footprint for scope 2 (electricity) is higher compared with scope 1 (gas) and scope 3 (water, waste water and grid losses) as shown in Figure 2, this is due to large carbon conversion factor for this activity compared with others. Electricity emissions normally higher than other activities due to nature of the generation process.

Table 1: Comparisons against Energy and CO_2 benchmarks for the building with floor area 3,797m^2

Year	Electricity		Gas	
	KWh/m^2	$KgCO_2/m^2$	KWh/m^2	$KgCO_2/m^2$
2016	60	24.72	59	14.55
2017	47	16.52	61	15.04
2018	40	11.32	98	24.17
Benchmarks	**95**	**52.3**	**120**	**22.8**

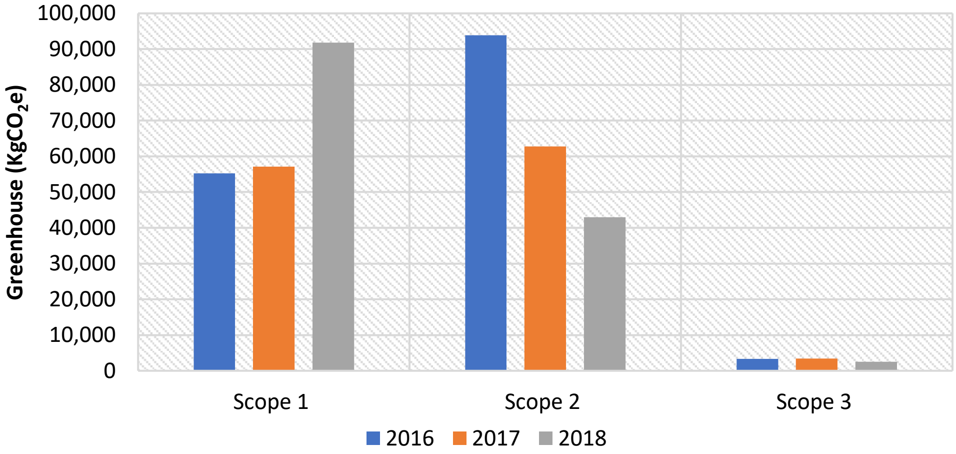

Figure 2: Carbon footprint by scope during three years

GREEN MESAURES

Carbon Neutral is the final accreditation step within the Carbon Footprint Standard, where it has been deemed an organisation has successfully demonstrated the criteria within the standard. The accreditation is granted to those organisations who have balanced carbon emissions by reduction, the selection of sustainably produced renewable energy, and any residual carbon emissions having been mitigated by the funding representative carbon savings. The primary initiative following on from the assessment step is to reduce the total consumption and therefore the equivalent emissions, this is often accomplished by the implementation of sustainable technologies. Results from IES-VE model for the recommended measures are described below:

1. Fabric Improvement:

Improving fabric is the first approach should be adopted which help in reducing the amount of heat required. Impact of roof, wall insulation and installing double-glazing could results in saving of 62% in heat loss from the building fabric (Figure 3). The total annual heat required for the building is 372,106KWh, which results in 92tonne CO_2e this has been reduced to 141,400 KWh and 35tonne CO_2e after fabric improvement.

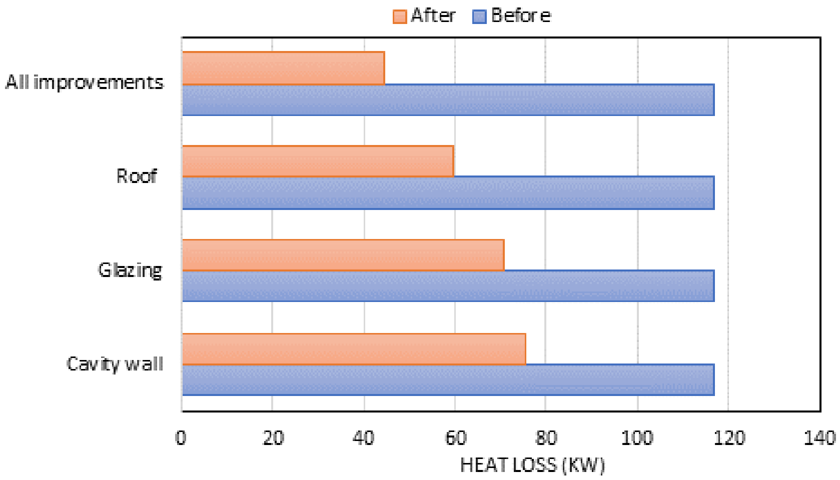

Figure 3: Impact of improving the fabric using insulation on heat loss

2. Ground Source Heat Pump:

Collection of heat from ground source is achieved by installing a series of pipes (a ground loop) in the ground which contain a water and glycol (a type of antifreeze) mix at a low temperature. Pipes can be laid in trenches or using boreholes for heat pumps (Figure 4). The surrounding soil is at a higher temperature, which gently warms the glycol mix as it is pumped around the ground loop. As Heat Pump simply move energy rather than creating it by burning fossil fuels, they are capable of producing up to 4kW of heat using just 1kW of electricity. It could be vertical (>50m deep) or horizontal (1.5m deep) loop based on the area available. Air heat pump (Figure 4) another way to absorb heat from air into the system and turned into a liquid a compressor increases the heat. This can heat the building and hot water all year round. However some electricity is needed to run the system but is the energy is produces is used to run its self.

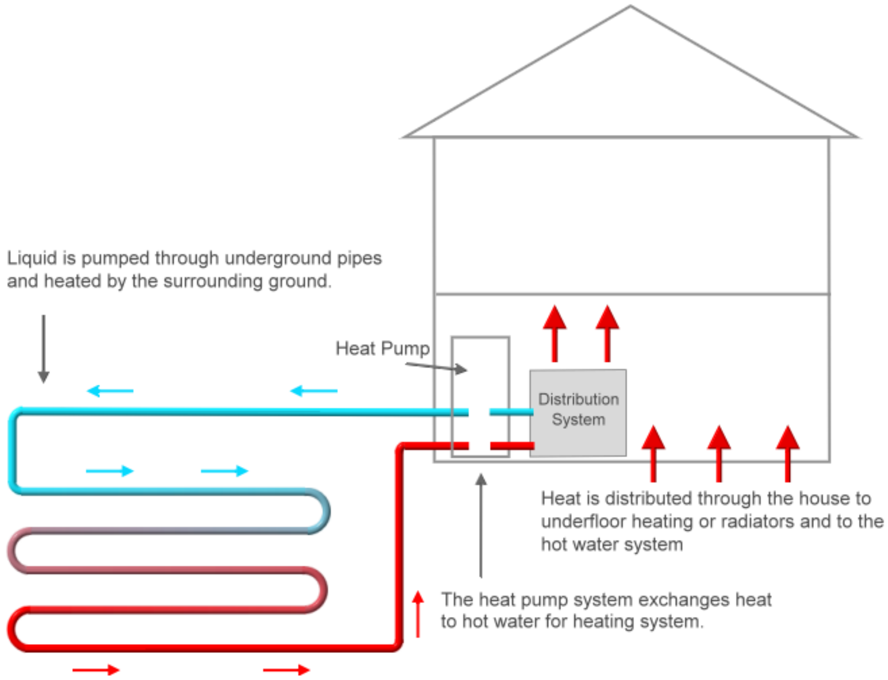

Figure 4: Ground source heat pumps

Replacing the fossil fuel completely with ground source heat pump after fabric improvement could help to reduce the carbon emissions. Heat pump seems to be the practical and efficient option in term of running cost and saving; however, this rewire the building to be well insulated to avoid any heat loss and based on the regulations. The technology has been supported by renewable heat incentive UK government scheme, which help towards the installation of the system resulting in a quick repayment.

3. Solar Photovoltaic (PV) Energy

The studied building has a large flat roof with no shading around which makes installation of the system is possible. The recent annual electricity consumption for the building is 151,882KWh, which results in 43 tonne CO_2e. Table 2 showed indicative prices and returns for projects based on 50% of power used on site and 50% sold back to the grid. Saving in annual electricity consumption ranging between 14%-69% using different solar PV panel sizes. The system provide reasonable repayment period 11-13 years using the government incentive scheme. Saving depends on the system size and available budget, the reasonable PV size was selected for the case study to reduce the carbon footprint and achieve the carbon neutrality is 50KWp.This would result in a potential generation of 42,160KWh and 12 tonne CO_2e reduction.

Table 2: Solar PV system assessment

PV size in KW	Cost (£)	Area of the roof	Electricity generated (KWh)	Annual tonne CO_2e reduction	Annual Electricity Saving%	Repayment (years)
20KWp	28,500	140	16,860	5	11%	13
30KWp	38,900	208	25,290	7	17%	12
50KWp	59,200	340	42,160	12	28%	11

CARBON OFFSETTING:

Ranges of carbon reduction methods have been proposed. The reality is that due to financial and practicality limitations, it may not be feasible to implement all these measures. This is where carbon-offsetting schemes can assist. In fact the entirety of the building carbon emissions can, in theory, be neutralised this way.

Table 3 reflects the carbon footprint resulted from running the ground source heat pumps (GSHP) and from the electricity used in the building after considering the PV system, which both classified as scope 2. The gas has been replaced with the GSHP results in zero carbon for scope 1 while the scope 3 the water and grid loss remained the same. The total footprint form the building has been significantly reduced with 50-90% over the three years after implementing the measures.

Varieties of carbon-offset projects are happening worldwide. These include large-scale renewable energy projects in developing countries, UN Certified Emission Reduction (CER) Credits, tree-planting schemes etc. Before making a contribution, it is important to examine the potential scheme. Ensure it is properly accredited; there are standards in place to assist with this. The cost of investment varies; typically, you would expect to pay £7-£12/tonneCO_2 offset. Based on the operational carbon emission scopes addressed Electricity (after reduction using PV), Gas (after reduction/ applying fabric improvement and Ground heat pump) and Water for different years 2016-18, at an off-set price of £7.5/tonne (using UN Certified Emission Reduction (CER) Credits); the cost to offset carbon emissions would be as in Table 3. Then the business could receive a certificate from international recognition body that this organization is become a carbon neutral business.

Table 3: Carbon footprint for the building after implanting the green measures

Year	Scope 2 -Carbon emission from electricity used in GSHP	Scope 2 -Carbon emission from electricity used in building	Scope 3	New total CO_2e (tonne)	Original total CO_2e (tonne)
2016	13.8	86.9	3.,3	104.0	152.4
2017	14.3	52.3	3.4	70.0	123.2
2018	22.9	25.6	2.5	51.1	137.3

Table 4: Offsetting amount for Carbon emissions using UN Certified Emission Reduction (CER) Credits

Year	Total offset cost
2016	£780
2017	£525
2018	£383

CONCLUSIONS

The case study investigated in the present paper is an industrial business that has been found to have high energy levels/carbon footprint. With the use of the carbon neutral protocol, the business can enable itself to work towards becoming not only carbon neutral but generates a zero carbon status by changing to solar panels and improve the fabric. This can be combined with the use of ground source heat pump; the system can be used all the year round with high efficiency ratings and last for around 20-30 years. Carbon reduction with these measures could reach up to 90%, which varies every year depending on the activities and energy consumption. The company can join a carbon-offsetting scheme and paying amount on average of £383 annually if the carbon footprint remains around this figure, however, they have the opportunity to cut more emission and reduce this figure.

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