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Article

Towards Net Zero Carbon Economy: Improving the Sustainability of Existing Industrial Infrastructures in the UK

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Abstract: To comply with the new net zero greenhouse gas emissions (GHGs) target set by the United Kingdom government by 2050, different sectors including the industrial sector are required to take action to achieve this target. Improving the building envelope and production of clean energy on site are among the activities that should be considered by businesses to reduce their carbon emissions. This research analysis the current energy performance and carbon dioxide (CO_2) emissions of an industrial building in Liverpool, UK utilizing the Integrated Environmental Solutions Virtual Environment (IESVE) software modeling. Then it has proposed some methods for improving the current performance and reduce the carbon footprint of the building. The results indicated that the installation of wall and floor insulation could decrease the energy usage and CO_2 emissions of the building by about 56.39%. Additionally, the production of clean energy on site using solar photovoltaic (PV) panels could reduce the annual CO_2 emissions by up to 16%. Furthermore, this research provided some figures about offsetting the rest of CO_2 emissions using different international offsetting schemes to achieve carbon neutrality of the building.

Keywords: carbon neutrality; CO_2 emissions; carbon offsetting; clean energy; insulation

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1. Introduction

Climate change is considered as the main reason for many of the extreme weather conditions worldwide such as floods, storms, droughts, apocalyptic fires, the spread of deserts, rising sea levels and collapse of biodiversity [1]. One of the main contributors to climate change is the emissions of GHGs such as the carbon dioxide (CO_2) from different activities. Statistic figures indicated a continues rising in the emissions of CO_2 although the pandemic of COVID-19 has temporarily contributed to decreasing the CO_2 emissions worldwide [2]. Therefore, to conserve the environment, considerable actions must be taken to reduce the effect of such worldwide challenges that might leads to major environmental disasters [3].

In 2016, 195 countries including the UK have committed to limit the global warming below 2 °C through Paris agreement [4]. During this agreement the concept of Carbon Neutrality has been laid down. Carbon neutrality means having a balance between the amount of CO_2 emissions produced and absorbing CO_2 from the atmosphere in carbon sinks [1]. The term carbon sinks are any system that absorbs more CO_2 comparison with releases to the atmosphere including oceans and forests. In 2019, the UK was the first nation to formally pledge to cut its CO_2 emissions to zero by 2050 [5]. This could be achieved by both decreasing the existing CO_2 emissions and removing it safely from the atmosphere.

As reducing the CO_2 emissions to zero is not realistic, therefore, the concept of Carbon Offsetting was introduced [4]. Carbon able to offset is the practice of compensating for Carbon dioxide emissions generated by one activity by engaging in programs that result in CO_2 reductions in the atmosphere that are comparable [4].

Although, the committee on climate change of the UK has an ambitious plan of planting about 25% of land with trees to achieve its carbon neutrality target, however, this alone wouldn't be sufficient [5]. Therefore, industrial companies, houses and transportation sectors are all required to take part in this action by making their activities as energy efficient as possible along with seeking for eco-friendly alternatives.

In the UK, the energy consumption of buildings is considerable, especially non-domestic buildings that account for nearly 35% of the greenhouse emissions [6]. Additionally, the building performance is considered as one of the main contributors to the negative environmental impacts such as the climate change and global warming [7]. In recent years, there was a considerable work conducted by the UK government towards sustainable buildings that would promote retrofitting existing buildings to be as energy efficient as possible [5]. This includes the installation of insulation systems and the use of smart technology to achieve the target of carbon neutrality and at the same time improves indoor comfort [5].

The quality of indoor environment is considered as one of the main health worries as people spend around 80–90 percent of their time within indoor environment [8]. The quality of indoor environment is affected by several factors such as the materials used for the building and the design of the building [9]. The energy consumption of any building is affected by several variables such as the building envelope (materials used for the building), the building's location and the behaviour of the occupants [10]. It has been reported by Watson [11] that the heat exchange between outdoor and indoor environments is controlled mainly by the building envelope. Additionally, Jannat [12] stated that the thermal performance of the materials used in a building has a significant impact upon the occupants' comfort conditions within this building. Therefore, the usage of suitable materials for the buildings would significantly improve the building performance by attaining the standard indoor comfort with reduced energy consumption and that would significantly help in achieving the carbon neutrality.

The use of building energy simulation tools by engineers and designers to analyze the building's performance under dynamic weather conditions has recently become popular to investigate various design options [12]. Therefore, this investigation aims to show a simulation analysis of an industrial building in the UK to evaluate its current energy performance and compare it with different potential improvements to achieve carbon neutrality. The building under study has been modelled with different building envelopes. Thus, the investigation conducted within this study concentrates on the installation efficiency of different insulation systems as well as the use of smart technologies to decrease the energy usage in the buildings. Moreover, some figures about the cost need to be paid to achieve carbon neutrality using international offsetting schemes have been included.

Although the topic of improving the energy performance of existing industrial building for lowering the CO_2 emissions have been covered by many studies worldwide [13–21], however, limited studies in the UK have covered a comprehensive evaluation of energy performance and CO_2 emissions of an existing industrial building that took into consideration the application of improvements for greener energy performance along with detailed economic analysis of optimization between the proposed improvements and carbon offsetting schemes. Therefore, the innovation of the current study is providing a comprehensive case study for evaluating the energy performance of an existing industrial building in the UK along with proposing some methods for improving its current performance and conducting a detailed economic analysis of optimization between the proposed improvements and carbon offsetting schemes.

2. Methodology

This research was conducted with the aim of investigating the weaknesses in the building covers of an industrial building and how the application of different insulation systems and the use of smart technologies would improve the energy efficiency of the building.

2.1. Description of the Case Study

The case study is a repurposed warehouse (220.8 m^2) based in Liverpool, UK at latitude 53.33° N and longitude 2.85° W. The minimum, maximum and average monthly temperatures of the city are presented in Figure 1. The building (Figure 2) is a café, bar and venue. The building also has facilities for hot-desking and co-working. The building currently poses problems regarding heating. The premise is very expensive and inefficient to heat in winter due to the lack of insulations for different parts of the building. This in turns significantly reason for increasing the building's carbon footprint. Full details of the current building fabric are provided in Table 1.

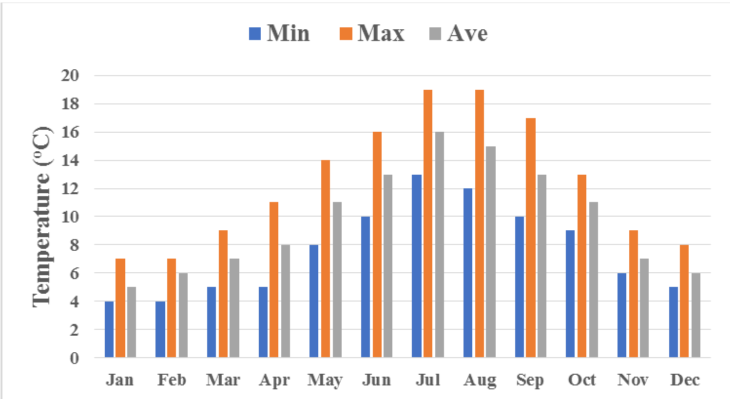

Figure 1. Climate data of Liverpool City, UK [22].

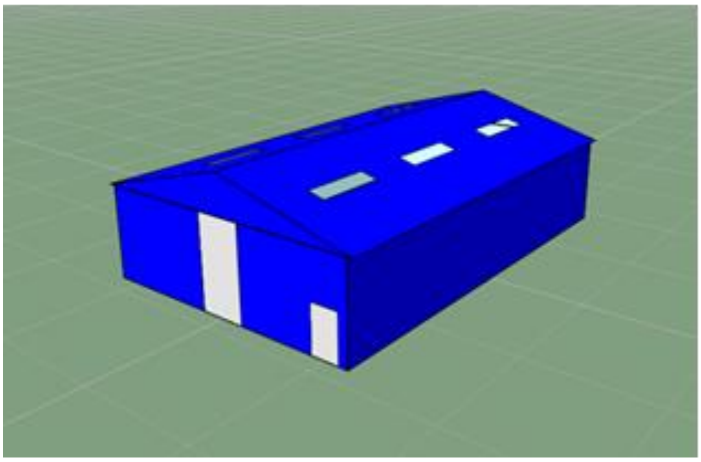

Figure 2. A computer model for the case study.

Table 1. Building fabric of the case study.

Items	Depiction	Thicknesses (mm)	U-Magnitude (W/m^2 K)
External wall	Steel sheet metal	10	5.880
Internal Partitions	Plasterboard-Cavity-Plasterboard	10-50-10	1.870
Doors	Wooden door	37	2.200
Skylight	Double glazing	24	2.300
Roof	Steel sheet metal-Insulation-Plasterboard	10-150-10	0.193
Floor	Reinforced concrete	100	3.950

2.2. Simulation Tool

To investigate the current energy performance of the studied case study, a simulation tool was needed to forecast the energy usage in the building. There are different simulation software that could be utilized to forecast the energy usage of buildings such as Design Builder and Integrated Environmental Solutions Virtual Environment (IESVE). During the last 50 years, IESVE software has evolved as a reliable and robust simulation tool and several academics have confirmed the efficacy of the IESVE software by validating the experimental data against numerical findings [12]. Additionally, IESVE software has proving capacity of simulating and analysing existing buildings at various locations in the world. Therefore, IESVE has been chosen in this research for the purpose of predicting the energy performance of the case study building taking into consideration the location of the building, the behaviour profile of the occupants and the current design of the building. In addition to the energy performance, the IESVE can predict the CO_2 emissions associated with the consumed energy.

During this research, two IESVE models were built. The first one was for the current building to investigate its current energy performance and the corresponding CO_2 emissions. For the first model, the actual construction materials (Table 1) were used as inputs for the software. Additionally, a personal communication with the property manager was conducted to establish the behaviour profile of the occupants in this property. On the other hand, the second model was built taking into considerations possible solutions for the weakness identified in the first model to investigate the potential savings in energy consumption and CO_2 emissions after the application of such improvements.

In total, 8 simulations were used in this research. In each of these simulations the behaviour profile date inputs were fixed and the varied parameters for all the 8 simulations are as follows: the first simulation was for the current building, the second and third simulations were used to investigate the single effect of wall insulation and floor insulation, respectively. The forth simulation was used to investigate the combined effect of wall and floor insulations taking into consideration the optimum results obtained from the second and third simulations (50 mm wall insulation and 25 mm floor insulation). The fifth and sixth simulations were investigated the effect of installing 30 m^2 PV panels and 60 m^2 PV panels without the incorporation of any insulation system. The seventh and eighth simulations investigated the combined effect of installing wall and floor insulations along with installation of 30 m^2 PV panels and 60 m^2 PV panels, respectively. The version of the used IESVE software was IES Virtual Environment 2019 and the licence for this software was provided by Liverpool John Moores University. The data input methodology that has been followed in this research was conducted manually by the authors.

3. Results and Discussion

3.1. Carbon Assessment and Energy Consumption of the Current Building

The main source of energy for different activities within the building is electricity. The activities that contributes to the energy usage within the building were provided by the property manager and they have been used as inputs for the IESVE software to estimate the energy usage and CO_2 emissions of the building. According to the results obtained from the modelling (Table 2), the current energy usage of the building is 245.1 KWh/m^2 which is about 258% relative to standard benchmarks (95 KWh/m^2) [23]. Additionally, the current CO_2 emissions of the building is almost 243% the CO_2 emissions in comparison with standard benchmarks [23].

Table 2. Comparisons of the current energy usage and CO_2 releases of building against standard benchmarks.

	Electricity	
	KWh/m^2	**KgCO$_2$/m^2**
Current performance	245.1	127.2
Benchmarks	95	52.3

Figure 3 shows a breakdown of the activities that contributes to energy consumption and CO_2 emissions of the current building. As could be observed in Figure 3, heating is contributing to about 76% of the energy usage and CO_2 releases of the building, while lighting and equipment contribute to about 9% and 15%, respectively. This behaviour is mainly attributed to the high U-value of the building fabric that failed to resist or even lowering the rate at which cold air pass from the outside atmosphere to the building [7]. Therefore, in order to overcome such a problem, the installation of thermal insulation would be an ideal solution for reducing the energy usage and improving the building's sustainability as reported previously by other researchers [7,24–27].

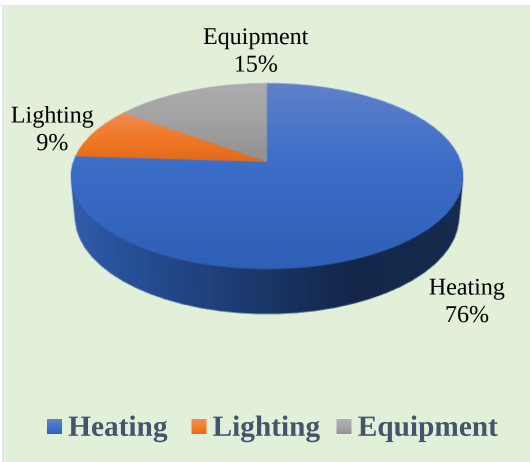

Figure 3. Breakdown of the activities that contributes to energy consumption and CO_2 emissions of the current building.

3.2. Carbon Assessment and Energy Consumption after Fabric Improvements

According to Table 1, the highest U-values of 5.88 W/m^2 K and 3.95 W/m^2 K were recorded for the external wall and the flooring, respectively. Therefore, to improve the resistance of the building to external weather conditions, the application of thermal insulation for these two parts were investigated. Table 3 presents the details of the building fabric after the installation of the thermal insulation at the external wall and the flooring.

Table 3. Improved building fabric of the case study.

Items	Depiction	Thicknesses (mm)	U-Magnitude (W/m^2 K)
External wall	Steel sheet metal-Insulation-Plasterboard	10-50-10	0.531
Internal Partitions	Plasterboard-Cavity-Plasterboard	10-50-10	1.87
Doors	Wooden door	37	2.20
Skylight	Double glazing	24	2.3
Roof	Steel sheet metal-Insulation-Plasterboard	10-150-10	0.193
Floor	Reinforced concrete-Insulation-Chipboard flooring	100-25-20	0.892

As can be seen in Table 4, the installation of 50 mm thermal insulation from the inside of the external wall has contributed to decrease the current energy usage and CO_2 releases by approximately 21.93%. Additionally, the installation of 25 mm thermal insulation above the reinforced concrete flooring resulted in decreasing the current energy consumption and CO_2 emissions by about 25.19%. Furthermore, the combined installation of wall and floor insulations has significantly reduced the current energy consumption and CO_2 emissions of the building by about 56.39%. This behaviour is mainly attributed to the reduced U-values of the walls and the flooring. According to Table 4, the amount of CO_2 emissions has been cut by nearly 16 tonnes form the inclusion of the proposed improvements and that would significantly contribute towards the carbon neutrality of the building.

Table 4. Energy usage and CO_2 releases of the case study building after application of different insulation systems.

	Electricity				
	KWh/m^2	**KWh**	**KgCO$_2$/m^2**	**KgCO$_2$**	**Reduction of CO$_2$ (%)**
Current performance	245.1	54,109.6	127.2	28,083	-
Wall	191.3	42,241.5	99.3	21,923	21.93
Floor	183.3	40,477.2	95.1	21,008	25.19
Wall and Floor	106.9	23,598.0	55.5	12,247	56.39
Benchmarks	95	-	52.3	-	-

As can be seen in Figure 4 that after the installation of the suggested insulation systems, heating is now contributes to about 52% of the energy usage and CO_2 releases of the building, while lighting and equipment contribute to about 20% and 28%, respectively. This is clearly indicating the role of insulation systems in improving the sustainability of the building. For further improvement in the sustainability of the building, the installation of occupancy/motion sensors along with the usage of energy efficient lighting systems such as Light Emitting Diodes (LEDs) could significantly help in reducing the energy consumption and cut CO_2 emissions from the lighting [28]. Furthermore, the usage of energy efficient equipment along with turning off unused machines could translate to significant energy savings and considerably reduce the CO_2 emissions of the building. For example, computer monitors are an easy way to save on energy bill as they use a lot of energy and are often left on without being used. Therefore, ensuring that monitors are set on automatic sleep mode or are manually turned off when not in use especially over the weekend/holidays is an easy method of energy saving.

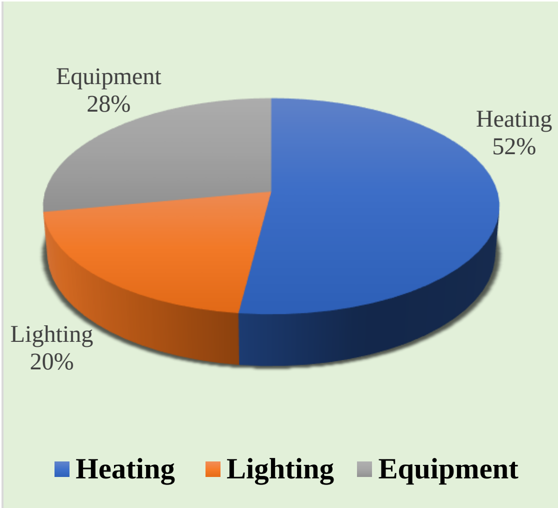

Figure 4. Breakdown of the activities that contributes to energy consumption and CO_2 emissions of the building after all improvements.

3.3. Production of Renewable Energy Onsite

To additional enhance the sustainability of the building, the production of renewable energy onsite through the use of natural resources could be one of the best options [29–31]. The choice of the best technology for producing renewable energy onsite is highly affected by different factors such as the location of the site and the availability of the natural resource in that area. The investigated building has a large pitched roof with no shading around which makes the installation of solar photovoltaic (PV) system on both sides of the roof possible.

The electricity produced from the installation of PV systems relies mainly on the hourly solar radiation through the year. IESVE database was used for accurately linking the weather profile with the generated energy from the PV system. According to the size of the roof and the orientation of the building it is possible to install up to 60 m^2 of PV panels. Table 5 presents full assessment of the PV system based on the results obtained from the IESVE simulation. As can be seen from Table 5 that the installation of 30 m^2 of PV panels is expected to generate about 4460 KWh per year. Saving in annual electricity consumption will be about 8% for the current building and will become around 19% if all the improvements were conducted for the building and for both cases there will be a reduction in the CO_2 emissions from the building about 2.3 tonnes. Additionally, this saving would be doubled if the size of the PV system increased to 60 m^2.

Table 5. Details of the PV solar system.

Size of PV (kWp)	Area of the Roof (m^2)	Generated Electricity (KWh)	CO_2 Reduction (Tonne/Year)	Annual Electricity Saving% (Current Building)	Annual Electricity Saving% (with Insulations)
5.8	30	4460	2.3	8	19
11.5	60	8920	4.6	16	38

3.4. Carbon Offsetting

According to the obtained results, the installation of wall and floor insulations along with the production of renewable energy onsite could significantly reduce the carbon emissions of the building; however, there are still some CO_2 emissions will be produced to the atmosphere from different activities of the building. Therefore, to achieve carbon neutrality of the building towards net zero carbon economy the schemes of carbon-offsetting could be the solution for that. Actually, the current building could achieve carbon neutrality through this scheme without the need for the proposed carbon saving methods.

Currently there are a rage of carbon-offsetting schemes worldwide [32]. Table 6 presents some of the carbon-offsetting schemes and the price per tonne of CO_2 emissions. The money that is paid for such schemes not only will help in reducing the CO_2 emissions, but it would also help is supporting community projects especially these based in the developing countries. According to Table 6, the price for carbon-offsetting ranging between £6-12.9 per tonne of CO_2.

Table 6. Carbon-offsetting schemes [32].

Scheme	Price/Tonne	Certified Body
Global Portfolio	£6	Verified Carbon Standard
UK Tree Planting	£12.9	Verified Carbon Standard
Reforestation in Kenya	£9.5	Verified Carbon Standard
Americas Portfolio	£7	Verified Carbon Standard or The Gold Standard
Community Projects	£8	The Gold Standard

Table 7 presents the cost required to offset carbon emissions of the case study building for different scenarios using different offsetting schemes. As can be seen from Table 7, the amount of payment could be reduced with improving the current performance of the building by the proposed methods. From Table 7, the company could easily become a carbon neutral business by paying a maximum of £362 annually. Although, this seems to be the cheapest and the easiest way to be a carbon neutral business in comparison with the cost required to conduct some or all the proposed solutions, however, companies are highly recommended to cut their CO_2 emissions rather than offsetting it.

Table 7. Offsetting amount for Carbon emissions using different schemes.

	Global Portfolio	UK Tree Planting	Reforestation in Kenya	Americas Portfolio	Community Projects
Current performance	168	362	267	197	225
Wall insulation	132	283	208	153	175
Floor insulation	126	271	200	147	168
Wall and Floor insulation	73	158	116	86	98
30 m^2 PV	155	333	245	180	206
60 m^2 PV	141	303	223	164	188
Wall and Floor insulation+ 30 m^2 PV	60	128	94	70	80
Wall and Floor insulation + 60 m^2 PV	46	99	73	54	61

3.5. Economic Analysis

This section presents a detailed economic analysis of optimization between the proposed improvements and carbon offsetting schemes. Table 8 presents an estimated cost for the proposed improvements. According to Table 8, the installation of insulation systems is much more expensive than the installation of PV panels. Additionally, although the 60 m^2 PV system has a higher initial cost than the 30 m^2 PV system by about £3300, however, it has higher economic and environmental benefits as it can produce double the energy that in turns improve the sustainability of the building. Furthermore, by installing higher capacity

PV system, the company could profit from it by selling part of its produced electricity to the grid that could considerably increase the economic viability of the system.

Table 8. Estimated cost of different improvements.

Improvement	Estimated Total Cost (£)
Current performance	0
Wall insulation	24,300
Floor insulation	23,800
Wall and Floor insulation	48,100
30 m^2 PV	7300
60 m^2 PV	10,600
Wall and Floor insulation+ 30 m^2 PV	55,400
Wall and Floor insulation + 60 m^2 PV	58,700

In comparison with all the carbon offsetting schemes, the proposed improvements seem to be much more expensive. On the other hand, with the ongoing effort towards net-zero carbon economy in the UK by 2050, the prices of different carbon offsetting schemes could be increased significantly. Therefore, conducting some improvements worth investment for the long term benefit of the company to cut more emissions rather than offsetting them.

4. Conclusions

This research was conducted with the aim of evaluating the current performance of an industrial building and propose some solutions for achieving carbon neutrality along with providing an economic analysis of of optimization between the proposed improvements and carbon offsetting strategies. According to the obtained results the following conclusions were drawn:

1. The current energy consumption of the building is 245.1 KWh/m^2 and its current CO_2 emissions is more than 28 tonnes annually.
2. The combined installation of wall and floor insulations have significantly reduced the current energy consumption and CO_2 emissions of the building by about 56.39%.
3. There are an easy method of saving energy through the usage of energy efficient lights and equipment within the building.
4. Depending on the size of PV system, the installation of PV solar panels could reduce the CO_2 emissions of the building by up to 4.6 tonnes annually.
5. The company could join an international carbon-offsetting scheme and pay a minimum of £168 annually and become a carbon neutral business and this figure could be reduced further with the application of some or all the proposed methods of improvements.
6. The installation of 60 m^2 PV system is the highly recommended improvemnt that could be implemented from both environmental and economic point of view.
7. The cost of the proposed improvment methods is significantly higher than that of all the existing carbon offsetting schemes.

5. Recommendations for Future Works

Despite the aspects that have been investigated within this resaerch several possible future studies can be recommended as stated below:

- ❖ Investigating the effect of using biomass for heating as a carbon neutral source

- ❖ Studying the possibility of producing clear energy on site using clean energy sources such as fuel cells and wind energy
- ❖ Investigating the effect of changing the location of the same building on the performance of the building
- ❖ Studying how human behavior profile could influence the performance of the building and how carbon literacy could help is saving energy.
- ❖ Investigating how the results would change if the building size increased or decreased.

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