Application of carbon life cycle assessment for a sustainable building design: A case study in the UK

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Abstract

In the construction industry a large amount of carbon dioxide is emitted, due to the embodied and operational carbon. RICS Guidance note shows the stages producing the most carbon dioxide is the operational stage and the second significant area is the production stage. Recent studies have investigated reducing the operational emissions, however there is limited research on the embodied carbon. To achieve climate targets by 2050, all operational emissions need to be phased out along with reductions in embodied carbon. This paper aims to analyse the carbon life cycle (LCA) of the case study building in the UK. Further implementing low carbon & clean technologies has been considered to reduce the embodied and operational carbon. Current state of the art carbon assessment is utilised incorporating methodologies such as 'Cradle to grave' from 'British standards' in conjunction with 'RICS Guidance note' and 'RICS Professional statement'. To measure the embodied and operational carbon using the 'cradle to grave' process, requires selecting a case study building and collecting related input data to process calculations such as construction materials and energy consumption. Results conclude that the operational stage is the largest CO_2 contributor of the whole lifecycle, therefore PV Solar panels were chosen to reduce CO_2 emissions. The product stage was the second most significant CO_2 contributor therefore low carbon strategies, such as use of recycled steel, light weight brick and SCM's for mortar and concrete, were selected. Re-calculation of the embodied and operational carbon of the building after implementing the low carbon strategies and clean technology comparing to initial results show reductions in CO_2 emissions by 22% creating a low carbon building. Therefore, this paper brings awareness and guidance globally to clients, building designers and the government to design sustainably using suitable low carbon solutions in all construction projects, leading to a low carbon future.

Key words: Building; embodied carbon; Carbon life cycle; low carbon; operational carbon

1. Introduction:

Global warming is caused by anthropogenic greenhouse gas emissions in the atmosphere, where carbon emissions cause temperatures to increase creating a major effect environmentally, socially and economically around the world (RICS, 2017). According to Dobson et al, (2013) 52% of the UK's CO_2

emissions are created by the construction and usage of buildings, which demonstrates that the construction industry is a major global exploiter of natural resources and contributes significantly to the

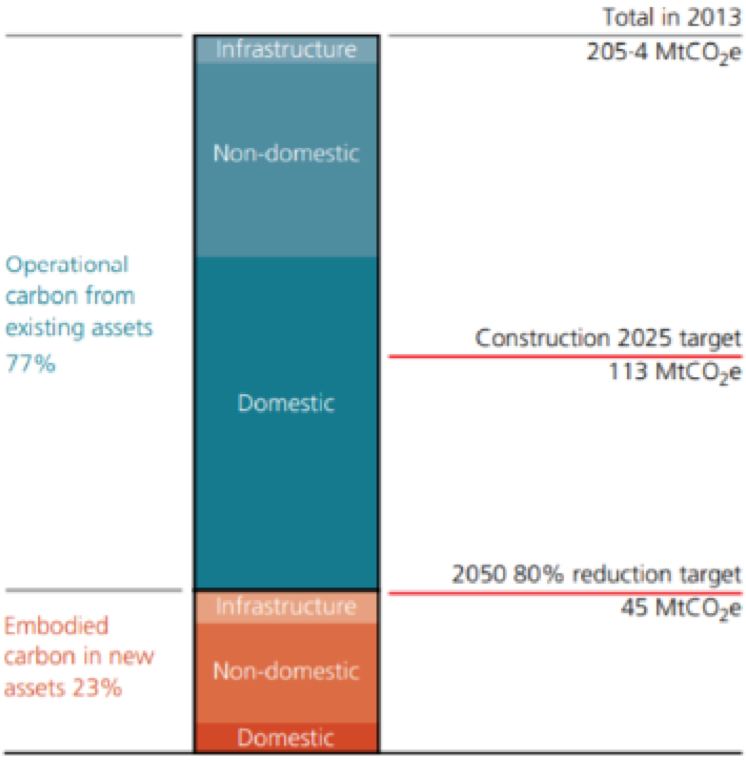

Figure 1: 2013 GHG Emissions in the UK Built environment (Giesekam and Pomponi, 2018).

unsustainable development (Spence and Mulligan, 1995).

In order to meet the Kyoto Protocol target of 80% CO_2 reduction by 2050, new low carbon strategies need bringing into the construction industry to reduce not only the operational carbon but embodied too (Chau, Leung and Ng, 2015). Recent updates show that although efforts have been made to reduce CO_2 emissions, they have failed to meet the reduction targets (Giesekam and Pomponi, 2018). One of the main focuses for the built environment industry is reducing operational carbon emissions in buildings where domestic buildings are showing a slow downwards trend (Giesekam and Pomponi, 2018). However, the non-domestic sector remains a large contributor to CO_2 emissions, where the trend is increasing (Giesekam, Hurst and Steele, 2015) as the built environment is widening and developing which could be why targets have not been met. This suggests focus is needed on reducing the non-domestic operational carbon. Figure 1 shows 2013 non-domestic and domestic operational and embodied carbon contribution within the built environment in the UK. It also displays the targets to be achieved of 113 $MtCO_2e$ for 2025, reducing to 45 $MtCO_2e$ by 2050 (Giesekam and Pomponi, 2018; Thorpe, 2017; UKGBC, 2020). Embodied carbon is responsible for almost a quarter of the total built environment emissions as shown in Figure 1. Recent studies have investigated the energy consumption at the operational stage reducing the operational emissions, by using new energy efficient designs of heating, lighting and ventilation (Chau, Leung, and Ng, 2015). Despite operational carbon emissions being reduced due to extensive research, embodied carbon is yet to be reduced. Embodied carbon has limited research therefore, this paper is to widen the knowledge of reducing the embodied carbon, as well as operational carbon so CO_2 reduction targets can be met.

The standard of general practice in embodied carbon assessment has improved over recent years, however, there are still several specific areas where practitioner knowledge is limited and guidance is lacking (Giesekam and Pomponi, 2018). There is a recent growth in the publication of EPDs (Anderson, 2017), but it continues to be difficult to source appropriate product data for embodied carbon (Gavotsis and Moncaster, 2015; Giesekam et al., 2016) and the use of outdated or geographically inappropriate data remains commonplace (De Wolf et al., 2017; Pomponi and Moncaster, 2016). Lack of standardisation in assessment procedures caused many key parameters remain at the discretion of the practitioner conducting the embodied carbon assessment. This has resulted in the use of various functional units, assumed service lives and no common procedure for selecting appropriate system boundaries (Anand and Amor, 2017). In 2017 at the Ecobuild event, a new embodied carbon guidance document was published to encourage client members to create their own embodied carbon briefs bringing awareness of embodied carbon at client level (UKGBC, 2015; Thorpe, 2017). This paper gives clients and designers an understanding of the requirements in future construction.

Embodied carbon is the carbon emitted during the construction of buildings including production, construction, maintenance and end of life stages. Low carbon strategies for embodied carbon are to be selected at the design stage of the building for the methods to be applied (Yadoo and Cruickshank, 2012). Embodied carbon can be addressed by improvement in the efficiency of structural designs, alternative building materials and the reuse and recycling of materials (Cabeza et al, 2014; Moynihan and Allwood, 2014; Tingley and Davison, 2011). Embodied carbon can be reduced by focusing on hotspots which are the high carbon materials within the building.

A previous LCA has been conducted for a case study of apartment housing where one of the main construction materials used was reinforced concrete accounting for more than 73% of the total CO_2 emissions (Lee, Tae, and Kim 2018). The CO_2 emissions related mainly to the transportation stage from the manufacture to the construction site. Therefore, for future construction projects the use of high-efficiency heavy transportation equipment could be considered in order to minimise CO_2 emissions (Lee, Tae, and Kim 2018). Another study by Ramesh et al., (2010) presented a detailed examination of 73 residential and office case study buildings from 13 countries. Whereas Sartori and Hestnes (2007) analysed delivered-energy and primary-energy studies separately, Ramesh et al., (2010) applied referenced conversion factors on delivered-energy studies to determine primary energy values for all studies. Results showed that the life cycle primary energy use of a conventional residential building was in the range of 150–500 kWh/m^2/y, whereas that of office buildings was between 250 and 550 kWh/m^2/y. Furthermore, the study found that embodied and operational energy accounted for around 10–20% and 80–90%, respectively, of building life cycle energy (LCE) use. Lane (2007), reported that since a downward pressure has been on operational energy use the ration of operational to embodied carbon, has gone from 80:20 ratio to 40:60. Thus, operational carbon will continue to reduce and more focus can be on the embodied carbon.

The aim of this paper is to analyse the carbon life cycle (LCA) of the case study building in the UK and implement low carbon and clean technologies to reduce the embodied and operational carbon. The LCA stages include product, construction process, operation, use and end of life. The paper identifies the main carbon contributors of the life cycle stages allowing adaptations to be implemented creating a low or zero carbon building. If an effective reduction of carbon strategy is used in new construction projects, it may reduce carbon emissions globally, minimising the effects of global warming.

2. Case study

The case study building situated in Liverpool (UK) is a commercial building including office spaces. It is made up of brick walls and the heating system is powered by electricity. The floor area is approximately 1225.68 m^2 which was calculated from the building plans provided. For the purpose of the calculations the building has been split into sections as shown in Figure 2. The age of the building was determined by the current landlord of the building. Section A was approximately built in the 1950's comprising of three stories and a basement. Section B building has been selected for this study as it is a reasonable size for completion of embodied and operation carbon calculations.

Section A of the building was built before Section B, therefore the use of construction materials such as bricks, mortar and insulation may vary. However, for the purpose of the calculations an assumption has been made, that the construction materials used for both sections will remain constant throughout the building. The indicative design working life is approximately 50 years as per Table NA.2.1 in BS EN 1990:2002 (BSI, 2002; Tanaka, 2006). Building plans were provided by the landlord and used to find dimensions throughout the study. However, details of the foundations were not provided within the plans, therefore assumptions were made that the building utilises a strip foundation due to the time of construction and the ground conditions.

Figure 2: Plan view of the building (section A and B)

3. Methodology

For this case study 'RICS Guidance note' (RICS, 2014) and 'RICS Professional statement' (RICS, 2017) were used in conjunction to calculate the LCA of the building. They are based on BS EN 15978: 2011 which are the most used procedure in the European construction industry (BSI, 2011; Construction Products Association, 2012). The procedure requires carbon conversion factors for all LCA calculations for the year the process occurred. If there is no source available for that year, a source closest to that year has been used. Therefore, Government conversion factors, inventory of carbon and energy UK and DEFRA Greenhouse gas conversion factor for company reporting UK are used for each calculation throughout this study (Department for Business, Energy & Industrial Strategy, 2013; Department of Energy & Climate Change, 2019; Hammond and Jones, 2019). Figure 3 shows the different stages of the building life cycle carbon assessment, in order to indicate which stage contributes most emission.

For this paper one case study building was chosen, so an in-depth evaluation could be conducted for each stage of the lifecycle.

3.1 Product stage (A1-A3)

The area and volume of each material were calculated using the building plans provided. Any additional dimensions that are not available were measured on site using a laser measuring tool. The total mass

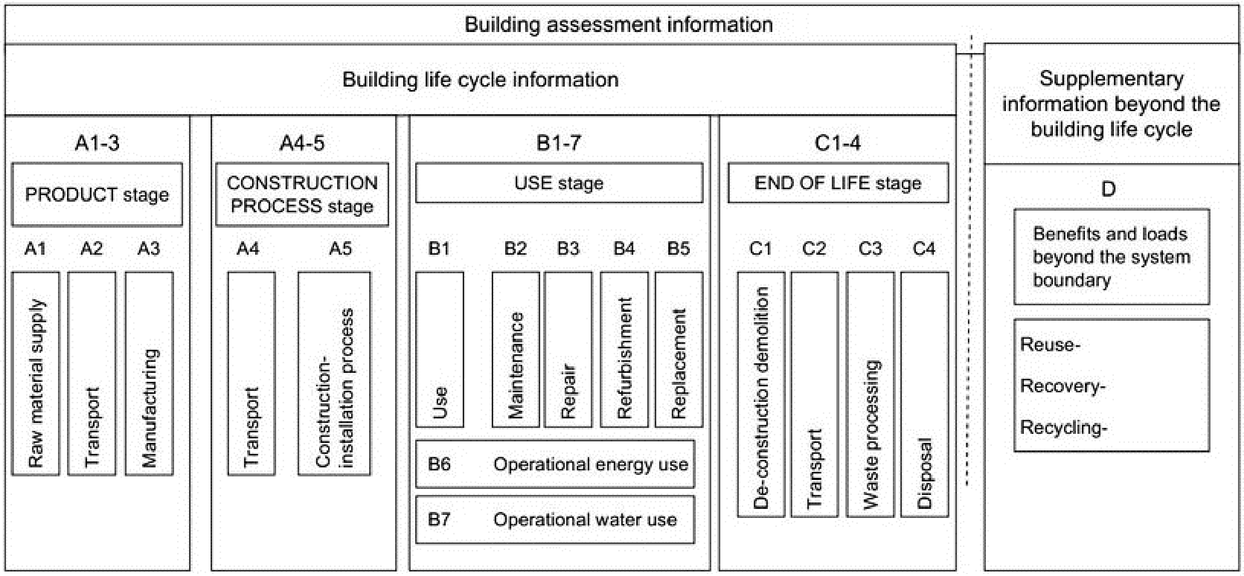

Figure 3: Different stages of the Building LCA (BSI, 2011).

was then calculated for each material.

For a single layer brick wall, 60 bricks are used per m^2 (Brick Hunter, 2020) therefore for the total amount of bricks used for partition walls eq. ((*1*) was used. A sample calculation is shown in eq. (2).

$$Area\ (m^2) \times bricks\ per\ m^2 \left(\frac{nr}{m^2}\right) = Total\ amount\ of\ bricks\ used\ for\ wall\ (nr) \tag{1}$$

$$773.975\ m^2 \times 60 \frac{nr}{m^2} = 46438.483\ nr \tag{2}$$

All UK manufactured bricks are produced according to BS EN 771-1: 2011+A1:2015, which states the mass of a brick is 2.13kg (BSI, 2011). Therefore, the total mass is calculated as shown in equation (*3*).

$$2.13\ kg\ \times 46438.483\ nr = 98913.969\ kg \tag{3}$$

The total mass of each material was multiplied by a carbon conversion factor to give the total embodied carbon for the product stage. Eq. (4) was used for the embodied carbon of each material at the product stage:

$$Total\ mass\ (kg) \times Carbon\ Conversion\ Factor\ \left(kg\frac{CO_2e}{kg}\right) = Embodied\ Carbon\ (kg\ CO_2e) \quad (4)$$

Sample calculation for the embodied carbon for total partition walls is shown in eq. (5):

$$98913.969\ kg\ \times 0.454\ \left(kg\frac{CO_2e}{kg}\right) = 44906.942\ (kg\ CO_2e) \quad (5)$$

3.2 Construction stage (A4 and A5)

3.2.1 Transport emissions (A4)

The embodied carbon for the transport of materials from the manufacturer to the construction site was calculated using eq. (6):

$$Transport\ distance\ (km) \times carbon\ conversion\ factor\ (kg\ CO_2e/km) = Embodied\ carbon\ for\ transport\ emissions\ (kg\ CO_2e) \quad (6)$$

There is no data provided for the transport distance from manufacture to the construction site due to the age of the building. Therefore, an average HGV Transport scenario's for UK Projects table was taken as an assumption for the transport distance (RICS, 2017). Sample calculation for concrete is shown in eq. (7), further conducting for each material.

$$50\ km \times 0.867\ kg\frac{CO_2e}{km} = 43.327\ kg\ CO_2e \quad (7)$$

3.2.2 Construction-installation process (A5)

The embodied carbon of the energy consumption is calculated by finding the electrical consumption and fuel consumption during the construction stage. For the electrical consumption eq. (8) was used to calculate the embodied carbon.

$$Electric\ Consumption\ for\ case\ study\ site\ area\ (kWh) \times Carbon\ conversion\ factor\ (kg)CO_2e = Embodied\ carbon\ (kg\ CO_2e) \quad (8)$$

For the embodied carbon of the fuel consumption eq. (9) was used. Refer to case study details of site area.

$$Construction\ Process\ Carbon\ Emissions\ from\ fuel\ consumed\ \left(kg\frac{CO_2}{m^2}\right) \times Area\ of\ site\ (m^2) = Embodied\ carbon\ (kg\ CO_2e) \quad (9)$$

3.3 Use stage (B2-B5) and End of life (C1-C4)

Use stage was calculated using the procedure in 'RICS Guidance note' and 'RICS professional statement where the same principles apply as above in product and construction calculations (RICS, 2014; RICS, 2017).

3.4 Operational carbon calculation

3.4.1 Operational carbon for Electricity consumption

To calculate the operational carbon for the electrical consumption eq. (10) was used as shown below:

$$Annual\ electric\ consumption\ (kWh) \times carbon\ factor\ ((kg)CO_2e) = Annual\ operational\ carbon\ for\ electricity\ (CO_2e(kg)) \quad (10)$$

3.4.2 Operational carbon for water supply, wastewater and fuel

For operational carbon for water supply, wastewater and fuel, the procedure in 'RICS Guidance note' and 'RICS professional statement' was applied as above in operational carbon of electricity calculations (RICS, 2014, RICS, 2017). Using an estimated building lifespan of 50 years, analysis has been conducted for the whole life cycle of the operational carbon (BSI, 2002; Tanaka et al., 2006).

3.5 Solar installation

The analysis was made on CO_2 emission comparison of no solar and solar installation for 2018 and 2019 electric consumption, as data was available for these years. Eq. (11) was used to calculate the operational carbon for 2018 and 2019.

$$(\text{Electrical consumption} - \text{solar production})\ (\text{kWh}) \times \text{carbon factor}\left(\frac{\text{kg CO}_2\text{e}}{\text{kWh}}\right) = \text{Operational carbon (kg CO}_2\text{e)} \quad (11)$$

Eq. (*12*) is a sample calculation that was conducted for 2018. 506 kWh of electricity will be generated by a 1 kW PV of $7m^2$ in 1 year (Energy Saving Trust, 2020). Therefore, a 50 kW PV will produce 50 times the amounts as shown in eq. (*12*). For a 50 kW to be installed on the case study building, a roof area of $350m^2$ would be needed to generate 25300 kWh per year.

$$(95600 - (50 \times 506))\ \text{kWh} \times 0.28307 \frac{\text{kg } CO_2\text{e}}{\text{kWh}} = 19899.821\ \text{kg CO}_2\text{e} \quad (12)$$

3.6 Embodied carbon reduction

The highest embodied carbon contributors were determined within the product stage and eq. (4) was conducted, using new carbon conversion factors for the replacement construction materials. Conversion factors produced in 2019 were used as they are the latest results reported (Department of Energy & Climate Change, 2019). The results are shown in Appendix A for the embodied carbon reduction. After all the stages of the lifecycle calculations were processed before and after implementing low carbon strategies, results were displayed in Section 4.

4. Results and discussion

4.1 LCA Implementation

Figure 4 shows the whole carbon life cycle analysis results of the building which includes the embodied and operational carbon. It shows that the highest CO_2 contributor is the 'operational water and energy' stage, producing 45.63% which is almost half of the total CO_2 emissions. The operational stage was a priority in reducing CO_2 emissions as it is the highest contributor. The product stage is the second most significant with a CO_2 contribution of 31.02%, thus was also a priority to reduce throughout this study. The reduction of the construction, maintenance, repairs, replacement, refurbishment, and end of life stages are still important and should be considered in building design (Ibn-Mohammed et al, 2013). However, this paper focuses mainly on the operational and product stage.

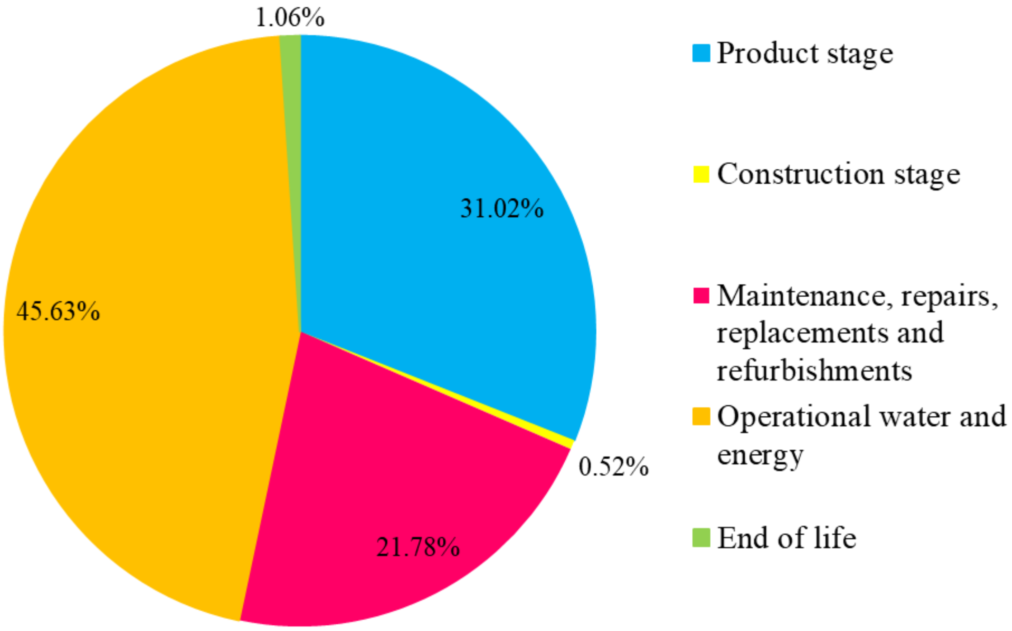

Figure 4: LCA, CO_2 Emission contribution of the building

4.2 Operational carbon

After conducting the LCA and finding the operational stage produced the most CO_2 emissions, investigation began on what contributed most within the operational stage. Figure 5**Error! Reference source not found.** shows the results for the annual operational carbon for wastewater, water supply, diesel usage and electricity, where electrical consumption contributes most to CO_2 emission. Investigation was conducted in finding new technologies that were appropriate for the building type, location and operation.

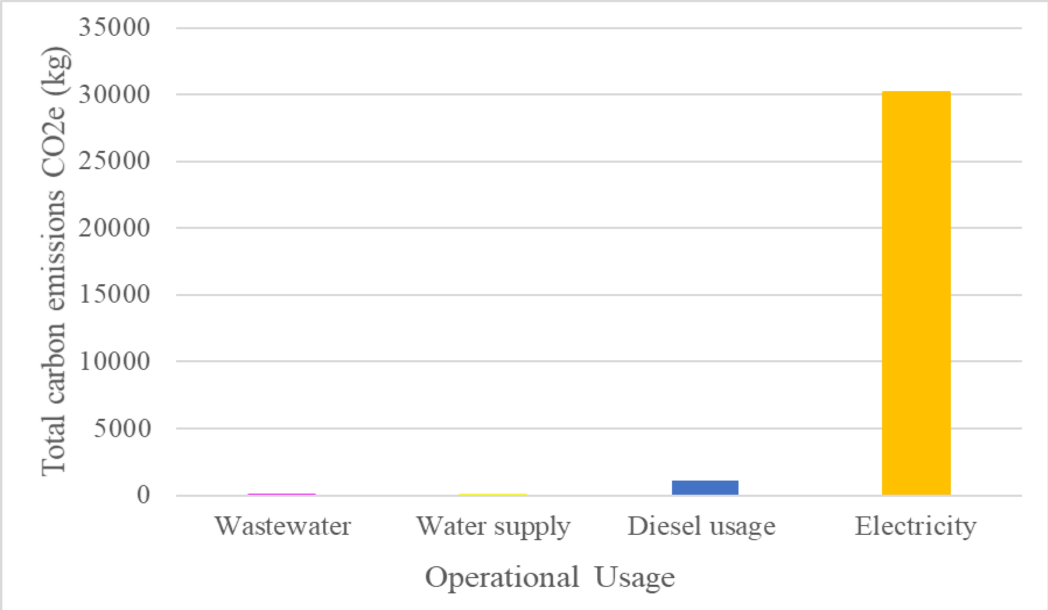

Figure 5: Annual operational carbon for wastewater, water supply, diesel usage and electricity.

PV solar installation has been increasing over the years (Tyagi et al, 2013). To aim towards a carbon neutral future, the continuation of expanding renewable energy resources such as PV solar panels is necessary. Installation of PV solar has been an effective solution world-wide for reducing CO_2 emissions at the operational stage. The investigation of renewable energy sources determined that Solar PV was the most appropriate for the case study building, as the requirements were satisfied. This included the location, orientation, cost range, roof type, space available and energy consumption (Smiths, 2019). The weather in Liverpool can often be cloudy which can reduce the total energy generation to 10-25% of the typical output (Richardson, 2018). However, Energy saving Trust (2020) solar calculator was used which generated a report for the specific location, producing a more accurate result of 25300 kWh per year for a 50 kW system as per solar calculations in section 3.1.5. For solar installation to be financially beneficial the energy generation should be over 20% of the total energy consumption (Kabir et al, 2018). The average annual electrical consumption is 112930 kWh taken from accumulation of invoice data, therefore the solar PV produces over 20% of the total electrical consumption meaning it would be financially beneficial. For a 50 kW system to be installed 350m^2 of space is needed, Figure 6 shows the roof area has the potential to fit a 50 kW of solar panels (Dimond and Webb, 2017). It also shows the most suitable places for the solar panels to be installed, assuming each panel is 3.5m by 2m. The 2 rooves with the PV panel installation of 6 by 4 and 10 by 2 will capture the most sunlight as they will not be overshadowed by other parts of the building or surrounding buildings (Prasad, 2014). Additionally, there are no trees in the case study area which could have potentially overshadowed the PV Panels. The roof in the middle section of the building shown in Figure 6 has 6 solar panels which could be installed to generate a sufficient amount of energy, approximately 25300 kWh for a 50 kW system. The roof in section A of the building is orientated south facing therefore will capture maximum sunlight (Chel and Kaushik, 2018). The other 2 rooves are flat therefore, a PV racking system could be installed to ensure the solar panels are orientated south facing collecting maximum sunlight and reducing maintenance (Banks, 2013; Chel and Kaushik, 2018).

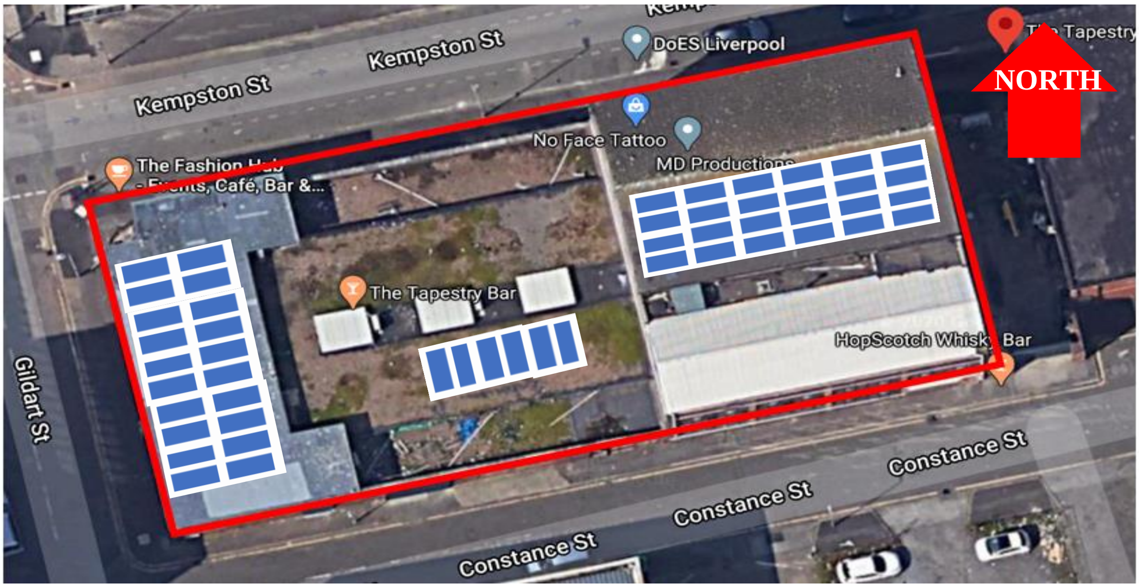

Figure 6: Potential PV Solar installation of the building.

The PV system could be a grid-connected system, transferring electricity from the grid when electricity generated from the solar panels have been used (Rashid, 2007). Installing the PV Solar system shown in Figure 6 will reduce energy consumption from the grid, limiting the use of non-renewable resources, thus minimising CO_2 Emissions (Dimond and Webb, 2017).

The electricity consumption data available for the case study building was for 2018 and 2019. Figure 7 shows the CO_2 emissions for the electrical consumption with and without solar installation for 2018 and 2019, where the solar installation reduces CO_2 emissions of electricity by approximately 20-25%. Assuming subsequent years consume approximately the same amount of electricity as 2018 and 2019, the installation of a 50 kW solar panel would be beneficial as it would reduce CO_2 emissions producing a lower carbon building.

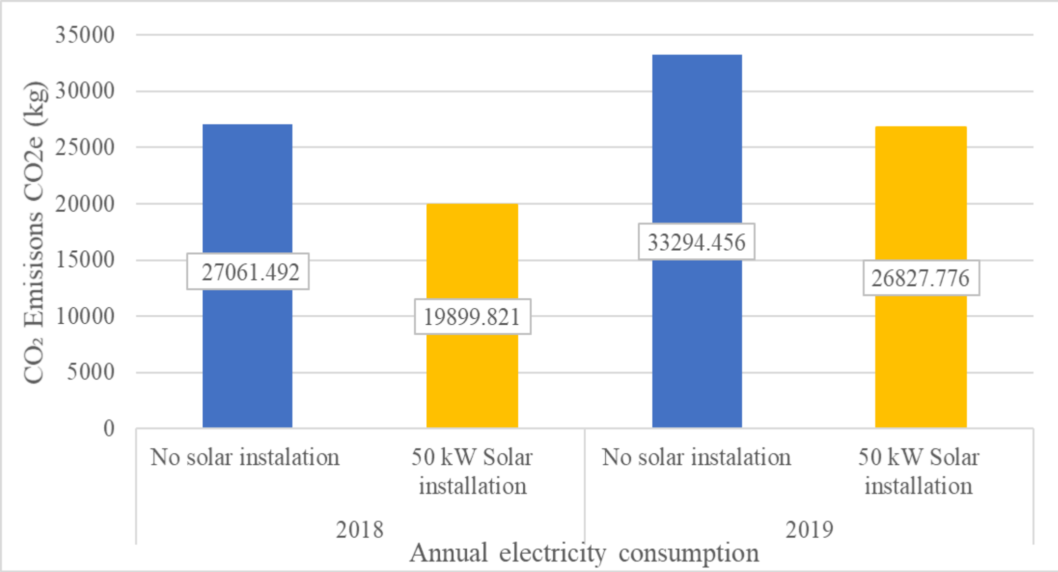

Figure 7: Electrical CO_2 emission with and without solar installation for 2018 and 2019.

4.3 Embodied Carbon

The product stage consists of every construction material at the beginning of construction and is usually the largest embodied carbon contributor for any type of building (UKGBC, 2015). Figure 9 shows the product stage for this case study building. The embodied carbon could be influenced by the century the building was constructed. During the 1950's to 1980's the effects of high carbon materials where unknown, therefore the choice of material was focused on selecting the cheapest and quickest to construct which was most often a high contributor to CO_2 emissions. (Cabeza et al, 2013). If the building was redesigned and constructed to reduce the CO_2 emissions of this stage, carbon neutral building strategies could be adopted such as using reused, recycled and low carbon construction materials. Figure 9 shows the CO_2 contribution for each construction materials within the product stage. The largest contributors to CO_2 emissions in this case study are steel, brick, mortar, glass and concrete which are focused on in this study in order to reduce the embodied carbon. Reducing the embodied carbon of materials in this case study, will bring awareness to clients to design similar projects sustainably to reduce embodied carbon across the whole industry (Ozorhon, 2013).

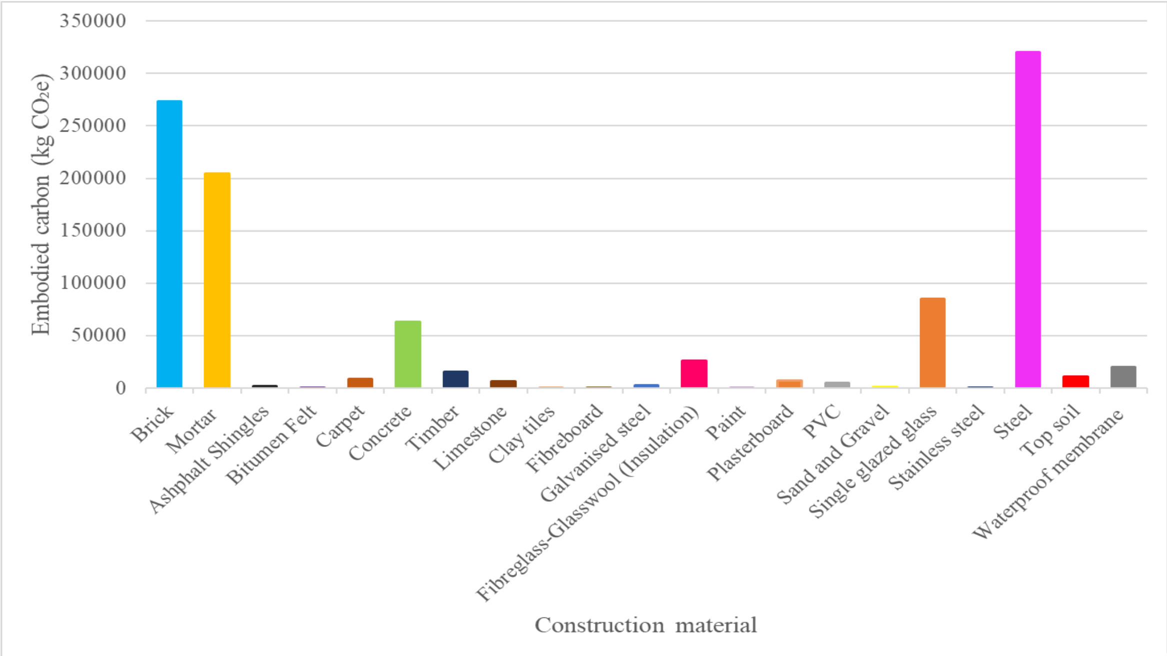

Figure 9: Product Stage: CO_2 Emissions of each construction material.

It was found that the best solution in reducing the embodied carbon of the construction materials without reducing the lifespan of the structure was to reduce the overall consumption and lower the environmental impact of materials. This could be carried out by using lightweight structural solutions (Wrap, 2020), reusing materials, using recycled materials, substitution of bio-based and raw materials, designing to low maintenance and designing for a lower impact end of life stage (Lupíšek et al., 2017). Figure 8 shows the results of embodied carbon for each construction material after the implementation of the low embodied carbon methods.

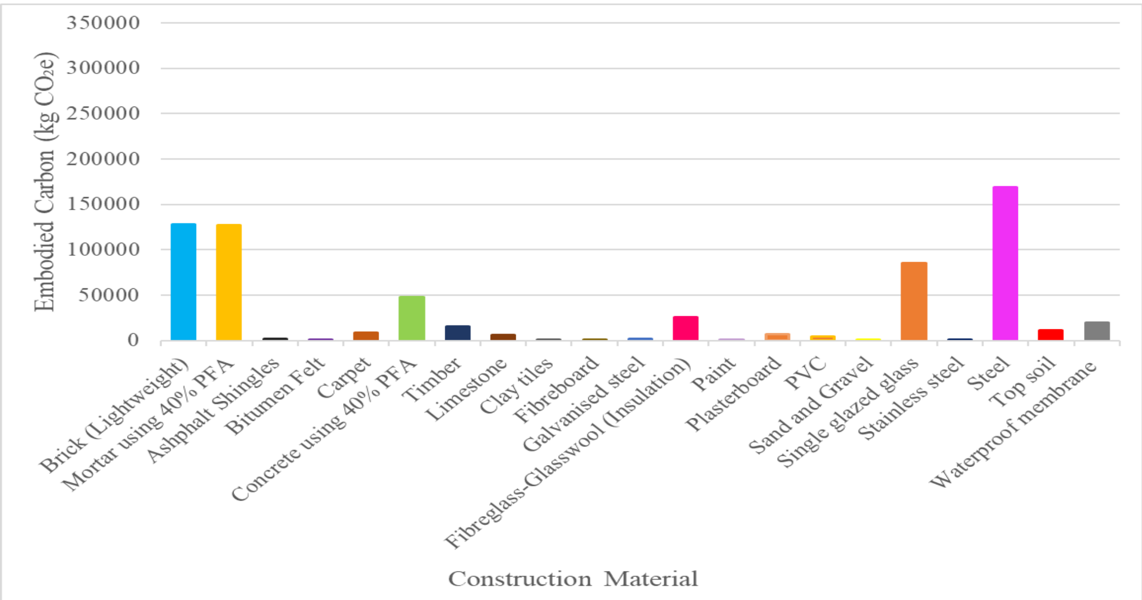

Figure 8: Product stage: CO_2 Emissions of each construction material with implementation of low embodied carbon methods.

The embodied carbon of steel was reduced by using recycled steel that has been treated for any contaminants, lowering the carbon conversion factor without affecting the structural integrity of the steel (Brakefield, 2017). The bricks originally used were clay, which have been substituted for lightweight bricks in the re-design which has reduced the embodied carbon by approximately half the original contribution as shown in Figure 8. The foundation of the case study building was assumed to be a strip concrete foundation, which was most probably constructed with Original Portland Cement (OPC) emitting a large amount of CO_2 during the production. Therefore, for the redesign the utilisation of an SCM could be implemented such as PFA reducing the amount of OPC whilst utilising the by-product waste extracted from the coal burning power stations (Taylor, 2002). Using PFA can improve the properties of the concrete such as strength, density, durability and reduce permeability therefore increasing the lifespan of the building reducing CO_2 emissions by avoiding construction of new buildings (Taylor, 2002). PFA was used for 40% (Bai, Wild and Sabir, 2002) of the concrete mix which reduces the embodied carbon of the overall concrete as shown from the comparison of concrete in Figure 9 and Figure 8. For the mortar used to lay the bricks, 40% PFA can be used as a replacement of part of the mortar which will also reduce the CO_2 emitted (Bai and Wild, 2002) as shown in the comparison of results Figure 9 and Figure 8. Figure 10 shows the percentage of the embodied carbon of each construction material within the case study building after the implementation of the low carbon strategies.

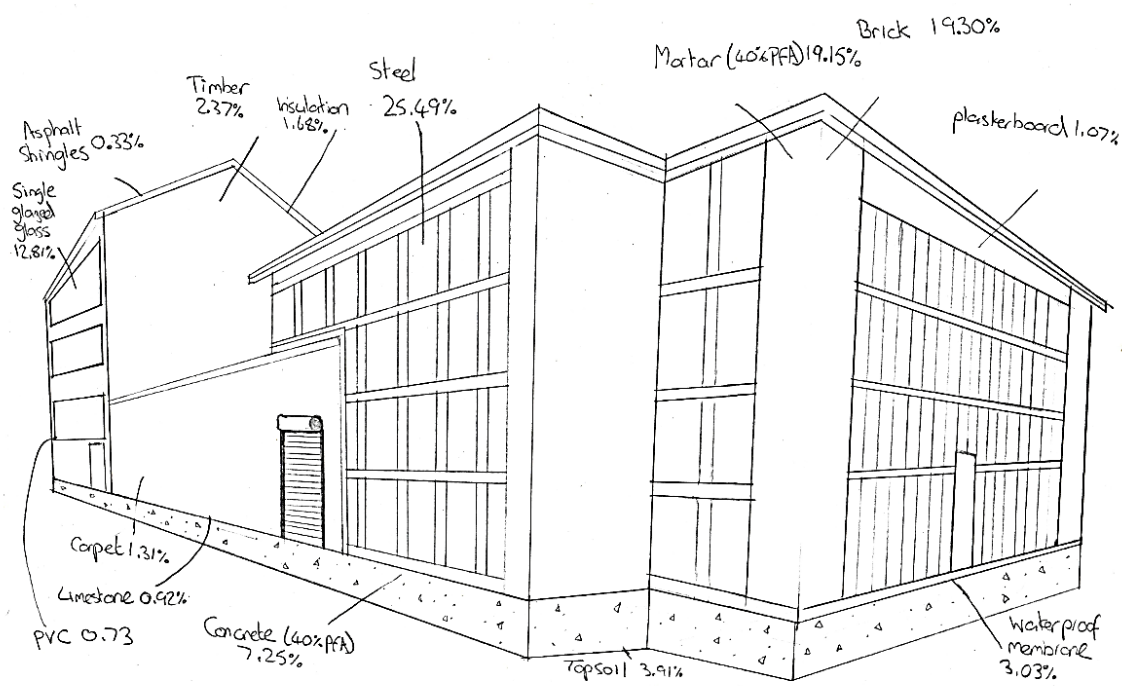

Figure 10: Embodied carbon of each construction material after low carbon strategy implementation

4.4 CO_2 Reduction

Figure 11 shows the reduction of CO_2, if low carbon strategies and clean technologies were implemented in a redesign of the case study building over its whole life cycle. It shows that by using PV Solar installation the operational carbon would be reduced by 9.95% and by using the low embodied carbon strategies stated previously the embodied carbon would reduce by 11.68%. This reduced the embodied carbon to a lower CO_2 contribution than the maintenance stage making the product stage no longer the most significant embodied carbon contributor. The whole lifecycle CO_2 emissions have reduced by approximately 22% demonstrating it is achievable. Therefore, going forward all clients should investigate implementing low carbon strategies, to reduce the CO_2 emissions of the building design and contribute towards reducing their environmental impacts for all future projects (Yadoo and Cruickshank, 2012).

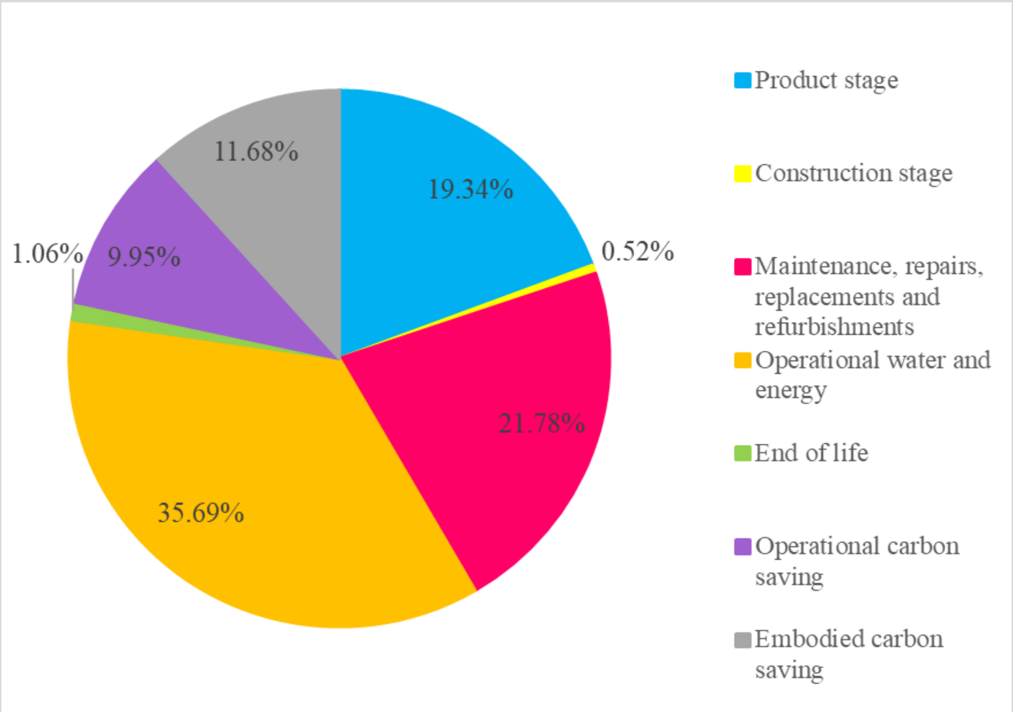

Figure 11: Embodied and operational carbon of the whole lifecycle with the implementation of low carbon strategies

The results from this study can be used as guidance and inspiration for clients and designers on how low carbon strategies can be implemented when designing any commercial building. Clients are usually the instigators of the projects sustainability agenda, therefore by increasing awareness and action on low carbon strategies at a client's level, it will be introduced to the construction industry (UKGBC, 2017). This study provides a clear methodology on where to collect required data from and how to conduct an LCA of any type of building by using BS EN 15978: 2011, government conversion factors and RICS guidance notes which are the most recommended guidance to provide accuracy (BSI, 2011; Department of Energy & Climate Change, 2019; Giesekam and Pomponi, 2018; RICS, 2014; RICS, 2017). The LCA results gave an indication to where CO_2 emissions could be lowered specific to the case study building. Other case studies may require different strategies as they will have different results for the highest CO_2 contributor. Lee, Tae, and Kim, (2018) provides a case study of apartment housing where the reinforced concrete is the highest CO_2 contributor dissimilar to this case study results. This proves that low carbon methods can differ depending on building type, location and operation (Lee, Tae, and Kim 2018). Varied strategies can be used for different case studies, however the strategies suggested in this study are most suitable for commercial buildings. Throughout this study an analysis and classification of the embodied and operational carbon of each stage has been conducted for the whole carbon life cycle of the case study building. The purpose has been met by identifying the main carbon contributors and being able to process low carbon strategies creating a low carbon building. Therefore, this study brings awareness on how an effective carbon reduction strategy can be used in new construction projects, reducing carbon emissions globally and minimising the effects of global warming (Cabeza et al, 2014; Tingley and Davison, 2011).

5. Conclusion, limitations and recommendations

5.1 Conclusion

The aim was to analyse the carbon life cycle of a building implementing low carbon strategies and clean technologies to reduce the embodied and operational carbon. By investigating current carbon assessments of buildings, it was found that the best method was the 'Cradle to grave' from 'RICS Guidance note' in conjunction with 'RICS Professional statement' which is based on BS EN 15978: 2011. Implementing clean technologies (PV solar) and low carbon strategies for the case study has reduced the CO_2 emissions of the building by 22%. If the same procedure is conducted within the construction industry during the design stage of a building, targets to reduce CO_2 by 80% by 2050 could potentially be met. However, for this to happen, action is to be taken in reducing the embodied carbon in addition to operational. It was found to reduce the embodied carbon of the building, low carbon strategies, such as use of recycled steel, light weight brick and SCM's of mortar and concrete, were implemented in the product stage as it was the second most significant CO_2 contributor.

5.2 Limitations

A limitation encountered during the LCA throughout this study was the uncertainty of predicted data as there was a high level of unavailable data, particularly for embodied carbon. The data collection procedure of the embodied carbon was difficult and time consuming as there was no bill of materials (BOM) available, therefore it involved collecting building plans and conducting a site visit measuring all building components. Whereas operational carbon had bills available to calculate the total operational usage therefore required less time. LCA will bring awareness and guidance globally to clients, by highlighting the main carbon contributors therefore encouraging building designers and the government to design sustainably, using clean technologies and low carbon solutions such as PV Solar panels, use of recycled steel, light weight brick and SCM's for mortar and concrete.

5.3 Recommendations

If an LCA was conducted again it would be more accurate and less time consuming if more data were available during the data collection procedure. Therefore, using a newer building may provide this as there is less chance of data being lost or unknown. For future work two or three clean technologies could be combined for the operational carbon stage aiming to reduce operational carbon further, leading to a zero-carbon building. Combining renewable resources will also be affective for energy generating when PV solar installation is not generating energy at night. Low carbon strategies could be investigated and implemented for each stage including, construction, maintenance and repair and end of life, in order to reduce CO_2 emission contribution further.

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Appendices

Appendix A Embodied carbon reduction of construction materials in the product stage

Embodied carbon reduction of building materials			
Building Material	**Total Mass (kg)**	**Carbon factor**	**Embodied Carbon (kg CO_2e)**
Recycled Stainless steel	147.6345	1.07	191.92485
Recycled Steel	130216.433	1.3	169281.3629
40% PFA for mortar	281898.1525	0.037	10430.23164
40% PFA used for concrete	272652.0577	0.037	10088.12614
Use of lightweight bricks	601857.5325	0.213	128195.6544
60% mortar			122988.0826
60% concrete			38034.96205