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Assessment of CO_2 Emissions Reduction in a Distribution Warehouse

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ABSTRACT

Building energy use accounts for almost 50% of the total CO_2 emissions in the UK. Most of the research has focused on reducing the operational impact of buildings, however in recent years many studies have indicated the significance of embodied energy in different building types. This paper primarily focuses on illustrating the relative importance of operational and embodied energy in a flexible use light distribution warehouse. The building is chosen for the study as it is relatively easy to model and represents many distribution centres and industrial warehouses in Europe.

A carbon footprinting study was carried out by conducting an inventory of the major installed materials with potentially significant carbon impact and material substitutions covering the building structure. Ecotect computer simulation program was used to determine the energy consumption for the 25 years design life of the building. This paper evaluates alternative design strategies for the envelope of the building and their effects on the whole life emissions by investigating both embodied and operational implications of changing the envelope

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characteristics. The results provide an insight to quantify the total amount of CO_2 emissions saved through design optimisation by modelling embodied and operational energy.

Keywords: embodied impact, CO_2 emissions, operational impact, carbon footprint, distribution warehouses

1. Introduction

Building energy use is quite an important issue as energy is one of the most critical resources used over the lifetime of a building. UK energy policy is leading the construction industry towards dramatic reductions in energy use in buildings with the zero carbon targets by year 2016 for domestic and by 2019 for non domestic buildings. Buildings require direct energy throughout their life cycle during construction, operation, and end of life treatment and indirect energy with the production of materials. Besides this, materials used in buildings are also responsible for other environmental impacts such as resource consumption, waste generation and other air emissions.

The building environmental concerns have motivated industry professionals to pursue low impact building designs and strategies. Globally the construction industry has an immense contribution to socio-economic development but is also responsible for the consumption of energy and natural resources. Ideally, a multi disciplinary approach covering issues like emissions reductions, improved use of materials, reuse and recycling is needed to achieve the goals of building sustainability [1].

Life cycle assessment (LCA) is a key approach to analyse the whole life impact of a building as it allows for the estimation of impacts distribution across all the life cycle stages by integrating upstream and downstream material and energy flows. There has been an increasing interest in the energy use of buildings in a lifetime perspective in the last few years [2] and descriptive work on residential and non domestic buildings (primarily offices), but limited research has been published thus far on the lifecycle emissions assessment of a distribution warehouse. Much of the work on the life cycle environmental impact of construction has focused on estimating greenhouse gas emissions because of the relative ease of quantification, and the establishment of international protocols (particularly Kyoto) [3]. Scheuer et al., [4] assert the importance of LCA of whole buildings to identify and evaluate how key design parameters will influence a building's environmental performance. Life cycle thinking is a conceptual aid to the decision making process for the balancing of the effects of manufacturing, use and disposal of the products within construction [5]. Operational energy of buildings is the energy required to condition (heat, cool and ventilate), light the interior spaces and to power equipment and other services, however it varies considerably with building use patterns, climate and season, and the efficiency of the building and its systems [6].

In a Canadian office building study, Cole and Kernan [6] conclude that operational energy is the largest component of the life-cycle energy consumption. The study states that for a building designed following conventional energy performance standards, the embodied energy will represent an increasing component of the life cycle energy consumption with the increasing building operational efficiency [6]. Sartori and Hestness' [7] analysis of 60 building case studies also revealed that operating energy represents by far the largest part of energy demand in a building during its life cycle. They illustrated a linear relation between operating and total life time energy which is valid through all the case studies despite climate and other contextual differences thus demonstrating the life time efficiency of low energy buildings compared to conventional ones even with a higher embodied impact [7]. Fay *et al.*, [8] emphasized the importance of analysis of embodied energy in assessing and managing the environmental impacts of construction projects. Trusty and Meil [9] highlighted the importance of the initial structure and envelope embodied energy with improving operating energy efficiency in an analysis of a two versions of an office building design in Canada and concluded that a modest increase in material use of a building design contributes to a 2.5 fold increase in heating, ventilating and air conditioning (HVAC) efficiencies improvement in its annual operating energy use. The relative importance of the production phase may also be expected to increase in the future since the energy use in the use phase can be reduced substantially by means of well proven technologies [10]. In a study comparing the two distribution warehouses in the UK, Fieldson and Siantonas [11] suggests that over the life cycle of the building, embodied and operational emissions will be about equal, which is mainly a reflection on the efficient operational performance with services and fabric improvements in combination with a short design life.

In a University building study on optimal selection of different wall cladding systems and materials (stucco, masonry, aluminium, vinyl and exterior insulation and finish systems) Radhi [12] found that vinyl has the best performance in reducing embodied CO_2 emissions, but provides a moderate reduction in terms of operational energy, however exterior insulation and finish systems positively impact the embodied energy and can optimise the operational energy performance. Hence, a careful evaluation should be carried out in selecting wall systems and cladding materials in order to effectively reduce the life cycle CO_2 emissions [12]. The initial design phase presents an opportunity to considerably reduce the building lifecycle energy and associated emissions. At early stages of design, architects can make critical decisions to formulate the most effective design strategies and solutions through principles of bioclimatic design and to establish the future lines in selecting low carbon materials as the total performance of a building is the result of the collective effects of all design parameters. [13]

LCA and carbon footprinting approaches can not only quantify the building environmental burden but can also show reduction measures [14], however some of their aspects can present significant challenges to support building decision making from a life cycle perspective. In order for such an approach to fulfill its potential in assisting design decisions, there is a need for detailed data on specific building systems and components that will enable the design team to construct and customize LCA for an evaluation of performance and material tradeoffs across life cycles [4].

Building CO_2 emissions optimization adds to this complexity mainly due to the various parameters and variables that interfere in a building life cycle. Reijnders [15] highlights that due to the scale and life span of building, generally the material and operation impacts could only be addressed as other aspects like indoor climate, siting etc. are beyond the scope of a typical LCA study. Essentially achieving an energy-optimised design requires the ability to investigate both operational and embodied energy implications of alternative design options [16]. Typically the relationship between initial impact and operational emissions varies for different building types depending on the extent to which the operational rating has been reduced by the effectiveness of the design and the anticipated design life of the building [17]. The introduction of the Energy Performance in Buildings Directive has had a major impact of the way energy performance is measured and has rightly become part of client requirements in the UK [17]. This increasing carbon focussed approach has also been supported with UK Government's zero carbon targets for commercial and domestic buildings, which has resulted in interests across the industry in minimising the operational carbon emissions from buildings. With this approach, it is likely that environmental burden across the building life cycle is going to shift for many building types.

There are a variety of approaches for designing low-energy building; however, a peculiarity is that a reduced demand for operating energy is achieved by an increased use of materials, both in the building envelope and in the technical installations [7]. The benefit of reducing operational energy, to a large extent can be counterbalanced by similar increases in the embodied energy. Embodied energy data and life cycle analysis should be included in global energy certification schemes in order to effectively lead the building sector toward sustainability [18].

2. Research objectives

1. To identify the influence of design and construction materials on operating CO_2 emissions.

2. To identify the relative importance of operational and the embodied impacts during the life span of the building.

3. To identify the effect of materials substitution on operating and embodied CO_2 emissions.

3. Scope and methodology.

This study arises from the need to compare embodied and operational solutions for reducing life cycle emissions in a distribution warehouse and aims to analyse how different designs and building materials affect the results of the carbon assessment over the building design life. The research was carried out to assess the burden of embodied materials and heating impact over the design life of 25 years for different scenarios of rooflight ratio (RLR) and improved insulation in a life cycle perspective. For the latter, Ecotect building design and environmental analysis tool [19] was used that covers the full range of simulation and analysis functions to simulate the operation and performance of a building design. Carbon emission inventory data was developed from a variety of sources including Bath University Inventory of Carbon and Energy (ICE) [20], commercially available Simapro software [21] for wall and roof cladding systems and manufacturer's data for alternative materials (Hemcrete). Bath ICE is a publicly available embodied energy and carbon dataset representing typical building materials employed in the British market and hence used to assess most of the installed materials in this study. Simapro is a professional LCA tool to collect, analyze and monitor the environmental performance of products and services. It is important to note that the issues relating to construction or embodied energy of building materials varies in different countries, depending among other things considerably on the energy mix used for manufacturing materials [22].

3.1 Building Description

The case study building is a conventional distribution centre, one storey building with two storey open plan offices and workshops. The building has a footprint of 7807 m^2 with a total floor plan of 8060 m^2. Fig. 1 shows floor plans and the 3D image of the building. Table 1 lists assumptions made to represent the base case scenario. Table 2 illustrates the material inventory for the estimation of the embodied impact of the main materials specified for the base case building. It is assumed that the distribution centre is located in Sheffield, UK, which has a generally mild and temperate climate representing the climate of eastern England.

3.2 Assumptions

The paper strictly focuses on embodied and heating impacts excluding construction, waste generated, transport, maintenance, refurbishment, and end of life emissions. Refurbishment impact is not so significant in this particular building type owing to its low maintenance and short design life. In reality the service lives of different building materials and components, and their effect on the building and its service life need to be analysed thoroughly [23]. As for most building types, replacement and repairs of building components throughout the service life could raise the annually repeating impact shifting the environmental impact distribution balance [24]. Materials like internal finishes, carpets, plasterboard, sealants etc. were excluded, as they were not found to be significant. In addition Mechanical & Electrical (M&E) services installations were also excluded due to the uncertainty in estimating the impacts from plastics and metal components. Controls, schedules, air-infiltration rates, system performance characteristics and occupant patterns of distribution centres vary depending on the products stored within. Assumptions made for this study closely represent those typical of a non-food product centre. It is important to note that the design life of a building is dependent on the durability of its materials and construction. In this study, the materials and designs selected were limited to those which could be assumed to have a design life of 25 years, without significant energy expenditures for recurrent embodied energy i.e. maintenance or renovation as this is representative of the light industrial/commercial distribution construction sector.

Ecotect computer simulation program was used to determine the heating demand of the building. The program was also used to estimate the availability of daylight under different roof configuration. The building is naturally ventilated and the operating equipment in the warehouse area is considered to be negligible limited to a few lift trucks operating in this area. By increasing the rooflight ratio (RLR) in the warehouse and workshop, one may assume that the need for artificial lighting during the daytime hours may be reduced in these areas through good housekeeping and control systems resulting in the heating loads to be the dominant component of the operational impact.

4. Material Burdens

In order to determine the embodied impact of the total structure, the quantity of construction materials used is measured from drawings and design specifications and a material life cycle inventory for the building is established (Table 2). Bath ICE dataset [20] has been primarily used to estimate the embodied impact of most of the materials with the exception of cladding systems and glazed windows and doors where Simapro [21], manufacturer' data and in house calculations based on general industry practice have been used. Though Bath ICE [20] is a limited inventory, yet it is one of the most useful generic data source for a range of building materials in the UK. In the future, it is expected that more specific, geographically relevant and publicly accessible product data could be obtained from manufacturers and suppliers in the form of environmental product declaration (EPD). This could further improve the level of comparability in calculations between different types of materials by addressing the limitations in data gaps.

As shown in table 2, the embodied energy of concrete (in situ, paving and precast) and steel (superstructure and doors) represents the largest component (46.23% and 34.21% respectively) in the building's total material burden. Embodied energy of the building envelope's materials (roof, wall and parapet claddings) represents a lower but significant proportion (16.81%) of the building's total burden excluding parapet wall.

5. Results

To investigate the effect of different design options on the energy demand of the building, a series of parametric environmental analysis was carried out using Ecotect computer simulation program [19]. The heating (operational) load of the building has been calculated by taking into account the level of occupancy, working patterns, building characteristics and the local climate. Table 3 shows the variation in heating loads for different roof light ratios under different insulation levels. Roof light area was increased from 15% (base case) to 30% and 50%. By increasing the thickness of insulation, the U-Values of roof and external walls were improved by 50% and 70% from the base case scenario. The operational (heating) and embodied impacts of the building were recalculated to accommodate for the changes in the envelope (Table 4).

Increased roof light areas resulted in higher levels of daylight availability as expected. Table 5 lists the calculated average daylight factors and the equivalent daylight levels for different roof configurations. When roof light is 30% of roof area, the calculated light level in the warehouse and the workshops exceed the level of 200 lux as prescribed in CIBSE (Chartered Institute of Building Services Engineer) Guide F [25]. Increasing RLR would result in better lighting environment and potentially reduced electric lighting load. However increased RLR may increase the heating load as illustrated in table 3. This is mainly due to the lower thermal resistance of roof lights when compared with the opaque fabric of the envelope.

5.1. ***.*** *Embodied and heating emissions over the design life*

In reality many parameters could influence the projected emissions over the design life of buildings as there are dynamic conditions in every phase of a building's life that could influence the balance of impacts. The energy and material demand results presented in this study are largely related to a particular building type within defined assumptions on building operational characteristics.

To assess life cycle distribution of emissions of the building in this study, the increase in embodied impact emissions were compared with changes in the operational (heating) emissions over the 25 years for the three different scenarios (Table 4 and Figure 2). DEFRA [26] conversion factor for gas has been used to calculate the heating emissions in this study.

The overall net operational emissions saving for the whole design life due to the added insulation for the case with 15% roof light is 6% and 11.6% for the medium and high insulation compared with low insulation respectively. However the extra insulation resulted in higher embodied impact of the order of 12.4 % and 24.5% for the medium and high insulation compared with low insulation respectively. For 30% roof light, it is 3.1% and 8.9% operational savings and 10.9% and 21.7% extra spent on embodied. For 50 % roof light, this is 2.9 % and 8.8 % operational savings and 9.1% and 18.1% extra embodied spent.

The difference between the embodied and the design life operational (heating) impact illustrates that the decisions to address building emissions should be made on its relative differences. Theoretically, it suggests that if saving operational energy (and operational impact) is prioritized then improving the levels of insulation (and added embodied energy) may be justified. However, other factors like cost, payback and performance considerations come into play while making any decisions. The result of this comparison underlines the emissions savings achieved by the adequate thermal insulation of the envelope. It could be seen that the energy embodied in the building materials (including improving insulation) can be a highly significant part of life cycle energy consumption. For this study, it was only possible to model the heating load over the design life of the building however, the importance of embodied energy would be greater with the continuing reductions in building operational energy consumption due to more stringent codes and standards. There might be financial benefits initially in making a trade-off in low insulation levels (low embodied) with high insulation (higher embodied) however any procurement decision has to be based on the whole life impacts analysis. It is important to note that the results presented here to a large extent depends on the design life of the building as the balance of embodied and operational emissions will change with a longer design life.

5.2 Alternatives materials

Generally during the initial stages of design, the project team have an opportunity to reduce the embodied impacts of the building through reducing material use, waste minimisation, specifying higher recycled content (and recyclability) and specifying alternative materials with a lower embodied carbon per weight of material.

Table 6 presents an example of material substitutions which has the potential to reduce the embodied carbon of the case study building construction. This list is limited as only the primary materials like steel, concrete and cladding systems are compared. It is anticipated that the use of different concrete types with 50% ground granulated blast furnace slag (GGBS) content would have a potential for further emissions savings [20]. Production of typical UK steel used in construction requires substantial energy however significantly less energy is required to produce products using secondary steel with higher recycled content [20]. These substitutions emphasise the need to consider both energy intensity and recycling potential of the materials to minimize the use of energy and resources over an extended length of time [27].

The other alternatives considered are replacing steel wall cladding with timber cladding and hemcrete walling system. The results provide an insight into the effect of the type of construction on the amount of CO_2 emissions, and into the possibilities for carbon sequestration. By changing the cladding the U-Values were kept the same as indicated in Table 1.

Timber cladding would reduce the embodied carbon impact of the wall cladding from 121.07 ton of CO_2 (for steel) to 99.06 ton of CO_2 resulting in a saving of 18.8% without considering the carbon lock in benefits of timber [20]. Hemcrete is essentially a blend of hemp shiv and a special lime based binder and could be used in an array of applications from roof insulation to wall construction and flooring. Hemcrete is a highly insulating material with an improved thermal inertia and vapour permeability that makes it quite a unique and sustainable construction product. Without sequestration, the hemcrete walling has a much higher impact (290.93 ton of CO_2) [28] compared to steel and timber cladding systems. This is mainly due to the presence of lime and cement in the binder.

The embodied impacts of biotic materials might drastically change if their sequestration potential is considered. The lower fossil fuel energy required for processing of biotic materials together with the locked in carbon benefits makes timber and hemcrete walling systems much better choices compared to steel cladding. Embodied emissions associated with these biotic materials for both with and without sequestration are presented in Table 6 and illustrated in Figure 3. Sequestered carbon in timber results in reduction of the embodied cladding impact to 13.48 ton of CO_2, however if the sequestration property of hemcrete is taken into account that results in an overall negative embodied impact (-218.82 ton of CO_2) of the walling system [28]. The weight of hemcrete used in walling system is quite high compared to timber cladding system and thus their sequestration benefit varies considerably. However it is important to note that the quantitative knowledge on biotic products (cradle to grave perspective) about the effects of energy and carbon balances appears to be limited. This is especially true as the global assessment on released carbon (through soil disturbance) due to management and harvesting operations is relatively unknown. It can be argued that the carbon locking benefits of timber could only be justified if the timber is sourced from a legally certified source that ensures a corresponding increase in the forestry area for long term sustainable management.

In essence, a building is a complicated system mainly due to a complex product base, functions and a limited service life of its components and changing user requirements. In order to reduce the life cycle emissions of buildings, it is of great importance in the design phase to not only focus on reducing the operational energy but also to make informed decision based on low embodied materials, maintenance cycle as well as the recycling/reuse potential.

6. Conclusion

Total performance of a building and its whole life emissions is the result of a complex and interrelated system influence by climate, design, construction, materials used, operational regimes and the decisions made at the end of life stage. Importance of making the best decisions in the early stages of a design can reduce the capital cost of integrating low environmental impact, recycled or innovative materials and can reduce overall life cycle emissions [17].

Considered selection of materials and design can save energy, and reduce CO_2 emissions across the life cycle of buildings. This study investigates the additional insulation and change in rooflight ratio as an energy efficiency measure in an industrial warehouse in life cycle terms. In addition, material substitution and alternative cladding systems have been investigated to lower the building life cycle impacts. An attempt has been made to demonstrate that an integral building analysis considering both life cycle and operational simulations would be quite useful in achieving whole life building sustainability.

An intensive integral modeling investigating the relative values of embodied and operational impacts is time consuming and rarely utilized in the building industry. Dynamic building energy simulation models can be used to consider operational emissions, however simultaneous modeling of embodied burdens to model the whole life energy performance of building elements and systems will allow the design team to make a more considered proposal. Optimization of the design to minimize both operational and embodied impacts over building life should lead the design team to identify the most effective solutions. If utilized in practice in the construction industry, this form of modeling would not be able to avoid the variable of cost. Further study may have included structural and services design options. An additional limitation is the confidence held in the ability of any building emission modeling software to effectively model the operational loads of the building with variables and parameters offered. Similarly, the accuracy of quantities and completeness of data when modeling embodied burdens can distort results.

Two key areas of significance are provided here; firstly, by the variation in result that is demonstrated when LCA boundaries are changed as in the inclusion of sequestration from biotic materials. It is important that the construction industry is able to make similar studies quickly and rigorously using a standard for calculating the impact of the materials, secondly, that embodied burden is perhaps more than is generally assumed, and that in short lifespan commercial buildings like distribution centers may become a major concern of the construction industry as legislation and targets for operational emissions to be reduced in the future. Further software development will be vital to ensure this can be achieved accurately and economically.

REFERENCES

[1] Asif M, Muneer T, Kelley R. Life cycle assessment: A case study of a dwelling home in Scotland, Building and Environment 2005; 42(33):1391-1394.

[2] Thormark C, A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential, Building and Environment 2002 ; 37(4): 429 – 435

[3] Shipworth D. A stochastic framework for embodied greenhouse gas emissions modeling of construction materials, Building Research and Information 2002; 30(1):16-24.

[4] Scheuer C, Keolian GA, Reppe P. Life cycle energy and environmental performance of a new university building: modelling challenges and design implications. Energy and Buildings 2003; 35:1049-1064.

[5] Sodagar B, Fieldson R. Towards a sustainable construction practice. Construction Information Quarterly (CIQ), The Chartered Institute of Building (CIOB) 2008; 10(3): 101-108

[6] Cole RJ, Kernan P C. Life-cycle energy use in office buildings. Building and Environment 1996; 31(4):307-317.

[7] Sartori I, Hestnes AG. Energy use in the life cycle of conventional and low-energy buildings. Energy and Buildings 2007; 39(33): 249-257.

[8] Fay R, Treloar G, Raniga UI. Life-cycle energy analysis of buildings: a case study, Building Research and Information 2000;28(1):31-41.

[9] Trusty W, Meil J. The Environmental implications of building new versus renovating an existing structure, ATHENA™ Sustainable Materials Institute, Canada, 2000.

[10] Nassen J, Holmberga J, Wadeskog A, Madeleine N. Direct and indirect energy use and carbon emissions in the production phase of buildings: An input–output analysis, Energy 2007; 32: 1593–1602.

[11] Fieldson R, Siantonas T. Comparing Methodologies for Carbon Footprinting Distribution Centres. In: The construction and building research conference of the Royal Institution of Chartered Surveyors. Dublin, 2008.

[12] Radhi H, On the optimal selection of wall cladding system to reduce direct and indirect CO2 emissions, Energy 2010; 35(3): 1412-1424.

[13] Gonza´lez MJ, Navarro JG. Assessment of the decrease of CO2 emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact. Building and Environment 2006; 41: 902–909.

[14] Li Z. A new life cycle impact assessment approach for buildings. Building and Environment; 2006 41: 1414–1422.

[15] Reijnders L, Roekel, A, Comprehensiveness and adequacy of tools for the environmental improvement of buildings. Journal of Cleaner Production 1999; 7(3):221-225.

[16] Yohanis Y G., Norton B. Life cycle operational and embodied energy for a generic single storey office building in the UK. Energy 2002; 27(1): 77-92.

[17] Fieldson R, Rai D, Sodagar B. Towards a framework for early estimation of lifecycle carbon footprinting of buildings in the UK. Construction Information Quarterly (CIQ), Chartered Institute of Building (CIOB) 2009; 11(2):66-75.

[18] Ardente F, Beccali M, Cellura M, Mistretta M**.** Building energy performance: A LCA case study of kenaf-fibres insulation board.; Energy and Buildings 2008; 40 (1):1-10.

[19] Ecotect 2008, Autodesk: < http://www.ecotect.com/ >

[20] Hammond G. & Jones C. Inventory of Carbon and Energy (ICE). Bath University, http://people.bath.ac.uk/cj219/; 2006.

[21] Simapro 7.1 LCA software. PRe´ Consultants: < http://www.pre.nl/simapro/>

[22] Dias WPS, Pooliyadda SP. Quality based energy contents and carbon coefficients for building materials: A systems approach. Energy 2004; 29: 561–580.

[23] Haapio A, Viitaniemi P. Environmental effect of structural solutions and building materials to a building. Environmental Impact Assessment Review 2008; 28(8): 587-600.

[24] Sodagar B, Rai, D, Murphy J, Altan H. The role of eco-refurbishment in sustainable construction and built environment. In: 3rd CIB International Conference on Built Environment. Delft, The Netherlands, 2009.

[25] CIBSE Guide F, Energy Efficiency in Buildings. London; 2004. http://www. cibse.org/index.cfm?go=publications.view&item=6.

[26] DEFRA Guidelines to DEFRA's GHG conversion factors for company reporting, London, 2007. See also:

http://www.defra.gov.uk/environment/business/reporting/index.htm

[27] Thormark C. The effect of material choice on the total energy need and recycling potential of a building. Building and Environment 2006; 41:1019–1026.

[28] Tradical: The Carbon Footprint of Tradical Hemcrete. See also:

http://www.lhoist.co.uk/tradical/hemp-lime.html

Table 1.
Building characteristics (Base Case Scenario)

<table>
<tr><th>Elements or building systems</th><th colspan="2">Specific characteristics</th></tr>
<tr><td rowspan="3">Area</td><td>Warehouse(Ground Floor)</td><td>6430.34m^2</td></tr>
<tr><td>Workshop(Ground Floor)</td><td>1122.71 m^2</td></tr>
<tr><td>Offices(Ground and First floor)</td><td>507.33m^2</td></tr>
<tr><td rowspan="3">Height</td><td>Warehouse</td><td>10.5m</td></tr>
<tr><td>Workshop</td><td>10.5m</td></tr>
<tr><td>Offices</td><td>2.8m</td></tr>
<tr><td>Structure</td><td colspan="2">Steel</td></tr>
<tr><td rowspan="2">Floor</td><td>Ground Floor</td><td>Soil (Avg. Props), 450mm blinded hardcore, 100mm sandstone, 200mm concrete, 35mm expanded rigid board, 100mm concrete screed
U-Value=0.15 WK/m^2</td></tr>
<tr><td>First floor (office)</td><td>10mm plaster,100mm concrete, 25mm screed, 10mm carpet
U-Value=0.16WK/m^2</td></tr>
<tr><td rowspan="2">Walls</td><td>External Walls:</td><td>Metal cladding system:100mm rook wool, Metal cladding either side
U-Value=0.30 WK/m^2 (minimum building regulations)</td></tr>
<tr><td>Internal Walls</td><td>Workshop:110 mm concrete blocks
U-Value=1.97WK/m^2
Office: 110 mm concrete bocks, 10mm Plaster
U-Value=1.89 WK/m^2</td></tr>
<tr><td rowspan="4">Windows and doors</td><td>Roof lights</td><td>Double glazed polycarbonate glass with 20mm air gap
U-Value=2.06 WK/m^2</td></tr>
<tr><td>Windows</td><td>Double glazed windows with 8mm standard glass with 30mm Air gap
U-Value=2.19 WK/m^2</td></tr>
<tr><td rowspan="2">Doors</td><td>External:
Roller shutter external doors 3mm Steel and Wooden external doors</td></tr>
<tr><td>Internal:
Hollow Core 3mm Plywood</td></tr>
<tr><td>Roof</td><td colspan="2">Metal Cladding system:130mm Rook wool, Aluminum Cladding either side
U-Value=0.25WK/m^2 (minimum building regulations), Area 8067 m^2</td></tr>
<tr><td>Lighting</td><td colspan="2">Warehouse and workshop:200lux
Offices:500lux</td></tr>
<tr><td>Services (Heating only)</td><td colspan="2">Temperature set points:
warehouse and workshop: 16°C
Offices:21°C</td></tr>
</table>

Table 2

Building materials inventory

Primary Materials	**Usage**	**Amount (t)**	**Impacts tCO_2**	**% of total impact**
Concrete (In situ) Concrete (Paving) Concrete (Precast)	Substructure External hard standing Floors	4600 2300 136	777.4 292.1 29.37	32.7 12.29 1.24
Steel	Superstructure Doors	420 39.31	743.4 69.58	31.28 2.93
Aluminium/Glass	Windows and doors	78 m2	20.70	0.87
Block work wall First floor Plant Room Ground floor	 Plastered wall Unplastered blockwork Plastered wall Unplastered blockwork	 37.98 15.96 134.06 148.96	 2.31 0.97 8.18 9.08	0.86
Polycarbonate	Roof lights	3.99	23.94	1.01
Envelope	Roof Cladding Wall Cladding Parapet Wall Cladding	$6856.95m^2$ $3683.95\ m^2$ $801.6\ m^2$	250.99 121.97 26.52	10.56 5.13 1.12
Total			2376.51	

Table 3.

Heating loads ($KWh/m^2/year$) for different envelop insulation levels and roof light ratios

Roof Light Ratio (RLR)	**U-Values (W/Km^2)** Wall: 0.30 Roof: 0.25 Low Insulation (Base Case)	**U-Values (W/Km^2)** Wall: 0.15 Roof: 0.12 Medium Insulation (50% improvement)	**U-Values (W/Km^2)** Walls: 0.09 Roof: 0.08 High Insulation (70% improvement)
15%	111.22	104.55	98.28
30%	113.27	109.78	103.13
50%	118.73	115.27	108.29

Table 4.

Distribution of embodied and operational (heating) impacts for different scenarios over the life span (25 years) of the building

	Low Insulation (tCO_2) (Base Case)		**Medium Insulation (tCO_2)** (50% improvement)		**High Insulation (tCO_2)** (70% improvement)	
	Operational Impact	**Embodied Impact**	**Operational Impact**[a]	**Embodied Impact**[b]	**Operational Impact** [a]	**Embodied Impact** [b]
15% Roof Light Ratio (RLR)	4616.63	2376	4339.76 (6%reduction)	2670 (12.4%increase)	4079.50 (11.6% reduction)	2958 (24.5%)
30% Roof Light Ratio (RLR)	4700.99	2360	4556.85 (3.1% reduction)	2618 (10.9% increase)	4280.82 (8.9% reduction)	2873 (21.7% increase)
50% Roof Light Ratio (RLR)	4926.67	2338	4784.74 (2.9% reduction)	2551 (9.1% increase)	4495.00 (8.8% reduction)	2760 (18.1% increase)

[a] Figures in bracket represent the reductions in operational emissions from the base case

[b] Figures in bracket represent the increase in embodied emissions from the base case.

Table 5.

Average Daylight Factors (DF) and daylight levels (lux)

Roof Light Ratio (RLR)	Workshops		Warehouse	
	DF (%)	**lux**	**DF (%)**	**lux**
15%	7.16	252	3.91	137
30%	10.24	358	5.88	206
50%	25.29	885	29.91	1050

Table 6.

Embodied emission savings with alternative materials.

Material	**Base Case Specification**	**Alternative Specification**	**Embodied Base Case Impact** (tCO_2)	**Alternative Specification Impact** (tCO_2)	**Percentage Savings**
Concrete					
In Situ Concrete	0% cement replacement	50% cement replacement (GGBS)	777.4	441.6	43.2%
Paving Concrete			292.1	190.9	34.7%
Precast Concrete			29.37	15.9	45.9%
Steel frame	UK typical steel (42.7% recycled)	Secondary steel	743.4	180.6	75.7%
Steel Door			69.58	16.9	75.7%
Wall Cladding	Steel	Timber (without sequestration)	121.97	99.06	18.8%
		Timber (with sequestration)	121.97	13.48	88.9%
		Hemcrete (without sequestration)	121.97	290.93	138.5%(increase)
		Hemcrete (with sequestration)	121.97	-218.82	279.4%

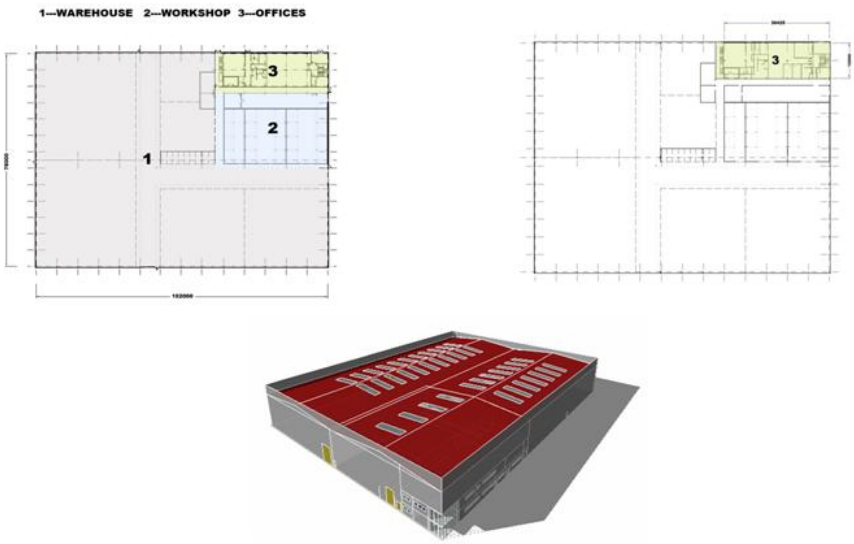

Fig. 1. Ground Floor (left) and First Floor (right) plans and 3D image.

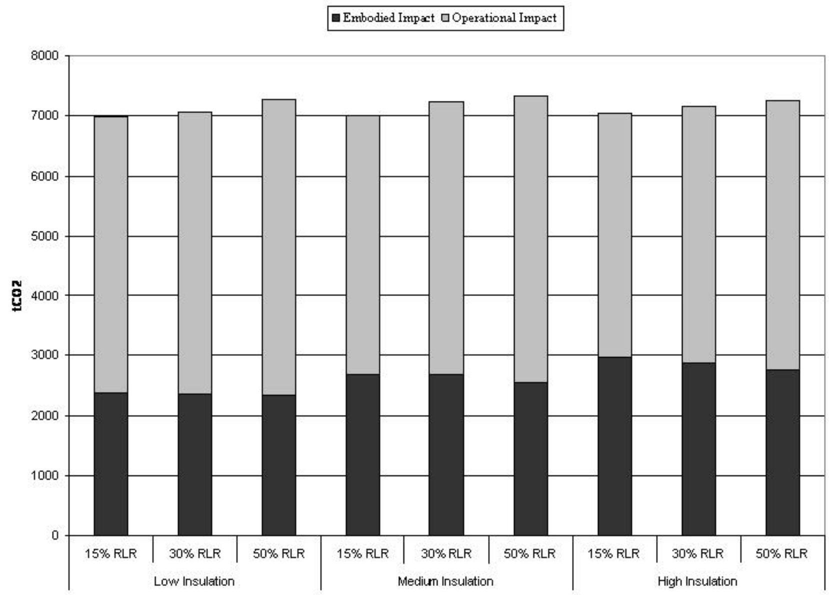

Fig. 2. Distribution of embodied and operational emissions for the 25 years design life

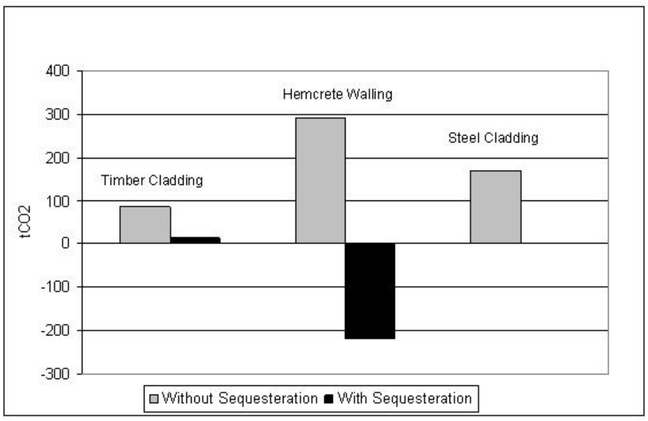

Fig. 3. Embodied impacts of different cladding and walling systems