Elsevier Editorial System(tm) for Journal of Cleaner Production
Manuscript Draft

Manuscript Number: JCLEPRO-D-16-01428R4

Title: GHG Performance of Construction Refurbishment Projects: Lessons from UK Higher Education Student Accommodation Case Studies

Article Type: Original article

Keywords: GHG; refurbishment; construction; student accommodation

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Abstract: The student accommodation sector in now the best-performing asset in the UK and US property markets and this is projected to further accelerate, with building refurbishment of existing student accommodations being the preferred method to satisfy growing demand. However, there are no published research studies on refurbishment projects within the student accommodation sector. Refurbishment is an emergent trend to upgrade existing stock to ensure that buildings meet rising energy efficiency demands. Moreover, it is widely affirmed that greenhouse gases contribute to climate change and notably the built environment is a significant contributor, both through its construction and during its operation and use. This paper demonstrates through a comparative case study approach, how greenhouse gases levels can be effectively measured during refurbishment works. There are multiple metrics used for quantification/ assessment of greenhouse gases performance and this paper aims to make well-argued recommendations for their best use. Four student accommodation refurbishment projects are presented to compare and contrast differing emission datasets. The results dictate that project cost and duration cannot alone be used to gauge greenhouse gases emissions; more too, in the instance of student accommodation refurbishment, gross internal floor area and the number of rooms offers a more predictable indicator. It is recommended that refurbishment developers reflect on these recommendations when reporting the primary energy and GHG performance of their refurbishment works. Best practice from this research may be adopted into domestic buildings refurbishment projects.

Greenhouse Gases (GHG) Performance of Refurbishment Projects – Lessons from UK Higher Education Student Accommodation Case Studies

1. Introduction

There is growing scientific and political consensus that climate change represents the greatest environmental threat and challenge of modern times. The key driver of climate change is the robust link between the generation of greenhouse gases (GHG) and rising global temperatures (CCC, 2016). GHG emissions from UK buildings have been reported to contribute up to 37% of the UK's total GHG emissions (TSB, 2014). Notwithstanding GHG emissions generated during the design, material manufacture, distribution and on-site construction of both the UK buildings - reflecting up to 18% of a building's whole lifecycle carbon footprint (BIS, 2010). A clear link has been identified between the whole lifecycle environmental and GHG performance of a building and the focus and investment during the construction phase. For example lower levels of initial capital investment spent on insulation or plant may result in increased operation or maintenance expenditure and reduced environmental performance over the buildings whole lifecycle (Bribián *et al.*, 2009). Therefore if the UK is to meet its climate change targets whilst maintaining a vibrant construction sector, the industry needs to also reduce the impact of buildings through improved construction practices.

The UK Department for Environment, Food and Rural Affairs (DEFRA) confirms that improvements driven by construction industry players will be crucial for reducing emissions (DEFRA, 2013). Considering that 87% of existing buildings in the UK will likely be standing in 2050 (UK GBC, 2016), a large focus of construction projects in the future will be retrofitting and/ or refurbishment of existing buildings. The Chartered Institute of Building reported that the UK has about 30 million domestic and non-domestic buildings, 28 million of which will be required to be retrofitted or refurbished for the UK Government to meet it's carbon targets (CIOB, 2011).

The importance of low carbon construction practices, refurbishment and maintenance works to reduce energy demands and GHG emissions is well reported (Ferreira *et al.*, 2013; Gaspar and Santos, 2015; Killip, 2013; Pombo *et al.*, 2016). Simple retrofitting projects such as adding thermal insulation to external walls, can provide higher energy efficiency and lower energy costs (Bojic *et al.*, 2012), whilst major refurbishment can provide an opportunity to significantly improve poor energy performing buildings by replacing old items with new energy efficient materials and technologies (Carroon, 2010). Research such as that by Tang *et al.* (2013) have also identified strong relationships between a project's GHG performance and the management focus and applied practices – different construction management strategies having significant influence on the overall GHG emissions generated over a project's lifecycle.

The UK has multiple guidelines, regulatory frameworks and incentive schemes that are designed to improve the standard of refurbishment and retrofit projects. Within the housing sector, initiatives such as Decent Homes, Warm Front and Green Deal have each provided guidance and funding avenues for construction work on retrofitting (DCLG, 2006). In the private sector, greater autonomy is given to allow stakeholders to determine the best options of individual projects. The BREEAM Refurbishment (BRE, 2015), Considerate Constructors Scheme (CCS, 2015) and SKA rating (RICS, 2013) schemes are examples of benchmarking methods that aim to improve environmental performance of construction and the resulting buildings. However in the UK the success of regulation and guidance for refurbishment has been widely criticised (CIOB, 2011; Killip, 2013; Rawlinson and Wilkes, 2014) and the uncertainties, risks and bespoke nature of refurbishment projects makes them inherently unsuitable for generic assessment schemes (Juan, 2009).

The student accommodation sector has emerged as a top performing asset in both UK and US property markets (Hammond, 2013) - £1.85 billion invested in the UK in 2013 alone (CBRE, 2013) as the demand for student accommodation has continued to accelerate. Deloitte (2013) reported in 2013 that 1.72 million fulltime students are hunting for 457,000 purpose-built student accommodation spaces in the UK. In response to demand non-domestic buildings are being increasingly refurbished and converted into student accommodation, alongside an increasing number of projects upgrading existing accommodation. The UK student accommodation industry is considered a 'niche market', in which supply is adapted to meet the needs from students (considered as a specialised tenant group) (Rugg *et al.*, 2013), as demonstrated in Manchester (Carver and Martin, 1987) and Edinburgh (Nicholson and Wasoff, 1989). With high anticipated growth within the niche student accommodation market (Savills, 2014), the construction sector is set to play a central role in determining the carbon footprint of these developments, where experience and good practices lessons will be key to increasing performance across the sector. As there is limited research into the carbon emissions of student accommodation refurbishment projects; this project aims to rectify this by:

1. Evaluating a series of representative comparative case study student accommodation refurbishment projects.
2. Analysing emission profiles of the comparative case study projects' refurbishment works, focusing on how the characteristics of the projects may provide an indication of the GHG performance.
3. Developing conclusions for how GHG emissions may be best measured in student accommodation refurbishment projects.

In summary, this paper aims to provide an analysis of the key performance indicators and GHG emission benchmarks for higher education student accommodation refurbishment projects, specifically for projects using Joints Contracts Tribunal Design and Build Contract (JCT), whereby the contractors are responsible for the building design in addition to the construction works (JCT, 2014).

2. Quantifying GHG Emissions

A myriad of methodologies have been developed aimed at quantifying the levels of GHG emissions from construction activities. These vary in terms of the method of calculation, and the choice of metric applied to estimate emissions (eg. transport distances, construction costs, material types, etc.). Methods include (1) quantitative approaches (Suzuki and Oka, 1998) for analyses that define set emission contributors; (2) analysis of interactions between direct and indirect energy uses and emission factors for each subsection of work within a project (Acquaye and Duffy, 2010); (3) carbon emissions analysis by particle swarm optimisation (PSO) to evaluate optimal construction pathways with reduced environmental impact (Liu *et al.*, 2013). The metric of $kgCO_2^{eqv.}$ is currently being drafted as the 'common carbon metric' by the United Nations Environment Programmes' Sustainable Building and Climate Initiative (UNEP, 2016) to be tested against organisation's benchmark key performance indicators (KPIs) of distance ($kgCO_2^{eqv.}$ per km), duration ($kgCO_2^{eqv.}$ per week), gross internal floor area ($kgCO_2^{eqv.}$ per m^2), rooms ($kgCO_2^{eqv.}$ per room) and project value ($kgCO_2^{eqv.}$ per £100,000).

Constructing Excellence (2014) has its own methodology to be applied when evaluating the GHG performance of UK construction activities using (KPIs) - a systematic measure of performance that allows the benchmarking comparison against both internal and competitive targets (Constructing Excellence, 2016). To undertake KPI analysis, data must be obtained during and/ or upon completion of the project that reflects: (i) the amount of energy used on site (electricity (kWh), diesel fuel (litres), petrol fuel (litres)); and, (ii) the project value. Second, GHG emissions per energy usage will be determined using standard fuel emission factors as determined by the National Atmospheric Emission Inventory database (NAEI, 2016). Third, results are normalised with respect to the value, duration and context of each project so that they can be directly benchmarked against each other. The Constructing Excellence (2014) methodology is becoming the industry standard in the UK and as such this research analyses the respective data for the comparative case study projects. However, the Constructing Excellence methodology is largely based on overall project cost, and given its recent adage of 'cheapest is not always best', cost alone cannot be applied to decipher specific emission savings or issues. Therefore, this research builds upon the case study's Constructing Excellence data by also benchmarking emissions based on overall GHG Scopes, and the organisation's internal KPIs.

Evaluating the different scopes of GHG emission data was found to be a useful tool for organisations to potentially monitor emissions from different contributors during the whole lifecycle of the project. The organisation has complete control of Scope 1 emissions (direct emission). The Scope 1 GHG data allow organisations to measure manage and prioritise internal resources for the project, such as internal staffing numbers, business travel and accommodation provision. Scope 2 data (indirect emissions) is the direct representation of the generation of purchased energy used on-site, with lower Scope 2 data implying to less consumption and lower costs. Scope 3 emissions are those that the organisation will have the least control over as they reflect the emissions from outsourced activities not owned or controlled by the organisation. Analysing Scope 3 data can provide the organisation with the opportunity to improve supply chains, exclusively appoint only certified sub-contractors who share the same environmental concerns, enhance wider corporate responsibility and potentially reduce costs through requiring minimum environmental performance levels by all sub-contractors and suppliers.

3. Methodology – Introducing the Student Accommodation Case Studies

This research engaged with a privately owned construction management company based in the North-West of England with projects across the country, specifically in student accommodation, hotels, social housing and schools. The company has a strong environmental focus that is integrated throughout their management systems, including a carbon management action plan developed in line with the principles of ISO26000 (ISO, 2010). A key element of company's core business is the management of projects including all contractors, sub-contractors and suppliers. Therefore this company is well placed to provide benchmarking data of overall environmental impact of refurbishment projects and to illustrate an evaluation of GHG emissions generated both on and off-site during the refurbishment process. Four comparative cases were offered by the organisation as projects representing typical UK student accommodation refurbishment works. Two of the case studies were long-term projects (more than 4 months duration) and the other two case studies were short-term projects. The clients for each of the case studies varied with each having differing requirements and project needs. A summary of the characteristics of the four student accommodation case studies is presented in Table 1. The projects were all developed under the JCT Design and Build Contract.

[insert Table 1 here]

Comparative GHG performance datasets for each of the case study projects were collected on-site through: organisational daily signing-in sheets (internal staff); sub-contractor daily signing-in sheet; delivery information; operational information for all machinery and equipment consuming fuels (for instance, petrol, diesel, gas, etc.); as well as data reflecting all other GHG emitting activities and processes related to the projects. Material delivery data is assumed to be a full load with previous and future destination distance recorded. Only generic vehicle data is recorded (eg. car-petrol, van-diesel, etc.). All accounted GHG's emissions are calculated in carbon dioxide equivalent ($CO_2^{eqv.}$) values reflecting the values and methodology of the National Atmospheric Emission Inventory database (NAEI, 2016). Each projects' emission data was collected on site and analysed on a periodic monthly basis where the data is reported by the organisation's Environmental Manager. An example of a project's emission data sheet is demonstrated in Figure 2. The GHG emission data for each of the comparative case study projects was guided by the Greenhouse Gas Protocol for Project Accounting (WBCSD & WRI, 2003); the 3 tier Scope GHG classification framework; and organisational KPIs reflecting 5 themes (distance, duration, gross internal floor area, room numbers and value) as summarised in Table 2 - these 5 KPIs provide the basis of this research analysis. The KPIs are reflective of those typically used by the UK construction sector (BIS, 2015) for organisations to measure and benchmark their construction performance.

[insert Table 2 here]

The comparative case study project datasets are presented in Table 3. These reflect performance data for each scope category of GHG emissions and for each of the organisational KPIs. Emission data is omitted for the first four weeks and final two weeks of the long duration projects (CS-1 and CS-2), and data from the first week and final weeks of the shorter duration projects (CS-3 and CS-4). This is to provide a more indicative and accurate picture of the emissions profile of the core activities associated with each project, and to allow better comparisons between the different datasets.

[insert Table 3 here]

4. Results analysis

Comparative analysis of the GHG emission scope datasets in Table 3 demonstrates the differences in emissions profiles across each of the case study projects. The breakdown of emissions within each GHG classification scope can be associated with the characteristics of each individual case study. For example although CS-3 and CS-4 are in the same city, there is great contrast in their emission profiles - the Scope 3 emissions for CS-3 are shown to be over 30% higher than those for CS-4, where a greater proportion of overall emissions are Scope 1. This reflects the higher proportion of sub-contracted work associated with CS-4 and therefore the out-sourcing of emissions. The proportional breakdown of Scope 1 and 2 emissions generated by projects CS-1, CS-2 and CS-3 are similar reflecting their comparative use of sub-contractors.

The indirect Scope 2 emissions reflect the use of purchased energy across all the projects - this data shows much greater consistency. Projects CS-3 and CS-4 demonstrate the least Scope 2 emissions, reflecting the short periods of onsite works associated with these projects and therefore less energy purchased. Differences in the proportion of Scope 2 emissions associated with CS-1 and CS-2 (both have long on-site refurbishment durations) may be attributed to the implementation of a new carbon action plan before CS-2, which increased the organisational focus on on-site energy saving practices/ technologies.

The refurbishment phase data (RP) presented in Table 3 demonstrates congruence between the datasets. These datasets provide more accurate representations of the GHG impact of the actual refurbishment works, as estimated emissions associated with the projects' start-up and move-out works are excluded.

4.1 Comparative Case Study Projects' KPI Data

The case study projects could be categorised in two distinct groups based on their project characteristics, as shown in Table 2. CS-1 and CS-2 reflect projects with comparatively longer work duration, larger project value, larger internal floor areas and higher number of rooms; compared to projects CS-3 and CS-4 that are both located further away from the organisational head office, are smaller in size, with lesser value and with less time onsite. The KPI emissions data documented in Table 3 can be analysed to evaluate relationships between the projects' characteristics and their emissions profiles.

Table 3 shows that the distance KPI data demonstrates that more emissions are generated by projects CS-1 and CS-2 despite CS-3 and CS-4 being greater distances from the organisational head office. This indicates that distance from the organisational head office may not be the strongest KPI to provide an indication of a project's GHG emissions. Analysis of both the duration KPI data and the value KPI data highlights the trend that greater emissions are generated by projects CS-3 and CS-4, despite projects CS-1 and CS-2 reflecting much longer duration of onsite refurbishment works and greater project value. Greater understanding of the influence of these KPIs may be gained through accepting that short-term projects require the same number/ amount of start-up and move-out equipment, transport and support as any other project. In addition, short-term projects often require a higher number of operatives on-site to complete the project within the allocated timescale. This is confirmed through comparing the whole life cycle (WLC) emission data with the refurbishment phase (RP) data for these KPIs in Table 3. When estimated emissions associated with the set-up of a project are not considered (comparing RP data instead of WLC), the disparity between the datasets is much reduced and therefore the duration and value KPI provide a fairer reflection of the projects emissions. Although the shorter duration projects are still shown to document proportionally greater emissions compared to the longer duration projects. Therefore, working to tighter schedules and involving larger teams to achieve this may result in proportionally higher project GHG emissions.

Evaluation of the emission data for the GIFA and rooms KPIs highlight further trends. The room KPI data clearly demonstrates that projects CS-1 and CS-2 each with a large number of rooms reflect proportionally higher GHG emissions than CS-3 and CS-4 each with lower numbers of rooms under refurbishment. The room KPI could therefore be construed as a close indicator of potential scope category of GHG emissions, and in this research where the analysed projects are student accommodation (typically highly cellular with a large number of rooms), this KPI provides a good indication of each projects' scale. In reality, rooms can be highly variable in size and therefore a GIFA KPI may represent a more accurate reflection of the characteristics of a project, and thus an indication of GHG emissions. The GIFA emission data in Table 3 highlights that there are only marginal differences in GHG emissions generated across the case study projects. This difference is reduced further when comparing just the case study RP data.

It has to be assumed that an organisation working on multiple projects and implementing the same work practices on each, should generate comparatively similar emissions from project-to-project / site-to-site, driven largely by the extent of work undertaken, not changes in work approach. Other potential attributes to why longer duration projects perform better include economies of scale (e.g. less transportation involved, improved learning curve for staff, and minimised fixed environmental costs for instance). The least variation in emissions profile across the case study projects is demonstrated by the GIFA KPI datasets. GIFA may therefore represent the most accurate indicator of a projects' GHG performance.

4.2 Performance of KPIs to Reflect Project GHG Performance

A further analysis stage that may be undertaken using the case study projects' emission data is to evaluate the ability of each KPI to reflect the different projects' GHG performance. Independently each of the KPIs provides an indication of the projects' GHG performance, and allows the projects to be benchmarked against each other.

Figure 2 has been designed to allow comparison of the GHG performance of each case study project according to the different KPIs. The values presented for each KPI have been normalised so that the different datasets may be presented on the same scale. The stacked column charts provide a breakdown of the whole lifecycle (WLC) and refurbishment phase (RP) GHG emissions for each project and allow the performance of each to be benchmarked against that of the other projects. The value labels across Figure 1 highlight the rank of each project in terms of GHG performance for each KPI. Projects ranked first for each KPI are those with the greatest GHG impact, and likewise projects ranked fourth reflect the project with the least GHG impact according to the KPI.

[insert Figure 1 here]

As Table 4 highlights there is much variability in the comparable GHG performance of the different case study projects according to the different KPIs. CS-1 is identified as the project with the greatest whole life cycle GHG impact according to three of the KPIs (distance, GIFA and rooms), the other KPIs highlight CS-4 as the project with the greatest impact. There are fewer consensuses reflected by the refurbishment phase data, the GIFA KPI identifying CS-2 as the project with the greatest GHG impact. Contrasting trends are also shown across the KPIs when identifying which project achieves the best GHG performance - projects CS-2, CS-3 and CS-4 all being identified as the best performing projects according to different KPIs.

[insert Table 4 here]

In summary, the analysis highlights that there is significant variability in the ability of the different KPIs to reflect the GHG performance of projects. This confirms the importance of consistently using the same KPI when comparing the performance of multiple projects, and also that some KPIs may reflect greater representation of GHG performance than others based on the specific characteristics of the project. Statistical correlation analysis was undertaken to directly evaluate the relationship between the KPI characteristics of the research's projects and the resulting WLC and RP emissions generated. As Table 5 demonstrates high correlation is shown between all of the KPIs and GHG performance, highlighting that each KPI may be used in their own right to provide an accurate indication of GHG performance. Negative correlation is shown between the distance KPI and GHG performance, reflecting reduced proportional GHG performance with shorter distance for the comparative case studies analysed. In contrast the other KPIs for the comparative case studies analysed show positive correlation with GHG performance – as the proportional GHG performance per KPI improves as project duration, GIFA, room number or project value increase.

The correlation analysis in Table 5 highlights that the duration, GIFA and project value KPIs were identified as the most accurate indicators of a project's overall WLC emissions, and the duration and GIFA KPIs are the best indicators of a projects refurbishment phase emissions. The value KPI ranked is shown to be joint-first in WLC emissions (0.990) and third in RP emissions (0.943). This came as a surprise considering that initial start-up and site removal costs are compulsory in all projects regardless of its size - demonstrating the value KPI as a potentially misleading emissions indicator. The duration and GIFA KPIs were the better indicator for refurbishment emissions, compared to value.

[insert Table 5 here]

5. Discussion

This research analysed refurbishment GHG emission data from an environmentally conscious organisation undertaking refurbishment works on four student accommodation projects. The aim of the research was to identify potential lessons that could be drawn from these projects for the wider construction industry, and to evaluate the methods in which the GHG performance of refurbishment projects are analysed. Although the research's case study sample size is relatively small, the projects analysed reflect a broad range of characteristics and are a typical sample of UK student accommodation refurbishment projects. There are currently no readily available emissions benchmarks for the UK refurbishment construction sector, let alone for the student accommodation projects – this research therefore provides a valuable contribution to this research theme. As the UK construction sector is currently undertaking widespread refurbishment of building stock such as social housing projects, there is clear scope for the analysis within this research to be adapted and extended to further categories of refurbishment and for different organisation and construction practices.

This research adds to the many existing studies that have focuses on the various elements influencing the energy and emission impacts of construction processes. This is a research areas with broad ranging themes, for example: Tang et al. (2013) who focused on analysing the influence of construction management strategies on GHG performance of construction; research by Gaspar and Santos (2015) analysing varying levels of embodied energy within the materials of different old, new-build and refurbishment buildings; and emissions LCA analysis research focusing on different categories of construction project such as the work by Pombo et al. (2016) on residential projects. The key fundamental thread running through each of these research themes are the ways in which GHG performance is measured and reported. As being able to compare and scrutinise the performances of different construction organisations, strategies and techniques is essential in order to improve the impact of the industry. The research presented in this paper highlighting the varying accuracy of emission performance reporting through the use of different KPIs adds weight behind the argument that industry-wide standard KPIs should be used.

As it stands most organisations only undertake internal comparisons and benchmarks of the GHG performance of their refurbishment works, in order to highlight potential improvements. A potential major issue faced by organisations can be the non-availability of common KPIs for comparison of GHG emissions. As this research demonstrates the ability of different KPIs to reflect potential GHG performance can be highly variable. Therefore, if organisations are determined to benchmark the GHG performance of their work with that of other competitors or partners, default industry/sectorial KPIs need to be applied.

Data collection for GHG emission Scope 1, 2 and 3 for construction/refurbishment projects is highly commended; however, this can be further improved and refined. One of the weaknesses of the project emission data collection was identified as being too vague in transport emissions for both organisational and sub-contracting staff. Data is collected based on the generic vehicle type (eg. car-petrol, van-petrol, LGV-diesel, etc.). More accurate data could be collected (daily signing-in sheets) from their vehicle types, daily travel distances and vehicle share. Emissions from specific vehicles are widely available. Another potential area for improvement is the emission calculation for materials transportation (delivery) - stating the percentage of space/load used for each materials delivery can refine data. Current practice assumes 100% loading for the vehicle, which is incorrect for most deliveries. All case studies analysed in this research were situated in central urban areas with readily available electric and/or gas connections, although benchmarks for GHG Scope 2 emissions could be considerably higher for rural projects with the use of high emission carbon-based generators (eg. diesel, petrol, gas) on-site.

Currently the duration and value of project are widely used as the indicators of potential emissions. This research finds that use of these KPIs may be highly misleading when used to compare the GHG performance of different projects. High value and long duration projects will result in larger overall emissions compared to lower value short-term projects. However, the nature of short-term projects having denser workloads and involving proportionally higher numbers of workers for the duration of the time on-site can result in the comparatively greater GHG impact across each emissions scope category. This is particularly acute in student accommodation projects, as refurbishment works usually take place during short student holiday periods when accommodation is typically vacant, or planned in a phased-approach whereby students have to relocate during the term whilst refurbishment work is on-going.

In theory the GIFA, value and the number of rooms of a project should provide the best emission benchmark as they reflect the scale of work to be undertaken; but this research demonstrated otherwise. Due to the nature of student accommodation having a large number of rooms (eg. variable student rooms, kitchens, foyers and landing area combinations), using the number of rooms KPI can be a misleading indicator of GHG performance. The GIFA KPI provided a more accurate reflection of potential GHG emissions for student refurbishment projects.

Findings of this research were presented back to the researched organisation, where the Director commented that the findings were surprising given that conventional wisdom would indicate project value as the key indicator for project emissions. These research findings now form the internal KPIs and benchmark to be met by all student accommodation refurbishment projects. This will assist the organisation to further reduce project emissions and improve collaboration with project partners. The organisation's work in identifying, calculating and reporting operational emissions must be commended as it is performing above and beyond legislative requirements. As the next step, the Director is also looking towards lowering embodied carbon of refurbishment projects.

6. Conclusion

The student accommodation sector in the UK and US is a top performing asset for the construction sector and is expected to grow further. The quickest method to satisfy demand is to refurbish current stock or change building use, however little is known of its environmental impacts. Being able to compare and scrutinise the performances of different construction organisations, strategies and techniques is essential in order to improve the impact of the industry. The GHG emission data from projects provides an opportunity for this analysis. This research compares the GHG performance of four UK student accommodation refurbishment projects based on their varying construction characteristics.

The key thread running through all research focused on the environmental and emission performance of construction is the ways in which GHG performance is measured and reported. This research evaluates the consistency and accuracy of using different key performance indicators to predict GHG performance - distance of the project to the construction organisation's HQ KPI ($kgCO_2^{eqv.}$ per km); duration of project KPI ($kgCO_2^{eqv.}$ per week); gross internal floor area KPI ($kgCO_2^{eqv.}$ per m^2); number of rooms KPI ($kgCO_2^{eqv.}$ per room); and project value KPI ($kgCO_2^{eqv.}$ per £100,000). The key conclusions were:

- KPIs can and are widely used to provide an indication of GHG performance of construction projects. The research finds siginficant variability in each KPI's ability to consistently predict GHG performance of projects.
- Positive correlation is found between a project's GHG performance and its duration, value, gross internal floor area (GIFA) and number of rooms. Whilst negative correlation is found between the project GHG performance and the distance of the project to the construction organisation's HQ.
- The research highlights the importance of consistently using the same KPI when comparing the performance of multiple projects. Although different KPIs are shown to provide varying levels of accuracy in predicting GHG performance based on the specific characteristics of the project.
- Project gross internal floor area (GIFA) was identified as the KPI that provided the most consistent and accurate prediction of the GHG performance of student accommodation refurbishment projects using JCT Design and Build contracts in the UK.

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Figure

Scope 1 Direct Emissions (Fuel used)

Business Travel

Person	Type	Distance [return] *(km)*	Emmision factor (kgCO2e/unit)	Site visit frequency M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
Managing Director	Car-petrol	168	0.2095	2	2	2	2	2	2	2	2	2	2	2	2	1
Operations Manager	Car-petrol	168	0.2095	3	10	10	11	13	10	12	11	12	13	14	13	5
Quantity Surveyor	Car-petrol	168	0.2095	3	12	13	10	12	9	10	12	11	13	12	10	0
Project Administrator	Car-diesel	168	0.1987	1	1	1	1	1	1	1	1	1	1	1	1	1
Enviornmental Manager	Car-diesel	80	0.1987	1	1	1	1	1	1	1	1	1	1	1	1	1
Site Manager	4x4 diesel	4	0.2635	15	21	22	23	22	17	23	20	21	22	23	20	10
Assitant Site Manager	Car-petrol	65	0.2095	6	3											
Assitant Site Manager	Car-petrol	50	0.2095		21	22	22	22	17	23	20	20	21	23	20	8
Labourer	Motorcycle	20	0.1067		21	21	23	22	17	23	18	21	22	22	20	9

Scope 2 (Indirect) (Purchased energy)

Stationary source

		Emmision factor (kgCO2e/unit)	Usage quantity M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
Electricity (kWh)		0.5452	474	764	809	829	912	1132	953	1021	982	972	921	871	542
Natural Gas (kWh)		0.1852													
LPG (kWh)		0.214													
Coal (kWh)		0.322													
Generator		2.322													

Scope 3 (Indirect) (Outsourced activities requiring fuel, energy, etc)

Business Travel

	Type	Distance [return] (km)	Emmision factor (kgCO2e/unit)	Site visit frequency M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
Client 1	Car-petrol	114	0.2095	1	1	1	1	1	1	1	1	1	1	1	1	1
Client 2	Car-petrol	114	0.2095	1	1	1	1	1	1	1	1	1	1	1	1	1
QS 1	Car-petrol	110	0.2095	1	1	1	1	1	1	1	1	1	1	1	1	1
QS 2	Car-petrol	110	0.2095	2	5	6	5	5	4	3	2	2	2	1	1	1
QS 3	Car-petrol	110	0.2095		1	1	1	1	1	1	1	1	1	1	1	1
CDM	Car-petrol	112	0.2095	1	1	1	1	1	1	1	1	1	1	1	1	1
H&S Consultant	Car-petrol	105	0.2095	1	1	1	1	1	1	1	1	1	1	1	1	1
H&S Consultant	Car-petrol	26	0.2095	1	1	1	1	1	1	1	1	1	1	1	1	1
Strip Out - flooring	VAN-petrol	110	0.2405	5	12	17	18	20	15	21	20	23	21	19	16	10
Mechanical	VAN-petrol	70	0.2405	10	21	22	21	24	21	24	21	24	22	18	15	7
Electrical	VAN-petrol	70	0.2405	10	21	29	26	26	20	25	19	24	21	22	16	10
Suspended Ceilings	VAN-petrol	145	0.2405	4	14	31	28	29	20	23	17	20	17	15	12	4
Hygienic Wall Cladding	VAN-petrol	55	0.2405	4	15	21	19	17	10	13	10	11	12	15	13	6
Floor Finishes	VAN-petrol	5	0.2405	5	21	29	28	29	21	24	19	17	16	18	15	8
Painting and Decorating	VAN-petrol	70	0.2405	5	21	28	27	28	21	28	22	25	21	23	18	10
FF&E	VAN-petrol	140	0.2405		21	29	27	27	19	21	17	19	20	19	15	8
Mastic Sealant	VAN-petrol	120	0.2405		10	18	17	16	10	14	12	13	14	16	14	6
Joinery	VAN-petrol	75	0.2405		15	19	18	20	11	17	15	19	17	15	12	7
Fire Alarm	VAN-petrol	140	0.2405		6	8	10	9	4	10	8	9	10	6	5	2
Cleaning	VAN-petrol	40	0.2405		12	17	10	10	6	11	9	10	8	9	7	3

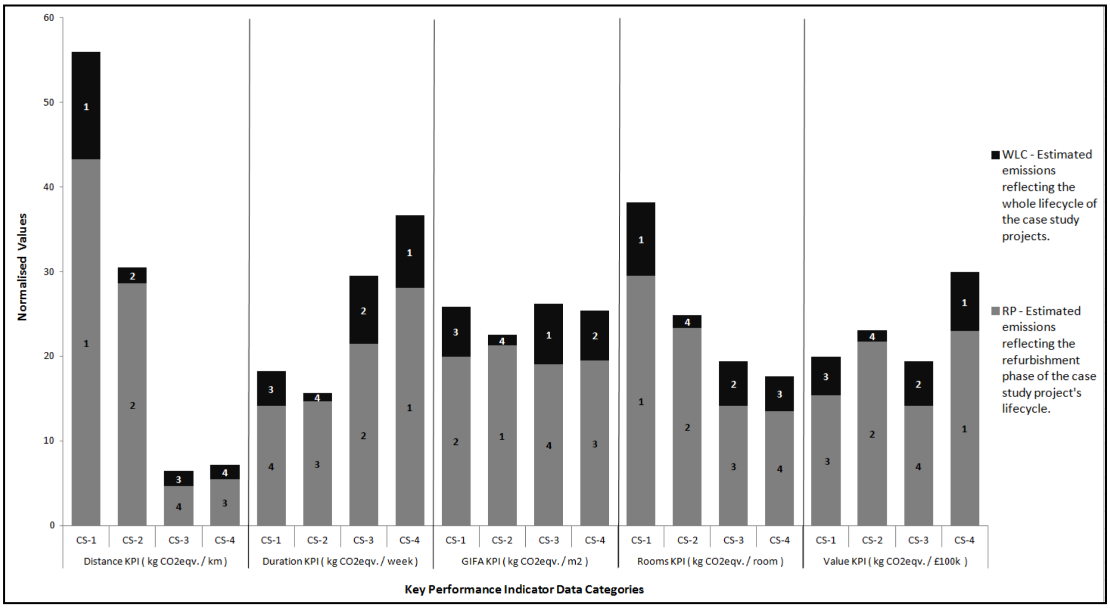
Material Transport (deliveries, suppliers)

	Type	Distance [return] (km)	Emmision factor (kgCO2e/unit)	Site visit frequency M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
Cabins	HGV	130	0.8952	2												2
Consumables	LGV - diesel	40	0.588	1	2	5	6	6	4	6	5	5	7	6	5	2
Floor Finishes	LGV - diesel	70	0.588	6	11	16	18	17	10	11	11	13	13	10	9	5

Project Vehicles

	Type	Distance [return] (km)	Emmision factor (kgCO2e/unit)	Site visit frequency M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
Skips	LGV - petrol	50	0.5637	4	10							3	4	3	3	3
Skips	LGV - petrol	70	0.5637			4	2	2	2	2	3				3	3
Recycling	HGV	100	0.8952			2				1						

Figure 1: Example of a Construction Project's GHG Emissions Data Sheet



<u>**Figure 2:** Comparison of the GHG Performance of each Case Study Project Reflective of each KPI</u>

Table

Table 1: Summary of the Student Accommodation Construction Project Case Studies

Details	Case Study 1 (CS-1)	Case Study 2 (CS-2)	Case Study 3 (CS-3)	Case Study 4 (CS-4)
Location	Lancaster, UK	Liverpool, UK	Leeds, UK	Leeds, UK
Project Brief	Refurbishment of 346 accommodation units, 45 offices, 14 common rooms, student bar, foyer and courtyard landscaping works.	Developing 495 flats into contemporary accommodation with en-suite shower rooms, kitchen and lounge areas with new fit-out.	Phase 1 (CS-3) and Phase 2 (CS-4) refurbishment works of existing accommodation including; study rooms, kitchen areas, bathrooms/en-suites and block entrances.	
Distance from Site to Head Office (km)	92	168	264	264
Project Duration (weeks)	49	57	10	9
Gross Internal Floor Area (GIFA) (m^2)	15,645	17,805	5,100	5,850
Rooms	324	495	210	258
Project Value	£4.77m	£4.10m	£1.16m	£1.17m
Estimated Overall Project Emissions ($kgCO_2^{eqv}$)	76,510	76,021	25,233	28,173

Table 2: Case Study Project Data Classifications

Greenhouse Gas Protocol for Project Accounting – GHG Scopes:	
Classification	**Description**
GHG Scope 1 (Direct Emissions)	Direct emissions occur from sources that are owned or controlled by the case study organisation, for example, emissions from staff business travel related to the project.
GHG Scope 2 (Indirect Emissions)	Emissions from the consumption of purchased electricity, natural gas, LPG, coal, etc. used on the project site.
GHG Scope 3 (Other Indirect Emissions)	Emissions from outsourced activities not owned or controlled by the case study organisation requiring fuel or energy. Some examples of Scope 3 emissions are travel by sub-contractors, materials transport, project vehicles, etc.

Organisational KPIs:	
Data Classification	**Description**
KPI 1 - Distance	The return (round trip) distance from Head Office to project site in kilometres.
KPI 2 - Duration	The project duration from start to finish in weeks.
KPI 3 - GIFA	The gross internal floor area (GIFA) of the project site in square meter.
KPI 4 - Rooms	The total number of rooms, which includes study rooms, kitchen areas, bathrooms, en-suites, offices, etc.
KPI 5 - Value	The final value of the project (including all refurbishment cost and fees associated to the project) as agreed after the Final Accounts with the Client.

Table 3: Case Study Project Estimated GHG Emission Data

Project	GHG Emission Scope	Organisational KPI Data									
		Distance (*$kgCO_2^{eqv.}$ per km*)		Duration (*$kgCO_2^{eqv.}$ per week*)		GIFA (*$kgCO_2^{eqv.}$ per m^2*)		Rooms (*$kgCO_2^{eqv.}$ per room*)		Value (*$kgCO_2^{eqv.}$ per £100K*)	
		WLC	RP	WLC	RP	WLC	RP	WLC	RP	WLC	RP
CS-1	Scope 1	133.0	111.6	249.6	209.6	0.8	0.7	37.8	31.7	2.6	2.2
	Scope 2	59.3	46.9	111.3	88.1	0.4	0.3	16.8	13.3	1.1	0.9
	Scope 3	639.4	483.7	1200.5	908.1	3.8	2.8	181.6	137.3	12.3	9.3
	Overall	*831.6*	*642.2*	*1561.5*	*1205.8*	*4.9*	*3.8*	*236.1*	*182.4*	*16.0*	*12.4*
CS-2	Scope 1	82.1	77.6	242.0	228.8	0.8	0.7	27.9	26.3	3.4	3.2
	Scope 2	12.3	11.2	36.3	33.0	0.1	0.1	4.2	3.8	0.5	0.5
	Scope 3	358.1	336.6	1055.4	992.2	3.4	3.2	121.5	114.3	14.7	13.8
	Overall	*452.5*	*425.5*	*1333.7*	*1254.0*	*4.3*	*4.0*	*153.6*	*144.4*	*18.5*	*17.4*
CS-3	Scope 1	16.3	12.1	431.3	318.8	0.9	0.6	20.5	15.2	3.7	2.8
	Scope 2	1.1	0.8	28.2	20.8	0.1	0.0	1.3	1.0	0.2	0.2
	Scope 3	78.2	56.5	2063.8	1492.6	4.1	2.9	98.3	71.1	17.8	12.9
	Overall	*95.6*	*69.4*	*2523.3*	*1832.1*	*5.0*	*3.6*	*120.2*	*87.2*	*21.8*	*15.8*
CS-4	Scope 1	52.1	39.3	1529.6	1151.6	2.4	1.8	53.4	40.2	11.8	8.9
	Scope 2	1.3	1.0	38.5	29.7	0.1	0.1	1.3	1.0	0.3	0.2
	Scope 3	53.3	41.5	1562.3	1216.7	2.4	1.9	54.5	42.4	12.0	9.4
	Overall	*106.7*	*81.8*	*3130.4*	*2397.9*	*4.8*	*3.7*	*109.2*	*83.7*	*24.1*	*18.5*

WLC : Estimated emissions reflecting the whole lifecycle of the case study projects ($kgCO_2^{eqv.}$)

RP : Estimated emissions reflecting the refurbishment phase of the case study project's lifecycles (excluding project start-up and move-out) case study projects GHG levels emissions analysis ($kgCO_2^{eqv.}$)

Table 4: Case Study Projects with Best and Worst GHG Performance According to Different KPIs

		Key Performance Indicators				
		Distance	**Duration**	**GIFA**	**Rooms**	**Value**
WLC GHG Emissions	Projects Identified with Best GHG Performance	CS-1	CS-4	CS-1	CS-1	CS-4
	Projects Identified with Worst GHG Performance	CS-3	CS-2	CS-2	CS-4	CS-3
RP GHG Emissions	Projects Identified with Best GHG Performance	CS-1	CS-4	CS-2	CS-1	CS-4
	Projects Identified with Worst GHG Performance	CS-3	CS-1	CS-2	CS-1	CS-4

Table 5 : Statistical Correlation between Project KPI Characteristics and Estimated WLC and RP Construction Emissions

	Case Study Project KPI Characteristics				
	Distance *($kgCO_2^{eqv}$ per km)*	**Duration** *($kgCO_2^{eqv}$ per week)*	**GIFA** *($kgCO_2^{eqv}$ per m^2)*	**Rooms** *($kgCO_2^{eqv}$ per room)*	**Value** *($kgCO_2^{eqv}$ per £100K)*
Estimated Whole Lifecycle Construction Emissions (WLC)	-0.930	0.989	0.990	0.815	0.990
Estimated Refurbishment Phase Construction Emissions (RP)	-0.840	0.996	0.998	0.911	0.943