Original Article

An assessment of carbon emissions from retail fit-out in the United Kingdom

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ABSTRACT Sustainability is increasingly being utilised as a marketing tool by retailers concerned with understanding and disseminating the whole life impact of buildings and focusing on declaration of the greenhouse gas (GHG), Carbon Footprint or business CO₂ emissions, waste reduction and recycling. Commercial fit-out design for retail use has a uniquely short design life and replacement cycle of typically 2–10 years. Traditionally, the financial cost of this practice has been managed by matching product performance with anticipated design life and concepts following fashion trends and brand image to dictate changing specifications. The highlighting of issues of embodied energy, waste, energy efficiency and reuse in the design process may have a role to play in modifying behaviour and practice. Quantifying emissions from materials waste and operation of retail buildings is the key to this argument. This article demonstrates the potential for savings, and dispels some of the myths surrounding specification and use of surface finishes in a retail setting. It is proposed that utilising whole life cycle methodology can support the decision-making process to reduce emissions from the global construction industry supply chain. The article will be of interest for commercial designers, their clients and supply chains.

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INTRODUCTION

The construction sector is generally thought to be responsible for 50 per cent of UK direct carbon emissions, estimated in 2008 to be 628.3 million tonnes of CO₂ equivalent (DECC, 2009). UK construction industry output for shops in 2007 was reported by DEFRA (2007) as £5146 million, 6.7 per cent of the total UK construction output. This percentage may also be representative of the 50 per cent proportion of UK greenhouse gas (GHG) emissions from buildings. Based on this assumption, some 21 million tonnes of CO₂ are released through the construction and operation of shops each year in the United Kingdom. Around 100 million m² of retail floor space is available in the United Kingdom, although at any one time between 9 and 14 per cent may be vacant (BRC, 2009). However, this represents only the emissions originating within the United Kingdom, from the National Grid and construction process, manufacture and transportation of materials taking place within the United Kingdom. The globalised market for construction products and materials means that it is not simply a matter of deducing that retail is responsible for only that impact. Thousands of tonnes of imported materials are used in retail fit-out each year, and this impact is largely ignored, as it is believed to be much smaller than that from the annual operation of stores.

The aim of this research is to demonstrate the importance of taking a whole life emissions-led approach to understanding the impact of store design. The article essentially highlights the importance of embodied impact of materials in retail interiors, as the authors believe that design teams use well-researched and established energy performance modelling techniques and tools to assess the operational performance and GHG emission impacts.

The objectives of the article are:

1. To consider the GHG emissions impact from typical retail interior materials, and demonstrate the relevance of these emissions with the use of quantitative data to model the embodied emissions impact of a typical department store fit-out.
2. To consider the GHG impact of the construction process itself.
3. To understand the scale of operational emissions through target setting, energy modelling and monitoring.
4. To compare the proportionality of whole life emissions.
5. To model four interior fit-out specification options for a department store to compare whole life GHG emissions and demonstrate the possibility of the optimisation of store design for lower emissions.

The first section outlines the background to the research in terms of recently changing brief of major UK retailers towards more sustainable practice and the development of whole life GHG emissions reporting as an aid to design decision making. The following sections describe in turn the scope and boundaries and the particular issues of the embodied materials, and the construction process, operation and end of life impact for retail interiors. The relationship between these four sections is then considered over the whole life of a retail interior using a modelled department store interior to consider what variations in scheme design

may have in the whole life of the interior. The article concludes on the comparative importance of each stage in whole life modelling and how this might affect longer-term management of stores and the GHG emissions for which retailers are responsible.

It is hoped that the conclusions will support the use of GHG emissions analysis in the design stage of retail interiors by the design team to manage the whole life emissions for each project as part of the GHG reduction strategy of retailers. The scope of this article is limited to large department stores of 5000 m² or more. These are representative of 7.3 per cent of sales on the high street and are often seen as leaders in the retail industry. It is hoped that the conclusions will be of benefit to other retail projects, particularly general merchandise, clothing and footwear.

BACKGROUND

Department stores provide anchors to major retail developments, such as Westfield, completed in 2008. The shell tends to be built by a developer and the fit-out of the interior carried out as a separate contract for the retailer as a tenant with a concept design and standardised specification. In this fast-changing area of design and construction, publication of research is limited, and the construction industry depends on relationships with clients, trial and review processes, and anecdotal evidence to develop energy and sustainability strategy.

Declarations and targets from the online Corporate Social Responsibility (CSR) Report publication from four major department store chains have been used here to provide the background for this study. Marks and Spencer's Plan A has been well publicised, and concentrates on energy, waste and water management, and responsible sourcing in all parts of their supply chain; the store hopes to cut energy use by 25 per cent by 2012. Debenhams have concentrated on bringing stores below CIBSE Guide F good practice benchmarks for energy use, and have changed lighting specification to avoid tungsten halogen, have improved switching circuits to limit lighting in stores overnight, and are using LED lights in jewellery displays. Their general aim in 2008 was to bring store emissions down by 30 per cent. John Lewis has a minimum BRE Environmental Assessment Method (BREEAM) Very Good requirement for new stores, and insists on zero ozone depletion refrigerants and Forest Steward Council (FSC) timber. House of Fraser hopes to cut energy consumption by 20 per cent annually with support from their in-store concessions.

A sustainable retail fit-out strategy presents an opportunity to emulate the environmental benefits of online shopping in a retail space by holistically assessing emissions reductions opportunities. Retailers' emissions reporting and communication adds value to their corporate objectives and further promotes a shopping behaviour that is environmentally conscious and sustainable.

The whole life emissions approach takes precedence over whole life costing with regard to financial decision making and environmental Life Cycle Assessment (LCA) methodology. Life cycle assessment methodologies present the platform for comparing the environmental performance of building materials and components through time. They are

extensively used in quantifying the overall environmental burden and distribution of impacts by modelling the impact of each building life stage: initial, operational and end of life. Typically, a building life cycle commences with the extraction of the raw materials that are used to produce building materials, manufacturing of components, transportation, on-site construction, and operation, and ends with the final disposal of these materials at the end of life and the reuse or recycling of suitable products. The total emissions attributed to a building life cycle are the summation of all these stages. The current building regulations have aimed at reducing the operational energy consumption; however, as operational emissions decrease owing to higher standards and improving energy efficiency, the other components in the building life cycle become extremely significant.

WHOLE LIFE GHG IMPACT OF A RETAIL STORE

This section describes the scope and boundaries of each life stage of a store fit-out and the methods employed to calculate the total GHG impact. The focus has been drawn towards embodied impact in materials and end of life disposal and recycling, as the authors believe that this has not been considered in depth in the retail sector. Figure 1 shows the life cycle impacts of a store. In other construction sectors, the whole life cycle would normally encompass the whole building shell and interior and would have a higher total embodied emissions rate of kgCO_2/m^2 of gross floor area (GFA). As a result, however, retail fit-outs typically occupy an existing building and therefore have a fraction of the embodied impact and a much shorter life cycle than the 25–60 years typical of other sectors (Fieldson and Smith, 2007; Lane, 2007).

Materials

The materials used in retail interiors materials can be grouped into the general categories of flooring, ceiling finishes and wall finishes. In addition to this, partitions to form staff and storage areas are constructed, and window and door enclosures are formed.

The most effective way to reduce the carbon impact of the fit-out project is to eliminate major material groups altogether – example floor or ceiling finishes. Life cycle analysis of generic building materials carried out by the Building Research Establishment (BRE) has demonstrated that over the lifetime of a building, floor finishes are most frequently replaced at 5-year intervals (Anderson *et al*, 2002). In a retail fit-out, almost everything may be replaced at this rate, particularly if the lease terms require a tenant to return the unit to an empty shell at the end of the lease; the next tenant may be able to make use of some of the elements such as ceilings and services.

Figure 1: Whole life emissions impact.

Source: Fieldson *et al* (2009).

The Green Guide provides helpful generic guidance and is used in BREEAM assessment to evaluate the environmental impact of materials in buildings; however, it is not sufficiently detailed to make specification decisions in relation to detail design and value engineering. Characterised Life cycle analysis or product carbon footprint (PCF) to recognised standard set out in PAS 2050 (BSI, 2008) will provide a more accurate metric. A national database of PCFs for generic building materials would vastly improve the comparability of designs and completed buildings and assist procurement teams in reducing the whole life impact of buildings generally. Preparation of PCF by the construction materials supply chain will in time drive down efficiency in manufacturing processes and promote low carbon and recycled content materials through market and regulatory mechanisms.

The principle of natural materials locking up CO₂ in their growth stages and this CO₂ being released in combustion or decomposition at end of life has been dealt with within PAS 2050 in a manner that allows sustainable production to be a negative value. There is some difficulty in defining sustainable timber although industry consensus assumes that FSC certified timber is the best option. Other natural farmed materials such as hemp, cotton and flax may be regarded as carbon negative if sustainable harvest practices and upstream processes are used. Timber carbon rates in this study are based on Bath University's Inventory of Carbon and Energy (ICE) (2008), which excludes the carbon sequestration and end of life aspects of timber; however, the authors of this study believe that timber products to be used in a building could act as a carbon sink if they are sourced from sustainable and well-managed forests.

Table 1 lists the embodied impact of materials commonly used in retail interiors in the United Kingdom. The mass or density per m² is based on technical data sheets of commercial ranges for UK producers commonly specified in retail applications, and Bath University's Inventory of Carbon and Energy (ICE) (2008) is used to calculate generic unit carbon dioxide emissions rates for each material. Specific products should be calculated based on the density and materials used in the product, as there is wide variance in the density and composition of sheet materials, and in the chemical composition of paints in particular.

Plasterboard in the United Kingdom typically has 50–60 per cent recycled content. Lafarge (2009) estimates that the cost of disposing of plasterboard will increase by 300 per cent in the next 5 years because of the legislation limiting Gypsum (sulphates), which can be put into landfills. Collection of waste plasterboard from sites is helping to increase recycled content as the gypsum can be reused; reducing waste plasterboard by design and efficient cutting, and very careful segregation of plasterboard waste to avoid this cost burden will promote resource efficiency and better recovery rates.

Screeds are generally applied by the first fit-out installation in a new shell to provide a level floor finish; under floor heating/cooling is sometimes incorporated, although generally screeds are required to perform for point loads of merchandising systems and some wheeled lifting equipment. Using anhydrite screeds can reduce the impact in two ways, the product has a much lower heat input in binder production, the source of which is also generally a waste product of another industry

Table 1: Common materials used in retail interiors and their associated embodied impact

	<i>Material type</i>	<i>Embodied impact rate kgCO₂ per unit</i>
Insulation, adhesives and closers	Silicone mastics (310 ml standard packs)	1.56 kg per pack
	Epoxy adhesives (cover approx 1 kg/m ²)	5.91 kgCO ₂ /m ²
Partition systems	Plasterboard at 8.3 kg/m ²	3.167 kgCO ₂ /m ²
	Laminated MDF at 20 kg/m ²	24 kgCO ₂ /m ²
	12 mm Plywood	6.75 kgCO ₂ /m ²
	High-density paper boards at 20 kg/m ² (washroom partitions)	1.32 kgCO ₂ /m ²
	Dry lining at 3000 mm high	12.3 kgCO ₂ per linear m
	70 mm metal stud partitions at 3000 mm high	8.64 kgCO ₂ per linear m
Wall finishes	Paint (three coats standard vinyl emulsion)	1.6 kgCO ₂ /m ²
	'Eco' or natural paint reduced carbon alternative with titanium dioxide (variable approximately 25% less CO ₂ 49% Volatile Organic Compound (VOC) reduction) ^a	1.2 kgCO ₂ /m ²
	Natural Paint emulsion (no published data – assumed 50% less CO ₂ owing to no titanium dioxide) (+25% for two additional coats) ^a	1.0 kgCO ₂ /m ²
	Wallpaper (Vinyl) at 0.3 kg/m ²	0.579 kgCO ₂ /m ²
	Wallpaper eco-ranges (wood and cotton)	0.45 kgCO ₂ /m ²
Floor preparation	75 mm non-wearing sand/cement screed	27.87 kgCO ₂ /m ²
	Anhydrite non-wearing screed ^a	18.39 kgCO ₂ /m ²
	75 mm wearing (or polished) reinforced cement-based screed	31.86 kgCO ₂ /m ²
	Raised access flooring steel encapsulated high-density board (floor finish is additional)	35.25 kgCO ₂ /m ²
	Raised access flooring steel with lightweight concrete infill	34.285 kgCO ₂ /m ²
	Particle board raised access flooring on steel pedestals	19.38 kgCO ₂ /m ²
Floor finishes	Self-finished raised-access polished concrete flooring slabs and mild steel pedestals at 66.7 kg/m ²	18.34 kgCO ₂ /m ²
	Carpet (80% wool) at 1.672 kg/m ²	9.162 kgCO ₂ /m ²
	Carpet (nylon) at 4.2 kg/m ²	14.91–30.7 kgCO ₂ /m ²
	Vinyl, Commercial grade @ 4 kg/m ²	9.16 kgCO ₂ /m ²
	Rubber at 4 kg/m ² (natural)	6.52 kgCO ₂ /m ²
	Rubber at 4 kg/m ² (synthetic)	16.08 kgCO ₂ /m ²
	Marmoleum at 8.73 kg/m ²	10.56 kgCO ₂ /m ²
	Ceramic tile at 23 kg/m ²	13.5 kgCO ₂ /m ²
	Terrazzo tile at 70 kg/m ² and 50 mm 1:4 cement screed	26.98 kgCO ₂ /m ²
	Stone tile (slate) at 45 kg/m ²	2.52 kgCO ₂ /m ²
	Hardwood flooring at 5.63 kg/m ²	2.8 kgCO ₂ /m ²
Ceiling finishes	Plasterboard or gypsum-based mouldings at 8.3 kg/m ²	4.167 kgCO ₂ /m ²
	MDF at 17 kg/m ²	10.24 kgCO ₂ /m ²
	Dense ceiling tiles i.e. Mineral wool at 5.2 kg/m ²	24 kgCO ₂ /m ²
	Metal ceiling tiles	16.05 kgCO ₂ /m ²
	Suspended ceiling grid and fixings	1.7 kgCO ₂ /m ²
Shop fronts	Aluminium-framed	279 kgCO ₂ /m ²
	Timber-framed	12–25 kgCO ₂ /m ²
	Frameless glazing at 45 kg/m ²	57.15 kgCO ₂ /m ²
	Stainless steel glazing	160–340 kgCO ₂ /m ²

^aMaterials not published in Bath University's Inventory of Carbon and Energy (ICE) (2008) assumed from trade literature without third-party-verified LCA.

(Flue Gas Desulphurisation or acid production). These screeds can be laid thinner and cure and quickly providing a good base for sheet and tiled flooring. However, they have not been found to perform well under point loads and turning wheeled vehicles.

Floor finish specification is based on the practicality of providing an attractive, safe and easily maintained medium. There is a very wide variety of choice for the designer. Departments and walkways may be expressed by changes in finish or colour. Natural paints have not been widely adopted by retailers because of extended drying times and the possibility of poor adhesion to walls.

Detailed information about the impact of mechanical and electrical equipment is limited, although a generic rate is used here based on a pro rata assumption of the weights of steel, plastic and aluminium found in equipment. It is possible for supply chains to commission life cycle assessment of the various materials and components in each piece of equipment; however, it is unlikely that they will do so until there is an obvious market advantage in the cost of LCA consultancy fees.

The quantities of materials used in each retail interior can be multiplied by the rates offered in Table 1, to consider the entire bill of quantities of the proposed retail fit-out works. It may be difficult to consider all of the works in which information on emissions rates or quantities is limited. The methodology for estimating whole life emissions proposed in the study by Fieldson *et al* (2009) recommends the use of factors to address missing information, in order to avoid underestimating the total embodied impact. Underestimation is not a major issue when comparing products at an elemental level but can prove misleading when whole life balance of different schemes is being compared at building level.

The largest material quantities can generally be expected to have the most significant impact within the whole project – often flooring and ceilings. Basing decisions on flooring on these data alone may be insufficient. It is important to put this basic comparison into perspective both within the store project as a whole and the implications of the material in the construction process. Vinyl tiles, which generally undergo quite an energy-intensive manufacturing process, were used on 5000 m² of floor requiring an application of levelling screed which almost doubles their impact. Stone tiles may require a deeper adhesive bed and a protective coating. The emissions from delivery of the heavier stone tiles may also be considered; however, ease of installation, maintenance and disposal will be significant to the decision-making process in selecting the flooring material.

Construction process

Shipping materials from the Far East and road haulage from the European Union is often thought to be a significant impact attributed to construction materials and used a reason to specify locally or regionally produced materials. Bulky equipment and products are very rarely transported by airfreight. Transport generally makes up a small proportion of the impact of manufacturing materials to create complex items such as air conditioning units or escalators; whether these are assembled in the United Kingdom or in the Far East, many of the parts come from a global supply chain. These impacts should not be ignored, as they are part of the business carbon footprint of the supply chains involved and will be recorded in some form, however complex it may be to extract the information. The supply chain impacts of the material manufacturer are often difficult to assess;

however, a globally harmonised LCA construction guideline could help them address the issues of assessment and reporting in order to allow more economic publication of product declarations across businesses. It is also important to establish that this impact has not already been accounted for in the embodied impact of a material if its life cycle has been assessed beyond the factory gate (Bath University's Inventory of Carbon and Energy (ICE), 2008).

Energy used to supply light and power to the project will generally be obtained from the mains supply, except in the rare instance when temporary supplies are required in a newly developed shell. Limited information is available to ascertain the energy needs of retail projects; they generally require much less heavy lifting and excavation work to be carried out than construction of shell buildings as whole at around 50–70 kg/m² of GFA constructed (Fieldson and Siantonas, 2008). A store measuring 5000 m² might expect to generate some 250 000 kgCO₂ while being built over the course of a 40-week construction programme.

Operational performance

The Energy Performance in Buildings Directive has led UK building regulations to require energy performance analysis to be assessed and Energy Performance Certificates to be lodged upon completion of buildings. The existing shell structure has an impact on this performance rating from the thermal efficiency of walls, roofs and windows which may be old and poorly maintained. However, the high use of lighting and air conditioning in deep-plan retail tenancies has by far the more significant impact. A large amount of cooling load is required to overcome the heat gain from the lighting. It is anticipated that the baseline emissions reduction required to pass Building Regulations will be amended in future to sequentially uplift to meet Building regulations approved document AD Part L (ODPM, 2006). Some evidence from the retail sector published in CSR reports would suggest that efforts to reduce emissions load are also responding to a desire to reduce operational costs and perhaps more critically position brands in the minds of their customers as responding to the sustainability imperative. It must not be ignored that many retailers have not (yet) taken this stance, and falling oil prices in late 2008 and 2009 have relieved pressure on facilities management budgets.

Figure 2 shows the average breakdown of annual energy use in retail buildings completed in the past 2 years since the use of heating, ventilation, lighting and cooling have been regulated by Building Control in the United Kingdom. It is clear that lighting is a significant energy use. It is traditionally felt by retailers in particular that directed lighting sells products by drawing the eye towards displays, and food retail lux levels have increased to levels of clinical brightness at around 900–1000 lux, also often assumed to utilise hue enhancement for sale of fruit and vegetables. Take-up of T5 and T8 fluorescent lamp types has resulted in a more recent reduction in watts per m² of lighting layouts. Cold cathode, LED and other low wattage lamps have the added advantage of longer life (it is critical that all lamps are operating in a retail display), but colour rendering between manufacturers remains problematic, for example one lamp with more blue or yellow in a white light display is not acceptable

Figure 2: Average emission rates for a building regulations-compliant retail building 2006.
Source: CLG (2008).

(Fieldson and Smith, 2007). Using lighting and movement sensors has also become acceptable in supermarkets, although retailers would hope to always be busy enough to avoid sales floor lighting going off. Natural light has traditionally been assumed to fade or cause other deterioration in merchandise, although in the age of twenty-first century logistics, product lines are rarely in one place for sufficient time for this to be possible. Windows within wall space will reduce merchandisable wall area, and for this reason roof lights or light wells are preferred in large-floor plate stores.

The second largest energy use in retail is cooling; some of the cooling load is required to address the heat given off by retail lighting, and therefore more natural light in stores should also reduce some cooling load provided that solar gain is also addressed in the window or roof light design.

Initiatives such as natural lighting, rainwater harvesting and external servicing solutions such as ground source heat pumps are limited for tenant retailers in existing buildings, but developers can utilise green leasing and tenant requirements for such measures to be incorporated with perseverance of all stakeholders.

Table 2 describes the CO₂ emissions rate or the operational performance that might be expected from a store based on monitoring carried out by CIBSE and records of Simplified Building Energy Model (BRE, 2007) SBEM calculations submitted to Building Control. A number of retailers have also published recent monitored data that show some variation against the more official figures. It is important that retailers are familiar with their own typical and optimum energy performance across their entire chain through monitoring, and that they use these data to set targets for new build projects and to upgrade existing stores.

Whole life operational emissions are calculated by multiplying the annual emissions rate by the area of the building and the number of years it will operate. In other sectors, buildings tend to operate for more than 25 years. The design life of retail fit-out projects is short for a number of

Table 2: CO₂ emissions rate for retail buildings

kgCO ₂ /m ²	CIBSE Typical (Guide F)	CIBSE Good Practice (Guide F)	CIBSE TM 46, 2008	SBEM-compliant regulated and unregulated energy use (CLG, 2008)	Average published by representative business	Design life of fit-out
Retail (general)	—	—	90.8	150	—	5–10
Supermarket	613.89	541.25	220	—	433 (Tesco, 2009)	10
Department store	208.82	167.21	70.8	—	108.5 (Debenhams, 2008)	15
High street fashion chain	174	144	49.7	—	118.4 (Next, 2008)	5–10
Retail warehouse	68.96	48.72	—	26	—	10
Do it Yourself (DIY) store	124.48	99.16	—	—	111.3 (B&Q Social Responsibility, 2001)	10

reasons. Stores may relocate if a better site becomes available that may improve footfall, fashion may require a brand overhaul and a new concept to be implemented, or space changes within a store may require major refurbishment. Sometimes the retail business is simply unsuccessful and the store is closed within a few years.

The retail replacement cycle (refurbishment of a store wherein the retailer remains at the site) is sometimes driven by changing fashion and changing sales strategy, and thus the increasing number of renovations resulting from obsolescence could have greater environmental impact, as the remaining service life of products is wasted if replaced before its design life. It is imperative to understand the relationship between the service lives of building components and how this affects the building life cycle impacts for different building types. Opportunities to install renewable energy generation equipment are often very limited in retail buildings. The shell is often leased and roof space is limited, and large shopping centres and high street environments in conservation areas pose many further difficulties. Major retailers have considerable influence on investing in renewable energy suppliers for off-site generation (Creevy, 2008; M&S press release, 2009 and Debenhams, 2008) and actually purchasing dedicated wind farms around the United Kingdom. Although this can be argued to be a less valid means to approach zero carbon than in-store efficiency, this investment is beneficial to the UK renewables market as a whole.

End of life

Replacement cycles are generally based on the operational or design life of the store fit-out, as shown in Table 2. To minimise the cost impact of replacement cycles, it is prudent to ensure that the design life of finishes is close to the length of the replacement cycle so that the materials are not wasted. Most materials used in hard flooring in supermarkets will exceed this cycle.

Strip-out of finishes may occur when the building is leased and the terms require that it be left as an empty shell. Most retailers have limited storage space in which to keep spare fixtures and fittings which could be

reduced, although retailers with many stores are able to move items to save them from disposal. Recycling of plasterboard and floor finishes may be possible if the strip-out contractor is able to adequately disassemble the materials.

Although published data for end of life emissions from retail strip-out are limited, it is thought that much of the plasterboard using in ceilings and partitions could be recycled and mineral fibre tiles could be remanufactured. Flooring is more difficult to deconstruct because of the adhesives used, but vinyl and nylon carpet product manufacturers are increasingly offering recycling options. Industry practice would suggest that this does not yet occur and that much of the materials stripped from stores are not segregated, with the exception of higher-scrap value metals from M&E equipment such as cables and ducts. Much of these materials will go to landfill, take up considerable space and become part of the methane production associated with decomposing materials, and could be calculated at 2 kgCO₂/kg of waste (Jacobs, 2007). With the short design life common in retail interiors, this situation must result in a significant increase in the whole life impact of the store. The calculation of this GHG impact is based on the tonnage of strip-out waste that is not recycled multiplied by the 2 kgCO₂/kg rate. Recycling of the materials is based on the current market, and not on what might be perceived to be the market in 5 or 10 years, as this is the basis of end of life impact calculation in PAS 2050. The energy used to strip out and transfer materials to the waste transfer station is also considered.

WHOLE LIFE BALANCE

In order to optimise or balance the design of retail fit-out, the approach developed by Fieldson *et al*, 2009 requires the whole life of the building to be considered. The model store data are based on an actual store layout with a measured bill of quantities. Four alternative specifications for major materials groups based on specifications used or proposed during 2008–2009 by other department store retailers. Although based on realistic scenarios, it is not intended by the authors to identify or directly compare the choices that have been made by these retailers.

Materials

Figure 3 shows the breakdown of embodied impact tonnes carbon dioxide (TCO₂) of the bill of quantities used in model 1 (see Table 3, comparing major emissions groups for alternative specification). It is clear that flooring and ceilings have the largest impacts.

Comparing embodied emissions for the same department store modelled for the three further scenarios (models 2–4 in Table 3) demonstrates that there is wide variance possible depending on choices made for major elements. These materials variables would have a limited impact on the operational performance of the department store, as it is assumed that all the window options have the same U-value. Provided that the building shell is well insulated and airtight, the same operational rating can be assumed for all four models. It is possible to reduce the impact of the fit-out by 50 per cent by taking a different approach to specification of finishes (by using natural materials) and eliminating suspended ceilings.

Figure 3: Breakdown of embodied impact in TCO₂ for a 5000m² department store fit-out.

Table 3: Comparing major emissions groups for alternative specification models

	Total embodied GHG impact TCO ₂	Embodied kgCO ₂ /m ² GIFA	Alternative specification		TCO ₂
1	439.1	87.83	Flooring	Vinyl	210.1
			Decorations	Standard emulsion	22.2
			Ceiling	Suspended ceiling tiles with some plasterboard features	133.5
			Shop front	Powder-coated aluminium frames	14.9
2	538.7	107.73	Flooring	Synthetic rubber walkway, nylon carpet departmental mats	298.9
			Decorations	Reduced VOC emulsion	16.6
			Ceiling	Suspended ceiling tiles with minimal plasterboard	154.6
			Shop front	Polished stainless steel frames	10
3	611.5	122.3	Flooring	Ceramic walkway Carpet departmental mats on raised access floor	432.7
			Decorations	Vinyl wallpaper	7.6
			Ceiling	Metal tile suspended ceiling with minimal plasterboard	109.8
			Shop front	Frameless system	2.9
4	218.7	43.73	Flooring	Slate flooring	150.4
			Decorations	Natural paint and eco wallpaper	7.0
			Ceiling	Exposed self-finished soffit with fire lining where necessary	1.4
			Shop front	Timber frames	1.3

Figure 4 illustrates the comparison of the bills of quantities with alternative specifications for all the four models. Apparently, flooring causes the highest GHG emissions in all four models. It is important to note that this analysis has not taken into account the embodied emissions of the shell building, which if newly constructed may contribute a further 500–1000kgCO₂/m² of embodied emissions to the whole life of the department store.

Operation

A comparison of the embodied GHG impact of the first department store scenario (model 1, as shown in Table 3) against operational ratings over

Figure 4: Comparing bills of quantities with alternative specifications as shown in Table 3 for a 5000m² department store.

Figure 5: Benchmarking operational data for a 5000m² department store over 15 years.

15 years at performance levels approximate to those that would be valid for a Display Energy Certificate from the average D rated to the highest achievable A rated is shown in Figure 5.

D-rated, average retail operational performance based on CIBSE TM46, 2008: 240kgCO₂/m²; C-rated: 25 per cent improvement 180kgCO₂/m²; B-rated: 40 per cent improvement 144kgCO₂/m²; B+-rated: 75 per cent improvement 60kgCO₂/m²; and A-rated: 90 per cent improvement 24kgCO₂/m².

None of the alternative materials shown in Table 3 are assumed to have an effect on the energy use of the store; however, removing the ceiling may allow the thermal mass of the structure of the building to be utilised for a beneficial effect provided that the roof of the building has sufficient insulation to limit heat gain. The ability of the store to perform at the

Figure 6: Comparing three scenarios for whole life impact of a 5000 m² department store.

highest levels is affected by the passive design performance for day-lighting and solar gain and the air-tightness of the shell. Stores developed in older buildings may also need to upgrade structural fabric and thermal performance in order to meet current standards (which would in turn increase the embodied impact of the project).

Comparing scenarios

Figure 6 illustrates the comparison of three possible scenarios depicting the life cycle impact of a 5000 m² department store. These scenarios from the two ranges developed in this section demonstrate that the outcome from decisions regarding the materials used in a department store fit-out and the operational performance that can be achieved can vary widely. For simplicity and owing to limitations in space to discuss the possible variables, the construction process GHG impact for all models has been assumed to be the same in all cases, and end of life impact has been calculated at 10 per cent of embodied impact. The scenario of model 1 with a B-rated operational emissions rate such as the average published by Debenhams in Table 2 may reflect a typical whole life emissions benchmark rate of 0.78 kgCO₂/m² over 15 years. Taking the highest embodied emissions model 3 with the performance rating of C (because a newly constructed D-rated building may not pass building regulations) demonstrates the largest whole life impact at 1.1 kgCO₂/m² over 15 years. If the lowest embodied impact embodied materials scenario (store model 4) is selected and the lowest energy use performance can be achieved in the selected design, then the total whole life impact of the store over 15 years is 16421 TCO₂ lower than the conventional D-rated model 1 store at 0.22 kgCO₂/m². This is a dramatic reduction, and demonstrates that there is a great opportunity for carbon saving between a store that is just better than the legislative baseline and the best practice that might be demonstrated by taking the lowest carbon approach.

The normalised annual GFA impact of the whole life of the store is reduced if the fit-out lasts longer between replacement cycles. This can

be achieved by ensuring that the finishes have a longer design life and designing low-maintenance and reusable surfaces.

This study illustrates that flooring options and finishing components that generally do not constitute a part of a building's primary or secondary structure can be responsible for a very high proportion of the embodied energy. Retailers might be best advised to seek shell buildings in which the floor and ceiling finish already in existence can be retained for reuse to most effectively reduce embodied impact.

CONCLUSION

The selection of building materials directly influences embodied energy, but also may effect construction, operation, maintenance and end of life emissions arising from the retail fit-out over the design life. Designers must address all of these impacts together to ensure that the GHG impacts of stores are reduced. Understanding the relationship between design lives of finishes and planning for deconstruction will dramatically improve impact, and may reduce fit-out cost at the same time. Although lighting and cooling remain the largest impacts for a retail carbon footprint, passive design of the shell and the materials used for floor and ceiling are important considerations.

Generally, LCA analysis presents limitations in using embodied energy data with regard to boundaries, accuracy and applicability. As a result, this research is limited by the use of a single study (Bath University's Inventory of Carbon and Energy (ICE), 2008) as the basis of conversion factors for materials in conjunction with information made available by some product manufacturers, which also limits the assessment of embodied impact of services installations. Designers working on store design in the future will have a wider availability of data as PAS 2050 becomes the standard measure of GHG emissions for construction products. To support this process, it is vital that supply chains provide these data as part of their specification. This process will reinforce selective product design towards optimisation of whole life emissions. It is hoped that this study will contribute to the accumulation of robust emissions assessment data required for complete embodied impact analysis. A further limitation of this research is the lack of detailed study of the complex relationships between material selection, transportation and end of life impact that must be considered in material selection. Further research into the range of impact of materials in which recycled content varies, and an understanding of recycling potential or fossil fuel displacement at the end of life, will help to support the use of whole life carbon footprinting as a decision-making tool in building design.

It is significant that cost analysis has a close relationship with carbon analysis and that many cost-saving measures can also reduce initial impact, but this strategy should not extend to energy-saving measures in the services design, which may become a greater proportion of the cost of fit-out as energy performance standards are raised. Whole life carbon footprint should not be the only measure used to demonstrate sustainability and studies during the design process should also consider responsible and ecological sourcing of materials.

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