OFFSITE CONSTRUCTION:
Sustainability Characteristics

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Front cover images:

Left – Open Academy, an offsite educational building built with cross laminated timber panels by KLH. Photograph by Hufton + Crow.

Top Right – Stockphoto of an offsite factory.

Bottom Right – Montgomery Primary School, an A+ rated, Passivhaus standard educational building built with Buchan Concrete's offsite concrete frame.

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EXECUTIVE SUMMARY

This report examines the credentials of offsite construction within the context of a definition of sustainability which has been based on the work of the World Business Council. This definition states that "Sustainability involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Sustainable construction needs to perform not against a single, financial bottom line but against this triple bottom line".

Offsite construction stands up well when tested against this definition. There are many attributes which have clear triple bottom line benefits ranging from the reduction of waste that is associated with factory-built processes to the reduced financing costs that are associated with shorter onsite construction programmes. In this report, the key attributes of offsite construction are systematically considered and then assessed with regard to their triple bottom line impact. However it is recognised that, in the world of business, commercial considerations will be dominant. For this reason, particular efforts have been made to provide guidance regarding the relative scale of the financial benefits which might be associated with each attribute, and to which party those benefits might accrue. The builder and the developer are identified as critical parties in making the decision to adopt offsite techniques, and so the particular benefits to these parties have been highlighted throughout the report.

Category/Attribute	Potential Improvement over Conventional Construction	Societal Benefit	Financial Benefit to Builder/Developer
SOCIAL			
Health & Safety	Up to 80%	Large	N/A
Improved Working Conditions	Significant	Significant	N/A
ENVIRONMENTAL			
Reduced Road Traffic Movements	Up to 60%	Significant	Small
Reduced Energy Used on Site	Up to 80%	Small	Small
Reduced Waste	Up to 90%	Significant	Significant
Reduced Energy-in-Use	Up to 25%	Significant	Small
ECONOMIC			
Faster Construction	Up to 60%	Significant	Large
Improved cash-Flow	Significant	Small	Large
Reduced Snagging & Defects	Up to 80%	Small	Significant

The conclusions of the report are that the triple bottom line benefits of offsite construction are numerous. However, the financial benefits are often seen to be the most powerful and, depending on where these benefits accrue, they can be expected to influence the choice of building method. In situations where the construction cost savings, operational cost savings, construction time savings, and quality benefits all accrue to the same party (e.g. owner/operators; PFI-consortia; etc), the case for adopting offsite methods is particularly compelling.

Definition of Sustainability

(Based on the definition adopted by the World Business Council):

Sustainability involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Sustainable construction needs to perform not against a single, financial bottom line but against this triple bottom line.

1. INTRODUCTION

Offsite Construction has many characteristic features which suggest that buildings constructed using this approach will have good sustainability credentials. However, whilst this argument appears to be well supported from a common-sense point-of-view, there is little objective work on the subject which sets out the case formally and attempts to put scale to the advantages which are claimed. This report attempts to redress that situation by reviewing the subject systematically and, wherever possible, setting figures against the key attributes which have been defined.

The approach adopted has been to address the subject at the broadest possible level. The study has been sub-divided into the three components of the so-called 'triple bottom line' – the social, environmental, and economic benefits – and, in each case, an attempt has been made to put scale to the benefits which have been identified. This has been achieved either through references to pre-existing literature, or through the development of simple numerate calculations where there is insufficient documented information on which to make a case.

A good summary of modern offsite projects may be found in the case-studies reported in the Buildoffsite 2012 Yearbook [1]. An overview of these projects is presented in the table below.

Case studies	Case study 1: Buchan Concrete	Case study 2: Caledonian Modular (CM)	Case study 3: NG Bailey	Case study 4: NG Bailey	Case study 5: Laidlaw Solutions	Case study 6: Yorkon	Case study 7: Tata Steel Products	Case study 8: SES PRISM	Case study 9: Tata Steel Products	Case study 10: McAvoy	Case study 11: Bryden Wood Limited	Case study 12: Bryden Wood Limited	Case study 13: Skanska	Case study 14: Pipe Center Modular Engineering	Case study 15: Accio Group	Case study 16: Sheffield Insulation Group (SIG)	Case study 17: Interserve Construction Ltd	Case study 18: Hull Royal Infirmary	Case study 19: Caledonian Modular	Case study 20: Interserve Construction
Air				✓																
Commercial								✓											✓	
Custodial													✓				✓			
Education	✓									✓				✓						✓
Health			✓		✓	✓						✓						✓		
Rail									✓											
Residential/ Housing		✓					✓									✓				
Retail											✓				✓					
Cost		✓	✓	✓			✓		✓		✓	✓	✓		✓	✓	✓	✓	✓	✓
Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quality	✓				✓		✓	✓			✓	✓	✓	✓		✓	✓		✓	✓
Sustainability	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
Health and safety		✓							✓	✓	✓	✓	✓							

The above projects cover a good spread of different building types and each project has been subjectively rated against several different attributes (including sustainability). This therefore represents a good starting point for the current work. Importantly, it draws immediate attention to some of the more frequent claims which are made for sustainability benefits. These include reduced materials waste, improved health and safety on site, and shorter construction programmes. (Time on site is an important sustainability factor because it can have marked and beneficial effects on contractor cash flow and the cost of finance).

In order to approach the sustainability assessment in a simple and systematic fashion, key sustainability attributes were identified within each of the triple bottom line categories as shown in the table below. However, there is considerable room for introducing overlap and confusion when assigning attributes to categories in this way because some attributes have multiple benefits. For example, reductions in traffic congestion in the vicinity of a construction site might be considered to be a social benefit because of the reduced travel disruption, or an environmental benefit because of the reduced emissions. To keep things simple, some judgement has been exercised and each attribute has been assigned only to one single sustainability category.

Sustainability Category	Attribute
Social	Health & Safety
	Improved Working Conditions
Environmental	Reduced Road Traffic Movements (congestion & pollution benefits)
	Reduced Energy Use on Site
	Reduced Waste
	Reduced Energy Use in Operation
Economic	Faster Construction
	Alternative Purchasing Models
	Reduced Snagging & Defects

Each of these categories is examined in some detail in the following sections. In each case, a discussion of the major sustainability attributes is presented and some attempt is also made to quantify the financial benefit which might accrue to the client (developer) or the building contractor. This has been done because the main driver for the adoption of offsite technology will likely come from one of these two sources, since the greatest impetus for adoption is likely to come from the desire to achieve commercial advantage. The scale of that commercial advantage is therefore worth estimating.

2. SOCIAL CONSIDERATIONS

2.1 Health & Safety

Conventional construction is a relatively dangerous activity. There are many tasks which inherently require risks to be taken and, whilst great improvements in site safety have been made within the past 20 years, operatives are still required to work at height, work in outdoor conditions, work in the presence of heavy machinery, and take other risks that are absent in other branches of industry.

Comparison with modern manufacturing practice suggests that working in a factory is less likely to pose a risk of accidents occurring than working on a building site. Therefore, if buildings are constructed in future using offsite methods in a modern factory environment, we might expect the health and safety record for the building industry to improve and, ultimately, converge to the norms for the manufacturing industry.

A study of the Health and Safety Executive (HSE) accident data [2] for the building and manufacturing industries reveals a more complex picture than might first be imagined. A record of overall accident rates (in terms of accidents per 100,000 workers per year) shows that whilst construction used to have a characteristically higher accident rate in the early 90's, the industry has made considerable improvements over the past 20 years and there is now no significant difference between accident rates on construction sites and accident rates in factories (Fig 2.1). Indeed, for the sub-category defined as 'Over 3-day Injuries', the construction industry now appears to have a better record than the manufacturing industry (Fig 2.2).

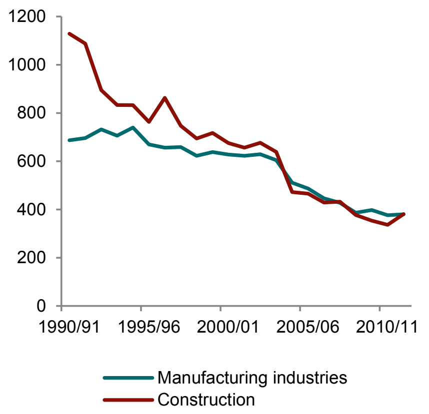

Fig 2.1 - All Injuries Rate per 100,000 (employees and self-employed)

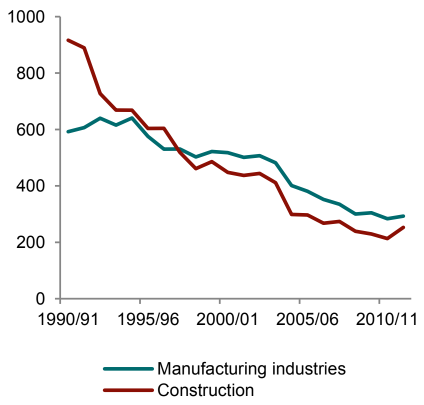

Fig 2.2 - Over-3-day Injury Rate per 100,000 (employees and self-employed)

It is important to note the definition of 'incident rate' which has been used by HSE in compiling these statistics. This is defined as the injury incidence estimate divided by the annual estimate of employment (taken as the number of individuals reporting themselves as currently employed (http://www.hse.gov.uk/statistics/lfs/injury.htm). Thus, if one industry typically works a longer week than the other, this must be allowed for in the interpretation of the data. Fig 2.3 plots the weekly working hours for the two industries over the past 20 years [3] and shows that there is now no significant difference in hours worked between the two. It is therefore safe to make a direct comparison of the HSE curves.

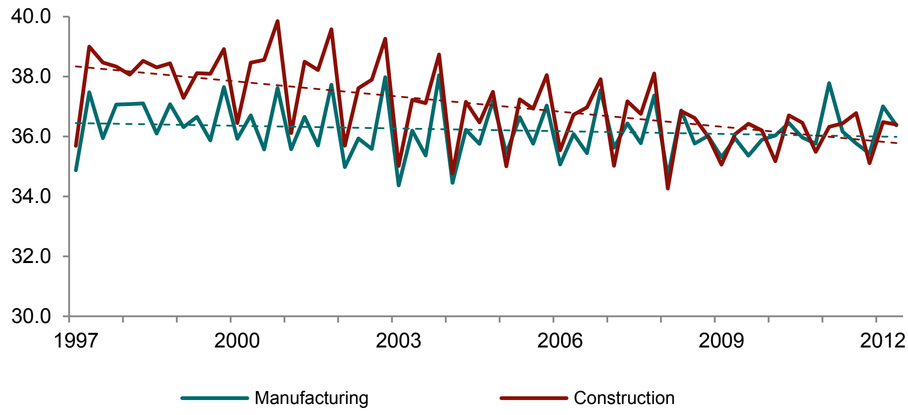

Fig 2.3 - Average actual weekly hours of work by industry sector

Despite the counter-intuitive headline that construction is as safe as manufacturing, deeper drilling into the data shows that, for the sub-categories of serious and fatal injuries, the manufacturing industry has a significantly better record than construction. This is shown by the data in Figs 2.4 and 2.5.

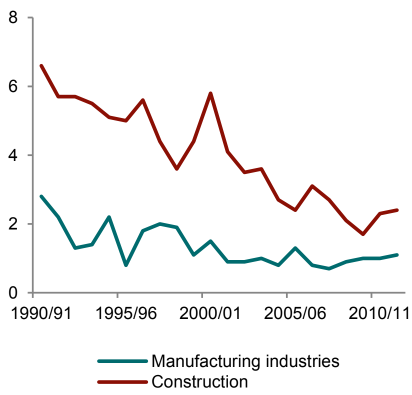

Fig 2.4 - Fatal Injury Rate per 100,000 (employees and self-employed)

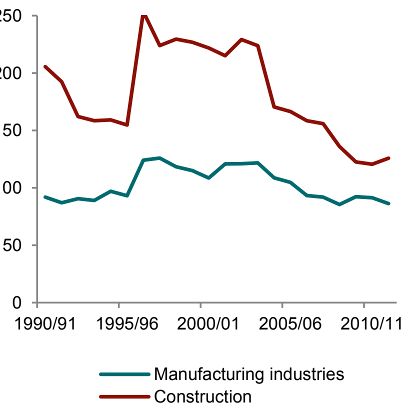

Fig 2.5. Major Injury Rate per 100,000 (employees and self-employed)

The accident rates in manufacturing are some 29% less for major injuries and 52% less for fatalities. (In both cases these improvements are calculated on the basis of the 3-year averages for the most recent years). Thus, if construction were to become more like a manufacturing exercise as a result of the widespread take-up of offsite methods, we might expect significant improvements to occur in the number of major injuries and fatalities which are recorded each year.

In fact, the figures for onsite health and safety would be even better than suggested above, because offsite methods have a dramatic effect in reducing time on site. (Reference to the case studies in the Buildoffsite Yearbook shows that all the projects, without exception, identify reduced time on site as a major benefit of adopting offsite technology). Actual savings in site-time are dependent on the type of building under construction, but typical savings for superstructure completion are in the range 50-75%. The number of people working on site at any one time is also reduced and, on this basis, the total reduction in site hours worked could easily lie in the range 60%-80%. This could be expected to produce a pro-rata reduction in the occurrences of major injury and death.

There is a clear societal benefit associated with reducing accident and injury rates, but it might also be argued that there is a financial benefit based on the cost of treating injuries (and deaths) within the national care system. This cost to society might be calculated using data published by the Department for Transport [4], where such calculations are used to assess the benefits of road improvement programmes. The figures are:

Cost per Incident	Injuries in Great Britain per annum*	Total annual cost associated with construction
£1,585,510/fatality	47	£74.2 million
£ 178,160/major injury	2,965	£527.8 million
£ 13,740/ over 3-day injury	5,911	£82.7 million

*Employees and self-employed, figures shown are an averages of the three most recent years, i.e. 2009/10, 2010/11 and 2011/12

2.2 Improved Working Conditions

There are several reasons why offsite construction might be considered to offer improved working conditions to the industry and its workforce which go beyond health and safety considerations. These include:

- **Job Security:** For the employees, a job on the permanent workforce of a factory represents stable employment with all the social and financial benefits that such status brings. This is in contrast to the itinerant uncertainty of the conventional construction industry, where site workers often have little certainty of employment beyond the end of any particular project.
- **All Weather Working:** For employees, the opportunities to work inside during the winter, and to take advantage of light machinery to assist with lifting, placing, and fixing components, represent a major improvement in working conditions.
- **Organisational Learning:** For employers, a stable workforce and a regulated means of assembly opens the way to developing continuous product improvements in the manner that has been achieved so effectively in recent decades by the consumer products industries.

3. ENVIRONMENTAL CONSIDERATIONS

3.1 Reduced Road Traffic Movements

In the conventional construction process, workers and materials arrive at site and leave subsequently in a random series of small, medium, and large vehicle movements. These movements occur throughout the working day and produce local traffic disruption and noise/ air quality pollution problems which are related to the total numbers and types of movements.

A simple calculation suggests that a large number of small vehicles will produce more exhaust emissions (carbon and other air quality-related products) than a small number of large vehicles. For example, a loaded one-tonne van may perform at 20 mpg on an average urban stop-start journey, but a heavy goods vehicle with a 20-tonne payload may return 4 mpg under the same driving conditions – a factor 4 improvement. To this benefit must be added the reduced number of onsite person-hours which are required for the construction of an offsite building. As remarked previously, this could be a substantial reduction and it suggests a pro-rata reduction in transport movements.

There are few documented studies of emissions due to traffic movements at site, but Quale [5] undertook a comparative study of the total CO2 emissions associated with onsite and offsite manufacturing in 2011 at Virginia University. He reviewed the procurement documentation of three identical offsite and five onsite buildings. In terms of metric tons of CO2 associated with transport his study shows site-based reductions in the order of 60%. Fig 3.1 illustrates these results but note that the total saving is less than is suggested for site-based movements alone because there are traffic movements associated with workers and material being taken to and from the factory which must be allowed for. Once these movements have been allowed for, the net savings reduce to around 20%.

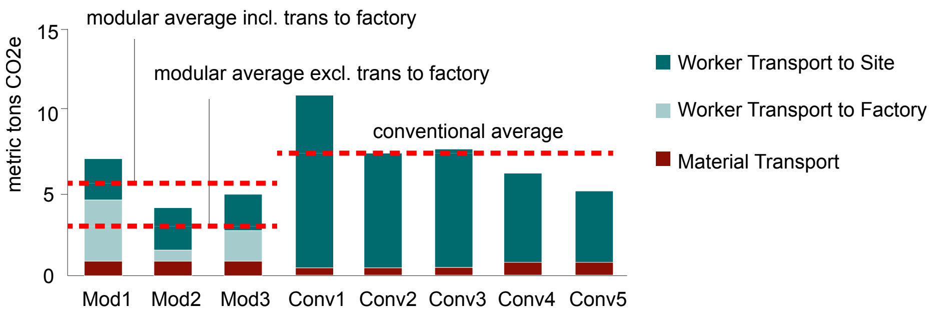

Fig 3.1 - Onsite-Offsite comparison of CO2 emmissions due to transport

From a pollution perspective, the offsite process seems to offer a considerable headline improvement over the traditional approach. However, with regard to the use of larger vehicles as suggested above, it might be argued that big vehicles could cause more traffic disruption than smaller vehicles. The extent of this disruption will depend on the road layout at the site entrance, the road traffic densities, and the absolute size of the delivery vehicles. Clearly, it is not possible to suggest rigid rules in this area – each case must be examined in detail on its own merits. However, as a general observation, most roads are designed to accommodate heavy goods vehicles and, with appropriate scheduling and access control, it is likely that the traffic disruption associated with larger vehicle movements could be minimised in most cases.

On balance, therefore, it is considered that offsite construction processes can offer substantial improvements with regard to environmental pollution and traffic disruption over the conventional approach. Any attempt to correlate this with a direct cost advantage, however, is extremely difficult. Apart from the fuel savings associated with the better overall mpg of larger vehicles (which can be easily assessed), the remainder of the environmental benefit can only be measured in terms of societal gain rather than in direct financial gain for the client or contractor.

3.2 Reduced Energy Use on Site

Energy use on site is related to a number of different activities:

- **Transport:** This has been discussed in Section 3.1
- **Staff Accommodation and Services:** This is directly related to the number of person-hours worked on site and will consequently be much reduced for an offsite building project. The energy used in this application includes heating and lighting, plus onsite services such as catering and staff welfare. For most projects the amount of energy consumed by these activities will be relatively small.
- **Lighting and Equipment/Plant:** These activities include power tools, plant, and site-wide lighting. Once again, the use of energy against these headings will generally scale according to the number of site-hours worked by the staff and therefore offsite construction processes should show considerable savings over conventional processes.

Quale (cited in the previous section) also researched energy use on site. Fig 3.2 below, extracted from his paper, shows that significant onsite energy savings were made in the cases which were studied. Once again, the net saving is less than the gross saving at site because of the need to allow for factory-based energy consumption. Nevertheless, gross savings of around 80% and net savings of around 30% are suggested.

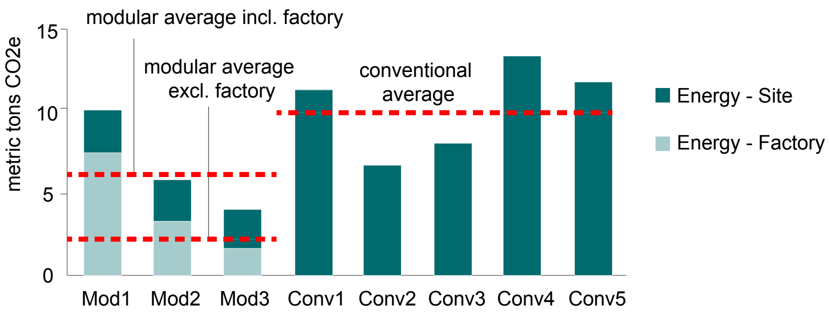

Fig 3.2 - Onsite-Offsite comparison of CO2 emmissions due to energy use

The advantages of offsite construction methods in reducing the amount of energy used on site can therefore be clearly identified. These benefits can be quantified directly in terms of energy cost savings to the contractor. However, it should be noted that the energy used on site for a conventional project typically accounts for a tiny fraction of the construction tender price, so the impact of these energy savings on the contractor's attitude to offsite construction is likely to be very small.

3.2 Material Waste

Conventional building practices are very wasteful in material terms. Waste streams can represent anything up to 20% of the raw material tonnages, with 10% being a reasonable average figure across all building types. In money terms, this might represent some 3-5% of the construction cost, so it is a significant number.

Manufacturing processes, by comparison, are very much less wasteful, with figures in the range 1%-3% being regarded as the norm. These low figures can be achieved for two reasons:

1. Design for manufacture ensures that the processes for ordering and cutting materials to size in the factory are much more controlled. Reduced wastage is therefore inherent to the manufacturing approach.
2. Waste collection, sorting, and re-cycling is easier to organise within a factory-

based production environment. This can result in much reduced volumes of waste for disposal and, if properly organised, can even produce a useful source of secondary income for the manufacturer. Recent work by Yorkon suggests that 85% of waste volumes can be diverted from landfill, and the cost of disposal can be transformed from a loss into a profit.

Despite the fact that a large fraction of an offsite building may be produced in a factory, there will always be a significant element of onsite activity and site-based waste will be produced. Studies by Jaillon et al (2008) [6] and Tam et al (2005) [7] examined records of the waste generated by offsite and conventional building projects. The data collection process consisted of a questionnaire survey (84 responses), interviews with professionals in the industry, and detailed case study analysis of more than 14 offsite and conventional building projects. The results suggested that the use of offsite processes reduced waste arising from timber formwork and concrete works by 74–87% and 51–60%, respectively. The authors concluded that net waste could be reduced through the adoption of offsite techniques, on average, by a factor of about two. Applying this factor to the overall cost of construction suggests that a direct saving in the order of 2.5% of the conventional tender price might be achieved.

Waste reduction at the end of building life should also be considered. It is possible to de-construct some buildings and re-use them elsewhere. This particularly applies to buildings constructed from large-scale sub-assemblies (e.g. volumetric buildings), and there are a number of examples where buildings have been de-constructed, moved, and re-used in other locations. The most common examples are probably the hire buildings that can have in excess of ten lives on different sites in different configurations. A more striking example comes from the large oil camps in Toft and Sollum Voe, Shetlands which had a first life of six years. They went in by barge and came out the same way and had a second life at a University in Africa.

3.3 Reduced Energy Use in Operation

Once a building has been commissioned, the environmental impact analysis shifts towards energy-in-use. Over the life of the building, this impact is significant (even dominant), but the annually recurring figures are generally low compared to the environmental impact and initial cost of construction.

Offsite construction techniques have the potential to reduce energy-in-use because the finished quality of the buildings is generally to a higher standard. Examples include structural quality (leading to improved air-tightness, for example) and operational efficiency (with pre-assembled/pre-commissioned M&E systems which perform much closer to their ideal specification targets than those which are assembled and commissioned onsite).

A survey of several different building types was carried out and their energy-in-use characteristics were assessed. The building types included educational, residential, leisure, and commercial office buildings. However, by far the best source of comparative data (offsite versus onsite) was found in the area of educational buildings, where examination of the energy performance records for a number of schools provided an objective baseline for the assessments.

27 Offsite Schools were identified and searched on the Non-Domestic Energy Performance Reregister [8]. Display Energy Certificates (DEC) and Energy Performance Certificates (EPC) for 7 of these schools were found. These 7 buildings were supplied by four different offsite manufacturers (Buchan Concrete, Elliot UK, KLH UK and Yorkon). A 93% improvement in EPC ratings and 26% improvement in DEC ratings was found when compared to the typical ratings recorded for this building type.

The 93% improvement percentage in EPC ratings is unlikely to be representative of most offsite buildings. This is due to the small sample size and the fact that Montgomery Primary School is an exceptional case. According to Buchan Concrete the building is the first zero carbon school in Europe and the first school to achieve Passivhaus standard in the UK. The authors therefore adopted the more conservative figure of 26% improvement in DEC ratings.

Fig 3.3 - EcoCanopy: an offsite system for nursery and primary schools

Even though the sample size is not much larger this is a more reliable result. DEC ratings are more reliable sustainability indicators since they are based on actual energy performance, whereas EPC ratings are not.

A more detailed examination of energy-in-use was then carried out for the 5 DEC rated schools. The average energy used for heating across the sample was found to be 124.8 kWh/m2/annum. This energy is primarily provided by gas, and the result represents a 24% improvement over the average found for conventional buildings. However, the average electrical energy used in the same buildings was 52 kWh/m2/annum, which represents a 13% increase against conventional buildings. In part, this reflects a shift from gas systems to renewable systems (which are more electricity oriented) in buildings which are designed to deliver improved EPC ratings. However, the anomaly serves to underline the difficulty in making even-handed comparisons across building types.

The total annual energy costs were calculated assuming that the cost of gas is £0.05p/kWh and the cost of electricity is £0.12p/kWh. On this basis, the annual energy costs associated with Lewisham Adult Learning Centre (by Yorkon) may be estimated at £16,634/annum. According to the DEC records, a typical building of this type would consume about 250 kWh/m2/annum, with an annual cost in the region of £29,000/annum. This suggests an annual saving for the Lewisham school in the order of £12,000 (approximately 40%).

Building name	EPC rating improvement percentage	DEC rating improvement percentage
Queen Emma Primary School	-24%	
Valentines High School		0%
Open Academy		18%
York High School		34%
The Bewdley School		36%
Lewisham Granville Park Adult Learning Centre		40%
Montgomery Primary School	210%	
Totals	93%	26%

Fig 3.4 - EPC/DEC rating improvements of 7 educational case study buildings

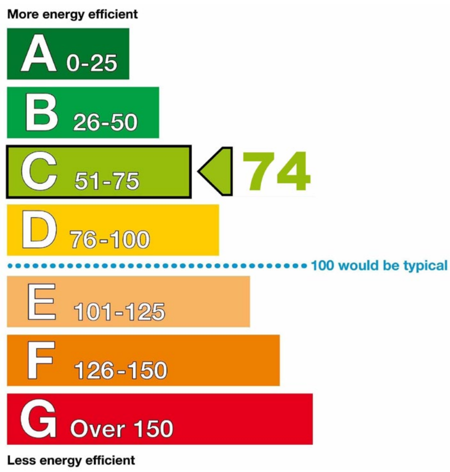

Fig 3.5 Average DEC rating of educational offsite case study buildings: on this scale, which includes the typical rating for conventional buildings of this type (which would be about 100) the rating is 74.

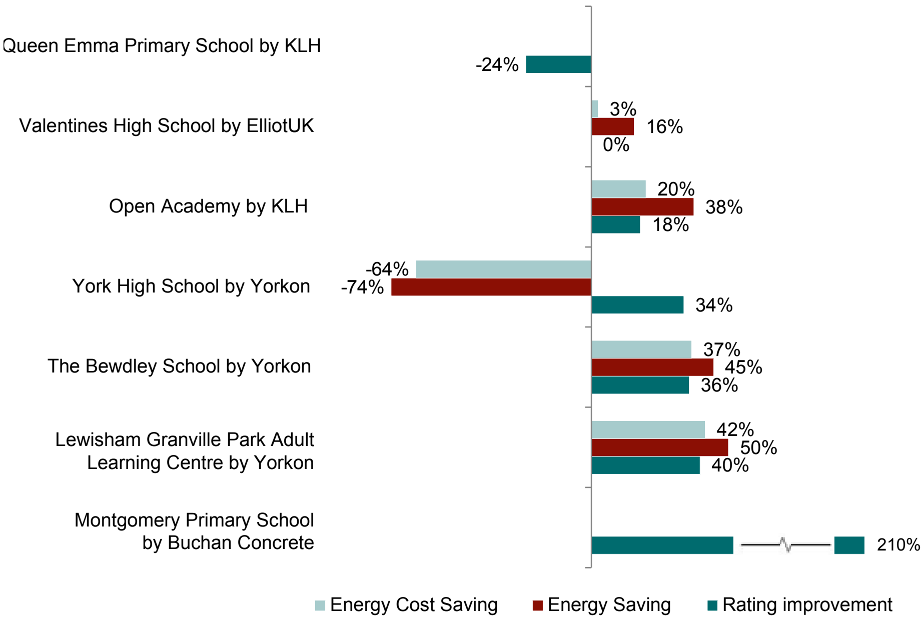

Fig 3.6 - Savings and rating improvements

Note: York High School has worse performance in terms of energy but a better DEC rating. This is as a result of a high amount of renewable energy, which the School produces (about 50%).

The studies of residential, commercial and leisure buildings were less successful in finding reliable data on comparative energy consumption. The results obtained from the analysis of schools have therefore been used to develop broader estimates for reductions in energy-in-use and energy costs across the remaining range of building types as outlined below.

For residential properties, the main benefits of offsite construction are likely to come through higher build quality (which leads to better air-tightness and better standards of insulation). The improvement to the energy-in-use characteristics will therefore be reflected primarily in the heating bills which, in turn, will lead to savings which are predominantly related to gas usage. Assuming a gas energy-in-use improvement of 24% (as recorded for schools), and a typical annual gas bill for a conventional property in the order of £700, a saving in the order of £200/annum might therefore be expected. Note that this is a very small amount compared to the average mortgage repayment of around £10,000/annum, and it is therefore very unlikely to feature as a serious driver for the adoption of offsite technology.

Similar arguments with regard to build quality and energy savings can be applied to commercial properties. A typical property in London’s West End (floor area 13,675m2) was examined and found to have a gas heating bill in the order of £14,000/annum. Assuming a 24% reduction for an offsite building of the same type would suggest savings in the order of £3,500/annum. At a construction cost of approximately £34M, the capital repayments for the building amount to around £2M/annum so, once again, the relative magnitude of the energy saving is small and is unlikely to drive the choice of offsite construction techniques.

Fig 3.7 - An offsite McDonald’s restaurant by Elliot Group

Within the retail/leisure sector, fast-food restaurants were selected for study because of the very large number of offsite buildings which have been completed in this field. Unfortunately, on closer examination, it became clear that the energy-in-use costs are dominated by cooking (not heating), and therefore the annual cost of energy is dominated by foot-fall rather than space heating requirements. No meaningful correlation between building quality and energy-in-use could therefore be developed.

In summary, therefore, it would appear that offsite construction can offer advantages to the building occupier in terms of reduced annual energy consumption and lower bills. However, in relative terms, these financial savings are small and are unlikely to drive the adoption of offsite techniques by either the building developer or the building contractor (neither of whom has a financial interest in the energy savings in any case). A bigger factor in driving change is the increasing visibility of Energy Performance Certificate (EPC) and Display Energy Certificate (DEC) ratings. A good rating is likely to attract developers and tenants with an interest in demonstrating their commitment to carbon reduction and the Green Agenda. The ability of offsite methods to improve performance ratings has been well illustrated by the schools examples.

4. ECONOMIC AND FINANCIAL CONSIDERATIONS

4.1 Faster Construction

Offsite construction has many advantages, but the clearest and most frequently cited advantage is speed of construction. Dramatic improvements over conventional techniques are commonly acknowledged, with the time required to construct and commission an offsite building being typically reduced by 50% - 60% in cases where large elements can be pre-fabricated (e.g. houses, budget hotels, small schools, prisons, etc). In the case of larger and more complex buildings (e.g. large office blocks, city-centre shopping/leisure buildings, etc) less dramatic savings are likely but, nevertheless, impressive results (programme reductions of 25%-30%) have been claimed.

Speed of construction confers a major financial advantage on the building developer in the form of reduced financing costs. For a typical small/medium building project, this may be illustrated as follows:

Building Type	Construction Cost (£/m2)	Typical Cost of Finished Building	Typical Land Cost	Reduction in Construction Programme	Savings in Financing Costs (at 8% p.a.)	Saving as a % of Construction Cost
School (small, single-storey)	1,500	£3M	£3M	60% (7 months)	£280,000	9.3%

It is important to note that the benefit suggested in the table above is magnified because it includes savings in financing the land as well as the construction of the building.

There are particular 'programme compression benefits' associated with certain classes of building which can be even more influential than the financial benefits outlined above. Examples are:

- **Air-side buildings at airports:** These buildings are highly sensitive to the length of the construction programme because operational disruptions can have huge adverse effects on the primary revenue-generating operations of the client. The value of time in such cases is highly magnified.
- **Prisons:** There is a clear benefit associated with minimising time on site for new prison projects, given the current conditions of overcrowding. Prison extension/refurbishment projects have added security considerations which add to the case for swift completion.
- **Hospitals:** Private hospitals have a very strong financial drive to open sooner, and National Health hospitals have a combination of financial and public policy drives.

4.2 Improved Cash Flow

A second financial benefit associated with the adoption of offsite technology lies in the fact that the cash-flow for the contractor and developer is improved.

For projects which adopt large-scale components or (better) volumetric systems, the standard terms of business from the supplier are likely to be more aligned with models from the manufacturing industry where the payment for goods supplied falls due after delivery and acceptance by the client (less some deposit or other initial payment). In extreme cases, this can mean that the cash demand on the contractor/developer for a significant fraction of the

Fig 4.1 - HMP Oakwood: 76,000 man hours of construction activity saved from using pre-cast solutions. Capital savings estimated at £5m.

total construction price is deferred until after the building has been completed (and, maybe, until after the building generates cash from sale or rent).

Another form of cash-flow benefit arises from the fact that the sooner the building is completed and commissioned, the sooner the owner will receive a cash–flow stream from sale or rent. Consider a small building such as a private residential block or a budget hotel. The construction cost might be £5M and the land cost might be similar, and the finished building might be delivered by a programme that is 6 months shorter than a conventional construction programme. If we assume the building yields a rental stream of 8% of the value of the finished building (construction cost plus land cost plus development gain), the cash generated by the 6 month advantage will be in excess of £400,000 (or 8% of the construction cost).

4.3 Reduced Snagging and Defects

Snagging and fixing defects following tenant occupation are by-products of an imperfect production process. Whilst the consumer products industry has adopted manufacturing processes which have close to zero defects, the same is not true for the conventional construction industry; the defect norms for buildings are far worse than they are for manufactured products, and this represents a back-end liability for the builder.

Experience shows that defect rates in finished buildings are far lower for buildings in which the complex elements have been pre-assembled and commissioned offsite (HVAC units, bathrooms/toilets, kitchens, etc), and where the structure has been assembled from large-scale factory-built components. It is logical to assume that the defect rates on these types of components will tend to manufacturing industry norms and, if this is the case, the reductions in snagging and defects rectification on offsite buildings will be considerable.

Most building contractors make an implicit provision for snagging and defects in the order of 1% of the tender price. The real cost to the industry is probably much larger than this, but a great deal of the snagging costs are passed directly to the trade sub-contractors and is not formalised in any bid documents. If we assume that the total cost of remedying defects is nearer 2%, and that defect rates might be halved, the benefit of moving to offsite methods is estimated to lie in the order of 1% of the cost of construction.

5. CONCLUSIONS

Offsite construction has many attributes to commend it from a sustainability point-of-view. The arguments presented in this report are overwhelmingly positive; indeed, it is difficult to find any aspect of offsite construction which has a negative implication for the sustainability case.

Given the strength of this case, it might be considered odd that offsite methods have not achieved a greater presence within the construction industry. It is the view of the authors that the reason for this lies in the fact that the benefits arising from the sustainability case bring no direct advantage to the developer or the building contractor (the key decision-makers at the time when construction methods for a project are defined). This point is illustrated in the table below, which sets out the main sustainability arguments examined in this report and attempts to identify where the main benefits arise and where they accrue.

Referring to this table, the following key points should be noted:

- Offsite construction has a very wide range of sustainability benefits, some of which are coupled with significant financial benefits.
- In cases where the financial benefits accrue to the developer/builder, it might be expected to influence the decision to adopt offsite methods for construction. However, the power of this influence depends on degree.
- The biggest financial benefits (by far) arise from the increased speed of construction which brings about reductions in construction programme and consequent reductions in financing costs. There are also significant cash-flow benefits to be had in terms of early completion and consequent early sale/rental income.
- Beyond those issues identified above, many of the financial benefits which have been estimated here are relatively small when measured as a fraction of the construction value. Their degree of influence over the choice of construction method is therefore unlikely to be significant.
- There are some offsite sustainability benefits which are difficult to express directly in terms of general percentages of construction value but which, nevertheless, are very powerful commercial factors. These include:
    - Early availability of the finished building – early sale/rental streams have been mentioned above, but there are particular benefits for certain classes of building which can be even more influential. Examples include air-side buildings at airports, (where the value of time is greatly magnified because construction disruptions can have huge adverse effects on the primary revenue-generating operations of the client), and ‘imperative’ buildings in the public sector (e.g. prisons and hospitals).
    - Higher EPC/DEC/BREEAM ratings - the value of a good energy/sustainability rating can be significant when determining the commercial value of a finished building to a property developer.

In summary, it may be said that the ideological and commercial benefits of offsite construction are numerous. Depending on where the financial benefits accrue, these factors can be expected to influence the choice of building method. In cases where the construction cost, operational costs, and time-benefits all accrue to the same party (e.g. owner/occupiers; PFI-schemes; etc), the case for adopting offsite methods is particularly compelling.

Category/Attribute	Potential Improvement over Conventional Construction	Societal Benefit	Financial Benefit to Builder/Developer	Commentary
		SOCIAL		
Health & Safety	Up to 80%	Large	N/A	H&S is a critical operational factor for the builder/developer, but it is not appropriate to record a financial benefit under this heading
Improved Working Conditions	Significant	Significant	N/A	Improved working conditions in the factory have little effect on the builder/developer
		ENVIRONMENTAL		
Reduced Road Traffic Movements	Up to 60% (20%)	Significant	Small (Less than 1% of construction value)	Improvements shown in parenthesis are net figures making allowance for factory-based traffic movements
Reduced Energy Used on Site	Up to 80% (30%)	Small	Small (Less than 1% of construction value)	Improvements shown in parenthesis are net figures making allowance for factory-based energy consumption
Reduced Waste	Up to 90% (50%)	Significant	Significant (Up to 2.5% of construction value)	Improvements shown in parenthesis are net figures making allowance for factory-based wastage
Reduced Energy-in-Use	Up to 25%	Significant	Small	Financial savings from reduced energy-in-use are not a motivator to the builder/developer (except where the builder/developer is also the operator/occupier of the building)
		ECONOMIC		
Faster Construction	Up to 60% reduction in onsite construction programme	Significant	Large (Up to 8% of the construction value)	Benefit realised through reduced project financing costs
Improved Cash-Flow	Significant	Small	Large	
Reduced Snagging & Defects	Up to 80%	Small	Significant (Up to 2% of construction value)	

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