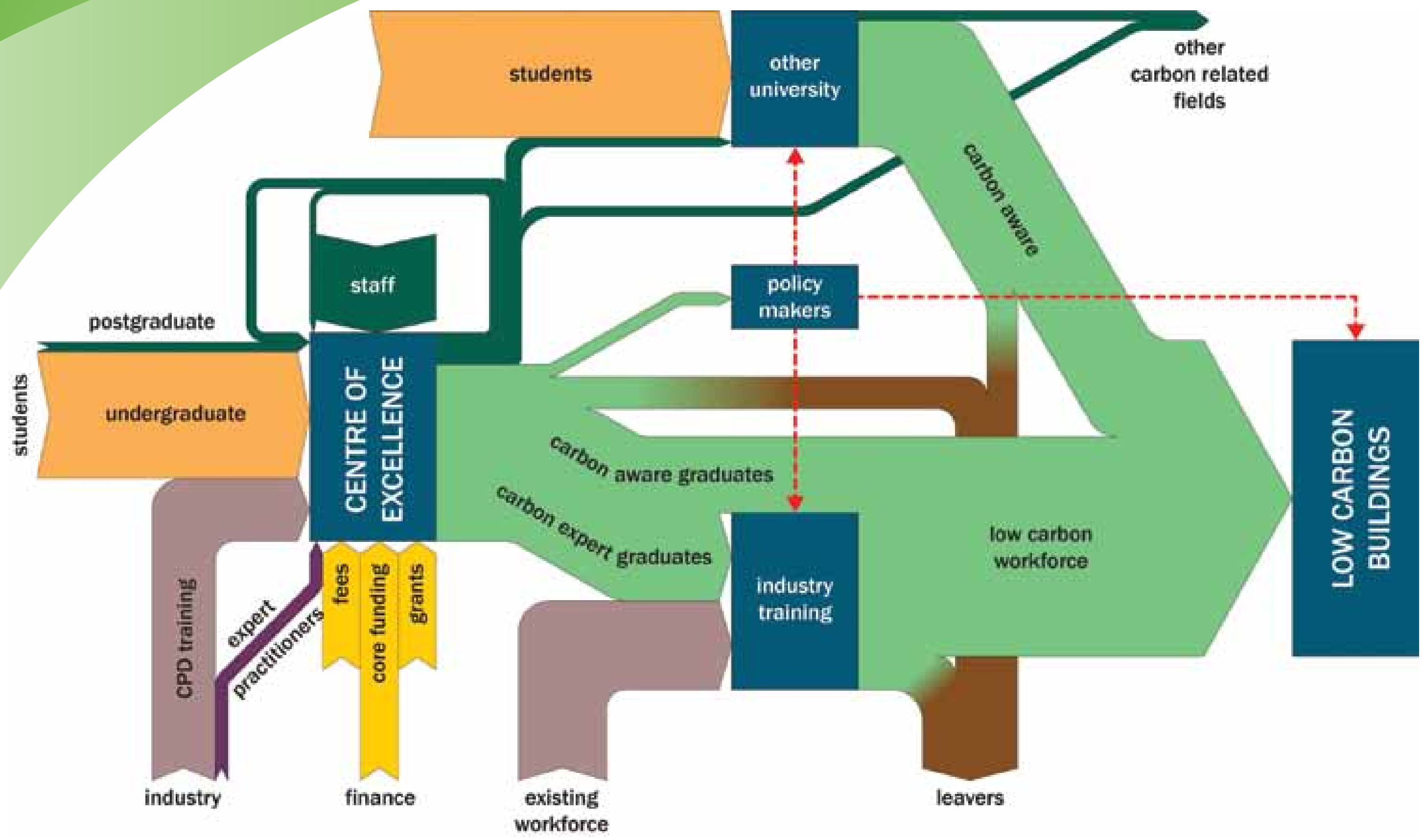
The Royal Academy of Engineering

The case for Centres of Excellence in sustainable building design



Front cover: Sankey diagram showing energy distribution in creating systems

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ISBN 1-903496-80-2

May 2012
Published by
The Royal Academy of Engineering
3 Carlton House Terrace
London SW1Y 5DG

Tel: 020 7766 0600
www.raeng.org.uk
Registered Charity Number: 293074
Copies of this report are available online at: www.raeng.org.uk/coe

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President,
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Foreword

The demanding climate change policies adopted in the UK have enhanced the need for engineers to create solutions to drive carbon reduction across society and industry. As the built environment is responsible for around 45% of CO_2 emissions, engineers have an exciting opportunity to play a key role in reducing the UK's carbon footprint by reducing energy consumption in existing buildings and engineering new energy-efficient structures and buildings.

When I meet young professional engineers, I admire their drive to succeed and their relish for shaping and improving society. The future will be safe in their hands but they need support in order to succeed. This starts with the engineering education they receive at university.

This report makes some important and effective recommendations on how the UK can better prepare its young engineers to reduce the carbon footprint of our buildings. I believe there is a compelling business case for change as well as a huge opportunity to promote knowledge and build a forward-looking professional workforce. By investing now in centres of excellence, we will not only make cost savings in the long-term, but help the UK become a world leader in low carbon construction.

Sir John Parker FREng
President,
The Royal Academy of Engineering

Doug King, Principal of King Shaw Associates Ltd and Royal Academy of Engineering Visiting Professor in Building Engineering Physics at the University of Bath

Preface

This report presents the outcome of an exercise to establish the costs and benefits for the UK economy of creating a network of centres of excellence in integrated, sustainable design for construction. These centres will promote knowledge, teaching and research in sustainable and low carbon design techniques and the application of technologies for the benefit of the UK low carbon construction industry.

The project was funded by the following organisations:

The Centre for Window & Cladding Technology

The Chartered Institution of Building Services Engineers

The Happold Trust

King Shaw Associates Ltd

The Ove Arup Foundation

The Royal Academy of Engineering

The University of Bath Knowledge Transfer Partnership

The report was prepared by Doug King, Principal of King Shaw Associates Ltd and Royal Academy of Engineering Visiting Professor in Building Engineering Physics, with contributions from Dr Paul McCombie, Deputy Head, Department of Architecture and Civil Engineering at the University of Bath and Steve Arnold of Metroeconomica.

The report could not have been produced without the support and guidance of Eur Ing Ian Bowbrick at The Royal Academy of Engineering.

The 2011 Low Carbon Construction Skills Survey was undertaken by IPSOS Mori.

This is the second report on building engineering physics that Doug King has written for The Royal Academy of Engineering. The first, *Engineering a low carbon built environment*, is available from www.raeng.org.uk/elcbe

Executive summary

Introduction

While the aim of climate policy in the UK is to reduce greenhouse gas emissions by 80% by the year 2050, energy consumption in the built environment is responsible for around 45% of emissions of CO_2, the principal greenhouse gas. Clearly the construction industry has a major role to play in achieving our policy targets, yet the knowledge and skills necessary to achieve such dramatic reductions are presently insufficient to meet the challenge.

This report recommends the establishment of a network of centres of excellence in integrated sustainable building design to support the construction industry through a period of rapid and unprecedented change. These centres will be:

- hubs for collection and dissemination of existing knowledge and the generation of new
- providers of interdisciplinary education both for students and established professionals;
- fundamental researchers into emerging low carbon design techniques and technologies
- portals to academic research capability for businesses requiring research support;
- repositories of unimpeachable expertise accessible to policymakers and the media.

This report has evaluated the economic benefits to the UK from just one aspect of the activities of the proposed centres: the provision of specialist undergraduate engineering education. By bringing together building engineering physics with engineering, architectural and systems design, these centres will equip students with the skills to implement passive energy conservation, appropriate renewable and low carbon technologies and appropriate, community-based, decentralised generation.

Engineering graduates trained at these Centres of Excellence will enter the construction industry equipped with the skills to deliver the necessary carbon abatement at a cost significantly below the present, business as usual, approach. Considering this aspect alone, the Centres of Excellence represent an unprecedented opportunity for the UK to strengthen its position as a leader in low carbon construction.

Seed funding of just £30 million over five years to establish four such centres of excellence would deliver cumulative savings with a net present value in excess of £1 billion by 2030 and a reduction in emissions of 3.5 million tonnes of CO_2 per annum. By 2050 the cumulative savings would have risen to over £6 billion net present value and a reduction in emissions of nearly 11 million tonnes of CO_2 per annum, about 2.5% of the target.

The other, unquantifiable benefits from establishing the centres of excellence have not been evaluated financially in this study, but nevertheless the cumulative impact will, without doubt, far exceed the simple savings quoted herein.

This report forms part of the Department for Business Innovation and Skills Low Carbon Construction Action Plan.

Background

For the last six years The Royal Academy of Engineering has been running a highly successful industry-initiated and funded pilot scheme placing expert practitioners in low carbon construction into top UK universities as Visiting Professors in Building Engineering Physics. These visiting professors have contributed a range of new skills and education in low carbon design for graduates who are now beginning to take up positions in the industry.

This scheme has demonstrated the opportunity that would arise from deeper penetration of wide-ranging low carbon design skills through the establishment of a network of Centres of Excellence for integrated sustainable building design across a number of UK universities.

This report evaluates the need for new skills and new approaches in low carbon and sustainable design in order for the construction industry to reliably and consistently deliver low carbon buildings at the lowest cost to society. It addresses the range of skills appropriate to implementing passive energy conservation such as natural ventilation and daylighting, the application of a systems engineering approach to the implementation of low energy heating, ventilation and air conditioning while integrating appropriate renewable and low carbon energy sources both at the level of individual buildings and community-based, decentralised generation.

This report presents proposals for the formation, governance and structure of the proposed centres of excellence, indicating the likely operating costs and typical outputs. Finally a cost-benefit analysis is provided to put a monetary value to society against the future work of specialist engineering graduates from the centres of excellence.

The case for centres of excellence

With the current state of the UK and global economies the prospect of large scale expenditure to secure our future energy supplies and combat climate change is less than welcome. It is therefore particularly pressing that we now instigate action to deliver future energy and climate security in the most cost-effective manner.

Evidence now being collected from the first tranche of prototype low carbon buildings is not promising. On the whole it appears that the industry is not yet adequately equipped to deliver low carbon construction, and where this has been achieved it has often incurred greater cost than anticipated.

Both the evidence from demonstration projects and the assumed cost of low carbon housing retrofits included in the *Green Deal* suggest that continuing with the present approaches to carbon abatement would be unaffordable if we accept the target expenditure rate for climate change mitigation arising from the Stern review. Stern also highlighted the potentially much greater future costs of failing to take early action on carbon abatement. Further, the demand for energy in the UK continues to grow and any delay in implementing action to reduce that demand will increase the present £200 billion predicted cost of renewing and upgrading our electrical generation and distribution infrastructure.

It is vital therefore, that we now pursue carbon abatement at the lowest possible cost in order to balance the future threats of energy and climate security with the need for economic recovery.

The construction industry needs to make a step change into the low carbon paradigm in order to meet the ambitious targets for low carbon refurbishment and zero carbon new build being set by government policy at a cost that is affordable for society. This represents an unprecedented challenge for an industry sector that has amongst the lowest investment in training, research and development of any in the UK economy.

While some knowledge of successful sustainable construction strategies does exist, the industry lacks a coherent and replicable approach to delivering such buildings. Some parts of the UK construction industry are world leading in their approach to integrated low carbon building design. However, it is estimated that 90% of construction effort in the UK is delivered by small businesses, employing 10 people or less, which do not have the resources to implement the rapid and radical changes needed, or even to absorb the growing body of knowledge about current best practice.

Further, the construction supply chain is highly fragmented with design and delivery of building projects divided across many different professions, none with overall responsibility for ensuring the sustainable performance of the finished product. These divisions also make effective dissemination of innovation and best practice extremely difficult and a great proportion of effort in the low carbon sphere is wasted on repeating similar initiatives without proper verification of the outcomes or dissemination of the learning.

IPSOS Mori, the leading research organization, was commissioned as part of this project to canvass opinion from business leaders across the construction industry as to the extent of their capability in delivering low carbon buildings. This research underscored the dichotomy between the leading actors in the field and the majority of firms delivering routine building projects.

Clearly, the construction industry urgently needs a repeatable, verifiable approach to integrating low carbon thinking in the design, procurement and construction process. Without this, the current poor understanding of carbon abatement techniques will persist and we risk an industry trapped in a cycle of experimental prototypes, never capturing the learning necessary to move forward to a replicable mass-market product.

Centres of excellence in integrated sustainable design would provide the focus for research and dissemination of low carbon techniques and technologies. Traditionally the construction industry does not engage well with academic research and often valuable new information may take many years to be widely adopted. By bringing together research, undergraduate and postgraduate teaching and continuing professional development (CPD), the centres of excellence offer rapid dissemination of the results of fundamental research and best practice case studies. The current growth in demand for training in low carbon design would ensure rapid take up within the industry.

The structure of centres of excellence

A centre of excellence needs to be much more than a typical university research centre. The primary aim of the proposed centres of excellence is to enhance the education of building designers, within a multidisciplinary environment, so that they are equipped to deliver the low carbon buildings using the most economic and advantageous techniques. In order to achieve this it is necessary that the centres of excellence become hubs for acquiring, refining and disseminating knowledge of low carbon design, construction and facilities management in addition to the traditional academic focus on fundamental research.

Such a focus of both new and collective knowledge will inevitably have far-reaching benefits beyond the host university and the centres should be planned and developed in order to maximise these opportunities. The centres should be established as a partnership between the construction industry and academia drawing on leadership from established and respected practitioners with proven expertise. The conjunction of practical and academic credibility in the field will enable the centres to provide independent and authoritative advice to researchers, designers, owners, developers, policy makers and the media alike.

Further, by engaging practitioners in leadership roles, the centres will become more aware of the demands and constraints of the construction industry, allowing them to respond more flexibly to requests for research support and so leverage the benefits of the academic research programmes. The centres could also provide facilities to allow the industry and manufacturers to engage directly with fundamental research and so anticipate future industry needs whilst also providing the expertise and consultancy that will allow them to address those needs.

All of these activities will enhance the ability of the centres to attract the brightest and best of our young people to become engineers and architects with a sound knowledge of low carbon design and so bring about the required revolution in the construction industry. The centres would continue to support these new professionals throughout their careers, as well as expanding the expertise of established professionals, through the integration of postgraduate education and continuing professional development.

In order to meet the goal of supporting the entire UK construction industry, centres of excellence should be established at a number of regionally diverse universities rather than concentrate the expertise in a single location. The university hosts must have existing strengths in architecture and engineering, an interdisciplinary design ethos and strong industry links. The greatest benefit will come from a network of centres, each building on the individual research strengths of its host, but collaborating both in research effort and dissemination.

The benefits of centres of excellence

This report evaluates the cost and benefits of initially establishing four Centres of Excellence. Once established, these centres could deliver between 200 and 250 engineering graduates each year with demonstrable expertise in low carbon design. These graduates will have received a unique education, encompassing both engineering theory and design practice, and will enter the construction industry equipped to deliver carbon abatement at low cost through the application of building science to energy conservation using techniques, such as natural ventilation and daylight with thermally efficient building fabric and envelope, rather than adopting the typical approach of applying expensive micro-generation technology to offset unnecessarily high energy consumption. Where micro-generation is required the graduates will have the skills to integrate these technologies with the remainder of the building systems to achieve the greatest efficiencies from the combined system of energy demand and generation.

By reducing energy consumption through inexpensive, passive design measures, not only does the building occupier benefit from lower fuel bills but society benefits by the reduced need to generate and deliver energy and by the reduced consumption of natural resources. By reducing the fundamental demand for energy we achieve a triple saving for the UK economy; firstly, by reducing the rate of growth of energy demand we reduce the investment required for new generation and distribution infrastructure; second, we mitigate the cost associated with abating the carbon emissions from the energy that would otherwise be consumed; third, we reduce the need to import fossil fuel.

Thus, by comparing the savings available through energy conserving design compared with the costs of applying renewable and low carbon generation technology it can be seen that graduates from Centres of Excellence can deliver carbon abatement at a lower cost to society than current business as usual.

Four Centres of Excellence are projected to require seed funding of £30 million over five years. The seed funding would be used to attract the appropriate calibre of academic researchers, teachers and industry-based tutors to establish the centres. After the first five years it is anticipated that the centres would become self-sustaining through their ability to attract students and research funding.

Analysis of the benefits indicates that, at a minimum, the graduates from just four Centres of Excellence could deliver carbon abatement through building energy conservation measures with a cumulative net present value well over £1 billion by 2030, reducing emissions by 3.5 million tonnes of carbon dioxide per annum at the end of the period.

Projecting the analysis forwards to 2050 shows an abatement potential of nearly 11 million tonnes of carbon dioxide per annum, or about 2.5% of the total abatement required from the relatively modest investment of £30 million. The cumulative abatement over the entire period would generate savings with a net present value of over £6 billion compared to delivering the same abatement through the present mix of energy-saving technologies and micro-generation.

Without the wider penetration of low carbon design expertise offered by the Centres of Excellence, policy and practice will likely continue to pursue technological fixes for carbon abatement which, on the face of it, appear beneficial, but do not necessarily deliver the desired outcomes. For instance, recently fashionable domestic wind turbines can actually consume more mains electricity for the metering and controls functions than they generate over the course of a year in an urban environment.

With the help of Centres of Excellence the construction industry can change direction, using the intelligence of building engineering physics and an integrated systems engineering-based approach to reduce the fundamental demand for energy in buildings. This will reduce not only the need to invest in expensive technologies within buildings, but will also reduce the need to build new generation and distribution capacity to feed ever-escalating demands from buildings. Reducing building energy demand must surely be a key element for energy security policy, not just for climate policy.

Centres of Excellence will also create a demand for high-quality, high-performance building products, as the expertise to utilise them becomes more widespread. Bulk building products, such as concrete, masonry, insulation, structural members and internal finishes tend to be sourced from within the region or country where the construction occurs, whereas microgeneration technologies are often imported. By equipping the UK construction industry to better utilise the bulk properties of buildings for energy conservation, demand for higher-performing products from our indigenous manufacturing industry will be reinforced while the demand for imports will be reduced.

Furthermore, through increased familiarity with energy conservation, the construction industry will be better able to specify the performance required from high-value elements of construction such as cladding, heating and ventilation systems. This demand will help to leverage new jobs in the low carbon manufacturing sector, and by driving improvement in the products, will enhance the ability of UK manufacturers to export into a wide range of new markets

UK universities already attract a significant number of overseas students. Graduates from Centres of Excellence who subsequently return overseas to work in their own construction industries will export UK expertise in low carbon design and create demand from those countries for the products and services on offer from the UK. Finally, such overseas students will also contribute significantly to carbon abatement in their own countries to the benefit of all.

Recommendations

It is crucial that the efforts to reduce carbon emissions in the UK start with the abatement potential at the lowest net cost to society. By delivering the largest abatement at lowest initial cost, finance can be conserved for research into improving the cost of future abatement using high-technology solutions. This report demonstrates the potential to deliver carbon abatement in the built environment at a high positive value to society through simple and relatively inexpensive investment in appropriate engineering education.

1. Government should commit investment to set up and provide pump-priming funding for at least four Centres of Excellence in Sustainable Building Design. The centres should be hosted by universities with an established record of multidisciplinary teaching for architects and engineers, expertise in building physics and an established record of engagement with the construction industry.

2. Universities hosting Centres of Excellence must commit sufficient resources to allow the staff to engage widely with the construction industry, with policymakers and with the media in addition to research and teaching.

3. In order to establish credibility with the construction industry, the Centres of Excellence should be led jointly by academics and by experienced and well-regarded practitioners with a track record of designing successful sustainable buildings.

4. Research Councils UK should commit funding for interdisciplinary research in low carbon building design, occupant behaviour and construction techniques that are available to a much broader range research endeavours, both commercial and academic, rather than the narrow fields of research presently funded.

5. The professional engineering institutions should develop common curriculum and standards of professional development for engineers practising sustainable building design.

6. The Engineering Council should augment the standards of competence in sustainable engineering design for the grades of Engineering Technician, Incorporated Engineer and Chartered Engineer.

Introduction

The UK's commitments to mitigating climate change mean that we need to achieve an overall 80% reduction in greenhouse gas emissions across the economy by 2050. This goal has been broken down into a series of future carbon budgets to ensure a manageable progression *(Figure 1)*. Energy consumption in buildings presently accounts for some 45% of UK emissions of CO_2 , a major greenhouse gas, and so the reduction of emissions from the built environment is a major plank of policy on climate change. It is already a requirement that all new buildings shall be zero carbon from 2019 with an earlier date of 2016 for new build homes and schools.

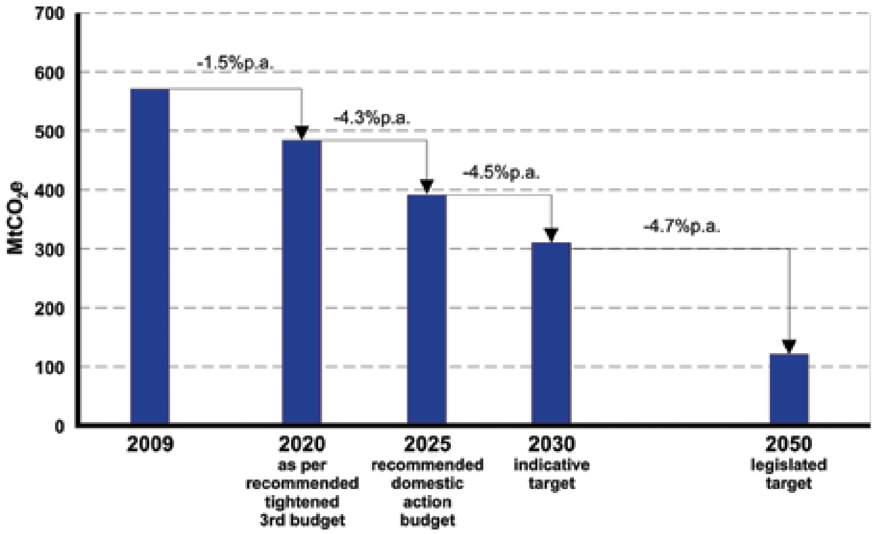


Figure 1: Required rate of reduction of greenhouse gas emissions (excluding international aviation and shipping) 2009 to 2050 [CCC, 2010]

The scale of the task facing our society is enormous and the future cost of meeting our future energy needs, while also addressing our climate change commitments, could have a significant impact on the health of the economy as a whole. It is essential that the necessary carbon abatement is achieved at the lowest possible cost to society, and yet recent policy announcements seem to indicate that, in relation to the construction industry at least, the best opportunities for low-cost mitigation are sometimes being overlooked in favour of costly, high-technology alternatives.

Policy is now being developed to target carbon emissions from existing buildings, principally dwellings. The Low Carbon Construction Innovation and Growth Team Final Report [BIS, 2010], estimates that in order to achieve a 60% reduction in CO_2 emissions from the UK housing stock by 2050 will require investment of £200 billion in energy efficiency retrofit and refurbishment. However, this alone will not achieve the overall policy requirement of an 80% reduction in greenhouse gas emissions. Energy efficiency in buildings is one of the more readily achievable savings and in order to compensate for the reduced abatement potential in other sectors of the economy. The Committee for Climate Change [2010] has estimated that it will be necessary to achieve a 90% reduction in CO_2 emissions from buildings.

In *Warm Homes Greener Homes* [DECC CLG, 2009] part of *The Green Deal*, Government sets out an ambition that 7 million homes should receive eco-upgrades by 2020 and that all homes should be upgraded by 2030 (approximately a further 15 million). The strategy estimates the average cost of an eco-upgrade will be £10,000. Thus, to achieve the required rate of eco-refurbishment a total spend rate in excess of £7 billion per year will be necessary up to 2020 and £15 billion per year from 2020 to 2030. This indicates a total expenditure required by 2030 of around £200 billion.

Even then, the anticipated reductions in CO_2 emissions may not be realised. Studies into the outcomes of early trials in low carbon housing indicate that the actual performance achieved often fails to reach the predictions by some margin *(Figure 2)*. At present there appears to be a very large disparity between the assumed cost and benefit of carbon abatement techniques in the domestic sector and what can be achieved in reality.

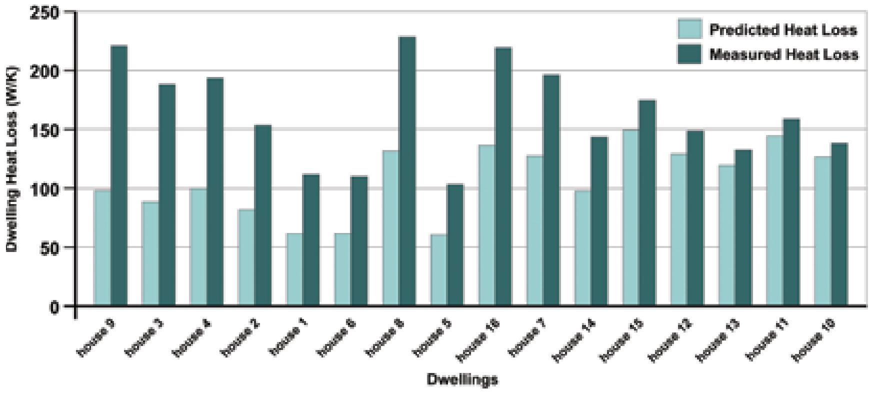


Figure 2: Comparison of predicted and measured heat loss in 16 low carbon housing trial projects [Bell et al, 2010a]

In addition, the UK has some 2 million non-domestic buildings with 596 million m^2 of rateable floor space [CLG 2009]. Commercial office space accounts for 84 million m^2 with 17 million m^2 classified as other office. With typical costs for an extensive sustainable refurbishment for commercial office space of £1,700/m^2 [Rawlinson, Harrison, 2009] and a median cost of £1,100/m^2 for a medium level of office refurbishment [Rawlinson, Wilkes, 2008] it would require a further spend rate of over £4 billion per year to refurbish just the existing UK office building stock by 2050. Nevertheless, once again it appears that low carbon refurbishment of non-domestic buildings is failing to meet expectation in some cases *(Figure 3)*.

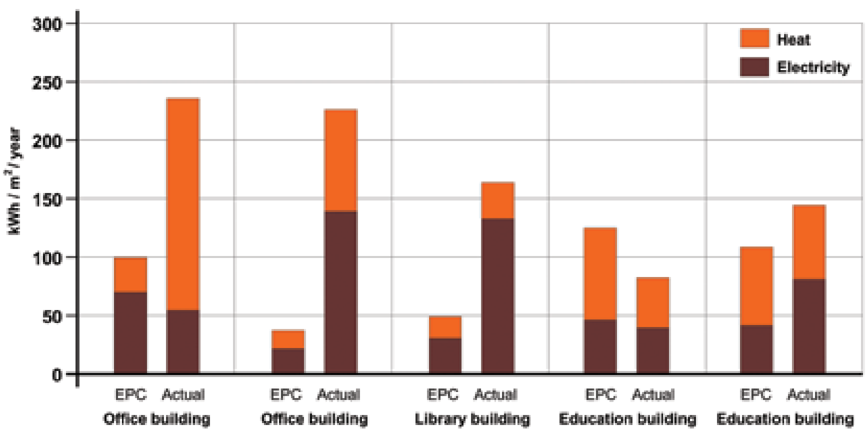


Figure 3: A comparison between actual regulated energy consumption and the output of modelling used to produce the EPC rating for 5 case study non-domestic buildings. [Carbon Trust, 2011]

Lord Stern [2006] estimated that implementing the measures necessary to achieve the UK greenhouse gas reduction targets across the whole economy should cost around 1% of GDP, or around £14.5 billion annually based on 2010 GDP. If this is the case, then the spend rate for retrofitting buildings implied by the application of current technologies and techniques would appear to be unaffordable.

In addition to the cost of retrofitting and upgrading buildings, OFGEM [2010] has indicated that expenditure of £200 billion will be required over the next decade in order to address the shortcomings in the electricity supply infrastructure. Much of this expenditure is required for the replacement of obsolete coal-fired and nuclear generation capacity, but what is not clear is how much of this expenditure is required to meet the growing demand for electricity in the UK.

When we are faced with the prospect of having to spend many hundreds of billions of pounds, and potentially still not reaching our goals for climate change while reducing our reliance on imported fuels, we must surely consider all other possible alternatives to our current approach.

Adopting alternative means of carbon abatement, primarily energy efficiency measures, in lieu of the more expensive technological fixes, will not only reduce the cost of refurbishing buildings for low carbon but potentially will reduce the investment required in additional infrastructure and generation capacity by slowing the growth in demand for electricity, or even reversing the trend and allowing the UK to keep going for longer on the existing capacity.

McKinsey [2010] indicates that on a global scale, the abatement potential from residential retrofit and new building energy efficiency exceeds the potential of Solar PV and High Penetration Wind which could be expected to be installed on buildings. However, building energy efficiency delivers a net benefit to the economy by reducing demands and therefore the need to invest in future additions to the energy infrastructure, while generation technologies are not only expensive to produce, they also demand upgrades to the infrastructure *(Figure 4)*.

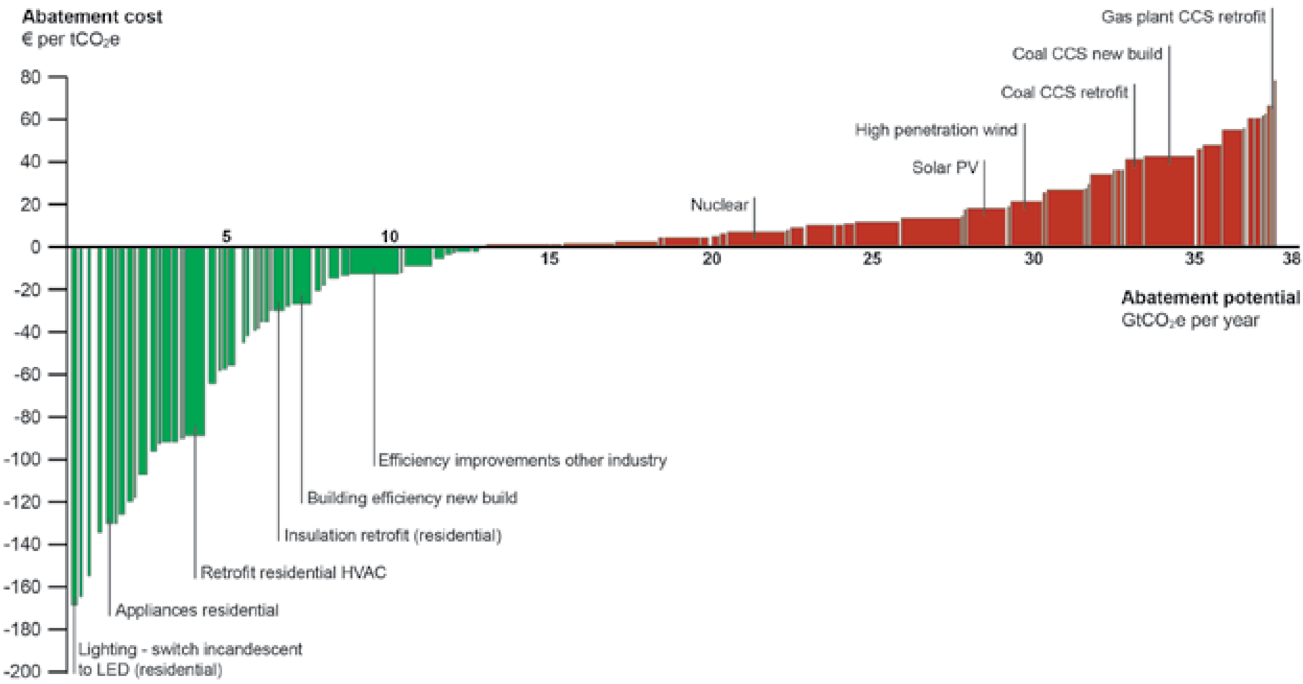


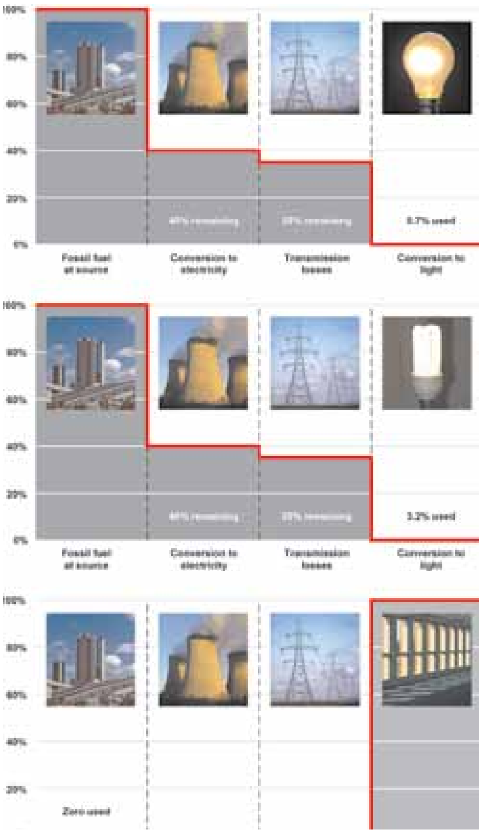
Figure 4: Global greenhouse gas abatement cost curve beyond business as usual to 2030 [McKinsey, 2010]

Government has recently estimated that, as a result of The Green Deal, jobs in domestic eco-refurbishment will rise from 27,000 at present to around 250,000 by 2030 [DECC 2010]. Given the similarity of expenditure rates for domestic and commercial low carbon retrofit and refurbishment, then it is likely that a similar increase in the workforce will be required to address carbon abatement in the commercial sector. Clearly all these new workers will need to be skilled in low carbon retrofit techniques and technologies. Not only will the individual workers need to be skilled in low carbon, but their management will also require new skills to design and lead low carbon installation and retrofit projects. Beyond the construction industry the regulators, such as building control officers, will also need to be fully conversant with the full range of low carbon techniques and technologies.

However, the construction industry is not yet equipped to train these workers while the necessary skills are not sufficiently widespread to consistently deliver low carbon buildings. Thus building designers, public and private sector clients, developers and contractors often resort to micro-generation technologies to reduce emissions from conventional building designs and meet current regulatory requirements rather than reducing the fundamental demands for energy. Building energy conservation is among the most cost-effective means of abating greenhouse gas emissions, while micro-generation installed on buildings is amongst the least cost-effective.

The combined challenge in reducing fossil fuel dependency in both new and refurbished buildings is vast and the construction industry presently lacks sufficient resource with the knowledge and skills necessary to properly address it. Without the appropriate skills in place, the cost to the UK economy of achieving carbon reductions from the built environment could be significantly higher than it need be, whilst possibly not achieving all of the required reductions.

Clearly it is vital to the health of the national economy to address the reduction of greenhouse gas emissions from the built environment in the most cost-effective way and not to simply adopt the path of least resistance. It has been demonstrated through contemporary projects that reducing demand through energy efficient design costs little more than conventional, inefficient design and the scale of emissions reduction that can be achieved substantially exceeds that which could be generated by expensive on-site renewable or micro-generation [King, 2008].



Using energy-efficient lamps does save energy compared to conventional tungsten lamps, but due to the inefficiencies in primary fuel conversion and distribution the overal benefit is small. By comparison lighting a building with daylight consumes no fossil fuel at all.

Low carbon construction

Construction is one of the largest industries in the UK, delivering just over 5% of UK gross domestic product and employing some 2.3 million workers in 2009 [CITB, 2010a]. However, the industry lacks cohesion and the vision to deliver large-scale change in the timescales necessary to achieve the UK's climate change commitments. The construction industry is highly fragmented and there are many parties in the supply chain, none of whom holds overall responsibility for delivering a building's carbon performance.

In *The Green Deal*, government has set out very ambitious strategies for reducing carbon emissions from buildings to contribute to the overall commitment of the Climate Change Act. The method of funding the necessary works is still under discussion, but is likely to rely heavily on private sector finance. However, the private sector will not invest in technologies that do not provide a reasonable rate of return no matter how great their contribution to achieving government policy.

It is vital, therefore, that this cornerstone of low carbon policy is supported by an equally strong drive in the construction industry and amongst client bodies towards delivering the necessary carbon abatement at the lowest cost to society. Otherwise, with the influence of the feed-in tariffs, this policy may just divert valuable funds into projects with short-term financial returns, but which, in the main, do not deliver real carbon abatement.

The benefits of conservation

Every tonne of CO_2 saved through energy efficiency measures represents energy that does not have to be generated and distributed. Thus savings to the economy accrue from energy efficiency, beyond the prime cost of the energy itself, as it becomes unnecessary to build additional energy generation and distribution infrastructure to serve growing demand and allows the existing infrastructure capacity to continue to serve a reducing future demand.

Technology versus Technique

There are two ways of approaching carbon reduction from energy use in buildings: to generate low or zero carbon electricity for supplying building needs, or to reduce the energy demands of buildings in the first place through good design, installation and operation.

In a typical contemporary commercial building about 75% of the total carbon dioxide emissions are associated with the fixed building services, providing lighting, ventilation and thermal comfort. These are the emissions regulated under Part L of the Building Regulations. The remaining 25% of emissions relate to the occupancy and business functions within the building and arise primarily from the use of IT and office equipment and are unregulated.

Considering just the regulated emissions, mechanical ventilation and comfort cooling represents about 35%, heating 25% and artificial lighting about another 25%. It is obvious therefore that avoiding or minimising the need for these artificial forms of conditioning is paramount in developing energy-efficient designs. Emission from all these areas of comfort design can be significantly reduced by attention to the passive design of the building fabric to reduce reliance on active systems. Further, designing the active system with knowledge of the passive building response can deliver substantial gains in operational efficiency.

For example, electric light fittings are highly inefficient, converting about 90% of the electrical energy input into heat and only 10% into visible light. Thus reliance on electric lighting often leads to the additional need for comfort cooling,

Wind turbines are often found as decoration on commercial buildings to make them appear to be more sustainable than they really are. However the increased surface friction due to the buildings in urban environments means that the power that can be extracted from the wind is only a fraction of that possible in open countryside.

compounding the dependence on electrical energy. On the other hand, in most of the UK, it is possible to design office buildings where artificial lighting is not required for 80% of working hours for desks within 6-8m of an exterior wall.

The technological fix

The feed-in tariffs were introduced to encourage the uptake of micro-renewable energy generation, primarily by householders. The need for subsidies is clear; micro-generation is simply not economic with the current low price of carbon. Small-scale wind power is a favoured technology being promoted under the scheme with one of the most generous feed in tariffs of 36.2p per kWh at the size of domestic installations.

However, the urban or suburban environment, where the majority of domestic installations will occur, is almost completely unsuitable for wind generation due to the increased surface friction created by buildings.

In a recent study, the Energy Savings Trust [2009] were unable to find a single urban or suburban wind turbine that generated more than 200kWh per annum, far short of the manufacturers' claimed performance figures, which are typically quoted for open countryside.

In some instances the amount of electricity generated by domestic turbines in the course of a year was less than the mains electricity consumed by the electronic controls necessary to synchronise the turbines with the mains. Thus, with the feed in tariffs in place on such an installation the government would be in the perverse position of paying a subsidy on the measured generation from the wind for an installation that actually achieved a net increase in carbon emissions.

The Jevons Paradox

William Stanley Jevons [1865], an English economist of the 19th century, discovered that James Watt's improvements to the efficiency of the steam engine did not reduce the consumption of coal as expected, but actually significantly increased the overall rate of consumption. The fundamental issue that Jevons identified was that improving the energy efficiency of a technology not only reduces its fuel consumption but also reduces its operating cost which, in turn, makes it affordable in applications that were previously marginal. This leads to more widespread use of the technology and thus to greater consumption of fuel or materials.

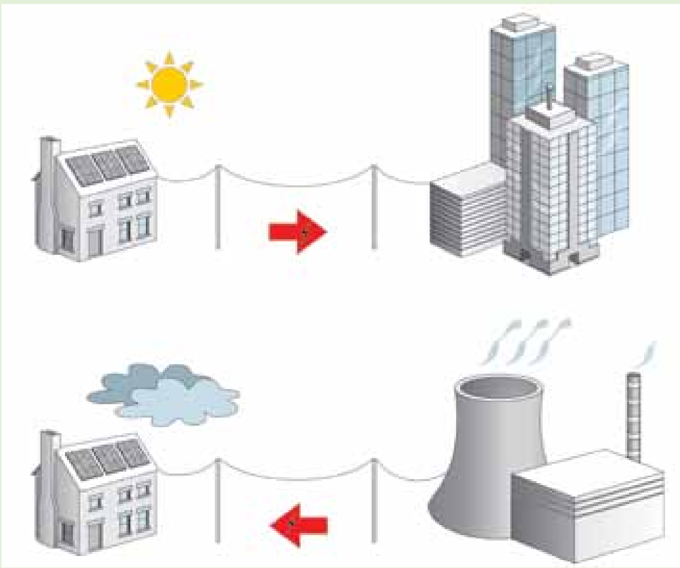
We can see examples of the Jevons Paradox in many aspects of energy efficiency in building technologies. The continuous improvement in the energy efficiency of lighting over many years should have led to substantial reductions in energy consumption for lighting in buildings. Instead what has happened is that commercial buildings have seen a marked increase in lighting levels in response to the reduced cost of operation.

A form of the Jevons Paradox applies to the use of small-scale renewable energy generation attached to buildings. The establishment of planning policies throughout the UK that require the integration of renewable energy into new building projects has, in some cases, led to reduction in the energy efficiency of building designs. Since a proportion of the energy demand for the building is generated from renewable sources, it is seen as free energy and this is used to justify an increase in overall consumption without placing additional demand on fossil fuel-supplied energy. Thus, rather than reducing the building's energy demand the incorporation of renewable energy merely maintains the status quo as far as carbon emissions and the national infrastructure is concerned.

Furthermore, construction is a highly competitive industry and projects are undertaken with tight budgets; there generally is not cash to spare for investment in renewable energy generation. So in order to incorporate renewable generation to satisfy policy requirements, developers may find it necessary to sacrifice some other aspect of the design. This sacrifice is often made in aspects of the building systems, such as variable speed drives and high-efficiency equipment that would have led to an overall reduction in energy demand. Thus, although the building may achieve policy objectives for on-site renewable energy, it is equally possible that the overall demand for fossil fuel energy also increases.

Most renewable generation is intermittent and thus during times of low generation the demand will have to be met from the conventional energy generation infrastructure. If, as a result of installing micro-generation, building occupiers have increased their energy consumption habits, this will necessitate expanding and reinforcing the infrastructure to deliver the additional demand. So the incorporation of renewable energy in building projects may actually result in escalating costs to society.

Zero carbon homes



The current approach to zero carbon homes illustrates the possible consequences of adopting technological fixes to carbon abatement in a narrow context without considering the wider context. The low-cost approach to zero carbon homes, typically adopted by the mass house builders, uses an electric heat pump to collect and amplify ambient heat energy from the environment to provide space heating. These homes also include some form of renewable generation, most commonly photovoltaics, to generate as much energy as the home consumes in the course of a year.

However, the photovoltaics generate energy predominantly during the summer, the heat pump consumes energy predominantly during the winter and thus a zero carbon home is not actually self-sufficient; it relies on carbon offsetting to achieve neutrality. During the summer the zero carbon home will generate sufficient surplus renewable energy to offset its consumption of electricity from fossil fuels during the winter. This works provided the minority of buildings are low or zero carbon. Once the majority of buildings become zero carbon, the offsetting scheme breaks down as there is no further demand to absorb the surplus generation.

If 20 million homes in the UK were to install sufficient PV to offset all their annual electricity consumption during the summer months then at peak production the total generation would be of the order of 80GW. The entire UK summertime electricity demand is presently of the order of 40GW. Unless the surplus electricity can be stored to use at a future time in place of fossil fuel then there is no carbon offset capacity available.

Conversely if just half of those homes were to switch to electric heat pumps for winter heating the demand for electricity during the peak winter months would require nearly 50% more than the current UK electricity generation and distribution capacity.

Thus by adopting renewable energy technologies in isolation not only does the homeowner incur the high initial installation cost, but society incurs a much higher cost in providing new infrastructure to deal with the hugely disparate generation and demand profiles. Reducing buildings demand for energy in the first place would provide a far more economical solution to reducing carbon emissions.

Design for passive energy conservation

The building envelope provides the primary means of controlling the internal environment, keeping out the weather and providing insulation against heat losses and gains. The proper application of insulation, shading and thermal mass in buildings can, in some cases eliminate demands for heating and cooling completely, but in all cases will deliver substantial reductions. Creating opportunities for natural light and natural ventilation also contribute to substantial reductions in the building energy demand.

The passive approach is not only good for the environment and good for the national economy, by reducing demands for energy; it is also good for the building occupier as, over the life of the building, much greater financial savings accrue from reduced maintenance costs associated with high- technology renewable generation.

However, the passive approach to design means that not only must the engineers be involved at the outset of a project, but that the architect and project manager must recognise the importance of building science and engineering to the early planning stages. Clients and their agents also need to be better informed of the benefits of engaging the engineering consultants early in the life of the project.

The argument for building science

The opportunities for delivering cost effective low carbon design features diminish rapidly with time elapsed through the life of a project *(Figure 5)*. It is essential therefore that construction projects, whether new build or refurbishment are commissioned from the outset with the appropriate design team members to evaluate and deliver the optimum low carbon performance.

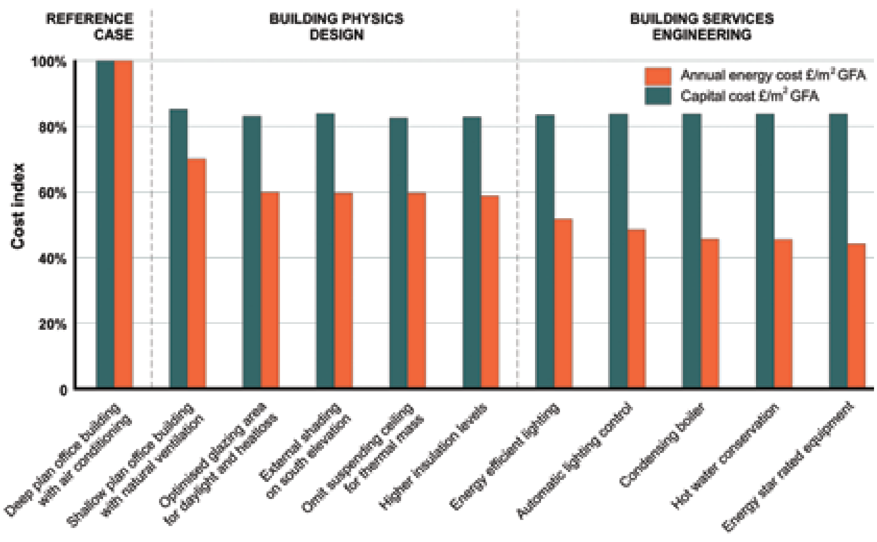


Figure 5: The potential for capital cost savings and operating energy cost savings at various stages of the design [EEBPP, 1999]

The opportunities to engineer the building fabric begin as various options for massing, orientation and layout are tested through the architects' sketch design. This is the stage at which most of the factors that influence the final energy performance are fixed, albeit sometimes unwittingly. For instance: designs with more than the optimum proportion of glazing will lead to excessive heat losses in winter and excessive heat gains in summer, both of which will require active systems to remediate their impact. Meanwhile the excessive glare caused by too

Over-glazed facades not only lead to unnecessary heat loss in winter and demand for air conditioning in summer, but the excessive glare means that occupants will close blinds increasing the demand for artificial lighting.

much daylight at the perimeter will typically lead to the occupants installing blinds, which are often left closed, leading to the excessive use of electric lighting.

An optimal design of the building fabric, on the other hand, will provide significant reductions in heating and cooling loads which in turn allow smaller heating, ventilation and air conditioning equipment to meet the remaining demands. In well-designed buildings, the extra cost of high-performance fabric will typically be offset by the capital savings achieved in reducing heating, ventilation and air conditioning (HVAC) equipment. Subsequently, further savings will accrue due to the lower operating and maintenance costs of the HVAC plant. Should micro-generation technology be incorporated, the low energy demands from the reduced HVAC requirement mean that the generation will be able to meet a more substantial proportion of the overall energy demand.

Furthermore, as the environmental performance of the building is passive and built in, it will not require the same levels of maintenance or energy to operate, it will not break down and it should not need to be replaced during the life of the building. Thus the construction industry can deliver genuinely sustainable buildings by making the durable parts of the building, the structure and envelope, work as hard as possible in controlling the internal climate.

However, in order to create buildings fit for the low carbon economy, the construction industry can no longer afford to continue experimenting with the physical form and energy performance of buildings. In construction, each product is essentially a prototype, and due to the product lifespan, it may take years or decades for building performance issues to come to light. The design of new buildings must henceforth be based on rigorous analysis with full knowledge of the passive and active performance of the fabric and systems.

Not only is the application of building science essential in the design process, the application of scientific method is vital in establishing a rigorous and credible body of knowledge that can be applied within the design and construction process. Architectural education proceeds on the basis of precedent and experience, often without the benefit of actual performance data or critical analysis. Engineering, on the other hand, is predictive of performance and must apply rigorous method to crystallising the existing body of knowledge.

A credible body of knowledge can only be established by applying scientific method to the examination of existing knowledge and interpretation of data. Judgement must be applied in order to refine knowledge based on reliable worthwhile data and to discard that which is obsolete or irrelevant to the subject in hand. The gaps in the knowledge need to be identified and research programs developed to fill those gaps. At all stages the data and knowledge must be subject to enquiry and challenge, and only that knowledge which stands up to scrutiny should be retained within the collective body. Finally there must be appropriate means to disseminate the tested and refined body of knowledge to the industry.

Without integrating the rigorous analysis brought by building science into the design, the industry will continue to construct buildings whose performance falls far below that which is necessary to achieve the carbon abatement targets.

Professional standards

The poor understanding of building science, coupled with the engineering skills shortage in the construction industry generally, have created significant gaps in this crucial field of low carbon and sustainable design. Some of these gaps have been filled by a new type of professional, a sustainability consultant or code assessor, who understands aspects of the regulations or environmental assessment methods in detail and can use software to generate the necessary calculations and certification for new buildings.

The field has no recognised codes of practice or professional standards and work is often undertaken by consultants from wide-ranging backgrounds who may not be conversant with the principles of building physics, or even engineering. There are many competing competency schemes run by professional engineering institutions, trade associations and private sector businesses. This lack of consistency results in enormous variations in the standard of service provided by practitioners.

In contrast with the field of civil and structural engineering, where rigorous method and education for integrated design exists, the field of environmental design is presently dominated by single issue, tick box methodologies. These methodologies cannot therefore evaluate integrated performance nor the benefit of good design, yet they are increasingly being used as substitutes for properly developed environmental design strategies.

There are now numerous single issue assessment methods applied to various aspects of building performance required by regulation, such as the Energy Performance Certificate (EPC) and Display Energy Certificate (DEC). There are also a number of broader environmental assessments, such as the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy Efficient Design (LEED) and the Code for Sustainable Homes. However, these assessments also amount to little more than tick box evaluations across a variety of single issues.

In many cases the application of these environmental performance assessments is undertaken by experienced building designers. However, it is equally true that, in many cases, sustainability assessors with little experience in the design or construction of buildings are being asked to lead the environmental design, or to advise on the application of renewable energy technologies for various government-funded initiatives. In some cases only two or three days of basic training with an exam administered by the training provider is required to qualify as an assessor. There is no prerequisite that such a "qualified" professional really knows how to design a building.

Thus the design of buildings, which has often seen little collaboration between the disciplines, has become fragmented. A design team may often now comprise many separate disciplines; architect, structural engineer, building services engineer, sustainability consultant and code assessor, all vying to be seen as the champion of sustainability. However these teams often still fail to communicate and co-operate to make the key strategic decisions that will reduce the need for mechanical and electrical solutions to comfort and climate control.

The solution to these pressing problems is to ensure that those responsible for design decisions have a thorough understanding of both the theory and application of building science as it relates to energy conservation. There is a clear need for identifiable competency in building physics and environmental design, as there is for civil and structural engineers and for building services engineers. Furthermore it is essential that those procuring buildings understand the distinction between practitioners who are experienced and qualified to design energy efficient buildings and those that are qualified merely to measure the results of the design.

Persistent failings

There is widespread misunderstanding about the cost and functionality of low energy buildings among construction industry professionals. These beliefs have arisen as a result of many instances of poor design resulting in unnecessarily high predicted energy consumption coupled with the adoption of expensive and inefficient microgeneration in an attempt to compensate.

The Joseph Rowntree Foundation recently published its findings from the construction of a small development of low energy housing [Bell et al, 2010b] (See Case Study). Their experiences are by no means unique and it is clear that the construction industry is failing on a number of fronts:

- Building performance modelling is often undertaken by people unfamiliar with the construction details. Therefore, predictions used for carbon emissions and systems design are not representative of the building as constructed.
- Specifiers and installers are not always aware of the impact that a change in specification for components may have on the performance of the overall system.
- Designers are not sufficiently familiar with new technologies and do not have the knowledge to evaluate the likely performance of systems in-situ.

These failures, which are consistently repeated throughout the industry lead to unnecessary expense and buildings that do not perform anywhere near to their potential; in some cases even performing worse than the conventional alternatives. In interviews with construction industry influencers active in sustainable development, conducted on behalf of Construction Skills, MRM Solutions [2004] found that:

> "Sustainable solutions delivered by the construction sector rarely, it is alleged, achieve the benefits propounded at an acceptable cost. Projects which integrate sustainability themes have been poorly thought out and overly complex. This has, it is suggested, left clients understandably wary of unproven sustainable construction methods and technologies."

This repetition of expensive failures has led to the widespread view that energy-efficient buildings are always more expensive to construct and this positively inhibits progress in an industry driven by cost. However, a range of studies indicate that buildings aiming for a high environmental performance should be no more or less expensive than conventional buildings [Matthiessen Morris, 2004, Davis Langdon 2007].

Barriers to change

The construction industry is highly segmented with a mobile workforce and features high levels of subcontracting and self-employment. The vast majority of companies in the sector are small, with over 97% employing fewer than 25 people [CITB 2010b]. Further, some 44% of construction design professionals (engineers and architects) in the UK are employed by small businesses of 10 people or fewer [ONS 2011a] which may not have the resources to implement rapid and radical changes.

These factors make it extremely difficult for the industry to act together to deliver against strategic goals, or even consistent high quality training and development.

The construction industry also has one of the lowest rates of investment in research and development of any sector in the UK economy. In 2007 construction output accounted for 5.2% of UK GDP [Eurostat 2011]but investment in research and development in the construction sector was just 0.04% of the UK total [ONS 2011b].

The situation is exacerbated by widespread ignorance of the impacts of the industry or the contribution it could make to climate change mitigation. In confidential development work conducted by the Construction Industry Training Board with 300 managers of large construction companies [MRM Solutions, 2004], it was discovered that "only 18% recognised the environment as part of their responsibility and of that 18% only 47% claimed appropriate competence".

Further, a large proportion of UK building construction is commissioned by small or occasional clients, who are not necessarily familiar with the way that construction is designed, procured or delivered or what performance targets can be achieved. These clients are therefore dependent on the advice that they receive from consultants such as architects and project managers. However, in the absence of sufficient rigorous and high-quality education in sustainable construction, these advisers are unlikely to be in a position to provide the best advice.

Clients therefore often being unaware of the services that they actually need, may procure engineering consultancy services on the basis of price rather than scope of service and quality. Without experience of the industry, clients may not always be able to tell if the service offered in a purely financially competitive situation will prove sufficient to fulfil their requirements, particularly in relation to low carbon performance.

Without clear quality standards and scope for professional services in relation to low carbon, it is not just clients that are unable to distinguish between the level of service on offer. Architects, project managers and other professionals are also confused as to both the requirements and the capabilities of other professionals. Thus services relating to low carbon design are often procured on the basis of inadequate briefing and examination of the needs.

Low carbon construction skills

Clearly the targets for carbon abatement cannot be met by the adoption of technology alone. Present policy encourages investment in the manufacturing technologies associated with the generation of renewable energy and with energy-efficient equipment and system components. However, as demonstrated, improving energy efficiency in energy consuming systems does not necessarily achieve the desired results. In order to deliver carbon abatement at the lowest possible cost to society, a step change is required in the level of available skills in building science and integrated low carbon and sustainable design.

New skills are required in building engineering physics in order to deliver buildings which are comfortable and high-performance through the use of passive, rather than active, energy-consuming measures. New skills are required in systems engineering to ensure that the many disparate parts of a building function in harmony to achieve the desired objectives with the minimum energy consumption. New skills in design synthesis are needed to bring together ideas and expertise from many different disciplines. New skills and understanding in human behaviour and building operation are necessary to ensure that buildings designed for low carbon can be operated as such. Finally a new level of understanding about the requirements for the low carbon paradise required amongst those creating and enforcing regulations.

The demand for low carbon skills

A number of government announcements around *The Green Deal* indicate that around 250,000 workers with specific low carbon skills will be required to deliver the strategy by 2030. This is around 10% of the current workforce and requires a growth rate in low carbon design and construction specialists of over 12,000 per year. In addition, this growth in construction and installation workforce will demand an equivalent growth in management, design professionals and specifiers.

A significant part of *The Green Deal* strategy is for financing the eco-retrofits from a Green Lending Bank. As with other finance-led policies such as the feed-in tariffs, it is almost certain that *Green Deal* finance will only be accessible for works designed or undertaken by approved persons.

The previous job creation schemes for approved persons, domestic and commercial energy assessors and air conditioning inspectors, had managed to accredit a total of around 16,000 persons across the entire construction industry by 2009 [Landmark 2010]. The accrediting bodies also reported that the majority of these registrants were already employed elsewhere in the construction industry and so this number does not represent entirely new jobs.

If allowance is made for potential new jobs in commercial low carbon retrofit pro rata to those in the domestic sector and the projected rates of expenditure in the two sectors, it can be seen that the total new job requirement could be double that in the domestic sector alone. Thus the future training and accreditation requirement annually could far exceed all the new energy assessor jobs delivered across the whole construction industry to date.

This is not only a significant issue for recruitment and training, but with such significant growth in the field it is essential that the training is appropriate so that the new jobs will focus on carbon abatement at the lowest cost to society rather than the lowest cost to the contractor. Thus the total number of new jobs to be created in the low carbon construction industry must be increased by the number of suitably qualified trainers also required.

Lessons from Elm Tree Mews

In 2005, The Joseph Rowntree Foundation commissioned, Elm Tree Mews, a small development in York aiming for "an exemplar for 21st Century suburban homes". The properties cover the full spectrum of housing types from three- and four-bedroom houses, to one- and two-bedroom apartments.

The construction and subsequent occupation was monitored by Leeds Metropolitan University [Bell et al 2010b]. These studies revealed that, although the project sought to achieve a standard equivalent to the Government's carbon emissions target for 2013, the performance achieved was only marginally in advance of 2006 regulations. The measured carbon dioxide emission was 6.4 tonnes per annum compared with the 2.7 tonnes predicted in the design. In 2010 the foundation published "Low Carbon Housing - Lessons from Elm Tree Mews" to allow the industry to learn from their experiences.

The problems experienced were primarily due to a lack of consistency between the thermal modelling calculations and the actual design and construction of the buildings. The calculations underestimated the amount of timber framing in the construction and failed to account for thermal bridging or heat loss via the cavity party walls. As a result the fabric heat-losses were 54% higher than predicted. Furthermore the measured air leakage for the completed properties averaged $7m^3/h.m^2$, more than twice the leakage rate of $3m^3/h.m^2$ specified in the brief and used in the energy calculations.

Further problems occurred due to the lack of a chain of custody for energy performance throughout the design and construction. This meant that, for instance, the energy impact was not evaluated when an alternative window supplier was selected with a lower performance than that originally specified.

Finally, the heating design relied on a communal ground source heat pump system. It appears that the heat pump was not properly integrated with the conventional heating and hot water systems in the dwellings and this resulted in overall performance some 30% below the rating assumed in the design. The Foundation concluded that if the development had instead been heated with ordinary gas condensing boilers, carbon dioxide emissions would have been about one tonne per annum lower.

The report concluded that many processes and cultures within the industry and its supply chain need to change if zero carbon housing is to become a reality.

- Design processes should be improved so that they:
  - take a much more rigorous approach to detailed design including undertaking and checking thermal calculations,
  - focus on as-constructed performance taking into account the interactions of the different components in both fabric and systems,
  - give more consideration to the needs of householders and provide controls that are designed in accordance with ergonomic principles.
- Services design should focus on whole system performance.
- The planning and control of construction needs to be improved and include in-production testing.
- Improvements are required in services commissioning, testing and monitoring to ensure effective performance.
- More support and guidance is required across the house-building industry.
- Policy aspirations will not be achieved without rigorous evaluation of low carbon schemes and ensuring that lessons are embedded in all parts of the industry.

Low carbon skills survey

In 2010, Ipsos MORI was commissioned by The Royal Academy of Engineering to establish the range and depth of low carbon design and construction skills available in the UK construction industry that would enable it to deliver against targets for low carbon buildings *(Appendix 3)*. The research was carried out by telephone interviews with a range of firms and supported by a postal survey of opinions.

This research revealed that while the majority of respondents felt that their firms had sufficient skills to address low carbon issues, they still revealed ignorance in relation to some of the broader aspects of sustainability and carbon policy. The fact that the majority of survey respondents reported that they had sufficient skills in low carbon may be a result of the recent downturn in the economy and a lack of demand from clients. This tendency to report skills sufficiency in the current climate, despite acknowledged skills shortage in previous years, is reflected in the annual surveys "Skills And Training In The Construction Sector" [CITB 2009, 2011] (see box).

The skills referred to by respondents often related to high-technology solutions such as micro-generation installations, but rarely to passive energy conservation features. This is confirmed by the fact that many respondents, contractors and consultants alike, referred to manufacturers as their principal source of information on low carbon, rather than universities, professional institutions or other research organisations. It is also interesting to note that, despite being largely confident in their own skills, most respondents criticised the lack of skills in others, revealing a wide diversity in the understanding of their basic skills requirement.

Few respondents in the survey were able to identify their future business and skills needs in response to the known direction of UK climate policy. The majority of respondents are simply responding to changes in legislation as they happen. This leads to the continuing drive towards a minimum cost approach for training and skills development, rather than identifying and preparing for future business opportunities presented by low carbon policy.

The survey revealed widespread concern about the lack of recognition for suitable qualifications and experience in low carbon design. Respondents noted the large number of new entrants claiming specialist expertise in low carbon design, perhaps without the experience to justify these claims. This means that it becomes harder for clients and building owners to identify those with genuine experience and expertise in the field.

In particular, respondents felt that graduates were inadequately prepared for the role that they are now expected to play in the construction industry, particularly in relation to low carbon design.

Achieving recognised qualifications can be very costly and even of questionable value. The number of conflicting training schemes for proprietary rating systems such as BREEAM and LEED, and even the need to undertake repeated training for different accreditations within the same scheme appears to be putting many businesses off undertaking the training.

There is the need for a nationally recognised accredited mark of competence in low carbon and sustainable design, with appropriate training, initial and continuing professional development, such as Chartered Engineer status, for those working in the low carbon design sector.

A clear need was identified for the collation and sharing of building performance information relating to energy efficiency and low carbon design. However, the degree of competition between organisations, and even between professional bodies in the construction industry is a further barrier to developing widespread low carbon skills. This suggests perhaps the need for a single supervisory body from amongst the professional institutions charged with maintaining professional competence in low carbon design in a similar way that the Construction Industry Training Board and the sector skills councils support the installation end of the construction industry.

Attitudes to skills and training

The annual Construction Industry Training Board report "Skills and Training in the Construction Sector" provides some useful background to the changes in reporting the skills gap as a result of recession.

One of the most striking results of the 2011 survey was that very few employers would state that any of their employees had skills gaps, in contrast to previous years, where approximately 10% of employers reported that at least one member of staff was not totally proficient in all aspects of their job. The report's authors suggest that perhaps this change is influenced by employers' unwillingness to admit to having staff that are not fully proficient, especially at a time where jobs are relatively scarce, and plenty of skilled workers are seeking employment.

It is also suggested that this may be explained by a combination of downsizing and the slow construction market at present making any skills gaps less visible, as the 2011 survey also showed a dramatic reduction in recruitment compared to 2009. Only 26% of employers had attempted to recruit skilled labour in the previous 12 months compared with 36% in the 2009 survey.

The 2009 survey found that 52% of employers across the whole construction industry (rising to 71% of those firms employing more 25 or more staff) considered that new legislation and regulations would impact on their future skills needs. It is likely that the drive towards low carbon construction with its high turnover of guidance, strategies, policy and new regulation will have featured highly in forming this response. By the beginning of 2011 however, those proportions had fallen to 45% and 54% respectively, despite the fact that the rate of introduction of new legislation is now increasing.

In relation to the introduction of new technology or equipment; 32% of contractors (39% in 2009) and 44% of professional services firms (50% in 2009) forecast an impact on their future skills needs. Although fewer respondents foresaw the need for increasing skills in the 2011 survey, it is still significant that this represents more than one third of the industry, rising to nearly half of professional services firms. Again, the need to innovate, adopt new working practices and integrate new technologies to achieve a low carbon outcome is likely to have been influential in the thinking of respondents to this survey.

Examining the professional services firms, where the majority of graduate employment is likely to occur, the 2011 survey found that the need to acquire new skills within the next year is highest amongst architectural firms (72%) and building services engineers (60%). Amongst the more traditional engineering roles only 40% of civil engineers and mechanical engineers reported the need to acquire new skills within the next 12 months. This would appear to bear out the perceived shift in demand for engineering skills away the traditional disciplines into those associated with low carbon construction.

During 2009 approximately 39% of people working in construction received training funded or provided by their employer, a slight increase over 2008, but this is mainly as a result of the recession reducing employment in the sector overall. That proportion increased again in 2011 to 41% of employers. Unsurprisingly the amount of training increases with the size of organisation.

The recession has also had an impact on the number of employers reporting problems arising from a lack of skilled staff, with very few now identifying a shortfall in skilled staff compared to their workload, presumably due to the reduced demand overall. However in 2008 45% of all construction employers had lacked sufficient skilled staff for their business and 29% had experienced difficulties in recruiting skilled staff.

Delivering low carbon skills

Whilst it has traditionally been the preserve of the universities to teach theory and leave the teaching of application to industry, the rate of change required in the construction industry calls for a radical transformation in education for construction professionals. To meet the demands of low carbon construction, it will be necessary, in the short term at least, for universities to contribute to the development of readily applicable skills and knowledge ready for the industry.

The principles of building science necessary to engineer the passive energy conserving elements of buildings are now essential in the education of anyone who will design or specify the environmental performance of buildings in the low carbon economy. The problem is that these principles are rarely covered in undergraduate or subsequent professional training and not at all amongst installers and tradesmen in the industry.

Recent initiatives by the construction sectors skills councils are beginning to address low carbon construction and installation skills, but skills development for professional designers and constructors is left largely to the professional institutions and little concerted effort has been seen in this sector.

Current provision of undergraduate teaching

Building science used to be offered at degree level by a number of UK universities but these courses have gradually been subsumed into general engineering degrees. The courses on offer in the UK that teach, at best, some elements of building science are generally building services engineering degrees and there are very few of these. Some universities offer general construction engineering; covering aspects of building physics and building services engineering alongside structural engineering, on courses described as architectural engineering.

The Chartered Institution of Building Services Engineers (CIBSE) presently accredits only 23 UK undergraduate degrees from 12 institutions, including the Open University [CIBSE 2011]. Of these degrees, only three courses of full time study and one from the Open University lead to the award of MEng and so satisfy the requirements of the Engineering Council qualification of Chartered Engineer without additional studies.

The guidelines for accreditation of undergraduate degrees by CIBSE require that fundamentals of engineering and building science comprise 25% of the taught content, the remainder being specific building services engineering or general professional topics.

In contrast the Joint Board of Moderators (JBM), for civil, structural, highways and transport engineering, currently accredits courses from around 50 universities, with over 100 degree courses at MEng alone [JBM 2009]. However, the JBM currently sets no requirement for building science and review of the accredited courses indicates that only around 10 universities offer any identifiable building science content, but this can be as little as one module.

Thus the opportunities for school leavers to gain any appreciable education in building physics are extremely limited, with only around 20% of universities providing any teaching in the field.

At the postgraduate level the profession is better provided for with a number of courses which feature some aspects of sustainable construction. However the technical content of these is extremely varied and only about 30 Masters' degrees are accredited by CIBSE for the additional learning required on top of a bachelor's degree to achieve the academic threshold for Chartered Engineer.

Current failings in undergraduate teaching

University courses take time to design, approve and implement and rely on there being sufficient authoritative reference material on a subject. Unlike other science, technology and engineering subjects, building engineering and architecture rely heavily on teaching and material generated from current practice, which is where most research and development takes place.

The lack of up-to-date case study reference material in the industry, the focus of academic research on narrow subject areas and in some cases the reliance on practitioner teaching means that University teaching can often fall behind current practice in the industry. With four years being the normal course length for engineers and five years for architects, the rate of change in practice and the uptake of new technology driven by revisions of the building regulations, at three to four year intervals, means that the education of construction graduates is likely to be out of date even before they leave university.

Many precedents and case studies presently used in undergraduate teaching are significantly out of date, as recent projects have not been evaluated to the same extent or are drawn from "Practice Books" written by commercial architectural or engineering practices to promote themselves and which are therefore sometimes less than candid about the real performance of their designs. The reliance on practitioners from industry, who themselves may struggle with keeping up to date with new developments, means that there is often little critical examination of the issues and inaccurate information about sustainability becomes received wisdom through repetition.

The lack of building physics teaching at undergraduate level impacts throughout the continuing education and development of professionals. Engineers presently in the middle of their professional careers will have started in the industry at a time when carbon did not feature in policy and the architect simply installed insulation to the standard details in order to comply with Part L of the building regulations. In 2004, 43% of professional engineering practices in the construction sector indicated that they had experienced skills and competence gaps among their professional engineering staff [CIC 2004]. That skills gap will now be propagating through the generation of engineering professionals in management positions and also those likely to be engaged with teaching and tutoring at university.

The need for excellence in undergraduate teaching

The construction industry relies on designers to develop and test new ideas in low carbon design and communicate these ideas in a form that can be delivered by the traditional construction supply chain. Without designers educated in passive energy conservation techniques, the industry will continue to pursue the prevalent approach, simply based on setting targets for carbon emission reductions in performance specifications. Without a holistic approach to design for energy conservation the only option for the supply chain is to try to achieve the targets with bolt-on technology.

The construction industry and academia do not engage well. This means that many of the usual routes for disseminating the results of academic research do not work with the construction industry. In the absence of research engagement, undergraduate teaching forms the best route for dissemination of new thinking in low carbon design into the industry. However the lack of industry engagement also works the other way, in that university teaching involves little input from the construction professionals who are daily testing and proving the new ideas in low carbon construction.

The scheme for Visiting Professors in Building Engineering Physics has demonstrated how placing experienced practitioners into university engineering departments has revolutionised the teaching of design and low carbon skills for undergraduates [King 2010]. With a grounding in appropriate engineering theory and holistic design practice, together with exposure to the challenges of real-world design projects, graduates from these courses are uniquely equipped to contribute to low carbon design industry.

Such graduates are in great demand and will quickly find themselves in positions of influence within the industry. Their knowledge in the field of low carbon design generally far exceeds that of their superiors and we see such graduates engaged with projects at all levels. Increasing the base of low carbon educated graduates across the construction industry therefore represents a substantial opportunity to drive change through the industry from the ground up.

The need for excellence in continuing professional development

Whilst creating cohorts of low carbon design undergraduates will undoubtedly change the construction industry from the ground up, in order to achieve the rapidity of change required it will also be necessary to address senior employees in the industry.

A number of specialist centres at UK universities, such as the Centre for Window and Cladding Technology at the University of Bath have successfully developed postgraduate teaching in a modular form. The modules can then be offered to the industry as a component of a practitioner's continuing professional development. This approach has proved very popular in allowing industry professionals to access new expertise without undertaking an entire Master's degree program.

The need for industry training and trainers

The *Green Deal* proposals, amounting to a need for training over 12,000 new low carbon specialists each year, will also create a significant demand for people to train them. There simply are not sufficient specialists in the industry at present to deliver this volume of training. Furthermore, it must be ensured that the training provided appropriately addresses techniques for carbon abatement at the lowest social cost as well as the simple technological fix approach.

Thus, in order to deliver the *Green Deal*, it will be necessary to educate further cohorts in energy conservation design techniques in order to be able to deliver the appropriate training across all levels of the construction industry.

The need for multi-disciplinary research in construction

The construction industry is unlike other sectors of manufacturing industry in that buildings are designed and developed on a project by project basis by broad teams from widely differing backgrounds. The majority of ground-breaking research in the construction industry is undertaken in commercial practices trying to solve real world problems and not in traditionally-funded research organisations. Dissemination of such research is therefore restricted by commercial confidentiality and the strictures of a competitive marketplace.

This fact has not yet been recognised by government or the research councils and so a great deal of valuable information generated by ongoing research efforts remains inaccessible to the industry and other researchers. It is important that new and more agile means are now found for supporting both fundamental research and transfer of the knowledge to industry that do not rely on the conventional frameworks and can overcome the inhibitions of market competition.

The research essential to revolutionising the construction industry must be provided by researchers collaborating across a broad spectrum of construction disciplines. This effort cannot be left to the industry as its competitive and adversarial nature inhibits disclosure of both successes and failures by the parties involved. Successes are jealously guarded by their innovators in order to gain marginal commercial advantage and failures are similarly concealed in order to avoid commercial disadvantage. Thus, it is typical for only the mediocre to be subject to scrutiny and becomes the benchmark for future practice and for teaching.

Similarly this essential research cannot be left entirely to academia where the focus of most research effort is typically far too narrow to generate results that are broadly useful to the industry. The need for researchers to demonstrate uniqueness, in order to obtain funding, drives research into narrow and highly specialised fields that may take many years or decades to find application in the construction industry. Further, the prohibition by Research Councils UK of funding any industrial partners' contribution to research acts as a barrier to collaborative effort between academia and industry on any aspect of fundamental research, which will not provide an immediate financial return for the industry partner. Thus, significant research opportunities are being lost.

There is also a need for fundamental research in many areas in industry, relating to energy supply and carbon reductions, not just in the area of building physics, which is inadequately supported at present due to the established funding mechanisms. In order to qualify for funding from bodies such as the Carbon Trust, or the Technology Strategy Board, researchers must be able to demonstrate a route to market, limiting the opportunities for more fundamental research with a broad range of application and not linked to a single industrial partner. Thus, again, we are failing to develop potentially beneficial lines of research due to restrictions in the funding criteria.

The need for post occupancy evaluation

The most pressing need in the construction industry today is for reliable and impartial information on the actual carbon performance of recently constructed or refurbished buildings. This information is essential for the establishment of benchmarks and standards, for the validation of new designs and techniques, for the development of robust national policy and for the development of up-to-date and authoritative teaching materials.

Post-occupancy evaluation not only measures the performance of buildings, but also engages building occupiers and facilities managers with their own behaviours and the consequences for energy consumption and carbon emissions. The research outputs from post-occupancy evaluation also therefore cover areas of human comfort and behaviour, and not just of physical building performance. Very few research funding mechanisms presently would encompass such broad multidisciplinary research, while the construction industry cannot be relied upon to generate such information itself. Access to such research information would allow the development of new research paths investigating areas of psychology and social science in relation to energy consumption. Ultimately such investigations will enable universities to develop materials suitable for the education of building maintenance and facilities professionals.

Centres of Excellence

For the last six years The Royal Academy of Engineering has been operating a highly successful scheme placing Visiting Professors in Building Engineering Physics into some of the UKs top universities for architecture and engineering. This scheme, summarised in *Engineering a Low Carbon Built Environmen*t [King, 2010], has helped host universities develop a new degree course in architectural engineering; deliver enhanced teaching in design and environmental science and engage a significant cohort of students with practitioners from the construction industry.

The success of the Visiting Professors in Building Engineering Physics demonstrates what could be achieved on a national scale if a network of Centres of Excellence in Building Engineering Physics or Low Carbon Sustainable Design were to be established. The goal is to create a continuous upwards spiral of teaching, research, industrial practice and regulation leading towards genuine low carbon performance in the built environment.

The primary purpose of a Centre of Excellence will be to educate graduate engineers to apply the science of building engineering physics, together with integrated systems design, to designing buildings that conserve energy by maximising their use of passive design principles. These engineering graduates could be described as 'carbon literate', as they will have the analytical skills and rigour to design, direct and coordinate low carbon design across a number of specialisms. A Centre of Excellence will also, through the use of interdisciplinary teaching, generate additional 'carbon aware' graduates, who may be architects, planners or project managers. Together, these graduates will form the basis of a new workforce equipped to deliver the most cost effective measures for carbon abatement through energy conservation.

To achieve these goals a Centre of Excellence needs to be much more than a typical university research centre. The primary aim of the proposed Centres of Excellence is to enhance the undergraduate education of building designers so that they are equipped to deliver the low carbon built environment using the most economic and advantageous techniques.

Thus, a Centre of Excellence can only exist through the satisfaction of three requisites; the establishment of a body of knowledge, research to improve the body of knowledge and education and training to test the body of knowledge and disseminate it to industry *(Figure 6)*.

Figure 6. The fundamental requirements of a Centre of Excellence

The body of knowledge is the starting point of a Centre of Excellence. Initially this body of knowledge will be the result of the individual research of staff members and the collation of publicly available data. Through rigorous examination, the body of knowledge is refined over time to augment the valuable and discard the obsolete or irrelevant. Through its application in education and training the body of knowledge is tested for relevance against current needs and practice. Elements of black art and indefensible claims contained in the received knowledge will be exposed and eliminated. This examination will also expose the need for research to fill the gaps in the body of knowledge.

Research not only generates new knowledge, but through repeated examination, analysis and comparison, the existing body of knowledge is tested and refined. Research in a Centre of Excellence, with numerous expert staff, can also feed directly into education and training, without the delay to dissemination involved in the usual round of external peer review and publication. Education and training, in particular industry CPD, is not simply a route for dissemination of knowledge and results of research, but provides a means for researchers to understand the needs of the industry.

Amongst the requirements of a Centres of Excellence there must also be a good supply of raw material – high quality undergraduate students; academic and research staff involved in pushing the profession forwards, who can communicate their knowledge, skills and enthusiasm to undergraduates, the industry and the public; involvement with those engaged directly in the design of buildings and engagement with policy-makers, which is essential given the proportion of building clients not willing to do more than the legal minimum.

Those involved in teaching undergraduates in the Centres of Excellence will necessarily have well-developed communication skills and part of the remit of a Centre of Excellence would be public engagement to promote knowledge of low carbon design and to help effect behavioural change. Having acknowledged experts in sustainable design appearing and writing in the media would help to raise the profile of effective energy conservation measures and combat the present popularity of ineffective solutions.

A Centre of Excellence may be engaged in fundamental research into the properties of materials or the applications of technologies, in gathering and collating performance data on existing buildings, in providing analysis services to local practitioners or providing research and development into specific aspects of real-world construction projects. This broad range of research and the opportunities for disseminating it would give a Centre of Excellence real value as a research partner to the construction industry.

Further, Centres of Excellence would be involved in, and become repositories for, post-occupancy evaluation studies of real building projects. The Centres of Excellence would be able to undertake the anonymised, aggregated studies necessary to overcome the commercial constraints on publishing individual building performance data due to the potential market implications of naming poorly performing buildings.

The cost of Centres of Excellence

In order to function as teaching centres at the cutting edge of building science and low carbon design, it will be necessary for the Centres of Excellence to engage with both in inquisitive and applied research and industrial practice. Without this widespread engagement the centres would not be able to deliver the breadth and depth of education that we require.

Therefore, a Centre of Excellence should build upon established research and teaching in the fields of building science and low carbon design, but will need sufficient appropriately experienced and qualified academic staff and industrial practitioners to deliver new research and teaching in the field.

In Appendix 1 we have evaluated a potential structure for a Centre of Excellence. This structure is designed to provide sufficient breadth and depth to deliver both the teaching, professional education and research goals set out above. Applying full economic costing to the staffing for such a centre indicates that seed funding of £7.5 million would be required to operate a single centre for five years. After the initial period it is expected that the centre will become self-financing from income derived from research grants, both from industry and the research councils; from the delivery of training; and continuing professional development to the industry and from the sales of publications where appropriate. For the purposes of the evaluation, it is assumed that four Centres of Excellence are pump-prime funded at a total cost of £30 million over five years.

Establishing a number of Centres of Excellence, geographically distinct from each other, strengthens the ability to support the entire UK construction industry and, through developing collaboration between centres with different local pressures and methods of working, creates the opportunity for more varied research.

The impact of Centres of Excellence

Centres of Excellence at some of the UK's top university departments in construction and the built environment have the potential to deliver several hundred new carbon literate and expert graduates every year, driving a sea change in the construction industry. By establishing the Centres at universities that already have active research in the field and healthy recruitment of students, the required growth in carbon literate graduates can be met by conversion of existing recruits rather than exclusively from recruiting new students.

Because of the current demand for such training these early career engineers and architects will quickly gain positions of influence. These people will then drive a demand for low carbon skills through the industry to the technical and craft levels and to clients and other professionals. These graduates will also create a demand for fundamental research back up to the universities. In this way targeting a small section of the industry could bring about dramatic change throughout the industry.

In Appendix 2, we present an economic analysis of the net present value to society of the Centres of Excellence evaluated over a 15-year period to 2030. This analysis shows a very significant return on the initial investment of well over £1 billion, with potential carbon abatement of 3.5 million tonnes per annum at the end of the period.

If we project forwards to 2050 then the abatement potential would rise to nearly 11 million tonnes per annum with a net present value of over £6 billion compared to abatement through the present mix of insulation, energy-saving technologies and micro-generation.

Unquantifiable benefits from Centres of Excellence

The Centres of Excellence are likely to have a number of beneficial impacts for UK manufacturers of technologies for the construction industry. For example, the UK has a low standard of façade manufacturing in comparison to many other European countries, particularly Germany.

Germany has a much higher prevalence of science and engineering in construction. Designers are much more demanding of the performance of building components, such as facades, and so the industry responds by manufacturing high-quality and reliable systems. Thus German manufactured facades are widely recognised as being of the highest quality and are therefore routinely specified for the most demanding UK construction projects to the detriment of UK manufacturers and the balance of payments.

By raising the level of scientific understanding of building performance across the construction industry we will be raising the demand for high-performance building components. UK manufacturers will be challenged by UK designers to improve the performance of their products, which will make them competitive against similar European products. Further, by engendering familiarity with building science, UK manufacturers will be able to effectively enter the European market and compete in a market where building science is demanded.

Centres of Excellence may also benefit UK manufacturing by focusing construction effort on the passive design measures rather than on the adoption of microgeneration technology. The most popular forms of micro-generation and low carbon technologies, such as photovoltaics and heat pumps, are typically manufactured in Asia, whereas low technology, passive energy-saving products such as insulation tend to be manufactured in the country of use. Therefore, by increasing the ability of construction professionals to utilise passive energy conservation we will increase demand for indigenously manufactured products.

While this study has evaluated the impact of graduates from Centres of Excellence entering the industry and thus directly mitigating carbon emissions through good design, it is inevitable that a number of graduates would remain in academia to further pursue research and to teach. Thus by establishing the Centres of Excellence we can reasonably expect a better understanding of low carbon design to permeate throughout other UK universities. As a result the numbers of carbon literate graduates will increase beyond those trained at the original Centres of Excellence and the carbon abatement will escalate. A number of these graduates will become the trainers for the future generation of low carbon workers proposed under the *Green Deal*.

Developing a body of articulate carbon literate researchers and graduates would also facilitate much broader engagement with the general public on matters of sustainability. The media would have access to expert opinion on matters of sustainable design and so the public debate could be much better informed.

It can be expected that personnel from the Centres of Excellence also to contribute to the refinement and implementation of policy for sustainable development. By combining the rigour of academic research with the practical experience of successful strategies from the construction industry staff from the Centres of Excellence will be uniquely positioned to advise policymakers.

Finally, UK universities are seen as highly desirable by overseas students. Overseas students tend to be self-funding, and so do not impose additional financial burden on the UK economy, but they bring substantial benefits. Many overseas students in engineering disciplines remain in the UK, either entering industry or pursuing academic research. Students from Centres of Excellence who return overseas to work in industry will take with them a significant level of expertise in low carbon design and construction which will achieve substantial carbon abatement in their theatre of work. Thus Centres of Excellence present a real opportunity for exporting UK expertise in carbon abatement to the benefit of the whole planet.

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Appendix 1:

A generic structure for Centres of Excellence in sustainable building design

Introduction

This appendix sets out the possible structure, operations and costs for Centres of Excellence in Integrated Sustainable Building Design. These Centres must combine leading industrial and academic expertise to serve the pressing needs of a new low carbon society.

A Centre of Excellence needs to be much more than a typical university research centre. The primary aim of the proposed Centres of Excellence is to enhance the education of building designers, within a multidisciplinary environment, so that they are equipped to deliver the low carbon buildings using the most economic and advantageous techniques. In order to achieve this it is necessary that the Centres of Excellence become hubs for acquiring, refining and disseminating knowledge of low carbon design, construction and facilities management in addition to the traditional academic focus of fundamental research.

Also key to meeting society's needs is the provision of independent, timely, expert advice to policymakers. This is necessary to ensure that the importance of integrated sustainable building design is translated into enforcement, with government-controlled estate leading by example.

The Centres must then engage with industry directly, on a number of fronts. The Centres must work closely with the best designers, manufacturers and constructors at the cutting edge, to develop the new thinking needed to meet the requirements of the enlightened policies which result from the higher level engagement. The Centres must work to ensure that the advances in knowledge, understanding and techniques are then used as widely as possible within the industry both at the leading edge and in the delivery of mass market buildings. The Centres must also engage with clients, both directly to owners/managers of large estates, and via representative organisations such as surveyors and project managers.

The Centres must then supply the people to deliver these new ideas into practice – carbon-aware architects, planners, surveyors and project managers and carbon-literate engineers to bring the necessary rigour and analytical skills. They will need a depth of understanding, imagination and inventiveness, supported by a huge enthusiasm for the task at hand.

The relationship with industry will call for the Centres to carry out scientific observation and analysis of the actual environmental performance of buildings, informed by the broad outlook, open-mindedness and concern with real-world problems which characterise the best engineering thinking. Closely related to this scientific work, and to an extent springing from it, will be development of new ideas and an increasing depth of understanding of existing concepts. This work will inform the undergraduate education, and elements of it can be communicated to industry through a range of publications, workshops and the full range of CPD.

Requirements for a Centre of Excellence

The rate of expansion required in integrated sustainable building design is such that the conventional university model of a research centre cannot meet the needs set out above. Departures from convention are required in all areas – industrial collaboration, engagement with policymaking, research and education. However, by comparison with the conventional centre that values itself by the amount of funding it brings in, the most radical change is required in their relationship to undergraduate education.

Education

In the conventional pattern, knowledge generated by research can take a long time to reach practice. The time from identification of a need, through development and testing of a research proposal, to carrying out and publishing the work can be over five years. Not all findings will be adopted by industry, and negative conclusions may not be publicised at all. Some, however, will become sufficiently established among the academic community to find their way into new textbooks, and so be designed into some undergraduate programmes ten years after the need was identified. The graduates then enter industry after a further four years, with a knowledge that addressed the needs of society 15 years previously.

There are, of course, ways to bypass this slow process. The most venerable model of a university is as a place where world-leading thinking is taking place, and where students may go to learn these ways of thinking, and the insights and understanding they have led to. As the scope of knowledge increases, the need for graduates to be able to use standard methods can come to dominate a programme which covers a broad field such as civil engineering. It is essential to have education as well as training, to provide the depth of understanding needed to bring out the abilities required for innovative thinking. In this model the educators are engaged with the industry visionaries, in both their research and their teaching, so that the goals of current research and the understanding of future needs continuously inform the education provided. Universities must to some extent anticipate the kind of education that industry will need in its graduates five or six years hence, and design courses which have the flexibility to adapt to the new developments which take place during that time. In this way, graduates can enter industry not just with an up-to-date understanding, but with a vision for how that understanding must develop, and an ability to contribute their own innovative thinking to that development.

This is only possible if academics are focused on their educational responsibilities as well as on their research. Indeed, academic research is likely to have only limited value, unless the researchers have a yearning to educate, and engage with the broad context in which their research may be used, as well as the pursuit of depth and rigour which makes their findings reliable. Excellence in both teaching and research is needed to deliver the education the Centres must provide. The publicly available Research Assessment Exercise and National Student Survey demonstrate clearly that this dual excellence is in fact quite common, and the included data on student entry standards indicate that such departments attract students who are bright enough to meet the needs identified in this report.

The Centres of Excellence must provide education on a number of levels. Their primary purpose must be to address the pressing needs for knowledge amongst those responsible for carrying out the design and construction of building projects, whether new build or refurbishment. The Centres need to communicate a sound understanding of the fundamentals of building engineering physics and what can and cannot be achieved, as well as the effectiveness of new technologies in delivering carbon abatement.

The Centres of Excellence must be multidisciplinary in their approach to building engineering. Advances in building engineering physics and environmental engineering skills and techniques must engage with the structural, architectural and building services systems engineering skills which are necessary to see them implemented in building designs. There must also be relationships with the social and psychological understanding of behaviour which is necessary to ensure that the resulting buildings can be used in the way intended by the designers.

In addition to supplying a stream of MEng graduates to industry, centres should provide CPD, which may consist of elements of MSc programmes. Many industry professionals possess elements of the knowledge and understanding required as a result of the combination of a good undergraduate education and appropriate experience and professional development. The Centres should provide appropriately designed MSc programmes from which modules could be taken as CPD to provide additional knowledge, depth of understanding, and synthesis to enable them to help meet the needs identified in this report. A secondary purpose of the Centres of Excellence is to educate the general public and policymakers in the broad principles of low carbon design and in what can and cannot be achieved realistically or at reasonable cost. This role requires specific skills which are not traditional strengths of either academia or consultancy practice. Though individuals exist who do have these skills, the scale of the public relations and marketing work will necessitate the employment of specialists within the Centres.

Engagement with industry

Within the construction industry, major advances in thinking are more likely to come from design practice than from academic research. Academic research is done with support from industry, and though the bulk of this work may be better described as 'product development', more fundamental work is also done which supports whole sectors of the industry rather than just individual companies. An example of a centre funded by an industry sector to serve their common needs is the Centre for Window and Cladding Technology (CWCT) at the University of Bath. A substantial proportion of the Centre's funding comes from manufacturers and construction companies with large turnovers.

A number of engineering research centres are supported by individual companies, and certainly do work which may eventually benefit their industry sector and society as a whole, as well as supporting the research and development needs of the sponsoring companies. The BRE Trust provides contrasting support to a range of research centres, through funded chairs and studentships, each with a broad theme. The vast majority of posts are funded by the universities or by other research income and the range of outputs is correspondingly broad and deep, with no connection to BRE's training and certification schemes. These centres are focused on societal needs, and the funding provided by the Trust facilitates their operation. The Trust also facilitates collaboration between the Centres.

CWCT provides a model for supporting the common good of an industry sector by the provision of independent, reliable guidance to industry practitioners through a range of channels, while the BRE Trust's oversight of the BRE Research Centres provides a model for the proposed Centres of Excellence. A single overview panel for all the Centres will give a mechanism for supporting co-operation and cross-fertilisation between them. Individual Centres of Excellence must also have local management boards through which industrial expertise is channelled into their operation. It would be inadvisable to have manufacturers involved in management boards because the Centres must be seen to be independent by politicians, their advisors, and the media. This also means that no matter how well-regarded they are, lobbying or pressure groups, or political parties, should not be directly involved in the management panels, though they could usefully have affiliation with the Centres. Policymakers must see the Centres as the trusted friends who will tell them the uncomfortable truths that they would rather not hear. To that end, it may be helpful to have an appropriate civil servant on the overview panel. Policymakers must see the Centres as providers of solutions, not as lobbying organisations.

The failures referred to in this report have generally arisen from ignorance, in spite of a strong will to do well. Leading designers are expected to advise their clients taking into account the long term concerns of both client and society. Their reputations and their future business rest on how well their buildings meet these needs; they are not dependent for their profits on selling devices, and have no interest in offering solutions with either high upfront or operating costs.
Their vested interests only lie in the Centres producing the graduates who can support them in achieving these aims. Their mission is therefore compatible with that of the Centres, and they should have strong involvement in the running of the Centres.

Research

A Centre of Excellence should be engaged in fundamental research into such things as the properties of materials, the behaviour of fluids or of people, the transportation, transformation and storage of energy, or any number of other fundamental aspects that influence the design of sustainable buildings. A Centre should also be engaged in the assessment of existing buildings, the collation and interpretation of those findings, developing understanding, and communicating that enhanced understanding to practitioners and to its own undergraduates. Centres would also usefully have direct engagement with designers, advising on particular problems, and carrying out the research needed to support innovative design ideas. Their research may also have contributions from psychology and social science in relation to the human elements of the whole complex system controlling energy use in a building.

Research in the built environment is typically supported by the Engineering and Physical Sciences Research Council (EPSRC) for pure research and the Technology Strategy Board (TSB) for 'year to market' technologies, often involving close links to commercial organisations. The bulk of the output of existing research centres is of a traditional academic form and rarely responds to the needs or timescales of industries such as the construction industry. A research programme will typically have a duration of two or three years following a year or more of work to obtain funding. Writing up, peer review and publication of the results may delay dissemination for a further year or two. In the face of a very urgent need for buildings to consume less energy and generate less CO_2, this is far too slow to be of use to the construction industry.

Other forms of output may be unpublished reports written for commercial organisations, usually for a very narrowly defined purpose where a centre has specific expertise. These research programmes are much faster, being driven by the commercial demand of a single organisation, but have very limited impact.

A number of research centres exist which have building science as part of their remit, while many universities have centres in 'sustainability' or 'low carbon', and others have taken the Low Carbon proposition on a systems engineering approach. However, what is clear is that the balance between broad academic and teaching staff and purely research staff varies considerably between these research centres. Most centres are involved in the delivery of taught postgraduate courses, but the larger centres may have little involvement in undergraduate courses, and be dominated by research staff. Much of the work done by these research staff in the built environment relates to the development of very specific electrical and mechanical systems, but work is also being done in relation to user behaviour, novel forms of construction, the development of analytical methods, and collecting actual performance data.

Doctoral Training Centres are effective in producing comparatively small numbers of individuals who combine specialist research knowledge with skills that can be applied more broadly in industry beyond the academic research environment. Such individuals are undoubtedly useful, but the capacity of doctoral training centres is such that they are too few and possibly too specialised to generate widespread change in the construction industry.

Catapult Centres (CCs), formerly Technology and Innovation Centres, are very specifically focused on research with a clear 'aim to exploit the most promising new technologies, where there is genuine UK potential to gain competitive advantage.' The Hauser Report [Hauser 2010] states that 'The mission of *[CCs]* is to help bridge the gap between research findings and outputs, and their development into commercial propositions'. These centres are placed firmly at the interface between research and technology/product development, but the development of a skilled graduate cadre is not part of their purpose. Indeed the supply of skilled personnel into industry is seen only as a 'trickle down' effect: 'However, the role of *[CCs]* in skills development ... comes mainly through the demand they create for technically skilled personnel, who then acquire further skills and knowledge, and then take these skills into business.' CCs have a clear but limited role to play, which does not address the needs identified in this report.

Centres of Excellence should be seen as research partners to the construction industry, rather than as traditional academically orientated centres. In this they will pick up on the broad, proactive engagement with industry exemplified by CWCT, but because of the range of disciplines involved, they must embody academic excellence which reaches the high standard where the whole picture is seen. By engaging practitioners in leadership roles the Centres will operate with an awareness of the demands and constraints of the construction industry, allowing them to respond more flexibly to requests for research support and so leverage the benefits of the academic research programmes. The Centres could also provide facilities to allow the industry and manufacturers to engage directly with fundamental research, and so anticipate future industry needs whilst also providing the expertise and consultancy that will allow them to address those needs.

The greatest benefit of a research centre comes when the ideas, knowledge, developing understanding and attitudes to exploration and experiment can be communicated to undergraduates and professional learners from the industry on a continuous basis. This is a key role for research in a Centre of Excellence.

Geographic location

In order to meet the goal of supporting the UK construction industry, Centres of Excellence should be established at a number of universities rather than concentrating the expertise in a single location. The university hosts should have existing strengths in architecture and engineering, an interdisciplinary design ethos and strong industry links. Connections with other construction industry professions could also be useful. Co-location of construction departments clearly helps interdisciplinary working, but well-established cooperation between separate departments does exist, even though the departments may be physically some distance apart. Given this, it is possible that an engineering department and an architecture department might not even be in the same university or the same city, provided that a suitable modus operandi can be found.

A broad geographic spread of the centres will allow a far greater proportion of the UK construction industry to benefit from them. The work of the Centres is expected to have international significance, and to draw on the experiences of different countries in addressing environmental problems arising from the climates they experience. This will inform the thinking about how building design may address the needs of future climate in the United Kingdom.

A number of different centres can allow different 'flavours' to emerge – even if centres are looking at the same issues, rapid progress is more likely if different approaches are explored. Different styles of leadership have advantages and disadvantages, and having leaders from different centres in dialogue is stimulating. The potential for personnel moving between centres as their careers progress strengthens cross-fertilisation. The panel overseeing the operation of all the Centres can help ensure that maximum benefit is obtained from this mix.

However, the most significant advantage of a geographical spread for the centres is simply in terms of catching more of the students who have the right abilities.

Educational provision

The precise details of the enhancements to engineering and architectural education provided by the Centres will vary according to what already takes place in the host institutions, but it is necessary to indicate core principles to meet the aims of the Centres.

A distinction can be made between what is provided to make graduates 'carbon-literate' or merely 'carbon-aware'. The 'carbon literate' graduate will be an engineer with a particular understanding of building physics and environmental design, and hence able to carry out or direct the range of design investigations needed to produce buildings which are genuinely sustainable. The 'carbon-aware' graduate (most likely architects or planners) will have sufficient knowledge of the issues to appreciate how the work led by the 'carbon-literate' graduate must be integrated into the design process.

The two types of graduate need to have some commonality in their education, and to have opportunities to carry out design project work together, in order to obtain insights into how the necessary integration can be achieved, and to have the necessary understanding of and respect for what the other disciplines bring to the design process. In practice, the greatest advances will be made when all the main professionals involved in the design of a building project are at least carbon aware, and engineers are engaged who are fully carbon literate.

It is normal for degree programmes in construction to be very crowded, as the views of a wide range of individuals on what is 'essential' are conflated and imposed on staff and students. Accrediting bodies are aware of this danger, and have been working for a number of years to ensure that individual institutions have flexibility to design their provision to reflect their particular strengths, leading to a healthy variety of courses. The fact remains that if appropriate new provision is to be made to meet the requirements of Centres of Excellence, then some other material or activities will need to be dropped. This may call for innovations to be made in the way in which some subjects are taught. It is to be expected that potential hosts for Centres of Excellence are already engaged in such innovations, and can adapt to achieve new goals. Accrediting bodies will need to recognise the importance of these goals.

Students

A Centre of Excellence cannot function without a good supply of raw material – high-quality undergraduate students.

At the heart of a Centre of Excellence are the courses which will attract the best undergraduates, as these are the people who have the ability and motivation to lead industry. The development of programmes for a Centre of Excellence will require not only traditional lectures and laboratory work, but also interdisciplinary design projects to encourage experimentation and the application of knowledge.

A typical undergraduate student should have obtained close to three or four grade 'A's at A-level, including Maths and Physics for the majority. The annual intake of students in subjects related to building design should be well in excess of 100. These numbers are necessary to maintain a critical mass of academic staff to be properly engaged in research as well as teaching, and to warrant the investment in building physics specialists and facilities necessary to form a fully active Centre of Excellence. The great importance of Building Engineering Physics to society makes the discipline an attractive one for students, and hosting a Centre of Excellence should lead to an increase in student numbers, which will help to ensure the long-term viability of the Centres. A Centre should aim to deliver into the building professions 60 carbon-literate engineering graduates per year, who will have been drawn from building services or civil/structural engineering cohorts. As an incidental consequence of the methods of teaching it is expected that Centres will also deliver of the order of 70 carbon-aware graduates in architecture and other closely related disciplines.

It is necessary to consider whether the resulting numbers of graduates from the Centres of Excellence would be sufficient to make a difference to the overall cohort of graduates entering industry. The total numbers of students in different fields are published by the Higher Education Statistics Agency (HESA). Table 1 indicates that the Centres of Excellence could deliver approximately 25% of graduate engineers entering the building design field and about 10% of other professionals.

Table 1: Graduate numbers from all UK universities in 2010 [HESA, 2011] and projected graduate numbers from Centres of Excellence.

	Graduate numbers	Estimated proportion engaged in building design	Final number
All UK universities (HESA Figures):			
Civil engineering	3,715	0.25*	929
Architecture, planning and others	3,420	0.7	2,394
Total	7,135		3,323
From one Centre of Excellence (Prediction):			
Carbon-literate engineers	100	0.6#	60
Carbon-aware architects, planners and others	100	0.7	70
From four Centres of Excellence:			
Carbon-literate engineers	400	0.6	240
Carbon-aware architects, planners and others	400	0.7	280

* It is estimated that the majority of civil engineering graduates in the UK will enter the industry either in contracting organisations, where it is difficult to identify design as a separate process, or will enter the infrastructure sector, rather than the building sector.

The Centres of Excellence will focus on design education relating to buildings and therefore it is estimated that graduates from the Centres will enter the building construction sector in higher proportions than the industry average.

Over time, the Centres of Excellence must support other universities in enhancing their own low-carbon education, so that the proportion of fully carbon-aware graduates steadily increases to over 50% over a 10 to 15 year period. However, after only five years, every office that is actively recruiting graduate engineers could have one graduate from a Centre of Excellence. This is an achievable goal.

Staffing

To deliver the educational aims, centres will need academic and research staff involved in pushing the profession forward. They must be able to communicate their knowledge, skills and enthusiasm to the undergraduates, and they must be involved with those engaged in the design of buildings. They must also be able to communicate with policymakers, the media, and the general public, calling for expertise in public relations, marketing and communications. The Centres must therefore be staffed by a range of professionals in addition to the expected academic and research staff.

The academics might have narrow specialist expertise, but it is most important that they have the broad view too, and an understanding of integration into design. This is most likely to have been obtained during a period in engineering design practice. The aim of the Centres is to replace trial and error with a systemic design approach that is scientifically sound and based upon real understanding of engineering. All the academic staff must be able to deliver this approach.

The range of expertise involved in the centre needs to go beyond what is seen in most civil building services or building engineering departments. At present, these may have no building physics staff at all, or only a very small number and they are likely to be focused on a specific field of research in a traditional academic research centre, rather than having a broad, interdisciplinary perspective on teaching and research needs. It would nevertheless be expected that any institution with the undergraduate intakes to support a Centre of Excellence will already have some of the academic staff required, and will have links with industry which support their teaching.

A particular requirement of a Centre of Excellence which differs from conventional engineering departments is for staff that can direct and support interdisciplinary design project work. There is a relationship between these needs and those of the traditional architectural design studio, which requires engineering academics and tutors to help students synthesise the many skills of architectural design. The academics or tutors who lead the design work need to be able to make a substantial time commitment to ensure that the students derive the intended educational benefit from these intense activities. This will require academic staff committed to design tutoring in addition to tutoring support provided by professionals engaged in design practice.

Centres of Excellence will need to have expertise in the following areas:

- Building construction & materials
- Building services systems including public health
- Human comfort and climate psychology
- Acoustics
- Ventilation and air conditioning
- Controls and automation

- Natural ventilation
- Lighting design
- Daylighting
- Thermodynamics and thermal performance of materials
- Thermal modelling
- Measurement and performance evaluation
- Coupled flow and distribution
- Energy generation and conversion

Each of these areas requires associated academic staff, though individuals may operate in more than one area. Individuals with purely theoretical expertise in any of these areas may be appointed as research fellows within a Centre of Excellence, but their expertise only becomes useful to the educational aims of the Centre when applied to the difficult and interesting problem of open-ended design in the real world. The staff will also need to have very close connection with expertise in structural design, architectural design, and construction materials, as well as links with psychology, social sciences and economics.

These requirements would generate an initial absolute minimum staffing of four, but the consequent teaching loads, especially in leading the design project work, would severely constrain the ability of the Centre to maintain an outward focus and meet the broader expectations of industry and policymakers. It would therefore be unrealistic to expect a Centre to meet its aims with fewer than seven academic staff.

The Centres of Excellence will also need excellent, committed professional support staff to handle administration, marketing and public relations, and will need support in managing finances.

The full-time academic staff, comprising lecturers, senior lecturers and professors, would be supported by research fellows/ senior research fellows/ readers. All must have a major involvement in teaching, which perhaps rules out some traditional models of 'reader'. Visiting staff from design practice should be involved in research and policy work as well as teaching. It is most likely that leadership within a Centre would be provided by a professor with expertise in human comfort and energy analysis in a building design context, with an emphasis on design practice as well as theory.

The teaching fellow would have a particular remit to coordinate teaching methods, and the industrial input to the teaching, which requires considerable support. A number of research associates would support the work, focused principally on their research, but also involved in teaching. A steady turnover would be expected in this category, with those leaving supporting the development of building physics teaching in other universities, or going into or returning to industry. This category should number a minimum of 10, increasing to 20 or more as research income increases.

Table 2: A typical staff profile for a Centre of Excellence.

Academic staff	Research staff	Other staff
Two professors	Three or four senior research fellows	Administration
Two or three senior lecturers	Three or four research fellows	Public relations
Two or three lecturers		Marketing
		Industry outreach support
One teaching fellow	Research students	Technical support
Visiting tutors		

Governance

Even though a Centre of Excellence is much more than a traditional 'Research Centre', it would be expected to have at least equivalent status within the host university due to the research aspects of its activities. The Centre would normally be based within a department, school or faculty, but might include staff in other departments or faculties. Line management of staff would be from within their own department, whilst a specific fraction of their time, normally 90% or greater, would be committed to the activities of the Centre. Financial management of the Centre would normally lie within the Centre and be accounted for separately from the finances of the host department.

A Centre should be governed by a management board, or equivalent. The board should include at least three representatives from industry to include two representatives of progressive design practices, and one representative of a similarly progressive client organisation. The composition of the management board would need to meet with the approval of the host university, but would also be guided by the overview panel hosted by The Royal Academy of Engineering.

The day-to-day leadership and direction of the Centre should be the responsibility of the Director, who should be a professor. A key aspect of this role will be liaison with the course or programme directors for the undergraduate programmes to which the Centre contributes. A commitment to making the necessary space within the undergraduate programmes is a prerequisite for the establishment of a Centre.

Having more than one centre with apparently similar scope and authority could be confusing, but it would not be appropriate to encourage too much specialisation on a centre just to create differences, as the broad teaching requirements are common to all. It is likely that centres will contain individuals with very specific expertise, but it is the broader expertise which is most likely to be needed by media and government.

Coordination of the work of the Centres and presentation of a coherent offer to the media and government requires close collaboration between the centres, especially at director level. It is recommended that the directors meet as a group with a Royal Academy of Engineering coordinator at least once every three months. Short annual conferences would help foster collaborations between individuals. These should cover teaching developments, research highlights, and policy engagement.

Identity and credibility

Giving the Centres of Excellence a common identity, in the way that has been done for the BRE Centres, will help to distinguish them as authoritative and independent. There could be no clearer assertion of this than naming them "Royal Academy of Engineering Centres of Excellence", which would also identify them with the Academy's ongoing programme to promote radical improvements in the design of buildings by the application of building engineering physics. The Royal Academy of Engineering could then provide the forum for coordination of the work between the centres, and would convene and host the overview panel.

However, a label alone will not endow the centres with the credibility they need in order to become a trusted partner to the construction industry, the media or policymakers. The leadership of the centres needs to be heavily influenced by construction industry professionals, and ideally the centre directors will have substantial experience in design practice. A major goal of the centres of Excellence is to provide much more rapid translation of the impacts of research into the construction industry. This will only happen if the centres are led by people experienced in the demands and constraints of the industry itself.

Operating costs

To achieve the objectives of the Centres of Excellence it is inevitable that additional funding will be required, above and beyond the normal research funding and student fees. This funding will allow the staff sufficient time to develop and deliver the new teaching modes required, to engage with industry in scoping future research needs and to be available to advise policymakers.

The additional cost of establishing a Centre of Excellence will vary from university to university, depending upon the research, teaching and support staff already in place. Therefore only a general indication can be given of the expected funding required, which becomes more complicated if the additional attraction of a Centre of Excellence leads to an increase in student numbers and hence greater direct income.

In order to obtain such an indicative cost, an assessment has been made on the basis of funding for additional staff to establish such a centre. The additional staff would comprise a professor, two senior lecturers, a teaching fellow and five research fellows who would be needed to carry out the core research work and contribute to the teaching. Additional allowance has been made for technical and administrative support, marketing and public relations and bought-in design tutoring.

This assessment indicates an overall cost per Centre of about £9 million for five years of start-up support. It would be expected that the university would be see some increase in teaching income over this period, and considering other benefits to the university of hosting a Centre, and the likely range of existing provision, it would be reasonable to aim for an average figure of £7.5 million per Centre. This results in a total cost for four Centres over five years of £30 million. Over the five years during which this start-up funding is necessary, a successful Centre of Excellence will have progressively increasing student numbers and research income, ensuring long-term viability.

References

Hauser, H., 2010 *The Current and Future Role of Technology and Innovation Centres in the UK*. Department for Business Innovation & Skills.

HESA, 2011 Students by subject of study, first year indicator, mode of study and level of study 2009/10. Higher Education Statistics Agency. www.hesa.ac.uk

Appendix 2:

Estimating the economic impact of Centres of Excellence in sustainable building design

Introduction

This appendix presents a simplified analysis of the economic benefits of providing enhanced undergraduate teaching in integrated sustainable design. This teaching is to be provided in order that graduates entering the construction industry are positioned to achieve the necessary carbon abatement measures at the lowest cost to society.

This analysis starts with the premise that, without appropriate skills in sufficient quantity, the majority of the construction industry will resort to high-cost measures to achieve the carbon abatement required by legislation and future policy targets. However, with a sufficiently skilled workforce, the required carbon abatement can be achieved more quickly and at lower overall cost. Conversely, without this education in appropriate low carbon design skills, it is possible that the industry will be unable to deliver the required carbon abatement at any cost.

For the purpose of this analysis, the measurable output of the Centres of Excellence in integrated sustainable design will be the engineering graduates trained in building engineering physics. This analysis compares the marginal cost of educating undergraduates in building engineering physics at the Centres of Excellence with the marginal cost of abating carbon emissions either through integrated design of buildings for these graduates or through the application of business as usual technologies for graduates without the benefit of an education in integrated design.

The Marginal Abatement Cost (MAC) of carbon is the monetary cost needed to reduce the carbon emissions (of a construction project) by one additional tonne per annum. Different abatement techniques and technologies and policies have different MACs. In fact, if a particular abatement technique saves on total energy generation costs to society over the lifetime of a building at a level greater than the upfront costs of implementation (e.g. materials, running costs, embedded carbon costs) then the net impact of the marginal abatement is a saving to society, hence a negative cost.

Current building practices do not always deliver carbon abatement at the lowest MAC, but more often at the lowest financial cost to the developer or contractor, taking into account the current economic conditions and, for example, government incentives. In addition, current practitioners may not know or be able to implement the state-of-the-art practices which would result in the lowest MAC. Graduates from a Centre of Excellence would be better positioned to provide abatement at the lowest MAC to society at the lowest cost to the developer or contractor.

The analysis assumes that Centres of Excellence are established according to the framework and costs outlined in Appendix 1. The full costs of operating the Centres of Excellence will be borne by society, whether this is through individual tuition fees, central university funding or through research grants. However, the aim of the Centres of Excellence is to enhance the education of students who would in any case be studying on courses for the built environment. Thus, the cost of educating a student to be expert in integrated low carbon design will be the additional cost over and above that of a student following a normal undergraduate course in the built environment.

After an initial start-up period the Centres of Excellence will deliver their full capacity of graduates into the UK construction industry. This analysis ignores students from overseas as their tuition costs would not be a cost to the UK economy. Further, while many overseas students will choose to return overseas for employment, some will remain and enter employment in the UK, thus contributing to carbon abatement in the UK above and beyond the conclusions of this analysis.

Recruitment into the new Centres of Excellence will initially be from those considering already established courses in the built environment. It is therefore anticipated that the Centres of Excellence will achieve capacity within two to three years.

Benefits not explicitly evaluated

There are likely to be a number of positive impacts of Centres of Excellence which have not been explicitly evaluated in this analysis. The Centres will provide high-quality teaching and research which will enable engineering graduates to enter the profession with a range of highly applicable skills such that they may make an immediate impact in their chosen fields. One key benefit of graduates trained in building engineering physics will be that carbon abatement techniques will be built into engineering projects, lowering the operating emissions of buildings as well as the emissions embedded in their construction. At present, many of the techniques used in industry are not state-of-the-art and may increase carbon emissions due to incompatibilities with other aspects of the building or systems designs. At the least, the currently popular approaches may not provide the abatement desired at the lowest abatement cost.

In addition, there is a good chance that the total carbon abatement achieved may be greater from graduates from the Centres of Excellence than from current practitioners, since the learning involved at a Centre of Excellence will include working with a range of people from across many disciplines, including current industry professionals, manufacturers and technologists as well as engaging in joint design projects between architects, civil and building services engineers. This encourages awareness of how wider issues within the construction sector affect carbon abatement techniques. For example, architects with a greater awareness of building engineering physics are more likely to develop designs that encourage and incorporate passive design features. By engaging with manufacturing industries, issues of system interoperability can be addressed early in the design. Also, by including carbon abatement practices from the design stage of new buildings, the scope for abatement is likely to be much higher than retrofit. However, even in the area of retrofitting, carbon abatement is likely to be increased by a Centre of Excellence-trained graduate, since the many issues facing retrofit practitioners are complex and often highly site-specific.

Graduates from the Centres of Excellence are likely to be amongst the top students in architecture and building engineering and therefore will quickly move into positions of influence. Not only will these graduates become strategic decision makers within the industry, it is likely that demand for their skills will develop amongst policymakers, regulators and even financiers. This will increase the awareness of the benefits of building engineering physics amongst stakeholders and influencers in the construction industry as well as the makers and doers.

Other benefits of Centres of Excellence include a substantial increase in the academic pool of low carbon- and design-literate teachers and trainers. This will help meet the demands for future increases in training at all stages of professional development in industry, even if not an increase in the numbers of Centres of Excellence themselves. This will then make the adoption of sustainable design across the construction industry an organically growing process.

In addition, by establishing Centres of Excellence, the state-of-the-art in building carbon abatement will be pushed forward, with a greater number of specialist researchers and a greater pool of students to enter the research arena. This will help reduce the MAC and increase the abatement potential of building physics techniques, potentially increasing the benefits to society beyond those outlined in this analysis.

Not all of these benefits are quantifiable, and of those that are, some assumptions will have to be made to make the estimations tractable. More details on the specific assumptions made are given below.

The costs of such a project will have to be considered too. These are broadly in two categories – the costs of training and the costs of employment. The training costs are the costs of setting up and running the Centres of Excellence. The employment costs are the opportunity costs of keeping a trained graduate in a position where they can use their training and expertise to reduce carbon at the lowest MAC, that is, in a building engineering physics-related post. In general, the opportunity cost is the cost of the next best alternative, and here we can suggest that the salary is a good proxy for the opportunity cost, as the individual can be assumed to be in the job that offers the highest salary, and would work elsewhere if the building physics engineer's salary was lower than the next best alternative. Given that the job market would offer a range of posts, we assume that the salary itself is a suitable level.

Methodology and assumptions

The following method of estimation and its associated calculations are based on estimating the *marginal* impact of the Centres of Excellence project, that is, the net project benefits (project benefits minus project costs) incremental to a business as usual (BAU) scenario. The business as usual scenario, in this context, is to continue with the current UK policy objectives of achieving the majority of carbon reductions through subsidies for high technology and in which there is no enhancement of education in building science for passive energy conservation. The marginal benefits and costs are therefore as summarised here and explained in greater detail below:

Marginal training costs are the cost of setting up and maintaining the Centres of Excellence. These costs are the extra over costs of providing the enhanced engineering education in the centres. As all other costs to the university and individual are the same in the project and BAU scenarios they do not need to be accounted for in the analysis.

Marginal employment costs are the costs of employing a building engineering physics- trained graduate compared with the cost of employing a 'regular' engineer in a building engineering physics role. We assume this to be a 10% salary premium in the first year, reflecting the advantage such a graduate would have in the job market, which decreases by two percentage points a year over five years until the salary premium is zero. This decrease in the premium reflects the fact that after five years in the industry, most engineers are likely to be a specialist of some sort anyway and so able to gain similar average salaries.

The marginal benefit is the decreased MAC cost per unit of carbon saved. We assume that the building engineering physics graduates can implement state-of-the-art practices which allow for carbon abatement at the lowest possible social cost, so that there is likely to be a net social gain due to the reduction in energy use over the lifetime of a building. We are not assuming an overall increase in carbon abatement, but rather that the carbon abatement continues happening at the same rate as the BAU scenario.

None of the learning effects or the knock-on effects in academia, such as the benefits of an increased research base, are being quantified here. We model a fixed quantity of graduates leaving a fixed number of universities. We also model a fixed abatement ability of each graduate.

Education costs

We assume that the project consists of four Centres of Excellence, each with a graduating cohort of 60 engineering students and 150 architects. This analysis considers only the contribution to society of the engineering graduates who have benefited from an enhanced education in building physics and integrated design. Thus we are apportioning the full start-up cost of the centres over the numbers of engineering graduates.

Over a five-year duration, the cost of running the four centres is £30 million. It is assumed that £10 million of this will fund research at the centres that would otherwise be funded and carried out elsewhere. This leaves an extra over cost of £20 million for teaching undergraduates at the four centres over five years or £4 million per year as the marginal cost of educating the graduates. Although the Centres are initially only funded for five years, they will continue to require the same operating costs throughout the analysis period and this is still a cost to the UK even though these future costs are likely to be met from industry and the undergraduates themselves as demand rises.

We assume there are no marginal ongoing training costs after graduation as all engineers are expected to undertake continuing professional development.

Employment costs

We assume that the starting salary for a typical engineering graduate in the construction industry is £25,000 (BAU scenario) and there is a 10% premium on this for a graduate from a Centre of Excellence (project scenario), making the marginal cost £2,500 in the first full year of employment. We assume this difference decreases by 2% a year for five years until there is no premium and the marginal employment costs reach zero. We also assume that the base salary rises by 3% each year. This is shown in Table 1 below.

Table 1: Employment costs per employee for the first 6 years.

Year of employment	BAU salary	Project salary	Marginal employment cost
1	£25,000	£27,500	£2,500
2	£25,750	£27,810	£2,060
3	£26,523	£28,114	£1,591
4	£27,318	£28,411	£1,093
5	£28,138	£28,700	£563
6	£28,982	£28,982	£0

After the fifth full year of employment, there are no additional employment costs. The graduate works six months of the year of graduation so received half the salary and pay rises do not come into play.

Additionally, it is assumed that 10% of graduates from the Centres of Excellence do not enter employment in a low carbon construction job, and the number of graduates in such employment decreases by 10% annually due to changes in job role or wastage from the profession. The modelling also assumes that there is sufficient demand in the industry for 90% of each year's graduate output.

Among the 10% of graduates modelled as leaving the industry each year, a good proportion will actually move into other jobs which will continue to contribute to carbon abatement, such as management, regulation, policymaking or training. However, we are unable to estimate the contribution that these people will continue to make and they are therefore excluded from future carbon abatement potential within the model.

Numbers of graduates

This analysis assumes that a Centre of Excellence grows to full capacity of 60 engineering undergraduates per year over the conception period of three years. It is further assumed that only 90% of graduating engineers will enter the profession and that there is an ongoing dropout rate of 10% per year thereafter. This dropout rate represents not only those engineers who choose to leave the industry, but also represents those who move into other job roles and therefore no longer directly deliver carbon abatement.

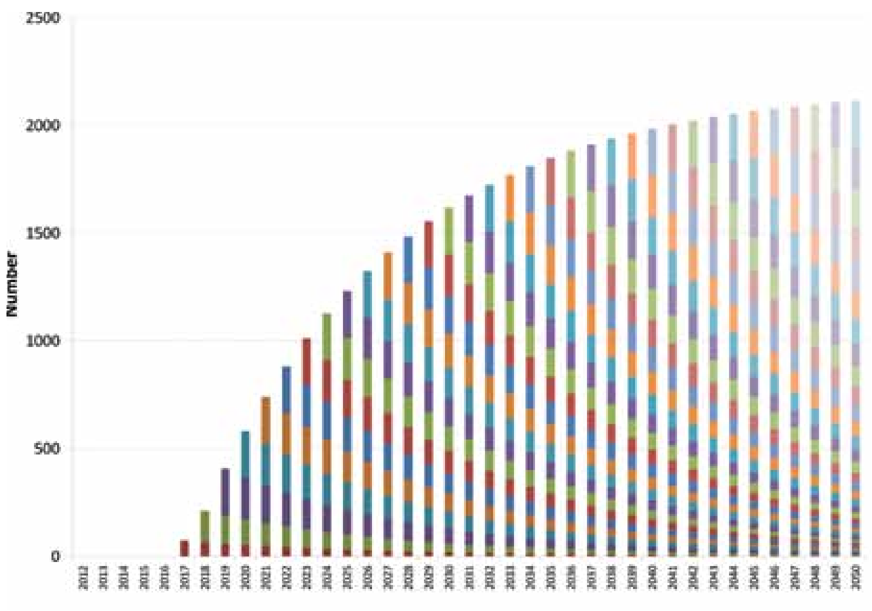


Figure 1: Number of graduates actively working on carbon abatement projects.

Based on the assumptions outlined above, a total of 7,128 graduates will enter the industry over the study period. Of these, 1,609 will still be engaged in carbon abatement projects in 2030 and a total of 2,093 in 2050.

Abatement potential

Figures for carbon abatement by practitioners have been compiled from data collected by CIBSE registered Low Carbon Consultants. CIBSE Low Carbon Consultants are experienced construction professionals who have undertaken specific training in carbon abatement techniques. As a requirement of continuing registration, Low Carbon Consultants must submit annual carbon returns detailing the projects worked on and the expected annual abatement from these projects. An appropriate proportion of the abatement is then attributed to the practitioner based on their role in the design and implementation stages.

A summary of the low carbon returns used in this analysis is shown in Table 2. The abatement shown is per year and ongoing for the lifetime of each project.

Table 2: Summary CIBSE Low Carbon Consultant annual returns - carbon abatement per project and per year

Consultant	Projects per year	Average annual abatement per project ($kgCO_2$)	Total annual abatement per year ($kgCO_2$)	Principal project type
1	7	13,435	94,042	Various
2	9	24,399	219,595	Commercial, mainly new build
3	8	23,583	188,663	Education, new build
4	1	4,761,299	4,761,299	CHP installation
5	36	134,275	4,833,885	Retail, installation of CHP
6	1	74,407	74,407	CHP installation
7	1	330,829	330,829	CHP installation
8	1	1,563,398	1,563,398	CHP installation
9	7	296,153	2,073,073	Retail, installation of CHP
10	9	5,372	48,350	Various: glazing and AC
11	3	133,643	400,928	Various
12	14	57,508	805,119	Mainly education; various techniques
13	1	0	0	
14	4	13,320	53,281	Education: various techniques
15	6	4,696	28,176	Residential; PV, U-values, plant efficiency
16	2	155,570	311,140	Various
17	2	111,724	223,449	Various
18	40	74,070	2,962,800	Mainly retail; mainly CHP
Mean	8	432,093	1,054,024	
Median	5	74,239	267,294	

Due to the small sample size and the highly skewed distribution of returns, the abatement potential for graduates from the Centres of Excellence has been assessed as the median value of the abatement achieved by Low Carbon Consultants; 267 tonnes CO_2 per year, rather than the mean.

The carbon abatement achieved in a construction project is delivered year on year. Even if a given engineer leaves the industry their past projects will still contribute to future carbon abatement. Since this analysis looks at a time period shorter than the expected lifespan of most buildings, but is longer than the life of some low carbon technologies, the abatement from a single project is expected to reduce over time. The replacement of low carbon technologies such as microgeneration or heat pumps at the end of their lives would be counted as carbon abatement for future practitioners. Therefore this must be excluded from the future abatement potential for present-day practitioners.

This is achieved in the analysis by applying a diminishing profile of future carbon abatement as shown in Figure 2. This profile has been derived by reference to The Carbon Trust persistence factors, shown in table 3, and applying these to the profile of work are likely to be undertaken by the new graduates drawn from examination of the low carbon returns and the McKinsey MAC curve.

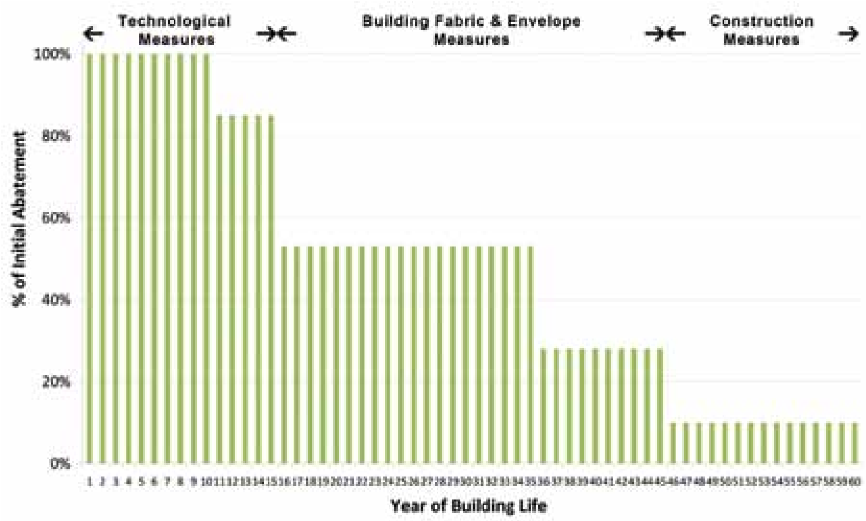


Figure 2: Persistence of building carbon abatement measures

Career abatement potential

It is assumed that in the year of graduation, graduates entering the construction industry will not achieve any meaningful project work to produce carbon abatement. Typically the first six months of graduate employment will cover the processes of induction and familiarisation with the new employer. The analysis therefore commences with a full year's worth of carbon abatement from the first full year of employment after graduation.

If the project to establish Centres of Excellence commences in 2012, the first cohort will graduate in 2016 and achieve carbon abatement from 2017 onwards. The analysis period runs until 2050, giving career duration of 34 years. This period is shorter than the typical life of a building and therefore it is expected that abatement achieved in the first year of a graduate's employment will still contribute to the overall abatement, albeit at a reduced level, at the end of the analysis period. The lifetime abatement for a graduate from the inception of the program is given in Figure 3.

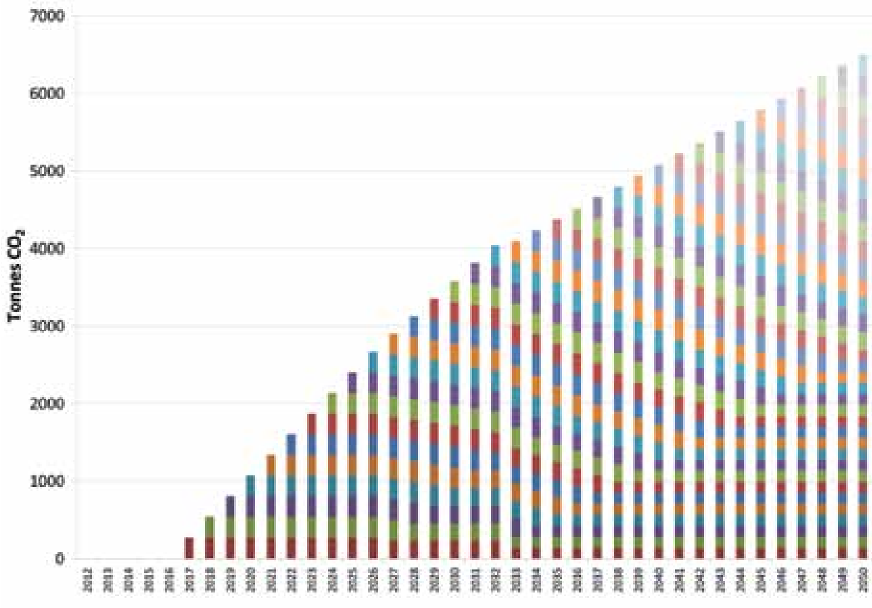


Figure 3: career carbon abatement for a 2016 graduate from a Centre of Excellence.

The work of a single engineer graduating in 2016, over the course of their career, will result in abatement of 6,493tCO_2 in 2050 and a cumulative reduction in carbon dioxide emissions to atmosphere of 130, 616tCO_2 over the whole period. Engineers graduating after 2016 would contribute proportionately less carbon abatement during the analysis period.

Marginal abatement cost

The marginal abatement cost of carbon emissions is normally based on the MAC curves published by McKinsey. They range in detail from the UK-specific curve (2007), to the building sector-specific curve (2010) and the post-credit crunch curve (2011). Unfortunately, it is not possible to combine these levels of detail, so the analysis has been based on the UK curve from McKinsey, published by the CBI [2007]. The relevant sectors were identified, and the abatement potential and the marginal abatement cost have been estimated from these as shown in Table 3.

Table 3: Marginal abatement potential, costs and persistence factors of a range of low carbon interventions [CBI McKinsey 2007, Carbon Trust 2010]

	Abatement potential MtCO$_2$ pa	Cost of abatement 2002 real €/tCO$_2$	Cost of abatement 2010 real £/tCO$_2$	Persistence factor Years
Building envelopes	10	-125	-126	45
Lighting	8	-100	-101	14
Cavity wall Insulation	5	-65	-65	60
Condensing boilers	5	-40	-40	14
Zero-carbon homes	8	20	20	10*
Solid wall insulation	10	35	35	35
Floor insulation	4	40	40	35*
Solar water heating	5	600	603	17

The McKinsey abatement potential indicates the ongoing annual reduction in carbon emissions that can be achieved through the application of each technology *or technique. The annual abatement cost is the net social cost or benefit of abating 1 tonne of carbon dioxide in a particular way. A negative cost shows an overall social benefit. The persistence factors are the lifetime of the abatement for each technology or technique, recognising that technologies require replacement before the end of life for a building project.*

From table 3 it can be determined that the average cost of carbon abatement using the range of techniques included in the McKinsey evaluation is £20/tCO_2.

Since the marginal benefit of the project is the change to using techniques for energy conservation that have a net benefit it is necessary to evaluate the difference from the baseline above. This is achieved by weighting the abatement potential derived from the McKinsey curves which represent the total abatement possible and not that which is achievable under the business as usual scenario.

In order to model the difference between the business as usual abatement potential and the potential including the benefit of graduates from Centres of Excellence, the McKinsey values have been weighted to reflect the limited ability of current practitioners to fully realise the abatement potential of certain technologies. The weightings are explained further below.

Table 4: Weightings used to adjust the McKinsey /CBI MAC curve for current practitioners and for building engineering physics graduates working in the field.

	Current practitioner abatement weight	Current practitioner	COE graduate cost weight	COE graduate abatement weight	notes cost weight
Building envelopes	0.5	1	1	1	Current practitioners do not fully utilise the potential of building envelope.
Lighting	1	1	1.2	1	Graduates will move beyond low energy lamp replacement to use daylight
Cavity wall Insulation	1	1	1	1	
Condensing boilers	1	1	1	1	
Zero-carbon homes	1	1	1	-0.1	Graduates will avoid active technologies hence a saving of 10% on maintenance
Solid wall insulation	1	1	0.1	0.1	Graduates will have limited involvement with solid wall insulation
Floor insulation	1	1	0	1	Graduates will not apply floor insulation
Solar water heating	1	1	0.01	0	Graduates will have limited involvement with solar water heating

The weighting of abatement potential is used to show how we predict the building engineering physics graduates to be able to provide either more abatement than McKinsey has predicted, or less. The weighting of cost indicates an assessment of the additional benefits of adopting the least cost solutions within a range included in the McKinsey predictions.

- A weighting of one indicates no change from the McKinsey abatement potential or abatement cost;
- a fractional weighting is applied where the assessment of costs or benefits is lower than the McKinsey prediction. In other words graduates from Centres of Excellence would not be responsible for achieving the entire abatement potential;

- a weighting greater than one indicates assessment of costs or benefits higher than the McKinsey prediction;

- a negative weighting indicates the reverse of the McKinsey prediction, i.e. a cost rather than the benefit or vice versa.

The sum of the weighted potentials is the total potential available for graduates in a year. The average abatement cost is the sum of the weighted costs multiplied by the weighted potentials, which is then divided by the sum of the weighted potential.

The marginal abatement cost for a building engineering physics graduate is the average marginal abatement cost for the current practitioners minus the average marginal abatement cost for the building engineering physics graduates.

Whilst the weightings may be open to discussion, they provide a more transparent way of estimating the benefit of a building engineering physics graduate compared with a current practitioner.

The marginal abatement cost for carbon saved by graduates from Centres of Excellence is derived from combining the total abatement potential and 2010 cost of abatement for each of the techniques indicated in Table 3 and applying the weightings from Table 4. The results are shown in table 5.

Table 5: Weighted potentials and costs for BAU practitioners and graduates from Centres of Excellence.

	BAU current practitioners		COE graduates	
	Weighted abatement potential $MtCO_2$ pa	Weighted cost of abatement 2010 real £/tCO_2	Weighted abatement potential $MtCO_2$ pa	Weighted cost of abatement 2010 real £/tCO_2
Building envelopes	5	-126	10	-126
Lighting	8	-101	9.6	-101
Cavity wall Insulation	5	-65	5	-65
Condensing boilers	5	-40	5	-40
Zero-carbon homes	8	20	8	-2
Solid wall Insulation	10	35	1	3.5
Floor insulation	4	40	0	40
Solar water heating	5	603	0.05	603
	Weighted average abatement cost	**£31/tCO_2**	**Weighted average abatement cost**	**-£71/tCO_2**

The marginal abatement cost for the work of graduates from Centres of Excellence over the work of current practitioners is -£102/tCO_2.

Conservative assumptions

In order to avoid overestimating the benefit of the Centres of Excellence, the study has erred on the side of caution in the assumptions. These conservative assessments are as follows:

- the MAC has been based on the earlier UK-specific McKinsey curves, rather than on the more recent global curve, even though the use of the UK-specific curve results in a lower saving potential;

- It is possible that the McKinsey MAC curve already accounts for persistence factors, but nevertheless the carbon trust persistence factors have been applied to the abatement potential;

- further weighting has been applied to the MAC derived from the McKinsey curve in order to differentiate between Centres of Excellence graduates and business as usual;
- the abatement potential per graduate is based on the median rather than the mean of the CIBSE low carbon returns to better represent passive rather than active carbon abatement measures;
- the abatement potential of graduates is held constant throughout the analysis period with no account being taken of learning effects or of the research contribution to the education of future graduates;
- no account has been taken for the contribution of non-engineering graduates from the Centres of Excellence such as architects or surveyors.

Estimated results

Carbon abatement

The impact of the Centres of Excellence project can be evaluated by multiplying the impact of an individual graduate over their active career by the number of graduates in each cohort and the expected career duration. During the study period 7,128 graduates will enter the industry. However, due to the attrition rates, few of these will remain active throughout the period of analysis.

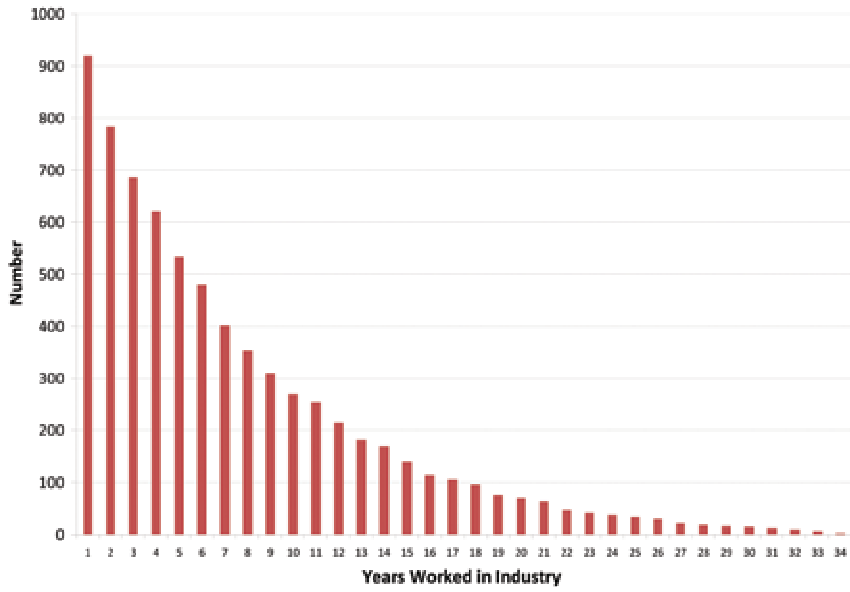


Figure 4: Career duration of graduates actively engaged in carbon abatement projects during the analysis period.

From Figure 4, it can be seen that only two graduates from the 2016 cohort remain actively working in the field through the entire 34 year period of the analysis and thus achieve the maximum abatement potential indicated in Figure 3. The remainder of the graduates entering the industry achieve reduced abatement due to their shorter career spans. There are 919 graduates engaged in the field for only one year; 216 of these are graduates in the year 2049. Nevertheless, the benefits from graduates entering the field during the late part of the analysis period will still continue to accrue beyond 2054 the lifetime of the building projects worked upon.

Aggregating the yearly abatement of an individual graduate gives the cumulative carbon dioxide savings for careers of any particular duration as shown in Figure 4.

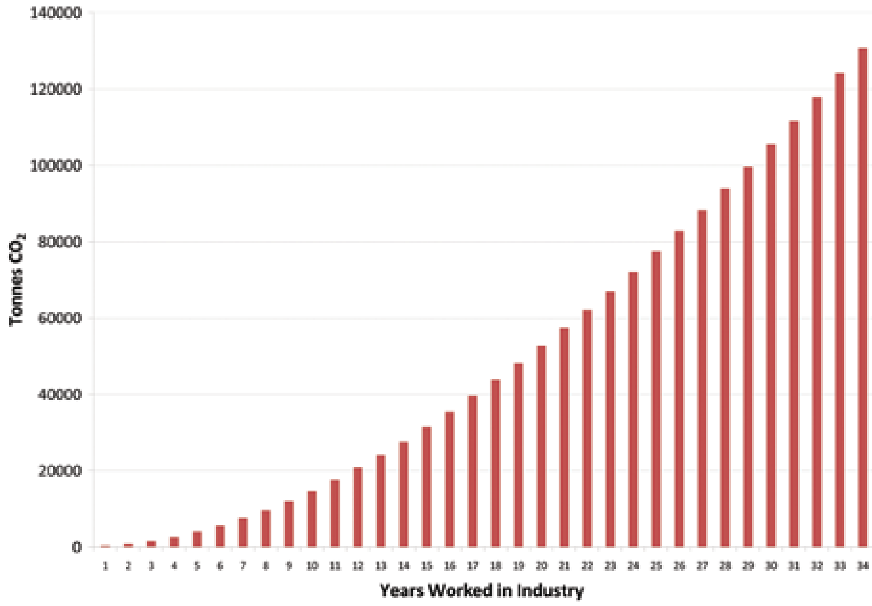


Figure 5: Cumulative CO_2 abatement for one graduate over the duration of a career 2016-2050.

The results of the analysis are given by summing the products of the number of engineers in each career cohort and the cumulative carbon dioxide savings achieved for each career duration as shown in Figure 5. A summary of the results is given in Table 6.

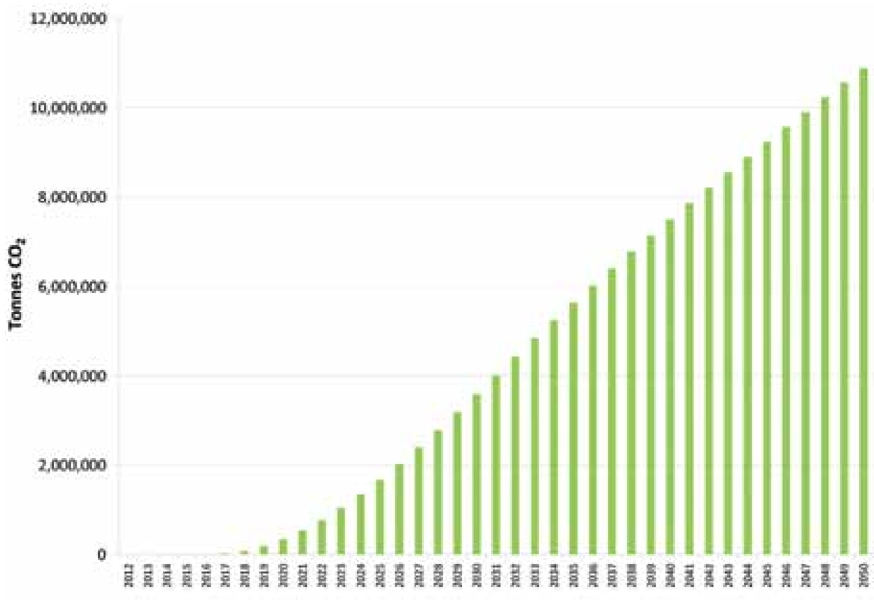


Figure 6: Cumulative CO_2 abatement for all graduates over the period 2016-2050.

Table 6: Summary of results

Final year of project	Graduates in employment	Carbon abatement in year t/CO_2/annum	Total carbon emission Saved t/CO_2
2030	1,617	3,589,842	19,939,894
2050	2,114	10,889,851	171,824,443

By 2050 the carbon abatement potential of the project is nearly 11 million tCO_2 per annum. This represents around 6% of the abatement required in the built environment to achieve an 80% reduction in line with UK targets. Thus, whilst this analysis indicates that the potential of the project is significant, it in no way approaches the limit of carbon abatement available from the building sector.

Net present value

The net present value of the carbon abatement achieved by graduates from the Centres of Excellence is calculated by applying the £102/tCO_2 MAC determined above to the cumulative carbon dioxide savings achieved and applying a discount rate of 3.5%. In order to evaluate the actual benefit of this project it is necessary to further account for the marginal costs of training and employing the graduates from the Centres of Excellence using the education marginal cost and employment marginal costs, also discounted at 3.5%.

The overall net value of the project is given in table 7 for two scenarios: firstly, if the project were to end abruptly in 2030 the date for completion of low carbon domestic retrofits; and, secondly, if it were to end in 2050 the target date for the UK carbon reduction programme. In both these scenarios the marginal costs of education and employment are included in full up to the final year. In reality if the project were to wind down, training costs would diminish towards the end of the period. This analysis also applies no value to the future carbon abatement beyond the analysis period achieved during the project.

Table 7: Net present value of project costs and benefits

Final year of project	NPV running cost for centres	NPV employment cost premium	NPV MAC carbon emissions abated	Net value of project in 2012
2030	-£52,758,727	-£11,349,417	£1,231,259,384	**£1,167,151,241**
2050	-£83,364,349	-£22,602,248	£6,838,381,569	**£6,732,414,972**

Sensitivities

Since the analysis is dependent upon a number of assumptions, it is necessary to establish how sensitive the project value is to the different assumptions. In order to validate the assumptions we test the sensitivity of the project NPV to variations in the assumptions. To make the tests more sensitive the NPV of the project to the year 2030 is used rather than the much higher NPV of the project should it run out to 2050.

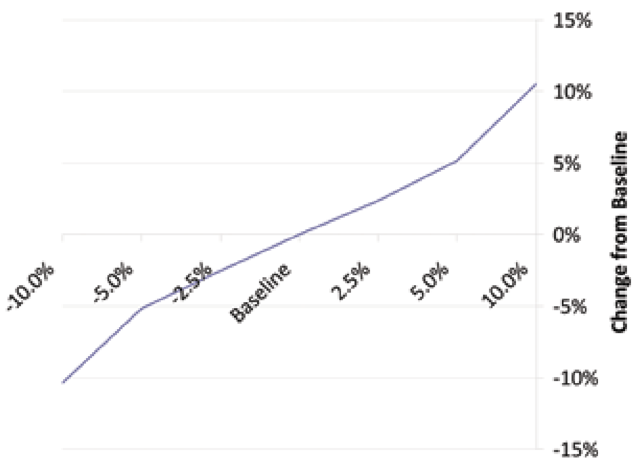
Value of carbon emissions abated

Since the value is the product of the MAC and the carbon abatement achieved, which in turn is the product of the number of graduates and the abatement potential per graduate per year, it follows that the NPV is equally sensitive to all of these starting assumptions. Further, since the MAC is derived from assumptions in interpreting the McKinsey curves and in applying the weightings to differentiate between business as usual and the project scenario, it follows that a test of the sensitivity to the overall value is equally a test of the assumptions contained in the weightings.

Nevertheless, the model was tested for sensitivity against MAC, number of graduates per year and carbon abatement per graduate per year. A change of 1% in any of the input assumptions results in a change in NPV of fractionally more than 1%. The results of this sensitivity test are given in Table 8.

Table 8: Sensitivity of the NPV to the value of carbon emissions abated (testing assumptions underlying the MAC and to the abatement potential of graduates

Test value	Project NPV to 2030	Change from baseline
10.0%	£1,289,973,402	10.5%
5.0%	£1,227,312,703	5.2%
2.5%	£1,194,724,352	2.4%
Baseline	**£1,167,151,241**	**0.0%**
-2.5%	£1,137,528,743	-2.5%
-5.0%	£1,106,686,818	-5.2%
-10.0%	£1,046,112,986	-10.4%



The response of the NPV to changes in the assumptions leading to the value of carbon abated is more or less linear. The carbon abatement potential of one graduate would have to drop to just 13.9 tCO_2 per annum in order for the NPV of the project to turn negative. Similarly the graduates from Centres of Excellence would only need to achieve carbon abatement at a value of £5.30 per tCO_2 better than their non-specialist counterparts in order to generate a positive NPV from the project.

As the number of students entering the profession increases, so the NPV increases. The number of students entering the profession could be as a result of more Centres of Excellence or of an increased graduating cohort from each centre.

Education and salary costs

The NPV is not sensitive to either the operating costs of the Centres of Excellence or the starting salary.

A 20% change in the annual operating cost for the Centres of Excellence results in a change in NPV for the project at 2030 of less than 1%. It follows therefore that the NPV is not sensitive to the assumed division of funding between research and teaching in the Centres of Excellence.

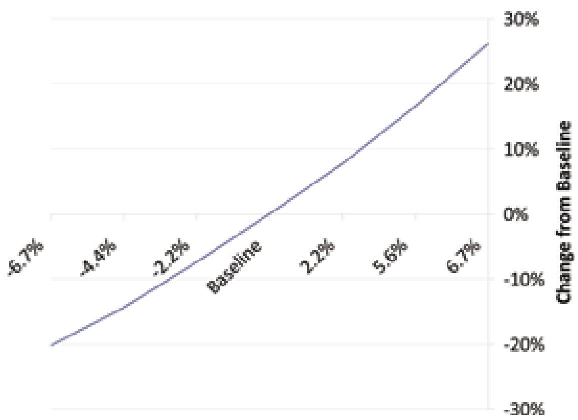
The starting salary for a graduate would have to be set at over £2 million for the NPV of the project in 2030 to be negative. It follows therefore that the NPV is neither sensitive to the starting salary premium for graduates from the Centres of Excellence nor to the annual salary rise assumed.

Graduate retention rate

The retention rate is the proportion of trained graduates that continues to work in the industry from year to year. The remainder leave the industry, either completely or moving into another part of the profession where they will not directly contribute to carbon abatement. For simplicity, the analysis assumes a fixed retention rate of 90% per year, assuming that 10% of the graduating cohort drop out between graduation and starting in industry and a further 10% of the remainder dropout each year.

Table 9: Sensitivity of the NPV to graduate retention rate

Test value	Retention rate	Project NPV to 2030	Change from baseline
6.7%	96%	£1,472,749,272	26.2%
5.6%	95%	£1,360,075,242	16.5%
2.2%	92%	£1,257,309,094	7.7%
Baseline	**90%**	**£1,167,151,241**	**0.0%**
-2.2%	88%	£1,080,802,809	-7.4%
-4.4%	86%	£999,080,386	-14.4%
-6.7%	84%	£931,218,069	-20.2%



Discount rate

Table 10 shows the sensitivity of the NPV to the discount rate. With a zero discount rate, the project has a net benefit of nearly £2 billion if allowed to run to 2030 or just over £17 billion if extended to 2050.

Table 10: Sensitivity of the NPV to the discount rate

Discount rate	NPV of project in 2030
4%	£1,087,000,000
3%	£1,254,000,000
2%	£1,448,000,000
1%	£1,676,000,000
0%	£1,945,000,000

Conclusion

The analysis shows that, based on the graduates from Centres of Excellence being able to abate carbon dioxide emissions at even a marginally lower cost than current practice achieves, establishing the centres will have a significant social benefit. Quantification of other benefits, such as research, not evaluated here, is likely to substantially increase the social benefits of the centres.

The key assumption underlying the proposal for Centres of Excellence is that graduates from the centres will be able to achieve the carbon abatement demanded from the industry at lower cost. This will be achieved through better training in building engineering physics allowing the graduates to save energy through passive design measures utilising the low-cost elements of construction such as the building frame and fabric. The energy saving thus achieved reduces the need for investment in microgeneration technology to mitigate energy consumption. Thus the carbon abatement is achieved at lower investment cost.

This analysis has shown that a graduate from the Centre of Excellence only needs to achieve abatement at a cost of £5.30 per tCO_2 below the business as usual approach to achieving net benefit to the UK economy despite the higher costs of operating the Centres of Excellence. The marginal abatement costs of the techniques that will be applied by graduates from Centres of Excellence are typically valued at orders of magnitude greater saving than the breakeven figure for this project.

Given the numbers of graduates that could be educated by just four Centres of Excellence and the ongoing nature of carbon abatement this project has potential to deliver very significant value for the UK economy over time scale commensurate with our needs to reduce carbon emissions. The project has the potential to generate a net present value in excess of £1 billion by 2030 and in excess of £6 billion if it continues on the same basis to 2050.

The results presented in the model here are not highly sensitive to most values used and so it can be taken as a reliable indication that the Centres of Excellence will have a lasting and significant social benefit.

There are, however, some key aspects of the study that should be noted.

It must be remembered that this is not a full CBA of the project, nor is it a full economic or financial analysis of all its aspects. Rather, it is a model to estimate certain quantifiable benefits of engineers trained in building engineering physics. Specifically, it is used to estimate the benefit to society of having carbon abated at the lowest possible cost. The key assumptions lie in the framing of the costs and, in particular, the benefits. We have assumed that the costs are primarily the training costs, and the social costs of keeping building engineering physics graduates in employment are not so significant. This assumption seems reasonable, since it is likely that people who have chosen to study engineering at a Centre of Excellence in Building Engineering Physics would tend to want to work in such a field.

The benefits to society are harder to quantify precisely. Instead of modelling the total carbon saved, we have assumed that the carbon abatement would take place anyway but at a standard marginal cost under a business as usual scenario, for example, non-specialists retrofitting houses or designing new buildings, or indeed in CCS schemes for power plants. We have taken the MAC curve for the UK published by McKinsey (2007) and have weighted the building sector results to reflect what marginal impact trained building engineering physics graduates would be expected to have.

While the results are dependent upon these weightings, given the method used and the relative insensitivity of the model to the resulting MAC, it seems highly reasonable to accept the result of the estimation. In fact, it could be argued that the abatement potential (here derived from CIBSE specialists' returns) could be a lower bound since the building engineering physics graduates would be expected to be at least as good as those who filled in the returns. So if this were the case, with a lower MAC but higher abatement potential, the results would still be positive and large.

The analysis suggests that each graduate has a net benefit after just two years of employment. This means that the more graduates there are, the quicker the project benefits will accrue, increasing the value to society. The accumulated benefit to society of this early focus on the lowest cost abatement will be to liberate finance for research and development to improve the MAC of the high-technology solutions that would be required to deliver ongoing abatement beyond 2030.

A further important, non-quantified benefit of the project is that it is likely that the original Centres of Excellence will provide graduates who go into research or on to other engineering departments in the UK where building engineering physics will be increasingly taught, thus spreading the benefits further than analysed here. The opportunity for multidisciplinary research between building physicists, manufacturers and technologists will lead to the state of the art increasing and the MAC curve will be pushed downwards (reflecting lower costs) and to the right (reflecting further abatement potential). Thus, the true benefit to society of adopting this approach, although impossible to analyse, may be many times higher than indicated by this simple analysis.

References

Carbon Trust, 2010. *Persistence Factor model (2010*). Carbon Trust.

CBI McKinsey, 2007 *Climate Change: Everybody's Business.* Appendix 1: UK Cost Curve (source: McKinsey). Confederation of British Industry

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