The great zero-carbon skills gap

The gulf between carbon reduction targets and what we actually build will only get bigger if we don't embrace the new discipline of building engineering physics, argues Doug King

Buildings such as the Innovate Green Office in Leeds demonstrate the possibilities of low carbon design. Achieving the highest BREEAM rating ever, and without using on-site renewables, the building reduced regulated carbon emissions by nearly 80% in comparison to the developer's previous standard for office buildings

Photo: Doug King

The UK Government has set out policy for all new buildings to be zero-carbon by 2019, with new homes leading the way in 2016 and public-sector buildings in 2018. But the UK construction industry is still struggling to get to grips with the 2006 revision of the Building Regulations that required a mere 25% cut in carbon emissions. This paper examines the current state of education and practice in Building Physics, a key discipline in the development of energy conservation design. The author makes key recommendations for educational and industry initiatives that are key to addressing the knowledge and skills gap in low-carbon design.

UK construction is facing an unprecedented challenge in delivering low- and zero-carbon buildings to meet Government targets and proposed changes to legislation. The urgent need to reduce fossil fuel dependency in the built environment is undeniable, but the necessary changes will also be far-reaching in the areas of policy, finance, procurement practice and management.

One of the most urgent problems is the lack of the scientific and design skills that are appropriate to the new low-carbon paradigm. Building physics is a key scientific discipline, the understanding of which allows designers to manipulate the thermal and environmental characteristics of buildings to achieve performance criteria without necessarily relying on energy consuming building services installations.

The need for professionals in the construction industry to be well-versed in building physics has never been higher. Unless the construction industry urgently addresses the fundamental skills necessary to design carbon-efficient buildings, the transition to a low-carbon economy simply will not happen.

Our national goal is to achieve an 80% reduction in carbon emissions across the UK economy by 2050. Buildings presently account for 45% of the UK's emissions. Government policy states that all new homes must be zero-carbon from 2016 and new non-domestic buildings must be zero-carbon by 2019. This is to be achieved by progressive cuts in carbon emissions allowable under revisions to Part L of the Building Regulations.

The rapid pace of change in regulation of building energy performance has created problems for the construction industry. Part L, introduced in 2006, already required a 25% reduction in carbon emissions over the previous standard. There are very few people with established low-carbon design skills, however, and the industry is struggling to deliver even this relatively modest improvement over what was common practice. The proposed acceleration of regulatory change towards zero-carbon new buildings will only widen the gulf between ambitious Government policy and the ability of the industry to deliver.

Few people in the UK construction industry are even aware of the discipline of building physics, let alone know how to apply the principles to the design of buildings. Building projects are traditionally led by architects, not engineers, but building energy performance hardly features in an architect's education. This lack of essential knowledge has led to the perpetuation of an experimental approach to building performance, rather than one based on rigorous analysis, synthesis, testing and feedback.

The life-spans of buildings are long and it may take years for performance issues to come to light. By that time the original designers have long moved on and the opportunity to learn from experience is lost. Furthermore, the competitive and adversarial nature of UK construction inhibits the dissemination of building performance information. Thus, the construction industry is generally still delivering buildings that are little better in terms of real carbon performance than they were in the 1990s. And renewable energy systems are not the solution if they simply offset energy consumption that is un-necessary in the first place.

What is building physics?

Building physics investigates the areas of natural science that relate to the performance of buildings and their indoor and outdoor environments. It deals principally with the flows of energy, both natural and artificial, within and through buildings. The application of building physics principles allows us to design and construct high-performance buildings which are comfortable and functional, yet use natural resources efficiently and minimise their environmental impacts.

Building physics emerged during the latter part of the 20th century, at the interface between building services engineering, applied physics and building construction engineering. Building services engineering provides mechanical and electrical systems to maintain comfortable internal conditions that enable occupants to achieve their performance potential. Through understanding the science governing energy flows, building physics complements and supports building services engineering. But building physics must also consider the engineering performance of parts of the building not traditionally considered to be systems, such as the frame and the envelope.

Building physics comprises a unique mix of heat and mass transfer physics, material science, meteorology, construction technology and human physiology, all of which is necessary to solve problems in designing high-performance buildings. Add to this the requirement for rigorous engineering analysis, creative design and a systemic approach to designing the whole building as an interdependent system, and it can be seen that building physics is quite distinct from any of the established engineering disciplines.

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Building physics will become one of the principal drivers in construction in the 21st century as buildings must evolve rapidly to meet emerging challenges. The urgent need to mitigate future climate change by reducing our carbon dioxide emissions is now well understood. But the impacts of inescapable climate change, warmer summers and an increasing demand for air conditioning, will coincide with the reduced availability of cheap energy as fossil fuels pass their peak of production and go into decline.

In order to conserve energy for the things we really need we will have to cut down on those we do not. It will not be possible to satisfy the UK's energy needs from non-fossil sources without a substantial reduction in demand. The need for sustainable buildings is, therefore, more pressing than ever and this means making real advances in energy efficiency through the application of building physics, and not just installing renewable energy generation to offset the demands of conventional, energy hungry, building designs.

In order to create buildings fit for the 21st century, energy prediction and rigorous performance analysis must replace the experimental building development of the preceding generations. In an industry where each product is essentially a prototype, and it may take years, or even decades, for building performance problems to come to light, we can no longer afford the luxury of experimenting with the physical form of buildings. Without integrating the rigorous performance analysis brought by building physics with the architectural design, and also with the empirical construction knowledge embodied in the industry, we will continue to construct buildings whose energy performance falls far below what we need to achieve.

Hit and miss solutions

In practice, building physics may be described by any number of names: building analysis, environmental engineering,

Unrealistic challenge

Our national goal is to cut carbon emissions by 80% by 2050. Buildings account for 45% of emissions. All new homes must be zero-carbon from 2016 and new non-domestic buildings must be zero-carbon by 2019. This is to be achieved by progressive cuts in emissions under revisions to Part L of the Building Regulations. But the rapid pace of change in regulations has already created problems. Part L, introduced in 2006, itself required a 25% reduction in carbon emissions over the previous standard. But there are very few people with established low-carbon design skills and the industry is struggling to deliver even this relatively modest improvement.

sustainable design, low-carbon consultancy. Substantial growth in the market for such services has been driven by the introduction of regulations, such as the Energy Performance of Buildings Directive (EPBD), which demand calculation of carbon emissions.

The solutions to the real problems of designing for low-carbon buildings can be hit and miss. There is no accepted scope of services for low-carbon design included in any of the standard forms of professional appointment. Building services engineers, who deal with energy issues, often lack detailed understanding of building fabric and construction. Architects and structural engineers, who understand the construction, are unfamiliar with energy issues and the interdependence of the services installations. Whilst a quantity surveyor can advise on the financial implications of design decisions, few teams have anyone with the necessary skills and overview to advise on carbon impact.

The building envelope is specified by the architect, but it is now necessary to consider thermal insulation, building air tightness, solar shading and window performance as part of the low carbon strategy. It has, therefore, become common for the architect to look to the building services engineer to define the performance of these elements, but clearly these do not form part of the building services installations. This leads to confusion over the responsibilities for specification of components and assemblies. The fees paid to the building services engineer do not cover the additional work necessary to properly analyse the construction components, nor will his PI Insurance cover liability in an area outside his expertise.

Similarly, the architect holds the responsibility for compliance with Part L of the Building Regulations. Now that Part L requires analysis of carbon emissions, however, this involves detailed knowledge of the building services systems in addition to the characteristics of the construction. Thus, Part L calculations are usually undertaken by the building services engineer, who operates analysis software capable of doing the calculation, but relies on interpretation of some of the building fabric characteristics.

If the design team does not have the necessary skills and software available, for instance under design and build, where the building services design is left to a sub-contractor, this work is often undertaken by a third party sustainability consultant who may only have scant knowledge of the design. This can, and often does, lead to buildings being certified on the basis of analysis that bears little resemblance to physical reality and when the building fails to perform, it is the designers who are held at fault, not the sustainability consultants.

The sustainability consultant, or code assessor, is a new type of professional who has appeared to fill the void left in the professional team structure. These people generally understand the new regulations in detail and can generate the necessary calculations for certification. But the work is often undertaken by consultants from wide-ranging backgrounds who may not be conversant with construction, architecture or engineering. Furthermore, the field has no recognised codes of practice, or professional standards. This lack of consistency results in enormous variations in the standard of the consultants' service.

The energy performance of buildings can be influenced by many diverse factors, from the location and construction, to the use of information technology. In order to assimilate sustainability into our construction projects we must re-integrate all the disciplines to deliver holistic solutions. By identifying component solutions that complement each other, by avoiding over-engineering and designing elements to deliver multiple benefits, such as using the concrete building frame for thermal storage, we can achieve the goals of both economic and environmental sustainability.

Systems engineering recognises that complex products, such as buildings, require many interdependent systems to function in harmony. The form, frame, aesthetics and choice of materials will all influence their final energy performance, as much as the building services installations. At times, conflicting functional, structural and performance requirements will make it difficult to find an optimal solution and engineering judgment is needed to achieve a satisfactory compromise. Building physicists, when they are employed on building projects, already operate across the established frameworks of architecture, structure, construction and building services.

But the skills required for a low-carbon approach often reside to a greater or lesser extent in existing design team members. The building services engineer is trained in energy conservation, comfort and thermal performance and generally absorbs knowledge about window design, shading

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and space planning through professional practice. Formally integrating a systems engineering approach with the fundamentals of building physics in the education of all building professionals would significantly strengthen their ability to design low carbon buildings. Awareness of the multidisciplinary nature of low carbon design allows individuals to influence the design of a wide palette of components and solutions.

The institutions and associations that represent all construction professionals must collaborate to draw up a standard form of appointment for low carbon design to be

Successful low carbon buildings, such as the Sainsbury's store at Greenwich, require close collaboration between architects, engineers and building physicists from the outset. Solutions for daylight and natural ventilation fundamentally affect the form of the building and by the time sketch design is completed the major opportunities for energy conservation will have either been incorporated or lost

used as a supplement to the existing professional appointments. It must define roles and responsibilities together with a scope of services. In this way, not only will the cost and outcomes of this professional service be controllable and predictable, but any suitably qualified, or experienced, member of the design team can take on this additional role without necessarily requiring another party to be involved.

Call for radical change

Building physics is relevant in the education of anyone who will design or specify the environmental performance of buildings. Whilst the fundamental principles of building physics are taught in our universities to some extent, there is insufficient exploration of the application of building physics to the creation of low-carbon buildings to prepare graduates for industry. Whilst it has traditionally been the preserve of the universities to teach theory and leave the application to industry, the rate of change required in the construction industry calls for a radical transformation in building physics education.

Chartered Institute of Building Services Engineers (CIBSE) guidelines for the accreditation of undergraduate degrees require that the fundamentals of engineering and building physics comprise 25% of the taught content, the remainder being specific building services engineering, or general professional topics. CIBSE presently accredits 16 undergraduate degrees, but only three of these are at Master of Engineering (MEng) level, suitable for registration as Chartered Engineer (CEng) without further study.

In contrast, the Joint Board of Moderators (JBM) accredits over 100 civil and structural engineering degree courses at MEng level alone, but sets no requirement at all for building physics. A review of the JBM accredited courses indicates that only around 10 universities with civil or structural engineering courses offer any identifiable building physics teaching, but this can be as little as one introductory unit in building thermal performance.

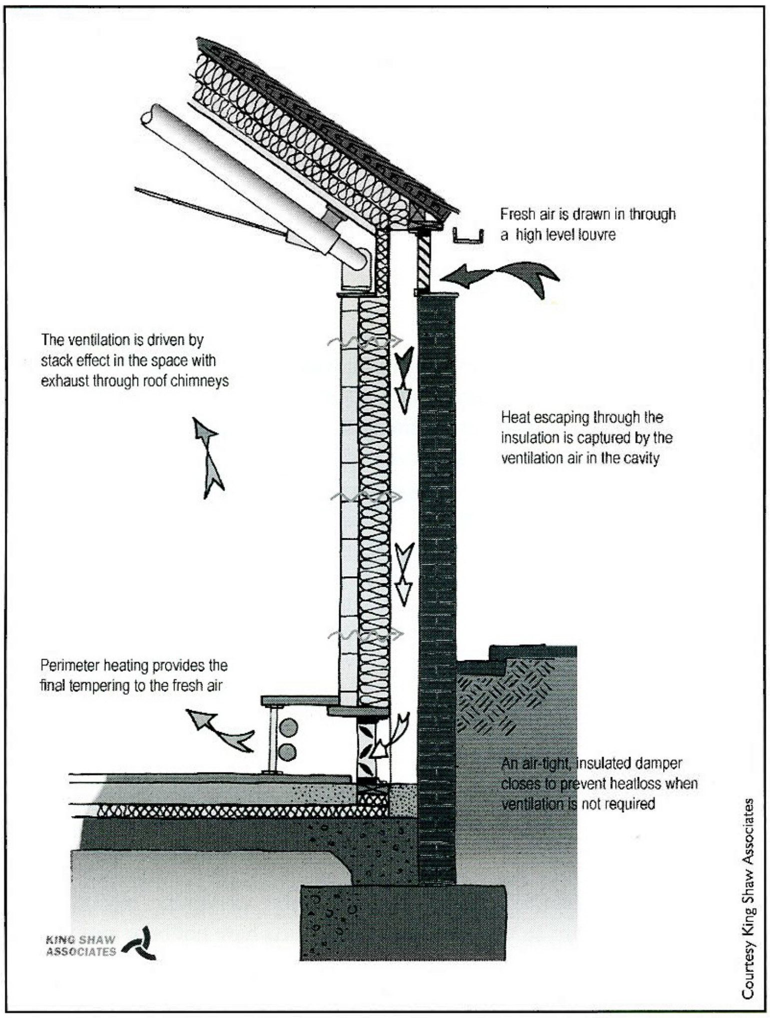
The Royal Institute of British Architects (RIBA) publishes criteria for the validation of degree courses, which includes the integration of technology. But technology here refers to the technology of constructing buildings, primarily structural, and building services engineering. Some university courses are beginning to teach low-carbon design, but architecture is a design discipline and therefore has even less opportunity to teach the analytical and engineering skills of building physics.

Teaching both building physics and low-carbon architectural design is hampered by the lack of experienced professionals, current research and reference material. University courses take time to design, approve and implement, and rely on there being sufficient authoritative reference material on a subject. Reliance on practitioners from industry, who often struggle with keeping up to date with new developments, means that teaching of construction technology and design is often still only relevant to the 2002 Building Regulations.

Many case studies used in teaching are significantly out of date, so that recently built projects have not been evaluated to the same extent as earlier projects. Sometimes case studies are drawn from "Practice Books" written by commercial practices to promote themselves. These are often less than candid about the real performance of their designs and contain no independent analysis. With insufficient low-carbon design knowledge amongst the teaching staff, there is often little critical examination of the issues. Inaccurate information about sustainability becomes received wisdom through repetition.

The trajectory for carbon reductions embodied in Government policy, and the plans for the Building Regulations, will require a dramatic up-skilling of professionals in the construction sector. Yet, the essential skills are not taught in most universities. Both the quantity and quality of teaching must be addressed and more practitioners familiar with cutting-edge low-carbon design will have to be involved in education. Otherwise, with a four-year MEng being the norm and planned revisions of the Building Regulations at three- to four-year intervals, the education of graduates is likely to be out of date even before they leave university.

The universities must develop new fields of multi-disciplinary research in energy and carbon efficiency, directed towards providing the industry with feedback on the effectiveness of current initiatives. This will bring the cutting edge of low-carbon design into universities, where it will benefit the teaching of all construction disciplines. It will also create numerous opportunities for industrial and international partnerships, supported by a wide range of new funding and revenue streams, not traditionally available to academic researchers. Linking undergraduate teaching with research embracing the environmental zeitgeist will make university courses in construction disciplines highly attractive to environmentally aware young people.



Building Physics examines the building fabric for energy saving opportunities as much as the services installations. In this natural ventilation system for the Clore Education Centre at Hampton Court Palace, the building envelope has been engineered to re-capture the fabric heat-loss to temper fresh air.

Carbon dark ages

One of the most pressing needs in the industry is for reliable information on the carbon performance of recently constructed, or refurbished buildings. This information is essential for the establishment of benchmarks 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.

The Energy Efficiency Best Practice Programme (EEBPP) was the UK Government's principal energy efficiency information, advice and research programme for organisations in the public and private sectors. Established in 1989 and run by the Building Research Establishment (BRE), it maintained the UK's biggest library of independent information on energy efficiency. Since the transfer of the EEBPP to the Carbon Trust in 2002 the wealth of information - amassed over many years - has gradually become unavailable.

There are now no other freely available central resources on energy efficiency best practice. In order to learn from experience and move rapidly to the new low carbon paradigm, the construction industry needs a national database of new building post-occupancy evaluations and carbon performance data.

The research must be provided by independent researchers, collaborating across a broad spectrum of construction disciplines.
This effort cannot be left to the industry participants 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, only the mediocre is subject to scrutiny and becomes the benchmark for practice and teaching.

The rate of change required to achieve our national objectives will not allow for the luxury of traditional, selective research and publication. It is important that we find new and more agile means of supporting both fundamental research and transfer of the knowledge to industry that do not rely on the conventional frameworks. In addition to funding conventional, high-level research, the Government must now give the construction industry the tools that it needs to deliver against the targets on carbon emission reductions.

The Government must also set a new benchmark for practice in the construction industry nationally, by setting and enforcing carbon performance targets linked to financial outcomes for all construction procurement within the Government estate. Furthermore, all Government building work since 2006 should be subject to full post-occupancy evaluation with the results published for the use of other designers. By publishing the design criteria and measured performance data for its buildings, the Government will quickly build a national database of successful low-carbon design measures. This information will not just inform future low-carbon building designs, but will also allow for the development of robust national policy.

Back to fundamentals

Solving the fossil fuel energy crisis is vital to our future welfare. If we are to mitigate climate change and secure our future energy supplies with the minimum social and economic impacts, we must fundamentally change the way we design, procure and operate buildings. The UK Government has set challenging targets for reducing carbon emissions from new and existing buildings.

But the construction industry presently lacks the information and mechanisms to design buildings to achieve such targets. The process usually adopted is to design a building following conventional methods, simulate the energy performance using software, and then try to address the shortcomings by adding expensive renewable energy technologies. This leads to unnecessarily expensive buildings and often a failure to meet the original performance target as the final expense of doing so would be too great. This repetition of expensive failures has led to the widespread view that energy-efficient buildings are always more expensive to construct, and this inhibits progress in an industry largely funded by speculative developments. In reality, a range of studies indicates that buildings aiming for a high environmental performance are neither more nor less expensive than conventional buildings.

Government policy must urgently prioritise education and skills development to deliver the big increase in low-carbon design professionals which is vital if we are to achieve our national policy objectives. The education of new and existing construction professionals requires a paradigm shift to stop the existing skills gap widening even further, and also to prepare for the new low carbon economy. A pressing problem is to identify how many experienced low-carbon designers will be required by 2020 to deliver new zero-carbon buildings at the rate the economy requires.

Many skills required for constructing low-carbon buildings do exist, but they are often scattered throughout a design team and there are no mechanisms or incentives to deploy them effectively. The education of construction professionals needs to address the fundamental issues of building physics and systems engineering in order to capture the diverse skills available and apply them to generate efficient, holistic solutions. This will require a change to the traditional partisan roles in construction contracts and for clear allocation of carbon accountability. There is also a need for substantially more professionals to be equipped with these fundamental skills.

The industry and construction clients need clear guidance on which parties in the design team should be responsible for which aspects of the design. Low-carbon designs may require the re-allocation of design responsibilities on the basis of building performance, rather than components. Thus, rather than the architect being responsible for the specification of the windows, the architect would become responsible for the construction detailing and weather-proofing of the window assembly, whilst the building physicist on the team, whether architect, building services engineer or sustainability consultant, would specify the thermal and light transmission characteristics. The institutions and trade associations must draw up a universally accepted scope of services and responsibilities for low carbon design.

It is vital that we raise the profile of sustainable engineered solutions, subjected to rigorous independent analysis, over the marketing greenwash that passes for environmental responsibility in the popular media. Producing accurate and impartial analysis and case studies of buildings, which will become the reference and teaching material for future designers and students, is far too important to be left to commercial interests. This work should be undertaken by new industry and academic partnerships, which will have the added benefit of bringing low-carbon research into the university departments which are teaching the next generation of designers. The Government can play a pivotal role by commissioning and publishing post-occupancy evaluations of all recent public building projects.

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Falling between the cracks

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