BRE TRUST REVIEW 2009

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The mission of BRE Trust is 'Through education and research to promote and support excellence and innovation in the built environment for the benefit of all'. Through its research programmes the Trust aims to achieve:

- a higher quality built environment
- built facilities that offer improved functionality and value for money
- a more efficient and sustainable construction sector, with
- a higher level of innovative practice.

A further aim of BRE Trust is to stimulate debate on challenges and opportunities in the built environment.

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FOREWORD

It is significant that in what has been called the deepest and longest recession since the 2nd World War that BRE Trust has:

- increased funding to its existing managed research programme
- widened the scope of its activities to include publications
- introduced a thematic research programme
- encouraged closer collaboration with the five BRE University Centres of Excellence and the PhD students that the Trust supports.

The funds available to support these initiatives are directly related to the success of BRE group, which gift aids its profits to the Trust to support research and education to benefit the built environment, and the ability of BRE Trust funding to act as a catalyst to attract support from government and like-minded organisations.

The industries which create and sustain the built environment are facing demanding challenges to reduce carbon dioxide emissions and to increase output but keep costs down in new and existing buildings. These are leading to the use of innovative building methods, technologies, materials, products and processes, sometimes with little certainty about the long-term outcomes. Lessons that were learnt over generations using traditional construction methods are being superseded. It is, therefore, vital that the innovation, which is essential to meet these challenges, is supported by research based on rigorous science (including social science) and that the results of this research are made available for the public good. BRE Trust and BRE group continue to have an important role to play in funding and carrying out this research and in ensuring that it becomes best practice.

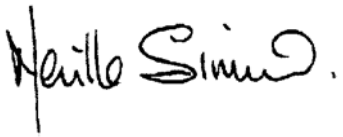
This *Review* provides an opportunity for BRE Trust to highlight its achievements for the year ending December 2009. In the *Review* you will find details of:

- the new publications programme
- the thematic research programme which has just commenced
- the launch of the BRE University Centre Chair meetings in July
- the university visits in December
- the change in the membership structure of the BRE Trust agreed in August.

BRE Trust encourages collaboration with like-minded organisations and this *Review* also includes a report on the work of NHBC Foundation (the joint venture between NHBC and BRE) and BRE Trust's new relationship with WRAP.

Our primary purpose, however, is to fund research, and so the main section of this *Review* introduced by Professor John Burland (Chairman of the BRE Trust Research Committee), is dedicated to summary reports from the 2009 research projects. The projects include those carried out by the BRE University Centres of Excellence and their final-year BRE Trust funded PhD students.

On behalf of the Trustees, I would like to thank BRE and BRE Global, the five BRE University Centres of Excellence, the PhD students and all the organisations who have contributed to this *Review* and to the important research that it describes.



Sir Neville Simms FREng
Chairman
BRE Trust

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BRE TRUST HIGHLIGHTS OF 2009

Box 1: Important new initiatives by BRE Trust in 2009

- Launch of the new BRE publications programme with a budget of £600 000 per year
- Launch of a £1.5 million 3-year thematic research programme
- Introduction of collaborative meetings of the five BRE University Centres of Excellence
- Implementation of a change in the membership structure of BRE Trust

BRE Trust has made some significant changes during 2009. All BRE Trust's initiatives (listed in Box 1) are designed to improve the quality and relevance of research and the communication of its results in a time of great change and innovation in the built environment. This innovation is being driven by the need to reduce energy and the use of natural resources, and to cut the production of greenhouse gases in ways that are affordable.

It is crucial that government and industry get this right — that we really understand the whole-building life-cycle implications of the decisions that are being made with regard to the way we manufacture and use buildings, and the kind of choices we make for their component materials, products, appliances and services. Untried solutions abound and 'green' suppliers, both sincere and unscrupulous, take advantage of public enthusiasm often with little science behind their claims.

In addition to these new initiatives, BRE Trust continues with its current support of:

- a managed research programme (see later section on *Summarising 2009/2010* and the papers presented in the *Research programme*)
- the five University Centres of Excellence
- PhD students
- NHBC Foundation.

Also in 2009, BRE Trust worked in partnership with WRAP to commission research into sustainability and reducing environmental impact in a number of sectors of the construction supply chain. This partnership has proved successful so the initiative is being continued in 2010.

The profit that BRE makes is passed to BRE Trust as 'gift aid' which in turn funds the research and education that BRE Trust supports. It is therefore in BRE Trust's interest as a charity to ensure the success of BRE — its major source of income.

LAUNCH OF BRE PUBLICATIONS PROGRAMME

BRE has for many years produced publications which provide data, information and knowledge relied on by the construction industry, and many are referred to in legislation. These were traditionally produced as outputs from research projects or by enthusiastic specialists within BRE who wanted to share their knowledge.

This year BRE Trust launched a £600 000 pa publications programme for the drafting of publications by the BRE Group companies in recognition of the important benefits to be gained from establishing a fully coordinated programme of publications that meets the needs of those working in the built environment. A Publishing Committee chaired by Hugh Ferguson has been set up to work in parallel with the existing Research Committee. This will select and let contracts for publications on a competitive basis, against a set of criteria agreed by the Trustees, in the same way that the Research Committee selects research projects to support.

Since June 2009, 52 publications funded by BRE Trust have commenced at the drafting stage, in parallel with 63 publications already underway as a result of earlier research contracts. The outputs of BRE Trust funded research projects published in 2009 and early 2010 as BRE Trust reports (FB), BRE Information Papers (IPs) and external publications (EP) are listed in Box 2. The first wave of BRE Trust funded publications started to appear in the period between January and April 2010 and are listed in Box 3.

The Publications Committee met in February 2010 to agree which titles would be produced by BRE and BRE Global in 2010/11.

The ninth (and final) edition of *Foundation,* the annual BRE Trust newsletter, was published in August 2009 in print and downloadable form. *Foundation* gave a brief summary of BRE Trust activities but it was not possible in its four pages to share the results of the research which the Trust has funded or to report in any detail. Therefore, *Foundation* is superseded by the *BRE Trust Review* which provides an annual forum for those who have benefited from BRE Trust funding to summarise their work.

Box 2: 2009/2010 publications arising from the BRE Trust research programme

Ref. no.	Title
FB 19	Automatic fire sprinkler systems: A guide to good practice
FB 20	Complying with the Code for Sustainable Homes: Lessons learnt on the BRE Innovation Park
FB 21	The move to low-carbon design: Are building designers taking the needs of building users into account?
FB 22	Building-mounted micro-wind turbines on high-rise and commercial buildings
IP 2/09	Structural composite connections for sequential seismic and fire performance
IP 7/09	Carbon reduction commitment
IP 1/10	Micro-wind turbines on tall buildings
IP 11/10	Sustainability in foundations
EP 97	The LifE Handbook: Long-term initiatives for flood-risk environments
EP 98	The LifE Project: Long-term initiatives for flood-risk environments

Box 3: First wave of titles from the BRE Publications Programme, January–April 2010

Ref. no.	Title
IP 2/10	Ground source heat pumps
IP 3/10	Sustainable refurbishment of non-traditional housing and pre-1920's solid wall housing
IP 5/10	Carbon emission reductions as a driver for economic regeneration
IP 6/10	A guide to GreenPrint
IP 7/10	SBEM for non-domestic buildings
IP 8/10	Digitally enabled communities
IP 9/10	SAP for beginners
FB 23	The real cost of poor housing
FB 24	A guide to the simplified building energy model (SBEM)
FB 25	Vacant dwellings in England

MEETING OF THE BRE UNIVERSITY CENTRES OF EXCELLENCE

The BRE Trust supports:

- five University Chairs with an anticipated budget to April 2010 of around £175 000
- PhD students at the five centres with a budget of £360 000.

The Trust provides financial support to the four Chairs at the following BRE Centres:

- University of Edinburgh (Fire Safety Engineering),
- University of Strathclyde (Energy Utilisation)
- University of Bath (Innovative Construction Materials)
- University of Cardiff, Welsh School of Architecture (Sustainable Design of the Built Environment)

and supports a new chair at the BRE Centre at:

- University of Cardiff, School of Engineering (Building Systems and Informatics).

In 2009, BRE Trust and the BRE Chairs of the BRE University Centres initiated the first two of what are to become regular six-monthly meetings to share information about their activities and to encourage collaboration and linked research projects. The first of these was held in June 2009 at BRE's site in Watford and was attended by the University Centre Chairs, the Chief Executive of BRE, the BRE supervisors and coordinators. Some exciting potential opportunities for collaboration were identified and terms of reference for future meetings were agreed.

The second meeting was held at the University of Cardiff in December 2009 following a visit to the University of Bath the day before. This was attended by

Box 4: Short reports on 2009 highlights from the five BRE University Centres of Excellence

Professor Jose Torero, BRE Centre of Excellence in Fire Safety Engineering, University of Edinburgh

- The fire safety engineering capabilities at Edinburgh have been re-energised through the partnership with BRE.
- There are now nine full-time employed staff and 31 PhD students of which five are currently being funded by BRE Trust.
- Funding of €7.2M has been obtained to launch a new MSc course to be delivered by the combined efforts of the top three universities for fire engineering in Europe. Currently there are 32 registered students.
- Stronger links have been formed with the Architecture and Engineering Departments, and priority areas for future research include:
  - building performance in extreme conditions
  - tall buildings, > 30–40 m
  - work with fire brigades to improve awareness and knowledge of engineering aspects. A training course was launched in collaboration with Glasgow Caledonian University.
- New funding bids include:
  - EPSRC for better integration of data into service operation
  - fuel spills and contamination
  - energy efficiency versus fire safety.

Professor Peter Walker, BRE Centre of Excellence for Innovative Construction Materials, University of Bath

- The current five BRE Trust projects are progressing well, and an additional seven PhD projects have begun in 2009 funded by EPSRC or URS.
- Over £700k of funding has been secured since June 2009, funded by EPSRC and FP7.
- Six bids have been submitted and are under review, totaling over £1.2M, 11 other bids are in preparation, totaling over £4.5M.
- Other significant activities in the last 6 months include:
  - 11th International Conference on Non-conventional materials (NOCMAT 2009), 6–9 September 2009
  - BaleHaus launch
  - Innovation Centre at Carpenter House where BRE is able to locate staff
  - Dina D'Ayala is taking a sabbatical at the Getty Foundation
  - appointment of Visiting staff: Professor Peter Bonfield and Tim Mander and Ian Pritchett (Visiting Research Fellow)
- Discussions are underway to set up a national blast testing facility at BRE Garston.

Professor John Counsell, BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

- Full-time employed staff now total seven, with eight PhD students.
- Over £1M funding has been secured, with £745k being passed to BRE.
- Over £800k funding is now being sought through bids.
- A strategy for growth is being built around alignment of various funding sources to develop an active collaboration with BRE for joint funding and industry exploitation.

Professor Christopher Tweed, BRE Centre of Excellence in Sustainable Design of the Built Environment, University of Cardiff

- Three new programmes have been approved for funding since the last review meeting, totalling over £4M funding, with over £250k being passed to BRE Wales.
- Three bids totalling over £1.1M are currently being evaluated and another six are in preparation (£2M+), resulting in over £500k funding being passed to BRE if successful. Three specific bids of note are:
  - the fuel story: personal experiences of energy in the home
  - folk physics: mental models of building behaviour
  - neighbourhood dashboards: real-time display of sustainability indicators.
- Specific interactions with BRE include FP7 SUSREF, LCRI Convergence and three new PhD projects:
  - understanding the impact of occupant behaviour on energy consumption within existing homes which will run in parallel with the EPSRC project: carbon, control and comfort – user-centred control systems for comfort, carbon saving and energy management
  - learning from low-carbon design, linked to the BRE bid: monitoring the performance of low-carbon buildings and technologies in Wales
  - developing effective strategies for design interventions to improve sustainability in existing urban communities which aims to develop guidance on 'urban acupuncture' for existing communities.

Professor Yacine Rezgui, BRE Centre of Excellence in Building Systems and Informatics, University of Cardiff

- The newest BRE Trust Chair to be set up, with a mission to adopt a multi-disciplinary and multi-faceted approach to the built environment underpinned by people, processes and technology.
- The Centre now has 10 active PhDs (one of which is BRE Trust funded) and will seek three new PhDs each year going forward.
- Research focus is on the building in its environment, considering:
  - the role of digital technologies
  - space and function in architecture
  - re-thinking human space relationships.
- Completed and ongoing funded research is in these areas:
  - sustainability
  - European Construction Information Portal
  - multi-objective decision-making for the fire and rescue services.
- Future areas for development are:
  - resilience of the built environment
  - renewable energy for the domestic sector
  - low-carbon design
  - assisted living/ageing.
- Six proposals have been submitted in the last six months:
  - towards self-organizing and environmentally responsible sustainable communities
  - HOMER: home energy advisor
  - RHECS: large-scale energy retrofitting in the domestic sector
  - cognitive agent-based interactive environment for low-carbon design
  - Knowledge Transfer Partnership on renewable energies
  - sustainability service platform.

Box 5: BRE Trust funded support of PhD students in 2009

BRE Centre of Excellence in Fire Safety Engineering, University of Edinburgh

A student fully supported by the BRE Trust has commenced a PhD studentship for a project on:

- behaviour of a nuclear containment structure under fire.

BRE Centre of Excellence for Innovative Construction Materials, University of Bath

In 2009 the Centre was awarded a fully funded BRE Trust PhD studentship for a project on:

- environmental benefits of recycling and reusing metallic structural sections.

The allocated student pulled out and new applications have been sought.

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

Four students, fully supported by the BRE Trust (three of which were supported by University-administered funds in their first year), commenced their PhD research studies with BRE Trust funding in October/November 2008.

The projects are as follows:

- the feasibility of buildings that predominantly utilise DC electric power
- how computational fluid dynamics (CFD) can be used in the modelling of buildings and their systems to aid a holistic approach to building design
- the use of dynamic simulation and its sensitivity analysis with particular emphasis on SBEM and ESP-r energy estimation methods and associated software tools
- advanced controls and modelling of control systems in buildings using fly-by wire technology.

BRE Centre of Excellence in Sustainable Design of the Built Environment, University of Cardiff

BRE Trust has agreed that two funded students should commence their PhD research studies. A further student has received support from BRE Trust to complete his PhD. The projects are as follows:

- developing effective strategies for design interventions to improve sustainability in existing urban communities
- understanding the impact of occupant behaviour on energy consumption within existing homes
- learning from low-carbon design.

BRE Centre of Excellence in Building Systems and Informatics, University of Cardiff

The Centre was awarded a fully funded BRE Trust PhD studentship for a project entitled:

- smart energy design and compliance checking environment for domestic building refurbishment.

The student commenced in May 2009 but was not able to continue. The award is open for completion of the PhD work.

BRE Trust Chairman, Sir Neville Simms, the Chairman of the BRE Trust Research Committee, Professor John Burland, and a member of the BRE Research Committee, Professor Les Clark.

A brief report from each of the five BRE Centres of Excellence is given in Box 4.

During 2009 several studentships were taken up and new awards were made (see Box 5). It is proposed that in July 2010 a two-day series of workshops will be held for the PhD students so that they can share their knowledge and identify synergies and opportunities for collaboration. Details of some of the recently and nearly completed PhD research projects are given in the section on the BRE Trust Research Programme.

LAUNCH OF THEMATIC RESEARCH PROGRAMME

The consensus is that the built environment has a major influence on climate change, global warming and other environmental impacts. More than 50% of UK CO_2 emissions originate from the construction and refurbishment of our buildings and their day-to-day operation. This high impact has been reflected in recent UK Government policies such as the Code for Sustainable Homes (which requires all new homes to be zero net carbon by 2016) and the Government's recently published target for all other new buildings to be zero net carbon by 2019.

There is a considerable and growing gap between the accelerating demands of clients looking to reduce their environmental impacts through the products they specify and procure, and in the capacity and capability of the supply chain to deliver the required solutions.

The need to consider the broad environmental impacts of how materials are developed, manufactured, incorporated into design, procured, used, reused and disposed is imperative.

BRE Trust is providing funding of £1.5 million for research projects over the next three years. BRE Trust thematic support funding has been sought to support this low-impact materials and products area to:

- address these critical gaps in knowledge
- facilitate an acceleration of the reduction of environmental impacts of materials and products used in construction
- help to avoid market failures that may otherwise arise.

In 2009 20 proposals were reviewed and refined to ensure that projects in the programme are focussed and collaborative and represent the best use of BRE Trust funds. Finding matched funding from Government and Industry is encouraged. The funding will also ensure that BRE is well placed to maintain its leading role in this area and generate significant business streams which are relevant across the whole BRE Group.

Subjects agreed by the Research Committee for the 'Low-impact products, materials and process' thematic research include the following topics:

- improving the energy performance of existing buildings
- whole-building life-cycle assessment (LCA)
- service-life performance of low-impact materials and products. Do green credentials fade over time?
- extending LCA methodology to the evaluation of building services and other non-building materials
- considering the implications of LCA methodology choices for the evaluation of construction materials
- liability of buildings at the end of their life
- whole life-cycle assessment of off-site manufacturing versus traditional methods of construction

- energy-efficient refurbishment
- low-impact materials in low-impact buildings (LIMILIB)
- sustainable substructures
- sustainable shop fit and equipment
- low-impact roofing
- the implications of using phase-change materials in buildings
- measuring the wellbeing benefits of interior material selection

- wireless technologies: providing low-impact solutions?
- integrating organic PV into the built environment
- the integration of renewable technologies, innovative control systems and materials in the Standard Assessment Procedure (SAP)

- high-value, low-CO_2-activated binder concrete products
- long-service-life concrete structures for aggressive environments
- fire retardants: a balancing act

CHANGE OF MEMBERSHIP STRUCTURE

Contributions to the future of the built environment are coming from areas which are not normally associated with it such as IT, renewable energy sources, factory production and the self-build sector. The previous membership structure based on a collegiate system made it difficult for these new contributors to gain access to the BRE Trust and the membership grouping did not reflect the desire of those involved with the built environment to break down traditional barriers and work across disciplines.

The membership agreed to a change of membership structure on 5th August 2009 by adopting a new Articles of Association and dissolving the collegiate system of membership.

Everyone with an interest in the built environment can now have access to the BRE Trust via its web site (www.bretrust.org.uk). The web site has an edited facility where all can log on and make suggestions for research projects or publications, or debate hot topics on matters relating to the built environment.

NHBC FOUNDATION

NHBC Foundation has been established by NHBC in partnership with BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice.

The NHBC Foundation is managed independently from the Trust's other programmes.

NHBC Foundation has published 10 reports in 2009, of which the following four reports appear on its web site:

- Pull the chain, fill the drain
- Understanding consumer attitudes to sustainable community infrastructure
- Improving sound insulation measurements in homes and other buildings
- How long should houses last?

Six NHBC reports have been printed in 2009 and copies are available from NHBC free of charge (Box 6).

All the NHBC Foundation publications are also available as free downloads at: www.nhbcfoundation.org.

BRE TRUST/WRAP PARTNERSHIP

In 2009, WRAP agreed to provide a grant of £160 000 to work in partnership with BRE Trust to commission research relating to the development of three sector resource efficiency plans. The preparation of these plans is of strategic importance and form part of the Construction Products Association (CPA) commitment as detailed in the UK Government's Strategy for Sustainable Construction.

The three plans that have been prepared focus on increasing the resource efficiency and waste reduction within the Flooring, Joinery and Construction Products sector and will have a huge impact on reducing the

***Box 6:* 2009 NHBC Foundation printed reports**

Ref. no.	Title
NF 15	The Code for Sustainable Homes simply explained
NF 16	A practical guide to building airtight dwellings
NF 17	Zero carbon compendium
NF 18	Indoor air quality in highly energy efficient homes – a review
NF 19	Open plan flat layouts
NF 20	Water efficiency in new homes

amount of waste sent to landfill. All three plans have been prepared in cooperation with a wide stakeholder network supported by the relevant trade associations including the British Woodworking Federation (BWF), Contract Flooring Association (CFA), as well as manufacturers, distributors, suppliers, merchants, contractors, waste management contractors and reprocessors.

Together, these plans form a wealth of new knowledge, practical recommendations and specific actions that will be owned and implemented by industry with the support of trade associations, industry partners and Government bodies.

Box 7: BRE Trust objectives

The principal objective, for the public benefit, is to:

- 'undertake, commission and support research in areas of science, engineering, information technology, management and economics associated with the built environment, including its processes and artefacts, and to advance knowledge, innovation and communication, and to promote education and excellence, in all such matters, and to collect, collate and publish useful information, ideas and data relating thereto'

and also to:

- 'undertake commission, facilitate and support carbon emission reduction projects and such other activities and services as are beneficial to the built environment and charitable in law'.

The aims of the Trust include:

- maintenance of a strategic plan for world-class research in the built environment
- to play a leading role in the development and expansion of research and by promoting its application to stimulate quality, innovation and excellence
- to contribute to the development of a sustainable built environment by disseminating and promoting the application of knowledge and innovatory practices through publications.

In order to deliver its long-term sustainable strategic plan to stimulate research-based innovation and its application in practice, the Trust continues its support of the Centres of Excellence within the BRE–Universities Partnership.

SUMMARISING 2009/2010

Some 2009/2010 statistics include:

- the number of active research projects within the established managed research programme was 43, including eight new research projects
- of the total active projects, one was suspended and 12 were completed
- 20 new research projects were instigated under a three-year £1.5 million thematic research programme focussed on low-impact processes, materials and products
- in the year ending April 2010 BRE Trust expects to provide:
  - £800 000 for the managed research programme
  - £200 000 on the thematic research programme.
- by the end of 2009/2010 BRE Trust will have contributed £500 000 to the BRE University Centre Chairs and the PhD students that they support
- up to December 2009 there were 20 active PhD/EngDoc projects within the BRE Trust PhD postgraduate scholarship scheme plus five appointments agreed (one commenced in January 2010, the contracts for the remaining four are being finalised at the time of writing)
- two PhDs were completed during the year.

The combined BRE Trust/NHBC contribution to the programme in 2009/2010 was around £400 000.

During 2009/2010 £550 000 was allocated to the BRE Trust publications programme and a further £50 000 to the development of a new web-based magazine: www.building4change.com.

For the fifth consecutive year, the Trust is again in 2010 providing Parmiter's School in Watford with support and financial assistance to enable a group of sixth-form pupils to participate in the Engineering Education Scheme (England), which is part of the Royal Academy of Engineering's 'Best' programme. This scheme gives pupils the opportunity to work on a project, guided by a mentor from a company, in this case BRE Global, so they can experience science, engineering and technology first-hand. An earlier student project on 'Measuring the moisture content of a brick wall' was completed in

April 2009 and gained them a gold award in the British Association for the Advancement of Science CREST scheme.

Achievements

Sustainable development

During 2009 BRE's Sustainable Development Action Group continued to drive forward a series of initiatives as part of BRE Group's environmental policy and strategy for continual improvement. The Sustainable Development Action Group continued to make good progress with a reduction in water use and an increase in recycling. BRE Group has benefited from investment in energy-efficiency measures on the Garston site and is making significant reductions in gas and electricity consumption.

On 24th May 2009, the Sunday Times announced that BRE Group had come 35th in the Sunday Times's *60 Best Green Companies 2009*.

Annual research review event

The fifth annual research review event will be held in early summer 2010. Under the title *BRE Trust Materials Conference 2010*, it will cover a selection of research projects completed in 2009/10 and a presentation from one of the BRE University Centres of Excellence on one of their current research projects.

These research review events are a continuing initiative to enable the Trustee members of the research committee (Professor John Burland, Professor Les Clark and Mr Richard Haryott) to assess the quality of the research projects funded by the Trust. Following presentations of research projects commissioned by the Trust, the research is discussed with the presenters and critically reviewed.

No charge is made to the invited audience and in the past it has proved a successful means of disseminating the research work of the Trust.

CONCLUSION

This has been a successful year for BRE Trust, encompassing a lot of change. The investment of over £2.4 million in research, publications, and the BRE University Centres of Excellence and associated PhD studentships has contributed across a broad spectrum to the data, information, knowledge and wisdom available to those interested in building a better world through improving the quality and performance of the built environment.

FOREWORD TO THE BRE TRUST RESEARCH PROGRAMME

BRE Trust (the charitable organisation that owns the BRE group of companies) was established to commission and support not only research and innovation connected with the built environment but also associated activities including education and knowledge transfer in science, engineering, economics, management and information technology.

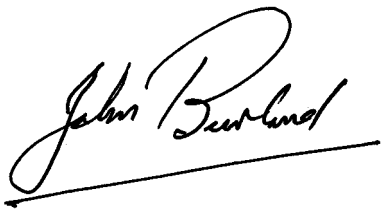
Since its inception not only has BRE Trust funded over 150 research projects in a managed research programme, but it also now supports five BRE University Centres of Excellence at Bath, Edinburgh, Strathclyde and two at Cardiff, and has provided support for over 30 PhD students.

In 2009, BRE Trust has commissioned 20 new projects in a £1.5 million three-year thematic research programme aligned with the Technology Strategy Board thematic call for low-impact building products, materials and processes. This programme is intended to encourage collaborative working between BRE centres of expertise and with the University Centres of Excellence.

BRE Trust funding leverages support from government and industry to develop the knowledge and tools needed for the future. A particular emphasis is placed on enhancing the expertise needed by the BRE group in its role as an impartial and highly respected consultancy and research organisation.

For this first *BRE Trust Review*, those who have completed, or are about to complete, BRE Trust funded research projects at BRE and the university centres were invited to submit a summary of their research project and its findings so far. They cover a diverse range of topics related to the built environment and demonstrate the complexity of issues faced by all those involved in the planning and building process from conception to demolition. The topics range from societal research, such as human behaviour or sustainable masterplanning, to scientific research, such as the detailed experimental analysis of the behaviour of pollutants in urban environments, fire protection systems, and tests of new building materials. Underlying this impressive research are common themes: how can we make the built environment healthier and safer for people and more sustainable and durable?

There are exciting changes taking place with challenges and opportunities for those involved in creating and maintaining the built environment. With inevitable innovation comes the potential for failures and it is vital that these are identified. For this reason, rigorous research based on sound scientific principles of the kind supported by BRE Trust is essential.



Professor John Burland
Chairman
BRE Trust Research Committee

MATERIALS

ENHANCEMENT OF TIMBER

Dennis Jones
BRE Wales

SUMMARY

Conventional wood preservative treatments are coming under increasing scrutiny, as the next generation of wood preservatives have to conform to wider European and national directives (biocidal, construction, etc.). In addition, they must have minimal or zero impact at the end of life of the treated timber. This means that the conventional concept of biotoxicity is worth reconsidering. To this end, a series of naturally occurring compounds and products have been assessed to determine their potential for timber treatments for the future.

BACKGROUND

Nature has, in many cases, found ways of protecting itself from exterior attacking organisms, with many plants and animals exhibiting a range of natural protective chemicals. Finding a way of using these protective chemicals or similar structures could provide wide-ranging benefits: from new medicines, to beauty products and protection systems. These protection systems could prove useful in preventing the decay of timber in use.

RESEARCH PROGRAMME

A series of experiments was designed to test alternative treatments, concentrating on the application of these treatments to UK-grown timber species. The testing concentrated on natural products that might deliver enhanced properties (eg durability, dimensional stability, etc.) and fell into three distinct categories.

- *Treatment with naturally occurring compounds, such as waxes and oils.* These can act as a barrier to moisture uptake, thus reducing the risk of fungal decay and imparting dimensional stability. Very little work has been published in this area, and a scoping study might provide an insight into areas where these naturally occurring materials might be exploited.
- *The use of naturally occurring monomeric components which, following impregnation into the wood ultrastructure, may be polymerised.* This can result in a non-leachable treatment. Among compounds that might prove suitable for such work are lactates and monoglycerides. The potential for modifying a naturally occurring molecule before impregnation and polymerisation into the wood could also be considered.
- *The use of natural biocides.* One such compound exhibiting such properties is propolis. This is the waxy coating used by bees to protect the honey and hive from infection. It has been shown to have a wide range of antimicrobial and antifungal properties, but its effectiveness against wood-decaying agents has never been tested. The fact that wooden bee-hives cannot be preserved (as this would harm the bees) but there is little or no decay of the wood seems to testify to some level of decay inhibition. Propolis is spun out as a by-product of honey production.

There are other natural compounds with biological activity, some of which are listed in Table 1 and represent some options worth investigating.

RESULTS

- The process of introducing waxes proved problematic, with no real benefits gained from treatments carried out.
- The preparation of alkyds for polymerisation resulted in interesting darkening of wood samples, in some cases producing very dark red colours. The ability of wood to repel water was assessed by applying water droplets and measuring contact angles with time.

Table 1: **Some known properties of a range of natural compounds**

English name	Latin name	Some known properties
St. John's wort	*Hypericum perforatum*	Antioxidant, antimicrobial
Pot marigold	*Calendula officinalis*	Antibiotic, antibacterial
Garlic	*Allium sativum*	Antibiotic, antibacterial, antifungal
Yarrow	*Achillea millefolium*	Antibacterial
Tea tree oil	*Melaleuca alternifolia*	Antiseptic, germicidal, antibacterial, fungicidal
Neem oil	*Azadirachta indica*	Insecticidal

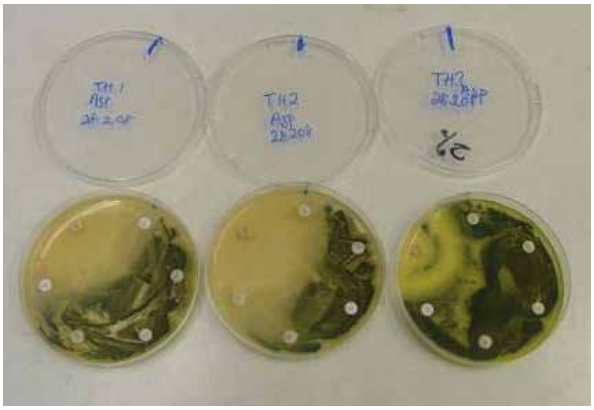


Figure 1: Effectiveness of thyme treatment in inhibiting growth

These showed an increased ability to repel water. This could benefit the wood by minimising high moisture contents associated with wood decay.

- The use of naturally occurring materials produced the most promising results, though not sufficient against all decay organisms tested. The use of thyme oil proved effective against certain moulds and fungi (Figure 1). Treatments using propolis also resulted in general improvements in durability, as well as enhancing the colour of samples (Figure 2). Results with propolis suggested further studies were warranted.

CONCLUSIONS

Work in this area is still in its infancy, but some promising results were achieved. Determining the effectiveness of treatments takes several years, and many more tests would be necessary to meet legislative demands for wood treatments. However, options appear to exist for the following.

- *The use of naturally occurring monomeric components*, which following impregnation into the wood ultrastructure, may be polymerised. The majority of work in this area concentrated on alkyds. Originally, attempts were made to synthesis alkyds in-house, though the processing required (removal of water at extreme temperatures) proved problematic at the scales under development. Early work suggested possible methods for dramatically altering the colour of the wood, but with limited dimensional benefit. Commercially available alkyds were sourced and tested, which proved that surface barriers could be generated, in much the same way as conventional coating systems. Further work is necessary in this area, to determine:
  - degree of UV and weather resistance
  - incorporation of natural products in alkyd synthesis
  - incorporation of secondary components in alkyd formulations to provide additional benefits (eg UV-absorbers, anti-oxidants).
- *The use of natural 'biological active' compounds*. The majority of work in this area dealt with propolis, and while some promising results were obtained, they were not as encouraging as hoped. Further research is needed to:
  - establish ways of enhancing the 'potency' of propolis, through fractional extraction and concentration
  - look at other sources of local propolis and determine their activity
  - re-evaluate action of propolis in other products (medicinal, cosmetic, etc.).

Note that natural biocides would still require registration under the Biocidal Products Directive.

Figure 2: Enhanced coloration of timber with propolis treatment

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SUSTAINABLE FOUNDATIONS
A scoping study

Tim Reynolds, Flavie Lowres and Tony Butcher
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SUMMARY

The objectives of this study were to review the sustainability agenda, investigate current practice in the choice of foundation systems, gather information on innovative foundation solutions, and to develop best practice guidance.

BACKGROUND

There is increasing interest in sustainable development, 'zero carbon' buildings and the use of local, renewable, low-embodied energy and recycled materials in construction. The trench-fill foundations for a typical semi-detached house typically comprise around 18 m^3 of concrete, or the equivalent of 3000 kg embodied CO_2. Cost considerations tend to dictate foundation choice. This may not always result in the most sustainable option. Foundation failures are extremely expensive and difficult to rectify, and not surprisingly there is considerable aversion to risk.

Although the choice of materials for the components of buildings above ground may often be determined by a preference for more sustainable materials such as timber, foundation design and construction is often executed as a separate entity. The foundation engineer is constrained by ground conditions, the form and loading of the building, with a quite limited choice on materials, usually in-situ concrete, pre-cast concrete or steel driven piles.

Figure 1: Modular buildings built near to trees supported on removable steel screw piles, as an alternative to permanent concrete foundations
Courtesy of ScrewFast Foundations

Other than building loads and soil type, other factors which may influence the choice of foundations include:

- proximity to trees
- constraints on noise and vibration
- site space and traffic management issues
- site safety
- adjacent structures.

Innovative foundation solutions which may improve sustainability include the use of removable screw piles (Figure 1), or ground-improvement techniques such as deep soil mixing (Figure 2).

Figure 2: Deep soil mixing using a triple auger system to improve weak soils.
Courtesy of Eco Foundations

RESULTS

The results showed that more sustainable foundations can be achieved with measures such as:

- better practice in site investigation and project planning
- improved accuracy in setting out
- reappraisal of foundation design with testing
- use of materials such as recycled aggregate and cement replacements with lower embodied energy.

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RESEARCH OUTPUT

The results of this project are given in a BRE *Information Paper* IP 11/10, *Sustainability in foundations* which:

- details the influences on current foundation practice
- discusses methodologies for assessing the sustainability of foundations
- presents best practice guidance.

BRE CENTRE OF EXCELLENCE FOR INNOVATIVE CONSTRUCTION MATERIALS, UNIVERSITY OF BATH

Peter Walker

BRE Trust Professor of Innovative Construction Materials

The BRE Centre for Innovative Construction Materials (BRE CICM) was founded in July 2006. Its primary aim is to conduct internationally leading interdisciplinary research in the development of innovative and sustainable construction materials and technologies. BRE CICM is a multi-disciplinary centre of around 40 researchers (full-time academics, contract research staff, and postgraduate students) drawn from across the Faculty of Engineering & Design at the University of Bath. The main research activities of BRE CICM to date are listed below.

ADVANCED COMPOSITES IN CONSTRUCTION

Experimental and analytical studies in this area include:

- Anchorage modelling of realistically sized and loaded fibre-reinforced polymer (FRP) confined rectangular reinforced concrete columns
- Development of an expert system for FRP strengthening projects
- FRP stay-in-place (SIP) participating formwork for new construction
- Anchorage capacity of near-surface-mounted (NSM) FRP bars
- Biopolymer matrix natural fibre composites for structural applications
- Evaluation of laminated joints for agave fibre composites
- Development of new flexible sub sea insulating systems from polymeric materials
- Lightweight FRP façades for retrofitting multistorey buildings

CONCRETE MATERIALS AND STRUCTURES

Current work includes:

- Low-carbon cements and concretes
- Lime-based concretes
- Size effect in shear strengthening of large concrete beams
- Shear capacity and strengthening of longitudinally and laterally-prestressed concrete bridges
- Assessment of seismic vulnerability for reinforced concrete in-filled frame buildings
- Fabric formwork for concrete structures (Figure 1)
- Blast resistance of concrete structures

LOW-CARBON BUILDING MATERIALS

Work in this area includes material development, structural testing and monitoring building performance:

- Development of hemp-based composite construction materials
- Carbonation development in non-hydraulic lime mortars
- Unfired clay brick systems for sustainable construction
- Characterising materials for rammed earth construction
- BaleHaus project (Figure 2): a modern innovative low-carbon housing system using prefabricated straw bale panels

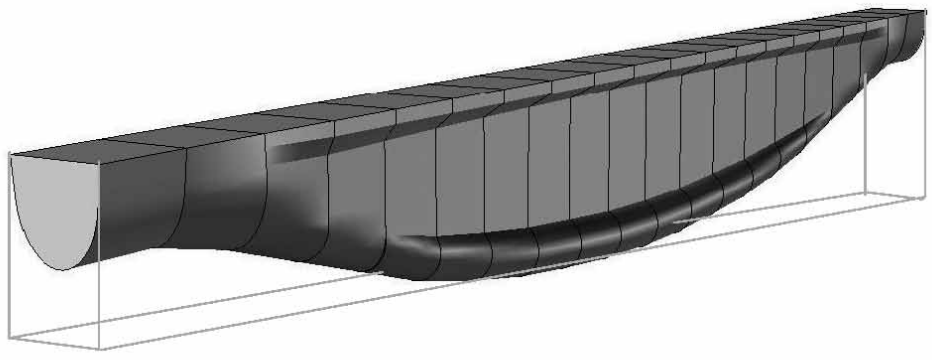

Figure 1: Fabric formwork beam profile

Figure 2: The BaleHaus

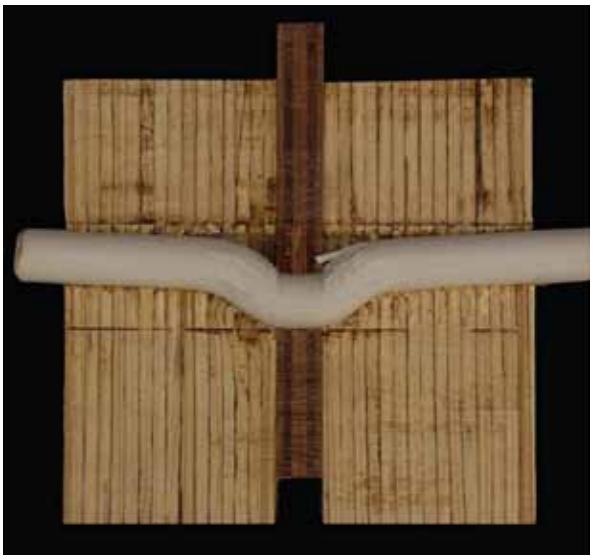

Figure 3: Metal-free timber connection using GFRP dowel and a densified veneer wood plate

- Selecting systems and materials for using roof construction to reduce the environmental impact of buildings

STRUCTURAL CONSERVATION AND SEISMIC ENGINEERING

Work in this area includes:

- Influence of climate change on historic buildings
- Seismic vulnerability of historic timber and masonry structures
- Inventory and multi-hazard and earthquake performance evaluation of the cultural heritage buildings in Istanbul
- Multi-body multi-scale dynamics for historic masonry structures
- Prototype of a dissipative anchor for the retrofit of masonry structures
- Preservation of the buddhist monastery of Adjina Tepa, Tajikistan

STRUCTURAL MASONRY

Work on masonry includes repair and retrofit of existing structures as well as development of novel materials and systems:

- An experimental and analytical study of dry-stone retaining walls
- Novel low-energy high-performance mortars for the construction industry
- Developing sustainable masonry walling

TIMBER ENGINEERING AND MATERIALS

Work in this area includes:

- All-timber connections for modern softwood timber construction (Figure 3)
- Improved adhesive systems for bonding timber
- Influence of nano- and micro-fillers and environment on the mechanical properties of DGEBA-based adhesives for bonded-in timber connections
- Evaluation of South West grown Douglas Fir for future construction
- Developing in-house structural engineering and novel cladding for traditional timber-framed buildings
- Creep of structural timber adhesives

Funding for these research activities has been secured from a wide variety of bodies, including: EPSRC, AHRC, FP7, Technology Strategy Board, DEFRA, BRE Trust, Carbon Connections, Highways Agency, Network Rail, Institution of Structural Engineers, Great Western Research, UNESCO, and the World Bank. In addition, many projects have received support from various industrial partners and publicly funded bodies.

For further information on any of these projects or those that follow, contact Professor Peter Walker,
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DEVELOPMENT OF HEMP–LIME COMPOSITE BUILDING MATERIALS

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University of Bath*

Building Technology Group, BRE+

SUMMARY

Hemp–lime is a low-carbon composite building material that combines renewably sourced hemp shiv with formulated lime-based binders. Its primary use is to form 'breathing' insulated solid external walls in timber-framed buildings. This BRE Trust funded PhD study is currently exploring the physical performance characteristics of novel low-density hemp–lime mixes, relating properties to the drying and carbonation of the material. This paper reports on some results of mechanical property tests and carbonation of the lime.

BACKGROUND

The UK has set a target of reducing net CO_2 emissions by 80%, compared with 1990 data, by 2050. In recognition that buildings contribute around 50% of the UK's CO_2 emissions, the Code for Sustainable Homes aims to ensure 90% carbon savings for all new housing by 2016. Although carbon savings are to be achieved primarily by reducing energy consumed during use, significant reductions can also be achieved through the adoption of renewable construction materials, such as hemp and straw, within the fabric of buildings.

Like all plants, hemp stores carbon during its growth as a result of photosynthesis. Combined with the relatively low net carbon emissions of lime production, following carbonation, hemp–lime has been marketed as having a 'better than zero carbon' footprint material, storing up to 135 kg of CO_2/m^3. Hemp–lime is made from hemp-shiv and a formulated lime-based binder, mixed together with water to produce a composite building material. Hemp shiv is the woody inner section of the plant stem, making up 40–60% (by mass) of the *Cannabis Sativa L.* plant. The main use of hemp–lime is for non-structural applications, where the material is cast or sprayed around a primary structural frame (Figure 1) and then lime is rendered to the finish. The primary function of hemp–lime is therefore to create a durable, weather-tight external non-structural external fabric without the need for additional insulation materials.

By reducing the pre-formulated lime binder content within hemp–lime composite mixes it is possible to reduce material costs, embodied carbon and density (so improving thermal insulation). There is little published data on the mechanical performance of hemp–lime for these lower density mixes. In addition, no national or international building standards exist for standardised empirical testing of hemp–lime.

Figure 1: Hemp–lime cast around a timber primary structure
Courtesy of Lime Technology 2008

RESEARCH PROGRAMME

Objectives

This PhD project aims to:

- characterise mechanical and physical performance of low density hemp lime
- develop and implement improved specimen fabrication and testing methodologies
- determine empirically the carbon sequestration value of the pre-formulated lime binders

- investigate empirically the hydration dynamics of the pre-formulated lime binders
- study the carbonation dynamics of the binder within the composite
- investigate the pore structure of hemp–lime composites.

Methodology

After an initial period of preliminary testing in which different fabrication and testing methodologies were investigated for repeatability and data reliability, a detailed programme for testing was produced. Successful fabrication of homogenous cylindrical specimens within 7% of the desired final air-dry density was achieved through implementing a fabrication methodology where the variables were reduced as much as possible. These methodologies may go some way towards outlining empirical standards for future testing of hemp–lime.

Standard sand mortar prisms were fabricated and tested in flexure and compression at different ages to characterise the performance of binders independently. Mechanical testing of the composite material was carried out under compression loading at different ages of curing with a typical testing set-up shown in Figure 2. Results indicated that the ultimate strength and stiffness of the composites does not relate directly to the strength of the binder itself but rather the ratio of water and binder used in the initial mix and the density of the specimens. The significance of this may be that it is not strictly necessary to include cementitious hydraulic components within the binder blend and these could be replaced, to a degree, with pozzolanic additions further reducing the carbon footprint of the material. Tests have shown that the initial tangent modulus (initial ratio of stress and strain) and compressive strengths increase with age as the material dries and the binder carbonates.

Extensive thermogravimmetric testing has been carried out to determine the extent of carbonation of the binder. Further testing is needed for a detailed analysis of the carbonation and hydration dynamics along with the final carbon content of the binders. These results may then be used to more accurately evaluate the life-cycle assessment of hemp–lime.

Figure 2: Compression testing set-up

CONCLUSIONS

To date the following conclusions have been drawn from this PhD study.

- Specimen fabrication methodologies have proved successful in producing homogenous cylinders to the required density
- The ultimate compressive strength of hemp–lime composite is not directly related to the compressive strength of the binder.
- The ultimate strength of hemp–lime is a function of the percentage of wet binder used during mixing.
- The stiffness of hemp–lime increases with time, following carbonation of the binder.
- The stiffness of hemp-lime (initial tangent modulus) increases with the percentage of wet binder used and with material density.

RESEARCH OUTPUT

The research carried out to date has been presented at one international conference in 2009 and has been accepted for publication at the forthcoming *Sustainable Materials and Technologies Conference* in Italy in the summer of 2010. Two journal papers are currently in preparation.

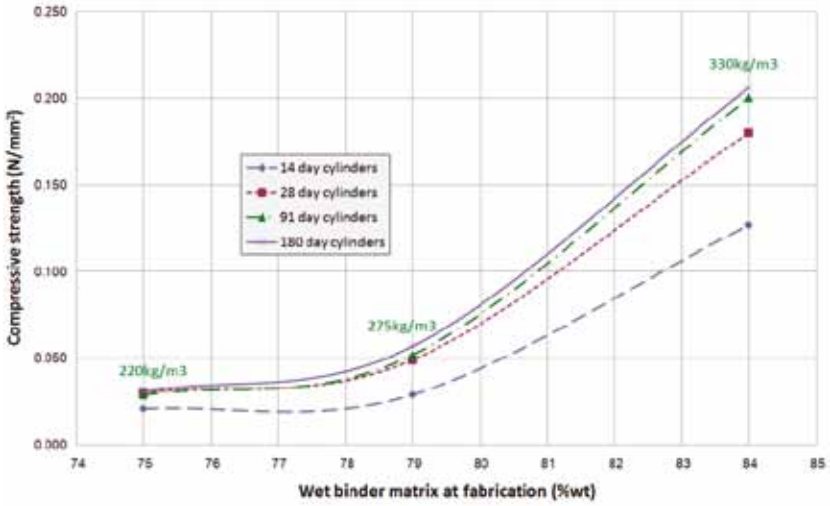

Figure 3: Compressive strength versus wet binder percentage

BIOCOMPOSITE MATERIALS FOR STRUCTURAL APPLICATIONS

Marek Prajer*, Martin Ansell* and Ed Suttie+

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University of Bath*

Building Technology Group, BRE+

SUMMARY

Composite materials comprised of fibres in a polymer matrix find many applications in aerospace and civil engineering. There are compelling environmental and economic reasons for employing naural fibre reinforcements as substitutes for synthetic fibres and specifying plant-based polymers instead of oil-derived polymers for the composite matrix. The research reported in this paper evaluates the performance of sisal fibre/polylactic acid matrix composites for potential applications in construction.

BACKGROUND

The market for natural fibre composites (NFCs) in the automotive industry is now mature, with extensive manufacture of composite panels by Toyota, Ford, Mercedes Benz, BMW, Proton and others for applications in production vehicles to satisfy end-of-vehicle-life directives on recycling. The aerospace industry is unlikely to employ NFCs in critical structural applications because of limited stiffness compared with carbon fibre composites. However, the strength and stiffness of continuous fibre NFCs is at least double that of commercial timber so there is considerable scope for using these composites in construction.

To date much effort has been devoted to evaluating the properties of hemp, flax, sisal jute and other commercial fibres in combination with thermosetting, highly cross-linked rigid matrices. In contrast, thermoplastic matrices offer the advantages of formability in the manufacture of construction components and recyclability at end of life. Furthermore, plant-based thermoplastics combined with natural fibres offer an ideal combination of natural materials with potential for the manufacture of construction components.

This PhD study has therefore been devoted to the development of continuous sisal fibre composites where the matrix comprises polylactic acid (PLA) thermoplastic derived from sweet corn starch. Its major focus is the development and evaluation of coherent interfaces between fibre and matrix to ensure effective load transfer and to minimise porosity. At the same time, fibres should be well aligned with high-fibre volume fractions to maximise mechanical strength and stiffness.

RESEARCH PROGRAMME

Extensive refinement of moulding techniques using a hot press and PLA films has resulted in high-integrity composites with low porosity and high-fibre volume fractions (Figure 1).

The dynamic mechanical properties of PLA and sisal–PLA composites are shown in Figure 2. As the fibre volume fraction increases from zero to 40 vol% and then to 60 vol%, the storage modulus increases from 2 GPa to 10.5 GPa and then to 18 GPa respectively at 20 °C. The glass transition temperature of the composites lies at about 57 °C so these composites will be stable at UK ambient temperatures. Composite strengths may exceed 300 MPa compared with ~100 MPa for softwoods so these composites are viable materials of construction.

Figure 1: (a) Cross-section through sisal–PLA composite, (b) external appearance of composite

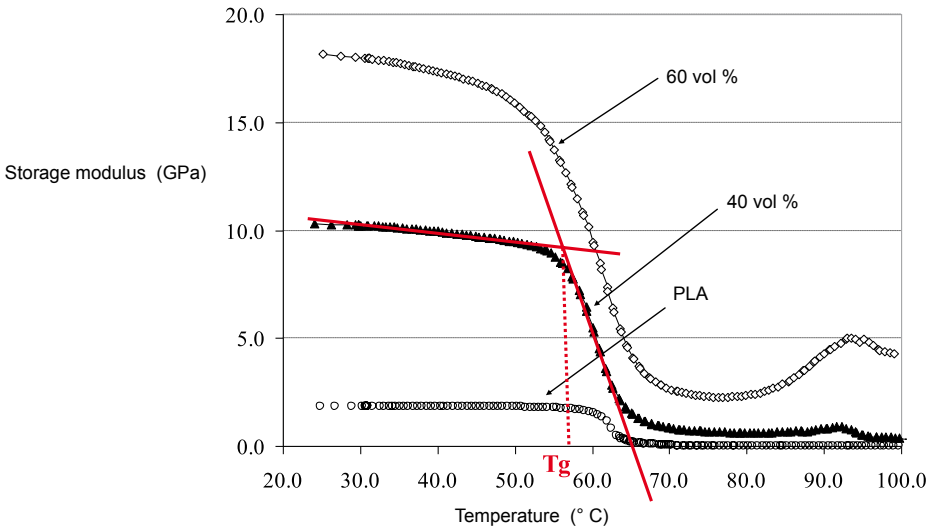

Figure 2: Dynamic mechanical analysis of PLA and PLA composites

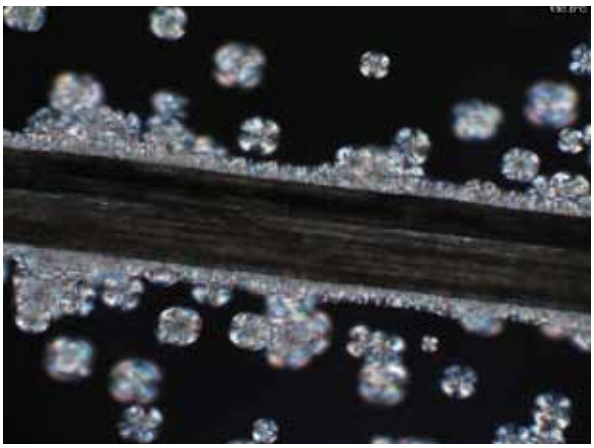

Figure 3: Transcrystalline growth of PLA crystals at the fibre surface

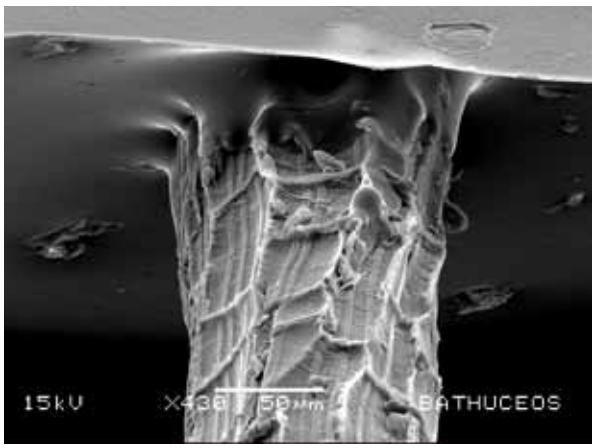

Figure 4: A sisal fibre bundle coherently bonded into a film of PLA

The research has been concerned with the crystallisation of PLA crystals at the fibre to matrix interface. Ideally, regular transcrystalline growth is preferred as seen in Figure 3 for a single-fibre bundle imaged in a hot-stage microscope within a cooling matrix of PLA.

A scanning electron microscope image (Figure 4) demonstrates good adhesion between the fibre and the PLA matrix leading to better stress transfer between matrix and fibre. The precise nature of stress transfer in the sisal fibre bundles is being measured by Raman spectroscopy in conjunction with the University of Manchester. Fibres are pulled out of the matrix in tension using the geometry of Figure 4 and the strain profile can be deduced along the fibre length.

RESEARCH OUTPUT

The results of the research have been presented at three international conferences in 2009[1–3] and the final phase of the work will complete the analysis of stress transfer and evaluate the potential of these composites for construction applications.

REFERENCES

[1] Prajer M & Ansell MP. Thermomechanical evaluation of sisal-PLA composites. Proceedings of the 17th International Conference on Composite Materials, 27–31 July 2009, Edinburgh

[2] Prajer M & Ansell MP. Interfacial micromechanics in PLA/sisal fibre composites. Proceedings of the 11th International Conference on Non-conventional Materials and Technologies (NOCMAT 2009), 6–9 September 2009, University of Bath

[3] Prajer M & Ansell M P. Interfacial micromechanics in PLA/sisal fibre composites. Proceedings of Natural Fibre '09, 14–15 December 2009, Institute of Materials, Minerals and Mining, London

PERMANENT PARTICIPATING FRP FORMWORK FOR FLOOR SLABS

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Sustainability Group, BRE Global+

SUMMARY

Fibre-reinforced polymer (FRP) materials offer a number of advantages over conventional materials for use as permanent participating formwork for concrete floor construction. Due to their strength, light weight and mouldability, the speed and ease of construction on site can be significantly improved. However, FRPs suffer from a lack of ductility, and owing to brittleness failing in a sudden and undesirable manner. To overcome this, other methods of achieving ductility at the system level have been investigated and have been shown to deliver the performance required.

BACKGROUND

Fibre-reinforced polymer (FRP) materials have been used for a number of years within the construction industry, primarily in non-structural or retrofit applications. However, there are opportunities to use these materials in new-build structural applications which take advantage of their strength, weight, mouldability and durability. This research project focuses on developing a prototype FRP permanent participating formwork for use in concrete floor slab construction. The formwork acts as a stay-in-place system which is structurally integrated with the concrete and not only acts as self-supporting formwork during construction, but remains to act as external, durable, structural reinforcement. The combined structural system makes appropriate use of the FRP in tension and concrete in compression. The system has the benefit of simplifying the construction process, with no laying of reinforcement required, thus reducing construction time as a well as increasing durability in corrosive environments.

The project focuses on providing structural stiffness, through choice of appropriate geometry of the formwork, developing a robust connection between the concrete and the FRP and creating ductility. FRP materials are inherently non-ductile so other means for providing progressive failure of the system are required. These investigations are carried out in the context of providing acceptable serviceability and ultimate limit state performance.

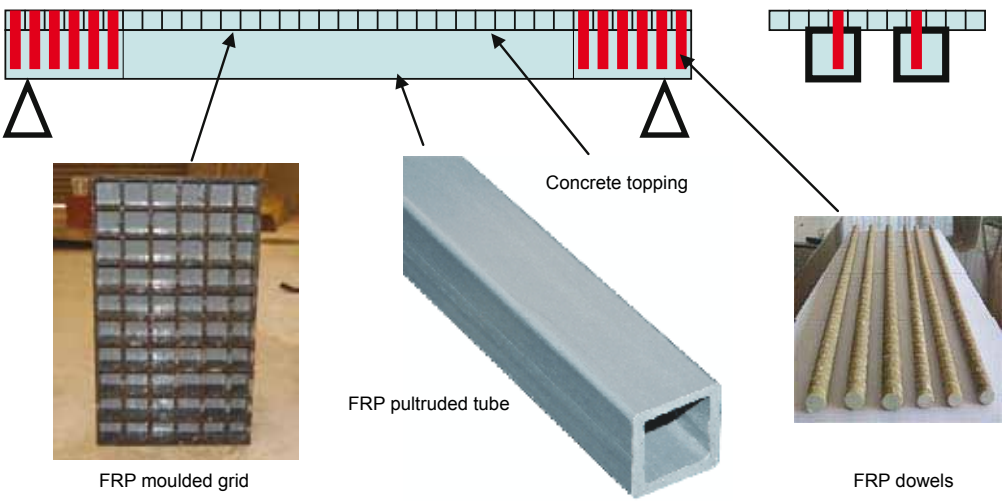


Figure 1: Proposed FRP formwork system

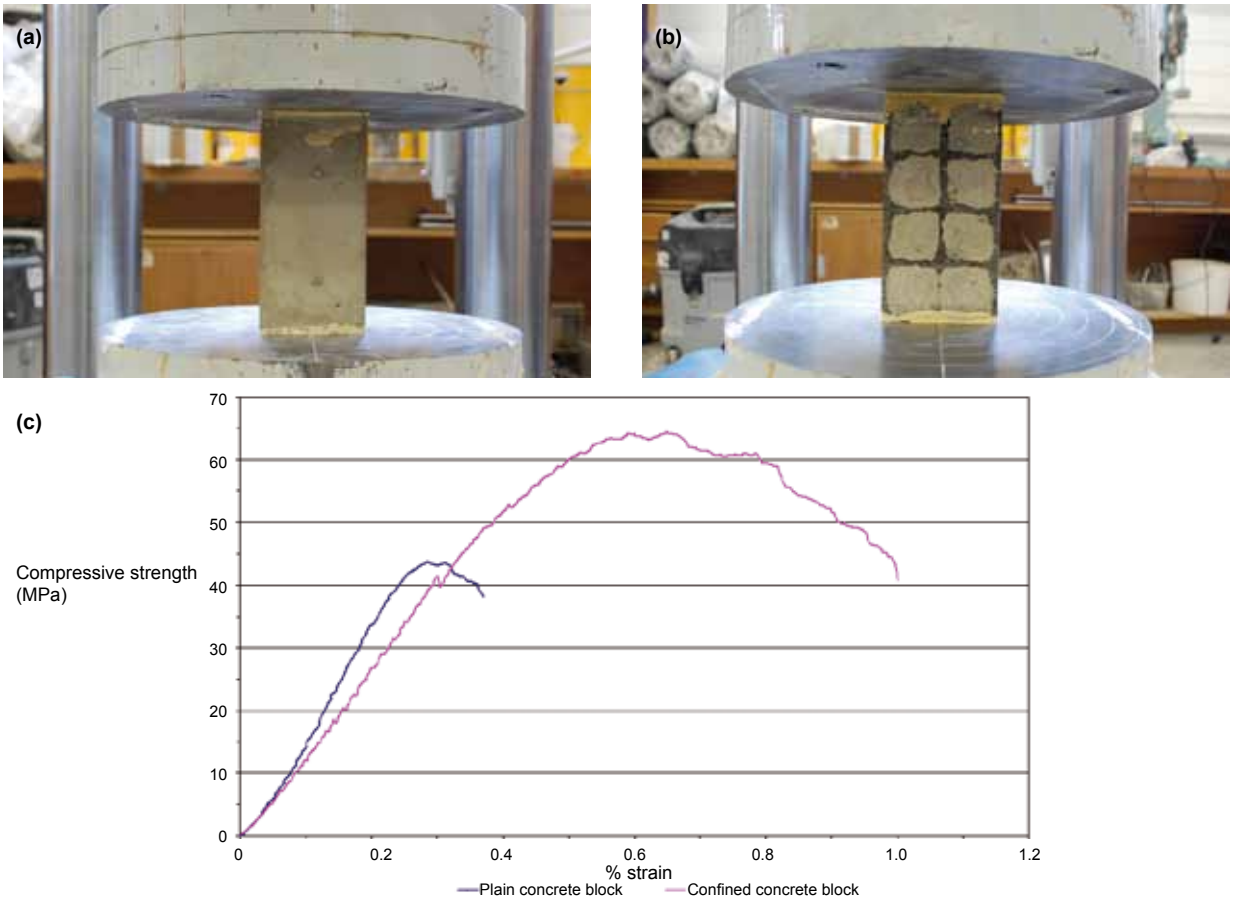


Figure 2: (a) Plain concrete, (b) concrete-filled grid, (c) stress–strain results

RESEARCH PROGRAMME

Following a comprehensive study and preliminary tests, a structural system has been proposed (Figure 1). To provide ductility the concrete in compression is utilised. Concrete by itself has minimal ductility, but, by using a FRP moulded grid filled with concrete in the compression zone, the concrete is confined, allowing much greater strain capacity to be developed as shown in Figure 2. The concrete confined by the FRP grid leads to a 50% increase in ultimate compressive strength, and a 170% increase in ultimate strain capacity compared with an identically sized plain concrete specimen. Thus, it is feasible to provide ductility to the complete system through the concrete in compression rather than the conventional approach for steel-reinforced slabs of yielding of the reinforcement.

The requirement to provide robust connection between the FRP in tension and the concrete in compression is addressed by using FRP dowels embedded into concrete in the regions of high longitudinal shear (typically at the ends of the slab). A set of longitudinal shear tests have been carried out to assess the robustness of such a connection as shown in Figure 3. Initial strength is provided by the concrete across the FRP/concrete filled grid interface followed by a residual strength provided by the FRP dowels acting in tension and shear along the concrete failure plane. Not only is integrity between the FRP and the concrete maintained, but another mechanism of progressive failure and warning of collapse is provided, enhancing overall ductility.

These component tests together with theoretical analyses demonstrate the potential for achieving ductility and robust interaction between the FRP formwork and the concrete. Research in now underway to test the complete prototype system at large scale under various load conditions to examine whether the behaviour is as predicted.

RESEARCH OUTPUT

Gai X, Darby A, Ibell T, Evernden M & Matthews S. FRP stay-in-place participating formwork: design considerations and preliminary testing. In: Advanced Composites in Construction 2009 (ACIC), 1–3 September 2009, Edinburgh, pp 376–387

Gai X, Darby A, Ibell T, & Evernden M. Development of a robust mechanical shear connector between FRP and concrete for FRP stay-in-place participating formwork. In: 9th International Symposium on Fiber Reinforced Polymer Reinforcement for Concrete Structures (FRPRCS-9): Current challenges and future trends, 13–15 July 2009, Sydney, 4pp

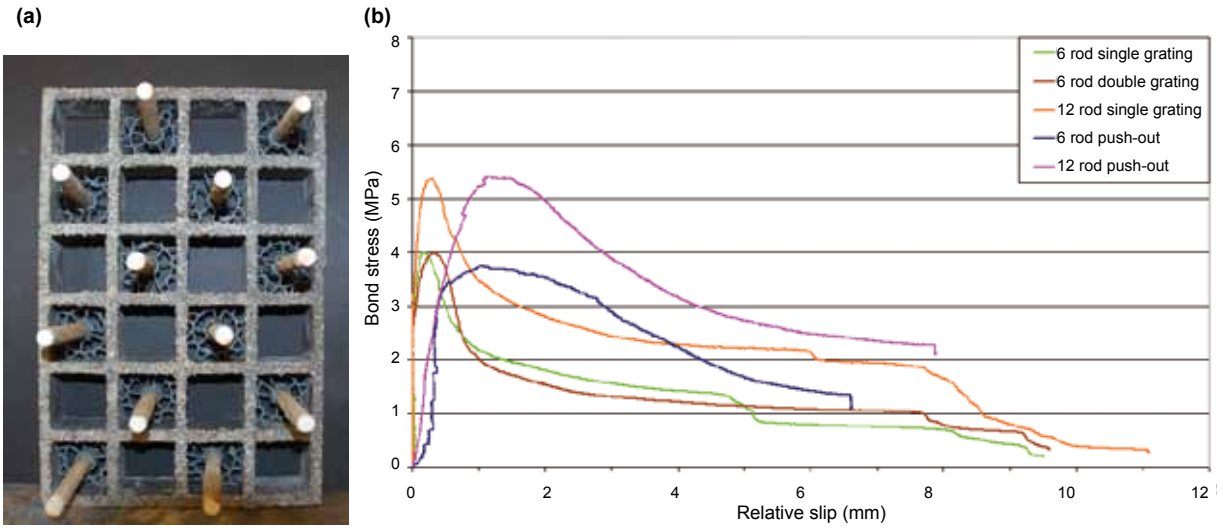


Figure 3: (a) FRP grouting and dowels, (b) bond stress versus relative slip

ENERGY AND ENVIRONMENT

BUILDING-MOUNTED MICRO-WIND TURBINES ON HIGH-RISE AND COMMERCIAL BUILDINGS

Paul Blackmore

Building Technology Group, BRE

SUMMARY

There is an increasing trend to mount micro-wind turbines on the roofs of tall buildings where they have the potential to generate useful levels of energy due to the advantages from increased wind resource at these heights and the reduced shelter and turbulence from surrounding buildings. This research aims to provide guidance on the most effective height and location for wind turbine installations on the roofs of tall buildings by characterising the wind conditions over a range of building heights from 15 m to 80 m.

BACKGROUND

It is UK Government policy (Planning Policy Statement PPS22[1]) that all non-residential or mixed-use developments above1000 m^2 will be expected to provide at least 10% of their energy requirements from on-site renewable energy generation. Wind energy produced from building-mounted wind turbines could be expected to provide a proportion of this renewable energy. This is likely to be especially true on taller buildings because of the greater potential wind resource and reduced shelter from surrounding buildings. However, without guidance, the most effective locations for siting wind turbines cannot be easily determined. Inappropriate siting could lead to ineffective installations and severely limited power generation with the result that this potential renewable energy source will not be effectively utilised which is why this research was needed.

RESEARCH PROGRAMME

A wind tunnel study was used to investigate the wind conditions over the roofs of a range of typical high-rise buildings and over the roof of a large plan-form building typical of a retail store. Measurements of wind speed were made at a number of locations across the roofs of each model. At each measurement location, the mean wind speed and the turbulence intensity were measured at heights representing the typical installed heights of wind turbines. It was found that the wind conditions over the roofs varied rapidly with distance across the roofs. In order to resolve the wind conditions, measurements were made at full-scale equivalent heights between 2 m and 30 m and at 17 measurement locations over the roof. Measurements were made on all building models for the two principal orthogonal wind directions (0° and 90°) and on some models additional measurements were made for wind directions 22.5°, 45° and 67.5°. Figure 1 shows measurements being made on a building model in the BRE wind tunnel.

Figure 1: A building model in the BRE wind tunnel

The measured mean wind speed was normalised by the local reference mean wind speed measured at the same height but without the model in position. This gives non-dimensional mean wind speed ratios which allow easy comparison between measurements from the different building configurations. If the mean wind speed ratio exceeds 1.0 then this indicates that the wind speed over the building is greater than the wind speed which would occur if the building was not present, ie the wind flow over the building is being accelerated. Conversely, a mean speed ratio of less than 1.0 indicates a reduction in wind speed over the building. The turbulence intensity measurements were normalised in a similar way.

RESULTS

Figure 2 shows the variation of mean wind speed ratio across the centre of the roof of the 80 m tall building model. From this figure it can be seen that the wind speed

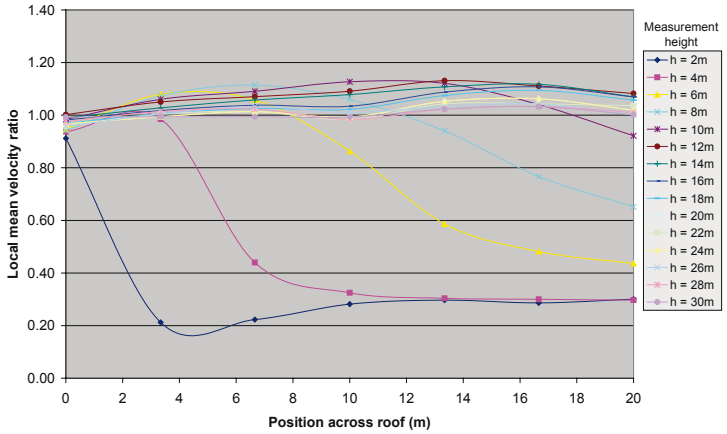


Figure 2: Mean wind speed ratio across the roof of the 80 m building

ratio at the upwind roof edge is close to 1.0 showing that the wind flow here is largely unaffected by the building-generated effects. However, the wind speed ratio reduces significantly with distance from the windward edge; at 4 m across the roof it has reduced to < 0.2; only recovering slightly to 0.3 at the leeward edge of the roof. As wind power is proportional to wind speed cubed, a wind speed ratio of 0.2 equates to a power output of <1% of the potential available wind energy. It is only at a height of more than 10 m above the roof of this building that the building-generated effects on mean wind speed become negligible across the whole roof. Turbulence intensity is even more sensitive to building-generated effects and on this building it requires a height of 14 m before these effects diminish completely.

Figure 3 shows a plot of turbulence intensity ratio contours over the 80 m building for wind direction 0° at a full-scale equivalent height of 10 m. It can be seen from this Figure that the turbulence intensity ratio exceeds 1.0 at most locations across the roof, indicating that the building-generated effects are still significant even at a height of 10 m above the roof of this building.

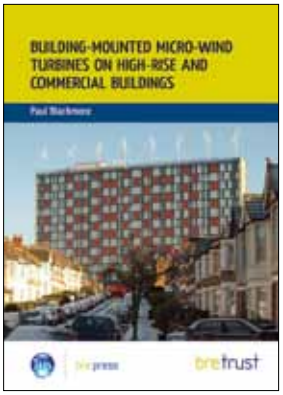
CONCLUSIONS

The main conclusions from this study are:

- The height and length of the disturbed flow region over the roofs of the buildings is strongly dependant on the building dimensions.
- The average mean wind speed over the roofs tends to converge to within 10% of the undisturbed free-stream wind speed at a height of 0.07 to 0.09 H.
- The average turbulence intensity over the roofs tends to converge to within 10% of the undisturbed free-stream turbulence intensity at a height of 0.12–0.17 H.
- A suggested simple 'rule of thumb' for the installation height of micro-wind turbines on flat-roofed buildings is for turbines to be mounted at a minimum hub height of 0.1 H, although a height of 0.15 H is recommended (where H is the height of the building measured in metres).

RESEARCH OUTPUT

More information about the findings of this research project is given in a BRE Trust report (FB 22), *Building-mounted micro-wind turbines on high-rise and commercial buildings*.



REFERENCE

[1] Communities and Local Government (CLG). Renewable energy. Planning Policy Statement 22 (PPS22). 2004. Available as a pdf from www.communities.gov.uk/publications/planningandbuilding/pps22

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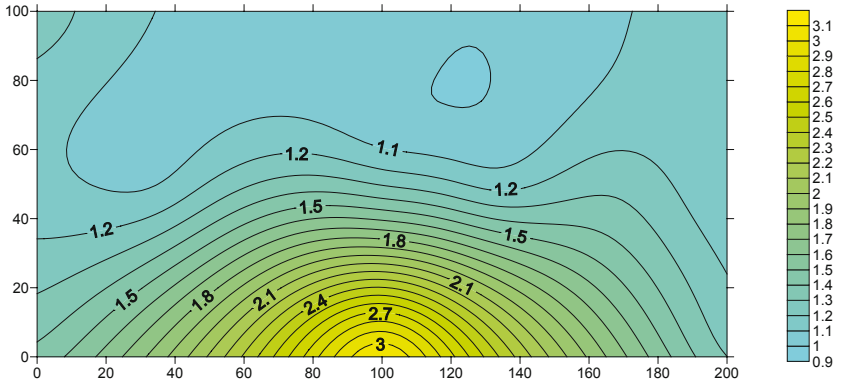

Figure 3: Turbulence intesity contours over the 80 m building at a height of 10 m

INSTALLATION AND PERFORMANCE OF HOUSEHOLD MICRO-WIND TURBINES

Panagiota Pantazopoulou

Sustainable Energy Group, BRE

SUMMARY

A trial of wind turbines mounted on a range of low-rise and high-rise buildings has been carried out to assess their performance in use by real families and homeowners. The results from this work have provided an insight into how grid-connected micro-wind turbines perform on real buildings and can be used by consumers, manufacturers and installers when considering wind turbine installations. The conclusions of the project are that micro-wind turbines may make a significant contribution to energy and carbon saving only on the most exposed sites and tallest buildings.

RESEARCH PROGRAMME

BRE Trust funded the monitoring of 13 turbines as part of the Warwick Microwind Trial, led by the energy consultants, Encraft Ltd. With further funding from the Pilkington Energy Efficiency Trust and Warwick District Council, the monitoring included another 13 building-mounted wind turbines on a variety of low-rise and high-rise buildings in urban and rural sites in the Warwick area.

The main aim of the Warwick Microwind Trial was to collect and publish data on performance when the systems are used by real families and homeowners. More specifically, the objectives in setting up the trial were to:

- examine how grid-connected micro-wind turbines perform on a variety of building types
- consider any emerging trends that could provide guidance to:
  - help consumers to make informed choices when considering a wind turbine for their home
  - help manufacturers and installers to direct their sales and marketing efforts appropriately.

The final report summarises the full findings from the Warwick Wind Trials Project covering 168 950 hours of operation of 26 building-mounted micro-wind turbines

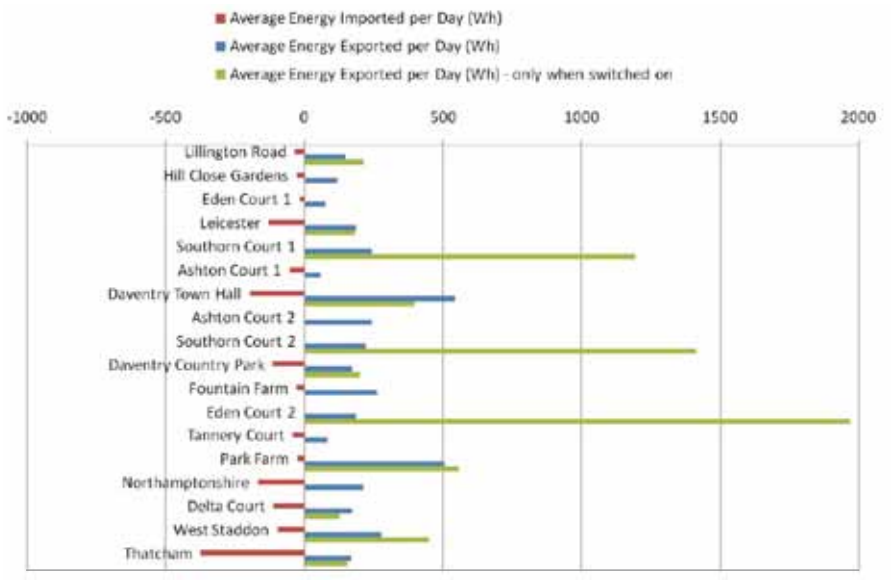

Figure 1: Average energy imported and exported per day

from five manufacturers across the UK during 2007–2008. These turbines were mounted on sites ranging from theoretically poor (single-storey urban buildings) through to theoretically excellent (45 m tall exposed flats in isolated settings on hilltops).

RESULTS

The average energy generated per turbine per day across the sample set was 214 Wh (including periods when the turbines were switched off because of breakdown or for maintenance). This is equivalent to an average of 78 kWh of energy produced per site per year and an average capacity factor of 0.85%. (This compares with typical capacity factors of between 10% and 30% for larger turbines on free-standing sites in good areas.)

The best performing turbine in the trial generated an average of 2.382 kWh per day when in operation, equivalent to 869 kWh in a full year. The poorest site generated an average of 41 Wh per day when in operation or 15 kWh per year, which is less than the energy it consumed to run the turbine's electronics.

Energy consumption averaged 80 Wh per day per turbine (29 kWh per year) which was significant on some sites. Figure 1 shows the average energy imported and exported per day by each turbine on various sites.

Overall, the trial has painted a picture of an industry and technology that is still at development stage and is likely to make a tangible contribution to energy and carbon saving only on the most exposed sites and tallest buildings.

CONCLUSIONS

Our recommendations from the trial are as follows:

- Great care should be taken in selecting suitable sites for building-mounted micro-wind turbines.
- More work is required to create a robust method for predicting average wind speed in urban locations.
- More research could be done on the appropriate choice of shape factor in the Weibull function when predicting wind speed in urban locations.
- The use of scaling factors for the UK wind speed database (NOABL) and the Weibull shape factor has potential to improve wind speed predictions, although more work is required in this area.
- Our data show the (now recognised) need for an industry standard that normalises the way in which manufacturers' power curves are produced and this data should be published.

ACKNOWLEDGEMENTS

This project would not have been possible without the support of the individual customers who volunteered their turbines for the trial, and we are very grateful to all of them.

Particular thanks are due to:

- Encraft Ltd for successfully leading this project
- Pilkington Energy Efficiency Trust and BRE Trust who have provided funding to enable the trials to maintain their independence
- Warwick District Council, in whose planning area 11 of the turbines are located.

The British Wind Energy Association (BWEA), the Micropower Council and the former UK Government Department for Trade & Industry (DTI) all offered support in kind initially which helped the trials get off the ground. The Energy Saving Trust has more recently provided financial support to the Warwick Wind Trial to fund the inclusion of additional sites and extend the period of data collection.

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VENTILATION MEASUREMENT USING NEW ENVIRONMENTALLY-FRIENDLY TRACERS

Stuart Upton

Building Technology Group, BRE

SUMMARY

It is important for a building to have the correct level of ventilation to ensure the health, comfort and productivity of its occupants, as well as energy efficiency. Any ventilation measurement method used needs to be safe, environmentally acceptable and properly validated. Most of the tracers traditionally used for this purpose have high Global Warming Potentials (GWPs) and their use is being restricted or prohibited. BRE has recently successfully completed a project to develop some new, more environmentally-friendly ventilation tracers. This has maintained BRE's capability to carry out these critically important measurements for its customers and the industry as required.

BACKGROUND

Ventilation in a building must be provided at the right level to ensure occupant health, comfort and productivity, and energy efficiency. Measurement of building ventilation rate is therefore important for demonstrating compliance with standards and also for diagnostic purposes when investigating, for example, problems of poor indoor air quality and overheating. The proposed revision in 2010 to Approved Document F of the Building Regulations (England & Wales) specifies that 'all ventilation systems (both natural and mechanical shall be inspected and commissioned'.

For many years, BRE used perfluoromethylcyclohexane (PMCH) for long-term ventilation rate measurement in buildings (typically over periods of 1–4 weeks) using the perfluorocarbon tracer (PFT) technique. For short-term measurements (typically over periods of 1–2 hours) sulphur hexafluoride (SF_6) was used. These chemicals have a high global warming potential (GWP) and hence it is the UK Government's policy to phase out their use.

RESEARCH PROGRAMME

The aim of this project was to develop alternative, more environmentally-friendly, methodologies for both long- and short-term ventilation rate measurements. The project was subdivided as follows.

- A literature review and scoping study to identify potential replacement methodologies
- A pilot study of candidate methods for both long- and short-term ventilation measurement
- Final development of the new long-term ventilation measurement method
- Final development of the new short-term ventilation measurement method.

For long-term measurements the replacement tracer ethoxynonafluorobutane (ENFB) was chosen for evaluation. This has a GWP of 100, compared with the GWP of ~10 000 for PMCH. However, it should be noted that the emissions of tracer using this technique are always very small, with each of the small tracer source tubes used emitting typically only around a few micrograms of tracer per hour.

For short-term measurements, the replacement tracer butane was finally chosen for evaluation. This has a GWP of < 10, compared with the GWP of 23 900 for SF_6.

RESULTS

Long-term ventilation rate measurement: comparison of existing and new methods

Sources for the new tracer were developed and evaluated to determine their emission rates. Following this, sampling tube uptake rates for the new tracer were measured and the analytical technique refined to increase its sensitivity. On completion of the development work, comparative measurements of ventilation rates (in air changes per hour or ACH) were made in an office, a laboratory room and a test house, using both the new and original ventilation tracer. The results of these measurements are given in Figure 1. From the comparison between the existing and new tracer measurements, the linear regression fitted to the data has a value for the coefficient of determination (R^2) of 0.9377, indicating good agreement.

Short-term ventilation rate measurement: comparison of existing and new methods

Sources of butane were required that were both easily transported (ie not subject to the same transport regulations as conventional gas cylinders) and also 'domestically acceptable'. After investigation,

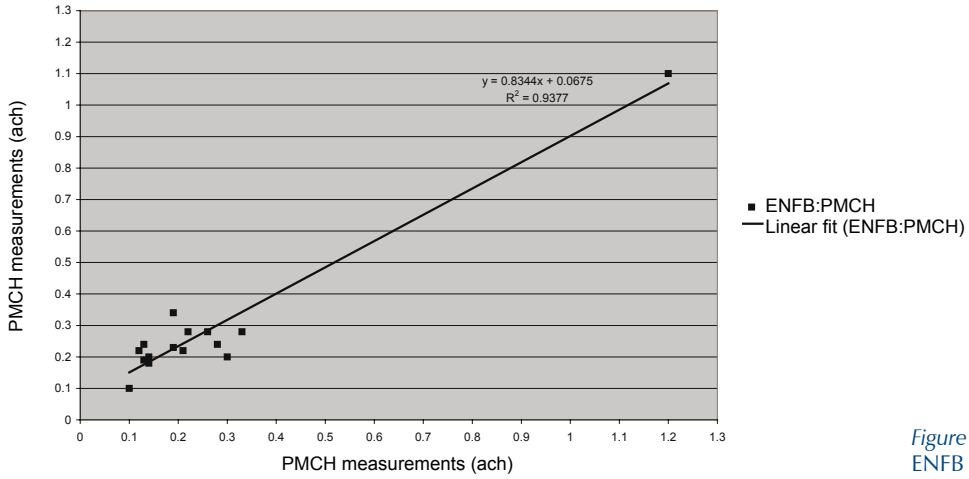

Figure 1: Comparison of ENFB and PMCH results

Figure 2: Butane sensor instrument developed by BRE

commercially available gas-lighter re-filling aerosol cans were deemed most suitable for the purpose.

A suitable sensor for detecting butane was also required. The specifications for the sensor were that it should be both portable and sufficiently sensitive for use in measuring the concentrations of tracer likely to be used. A sensor meeting these requirements, based on the adsorption of infra-red radiation, was identified and built into a small instrument enclosure which also contained a small pump and data logger. The output of the sensor selected was linear in response to concentration over the range 0–2000 ppm of butane. Figure 2 shows the sensor instrument that was constructed. Its dimensions are only 265 × 180 × 140 mm, making it easily portable.

Comparative ventilation rate measurement tests, using both the newly developed butane tracer method and the existing standard SF_6 method, were carried out in a small range of buildings at BRE. The test locations included a laboratory room, a BRE test house and a large industrial building. Figure 3 shows the results of the ventilation rate measurements made within the various types of buildings investigated. From the comparison between the existing and new tracer measurements, the linear regression fitted to the data has a value for the coefficient of determination (R^2) of 0.9707, indicating very good agreement.

RESEARCH OUTPUT

BRE has developed two alternative, more environmentally-friendly, methodologies for both long-term (averaged over typically 1-week periods or greater) and short-term (periods of approximately 1 hour) ventilation rate measurements.

The new methodologies have already been used in project work as follows.

- The ENFB tracer has been used in combination with the existing PMCH tracer in multi-tracer measurements to measure both ventilation rates and inter-zonal flows in a large commercial building.
- The butane decay-rate technique has been used to measure ventilation rates in a number of houses, both pre- and post-refurbishment.

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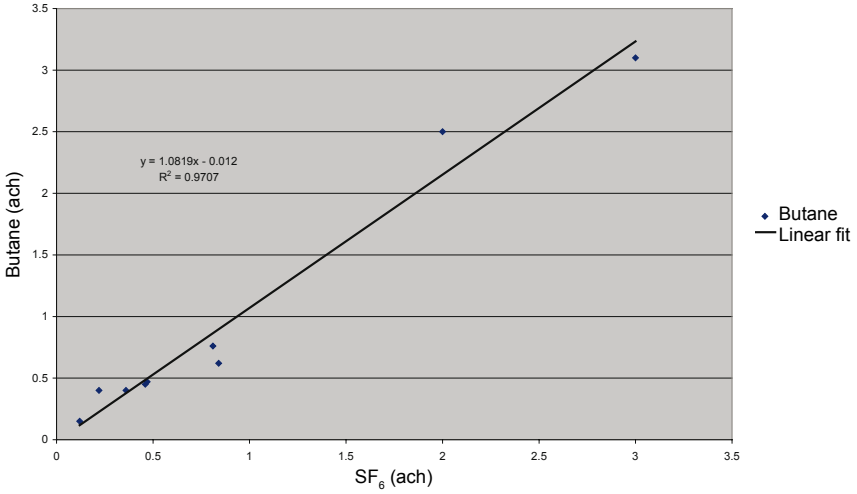

Figure 3: Comparison of butane and SF_6 results

BRE VENTILATION AND AIR QUALITY (BREVAQ) TOOL FOR GOOD INDOOR AIR QUALITY IN URBAN BUILDINGS

Vina Kukadia
Building Technology Group, BRE

SUMMARY

Air quality is an issue that building designers, developers and contractors increasingly need to consider when they are planning a new development or a major refurbishment project. With rising air pollution levels in urban areas, there is a growing need to reduce human exposure to this pollution by improving the quality of the air we breathe, both in and around buildings. In response, planning and environmental health authorities are now demanding that those who specify, design or construct buildings, take account of air pollution at all stages of the design process. The BRE Ventilation and Air Quality (BREVAQ) Tool has been developed to help minimise the impact of external pollution on urban buildings, thereby improving indoor air quality and ensuring adequate ventilation for occupants.

BACKGROUND

Ventilation requirements for building occupants usually assume that the external air supply is 'fresh', that is, it is largely free from contaminants. Air quality maps for London show how some areas of Central London suffer almost 'double the recommended limits for pollution'[1]. In fact, recent news has indicated that 'London has already breached the new EU pollution limits for the entire year'[2].

Thus, the incoming air may be contaminated by a variety of externally generated pollutants, such as those from vehicles, local and regional industrial pollution (eg from industrial plant, boiler flues, incinerators, combined heat and power (CHP) plant and ventilation discharges) and also from construction and demolition activities[3]. These can have an adverse impact on occupants' health, productivity, comfort and well-being; in particular, since up to 90% of time is spent indoors. Furthermore, planning and environmental health authorities are now demanding that those who specify, design or construct buildings, minimise the amount of pollution that infiltrates into buildings, as well as that which is emitted during the construction process and its subsequent use.

It is therefore vital to be able to identify and control the ingress of pollution into urban buildings by effective ventilation and building design, taking into account all relevant pollutant sources.

RESEARCH PROGRAMME

Mechanical ventilation systems are often favoured for reducing air pollution in the incoming air. However, such systems do not always provide clean fresh air. Figure 1 shows the results of monitoring studies carried out by BRE in two buildings located on a major road in a UK city, where external pollution levels are often found to be relatively high. The naturally ventilated building is a four-storey 1920's building with openable sash windows and secondary glazing for ventilation. The mechanically ventilated building is a modern 10-storey building with a façade which is mostly sealed. Ventilation air is drawn in from the 10th floor through grilles.

RESULTS

Nitrogen dioxide (NO_2) levels in both buildings were similar but lower than external levels. This implies that the building fabric provided some mitigation. However, on one occasion, the levels measured were considerably higher than the UK-recommended limits. It is likely that this was due to combustion products from another source at the high level of the intake to the ventilation system, especially as there were a number of boiler flues close to the intake.

In addition, extensive studies carried out in the BRE Environmental Wind Tunnel have shown that the interactions between pollutant sources and dispersion processes in the external environment with ventilation and indoor air quality are complex and depend strongly on a number of parameters such as:

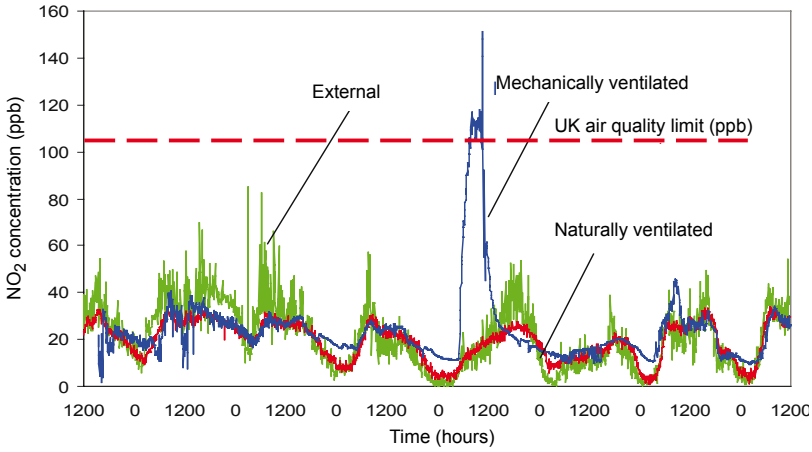

Figure 1: NO_2 concentrations in buildings

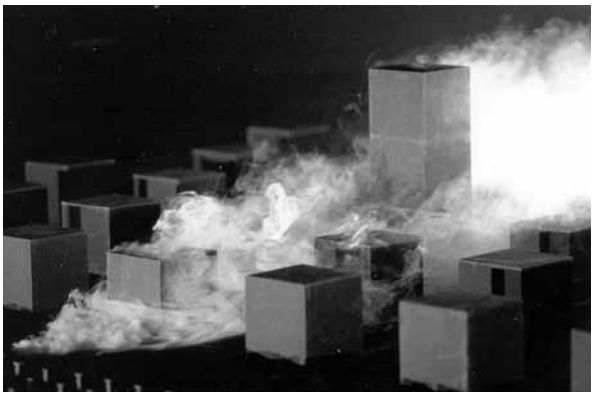

Figure 2: Wind tunnel studies of the dispersion of a simulated pollutant source in a generic urban area

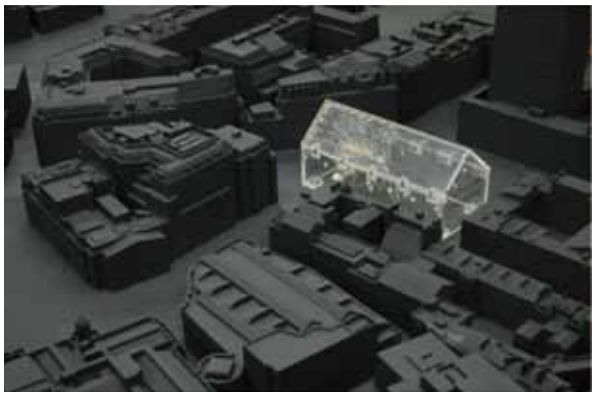

Figure 3: Development of a ventilation strategy for a new building

- urban layout
- building shape and size
- location, type and number of pollution sources.

Figure 2 shows an example of the dispersion of a simulated pollutant source at ground level in a generic urban area. The variability and the intermittent nature of the plume can be seen. In terms of location of ventilation inlets, it is conceivable that a designer would intuitively locate inlets away from the pollutant source and higher up the building façade. However, Figure 2 indicates that this may not be the correct approach as pollution tends to disperse upwards on the leeward side of a building.

In urban areas, there is a multitude of pollutant sources often at different heights. BRE studies have shown that all local pollutant sources need to be considered when determining the optimum siting of ventilation inlets, where pollution levels are likely to be the lowest. This in turn will minimise the ingress of pollution and also reduce the load on the ventilation system and the need for high specification filters.

RESEARCH OUTPUT

The BREVAQ Tool has been developed, based on BRE research over the past few years and original guidance by Kukadia et al[5]. It gives a step-by-step approach for predicting air pollutant levels around a building and on the facades of the building under design, and then estimating building internal pollutant levels. This enables an effective ventilation strategy to be developed that minimises the ingress of external pollution into the building. This can then be tested in the BRE Environmental Wind Tunnel (Figure 3).

The Tool has been validated using hypothetical test data. However, the next important step is to fully evaluate the Tool on one or more development projects (possibly in partnership with a developer and associated building designer). If you are interested in supporting this evaluation exercise with a development project as a test case or would like further information on the Tool and how the BRE Air Pollution Team can help to solve air pollution, ventilation and indoor air quality related problems, please contact the author.

REFERENCES

[1] GLA. Private communication, 2005

[2] Prigg M. www.thisislondon.co.uk, 21 January 2010

[3] QUARG (1993). Urban Air Quality in the United Kingdom. First report of the Quality of Urban Air Review Group, DoE

[4] Kukadia V & Palmer J. The effect of external atmospheric pollution on indoor air quality. 17th Annual Air Infiltration and Ventilation Centre Conference, Sweden, 1996

[5] Kukadia V, Hall D J & Walker S. Ventilation guidelines to minimise the ingress of external pollution into non-domestic urban buildings. BRE Client Report 75637. 2000

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FIRE PROTECTION AND PREVENTION

A MITIGATION TOOL FOR VULNERABILITY AND FIRE RISK ASSESSMENT
An assessment procedure for integrated safety and business continuity

Jeremy Fraser-Mitchell, Victoria Smith and David Charters
Fire and Security Group, BRE Global

SUMMARY

A risk assessment 'road map' establishes a common framework for all risk assessments. It is not prescriptive in the sense of specifying a particular risk assessment methodology.
An event such as a fire may have a range of consequences, for example deaths, injuries, building damage, contents damage, building closure, etc. To handle these different consequences (risk metrics) in a consistent manner, it is necessary to convert them to a common metric (money).
There is no theoretical reason why fire and other business continuity risks cannot be considered within a common framework.

BACKGROUND

Since the Regulatory Reform (Fire Safety) Order came into force in 2006, BRE Global has been increasingly involved in providing advice and/or performing risk assessments, as required by the Order. Some clients have sought to go further than just achieving legislative compliance, and have sought assistance on issues such as asset protection, business continuity, etc. Our response to these opportunities has been on an ad-hoc basis so the objective of this BRE Trust project was therefore to develop a more coherent and holistic service.

Although several draft international Standards for risk assessment (in general, specifically for fire, and business continuity) are under development, none has achieved the status of a full Standard. Rather than wait for this to happen, we needed to develop a process that would be consistent with a Standard when one does emerge.

RESEARCH PROGRAMME

At the heart of our approach is the concept of the risk assessment 'road map'. This establishes a common framework for all risk assessments. It may also be used to steer peer reviews of risk assessments performed by others. The road map is not prescriptive in the sense of specifying a particular risk assessment methodology. It is recognised that many techniques are available, and the most appropriate approach will depend on the circumstances of the risk assessment (or review).

Risk assessment

Explicit risk assessment uses the formula:

$$Risk = \{frequency\ of\ hazard\ occurring\} \times \{consequence\ of\ hazard\}$$

where the total risk involves a summation over all hazards or scenarios. This is the approach we prefer, rather than implicit methods. Note that the term 'frequency' is preferred, rather than 'probability', as this emphasises the importance of timescale.

We have reviewed fire risk assessment tools to see which have a business continuity dimension, and which could be developed to include one. There is also a need to consider business continuity risks arising from sources other than fire. Generally speaking, this is beyond the scope of models developed specifically for fire.

We concluded that a hierarchy of methods should be used, depending on the estimated risk level, the risk appetite, and the degree of uncertainty. For the initial assessment, hazard audits and checklists would be sufficient. At the other end of the spectrum, the most complex assessments could be performed using an extended version of BRE's Monte-Carlo simulation tool, CRISP. However, between these two extremes there is space for a simpler method, based on event trees, which can give a quantitative answer, albeit with some limitations.

As part of this project, we have developed Visual Basic macros that enable Monte Carlo simulations to be performed easily within Excel spreadsheet models. This is particularly valuable when the uncertainties are relatively large, and the approximations implicit in the standard 'error propagation' formulae are no longer appropriate. The preferred approach to uncertainty is to quantify it, rather than rely on conservative assumptions. We regard uncertainty and sensitivity analyses as essential parts of any quantitative risk assessment.

Risk metrics

There are too many different hazards, which may be specific to a particular business, for it to be worthwhile compiling a generic prescriptive list that must be covered by a risk assessment. However, there is a much more limited range of risk metrics (consequences), and it may be worthwhile to ensure that a specified list of these is considered when doing the risk assessment. An event may have a range of consequences. For example, a fire may cause deaths, injuries, building damage, contents damage, building closure, etc. To handle these different consequences (risk metrics) in a consistent manner, it is necessary to convert them to a common metric (money).

There is no theoretical reason why fire and other business continuity risks cannot be considered within a common framework. Although this BRE Trust Project started out with an emphasis on business continuity, that aspect has been downplayed in the final report. Business continuity is seen as just one of a number of different risk assessment metrics that could be applied.

Even if it is possible to convert all risk metrics into monetary equivalents, that is not necessarily the end of the story. The costs may be borne by a number of different entities, including individuals, companies, or society as a whole. This may influence how decisions are made regarding investment in risk reduction.

Audit or peer review?

Different approaches to assessment of risk assessments have also been reviewed. There is no single method, although most involve some form of audit and/or review process. Ultimately, all the methods for assessing fire risk assessments rely on the exercise of professional judgement and so the competency of the assessor of the fire risk assessment is also a key factor.

The risk assessment 'road map'

The 'road map' is described by a flow chart (Figure 1) which lays out the different steps of the risk assessment process in a logical sequence. By methodically following the flow chart, one can be sure that parts of the process have not been omitted or glossed over.

The process starts with setting the context of the risk assessment. This is the foundation for the entire process, hence it is vital to get this right. Once this is done, the risks can then be identified, and assessed. This assessment may either be qualitative or quantitative, according to the requirements determined by the context. Those risks that do not pass the acceptance criteria (defined at the context-setting stage) will require treatment (control measures), whose effectiveness (on the likelihood and/or consequences) must also be assessed. This is a cyclic process that continues until all risks are at an acceptable level. The various stages of the risk assessment process are all documented, and findings communicated appropriately.

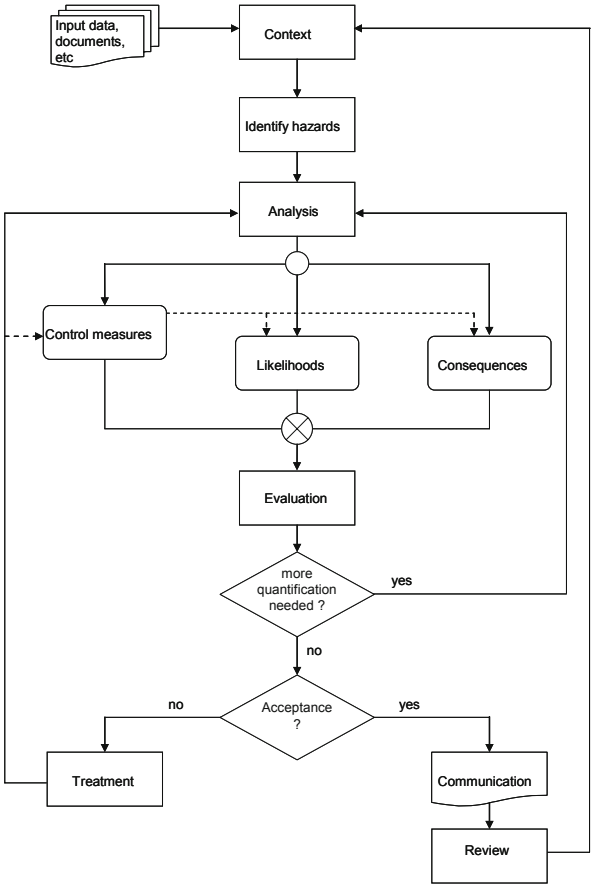

Figure 1: The risk assessment road map

The process ends with a review stage. The circumstances which trigger a review will be determined by the context-setting stage. The review is then the start of the next loop through the flowchart. Risk assessment is therefore a continual process, which lasts for the entire lifetime of the building or business.

The road map is not prescriptive in the sense of specifying a particular risk assessment methodology. It is recognised that many techniques are available, and the most appropriate approach will depend on the circumstances of the risk assessment (or review).

It may also be used to steer peer reviews of risk assessments performed by others, or to develop proposals for work. In either case, it matches the review or the proposal to the (intended) risk assessment itself. If there is not a 1:1 correspondence between the (intended) risk assessment and the road map, such gaps need to be identified and justified, or filled.

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STRUCTURAL COMPOSITE CONNECTIONS FOR SEQUENTIAL SEISMIC AND FIRE PERFORMANCE

Tom Lennon and Danny Hopkin
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SUMMARY

This project, undertaken in collaboration with a number of European partners, has provided high quality data on the performance of two types of composite beam to column connections specifically designed to achieve seismic resistance and fire resistance through a multi-objective, performance-based design approach. The adequacy of the connections has been demonstrated by experimental testing and numerical studies.

BACKGROUND

Traditional fire design procedures consider structural behaviour in terms of the performance of individual elements rather than building systems. Little consideration is given to member interaction or to the crucial role of connections in maintaining overall stability in a fire.

Major earthquakes in urban areas have often been followed by large fires that have been difficult to control. Seismic-induced fire is a scenario with a high probability of occurrence as evidenced by earthquakes in Northridge, California, and Kobe, Japan. This scenario should therefore be addressed in performance-based design for buildings in seismic areas.

Fire and earthquake are accidental actions and are generally treated independently. This project attempted to couple fire safety with seismic safety based on the design of partial-strength composite connections to provide:

- seismic safety with respect to accidental actions
- fire safety where seismic actions cause a reduction in the stiffness and strength of beam to column connections and the removal of any form of passive fire protection.

DETAILS OF TEST SPECIMENS

Two types of connection have been developed as part of a collaborative European project.

- *The Type 1 connection* consists of a partially reinforced concrete-encased H-section column connected to I-section beams supporting concrete decks consisting of either profiled steel sheeting or prefabricated slabs.
- *The Type 2 connection* consists of a steel circular hollow section filled with reinforced concrete connected to I-section beams and composite or prefabricated floor slabs.

Both internal and external connections were included in the experimental programme. Figures 1 and 2 show plan views of Type 1 and 2 connections.

RESEARCH PROGRAMME

The research programme aimed to evaluate the fire resistance of the connection following earthquake damage. The specimens were erected and cast at BRE. The experimental programme consisted of two parts:

- a static load test to simulate the damage due to an earthquake
- a subsequent fire test.

To simulate the damage due to a seismic event a specified deformation (in terms of both connection rotation and vertical deflection) was prescribed based on the results of cyclic testing of identical specimens in Italy. The complete schedule of testing is summarised in Table 1.

RESULTS

For both the Type 1 and Type 2 damage tests the internal specimens showed only superficial damage with some through-depth cracking of the concrete slab observed. Damage for the external specimens was more pronounced with some distortion of the column web panel and extensive cracking of the slab surface evident particularly for the Type 1 specimens.

No failures occurred for the Type 1 fire tests although the fire test did lead to localised spalling of the concrete in the area around the connection. The results indicate that the precast connections provided enhanced stiffness and strength at elevated temperatures compared with the composite profiled steel sheeting.

This pattern was repeated for the Type 2 tests with the composite specimens with steel sheeting failing by runaway deflection approximately 40 minutes into the fire test. At this stage, the profiled sheeting had separated from the slab, there was extensive cracking of the slab in two perpendicular directions and there was extensive buckling of both the lower flange and the web of the composite beam in the area of the connection.

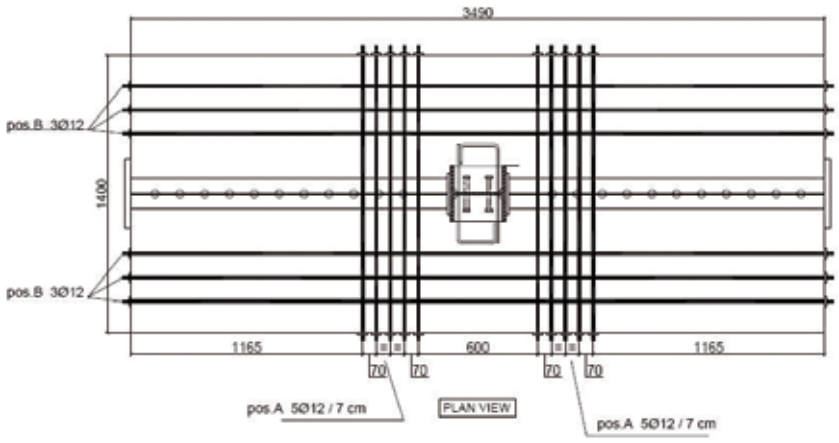

Figure 1: Plan view of the internal Type 1 specimen showing the reinforcement layout

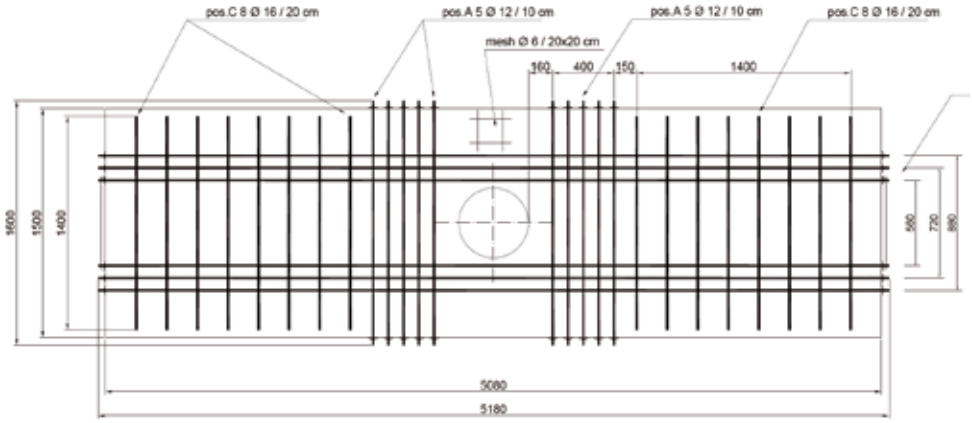

Figure 2: Plan view of the internal Type 2 specimen with profiled steel sheeting

***Table 1:* Summary of the experimental programme**

Test No.	Spec. ref.	Composite C/ Precast P	Internal I/ External E	Damage D/ Fire F test
Type 1 Specimens				
1	F15	P	I	D
2	F14	P	I	D
3	F12	C	I	D
4	F11	C	I	D
5	F16	P	E	D
6	F13	C	E	D
7	F15	P	I	F
8	F12	C	I	F
9	F11	C	I	F
10	F14	P	I	F
11	F16	P	E	F
12	F13	C	E	F
Type 2 Specimens				
13	T21	C	I	D
14	T23	C	E	D
15	T24	P	I	D
16	T26	P	E	D
17	T22	C	I	F
18	T25	P	I	F
19	T24	P	I	F
20	T21	C	I	F
21	T23	C	E	F
22	T26	P	E	F

CONCLUSIONS

As part of a collaborative European research project BRE has undertaken an extensive experimental programme to simulate the effects of a severe earthquake followed by a subsequent fire. The following conclusions can be drawn.

- All specimens tested are able to maintain the applied loading during the fire test for at least 30 minutes.
- In all cases, either no failure was observed for the duration of the test or a ductile failure mode was mobilised at large deflections.
- Design and detailing for seismic performance enhance the performance of the connection in fire. Dissipative zones (such as the web panel shear zone in the Type 1 connections) absorb the energy from a seismic event and allow for ductile behaviour at the fire limit state.
- Improved performance at the fire limit state may be achieved by specifying a bolt row within the depth of the slab to maintain shear capacity on heating.
- The precast slabs performed better in the fire tests than the corresponding composite specimens.
- The impact of damage from the seismic event on the performance of the connections in fire is minimal. The most significant impact would be the removal of applied passive fire protection.
- The research has shown that it is possible to evaluate the performance of structures subject to a combination

of accidental actions. Such a methodology may be applicable to other dynamic events such as fire performance following an explosion.

RESEARCH OUTPUT

A paper incorporating this work was presented at the *14th World Conference on Earthquake Engineering* held in Beijing, China, in October 2008.

More information about the findings of this research project is given in BRE *Information Paper* IP 2/09, *Structural composite connections for sequential seismic and fire performance*.

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THE EFFECTIVENESS OF FIRE TEST REQUIREMENTS FOR THIN FILM REACTIVE COATINGS FOR THE FIRE PROTECTION OF LOAD-BEARING STEEL COLUMNS

Norman Macdonald
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SUMMARY

The existing draft European test standard used to assess the fire performance of applied fire protection to load-bearing structural steel members is currently under review to turn it into a full test standard. The draft standard is referred to in national building regulations throughout Europe to ensure that the structure of buildings is safe against fire attack. This BRE Trust project aims to contribute to the development of this standard for reactive coatings by establishing whether there is a need to test a loaded vertical column following the testing of a loaded horizontal beam. Following a series of tests, this project concluded that it would be desirable to include the requirement to test loaded vertical column sections in the European test standard.

BACKGROUND

To ensure buildings are reasonably safe for their occupants and property is protected in the event of a fire, most buildings are divided into fire compartments and the load-bearing walls, floors, beams and columns are required to have a suitable level of fire resistance. In steel-framed buildings it is vital that the structural steel columns and beams are adequately protected against fire to provide adequate levels of fire resistance.

The use of structural steel to form the framework of a building can be an attractive alternative to concrete structures. Most steelwork in the UK is protected with fire protection paint, otherwise known as a reactive coating system, and the use of such coatings in other European countries is increasing. Reactive coatings expand (intumesce) to many times their original thickness to form an insulating carbon char when exposed to heat.

For life safety and property protection, it is important that the fire performance of any of these fire protection systems is properly assessed.

The existing European test standard for applied protection to steel members, DD ENV 13381-4: 2002, is a draft standard but is referred to in the guidance documents supporting the building regulations throughout the UK and in regulations in other European countries. The standard is currently being reviewed to turn it into a full test standard (EN 13381-8).

RESEARCH PROGRAMME

This BRE Trust project was designed to contribute to the development of the standard for reactive coatings. The main aim of the project was to confirm whether or not a loaded vertical column should be included in the test standard.

The objectives of this research were to:

- determine whether or not it is adequate to only fire test unloaded vertical columns, if a loaded horizontal beam has already been tested
- compare results of loaded sections with unloaded sections
- determine how close thermocouples have to be located to 'hot patches' in the steel.

RESULTS

A reactive coating system available in the market place was selected for the test programme. The same coating system was applied by the manufacturer to a number of vertical structural steel columns. The thickness of the coating on each column was the same. The coating system was expected to achieve about 60-minute fire resistance based on previous test results. Two columns were fire tested under load and four columns were fire tested unloaded.

The coating in all test specimens behaved in a very similar manner. On each section, the coating expanded to form a char about 100 mm thick. Unexpectedly, the first loaded 3 m column failed load-bearing capacity after

Figure 1: First loaded column. Note localised buckling of the steel in left-hand photo

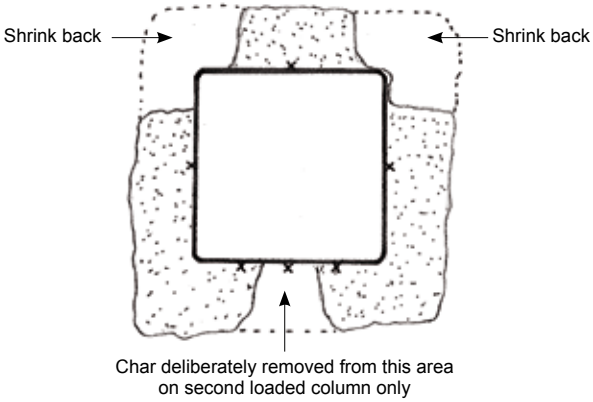

Figure 2: Charring pattern of coating on columns. Thermocouple positions are shown by an 'x'.

32 minutes. Photographs of the first loaded column are shown in Figure 1, the left hand photograph showing the localised buckling of the steel.

During the tests on all the sections it could be seen that the coating on each section shrank away from at least two corners of the column (see Figure 2).

To determine whether or not the number and location of the thermocouples used in the test standard to measure the temperature of the steel are adequate to detect hot-spots on the steel, a small area of the char in the second loaded column was deliberately removed after 30 minutes at mid height on one face (Figure 2).

If a protection system performs well and provides an even level of protection over the entire surface of the column, one would normally expect a hollow steel column to fail the load-bearing capacity performance criterion of the standard when the mean steel temperature is about 520 °C. However, if there are limited areas where the protection system falls off or shrinks, then the column may well collapse prematurely due to localised buckling at a hot-spot. At this time, the mean steel temperature will be lower than 520 °C. This was shown in the two loaded column tests in this project.

The test on the second loaded column demonstrated that when char is removed during the fire test, the locations of the thermocouples used in the test standard are inadequate to detect all the hot-spots on the steel caused by shrinkage or detachment of the coating.

If the results from the unloaded sections are analysed without considering the results from the loaded sections, the conclusion is that the coating system would ensure that the column had a fire resistance of 47 minutes. However, during the testing programme, the first loaded column was unable to bear the applied load (loadbearing capacity) after 32 minutes resulting in a fire resistance of only 32 minutes.

CONCLUSIONS

- The results from this work have shown that a loaded vertical column may be unable to bear the applied load at the times predicted using the test results of only unloaded sections.
- The temperature of hot-spots may not be detected by the thermocouples located at the positions required in the draft European test standard prEN 13381-8 so a test on a loaded column would be important.
- These tests have only been carried out on rectangular hollow sections, but they do suggest that similar results could be obtained from circular hollow sections and

I-sections. These findings confirm previous tests which also demonstrated that hollow sections can sometimes perform worse than similar I-sections because of their shape. It would therefore be advisable to ensure that the European test standard EN 13381-8 includes the requirement to test loaded vertical column sections of the different profiles as appropriate.

- The results from this work only relate to tests on one particular intumescent protection system for structural steelwork. However, they clearly show that the results obtained using the draft European standard have over-predicted the loadbearing capacity of the sections when based on testing of loaded beams and unloaded column sections only. The over-prediction of performance by 15 minutes is significant for a product designed to achieve 60-minute fire resistance. These results suggest that the adoption of prEN 13381-8 without the inclusion of a loaded column could have serious implications for the structural stability of buildings in fire.

RESEARCH OUTPUT

An article, *Intumescent coatings: fully loaded*, which discusses this work was published in *Fire Safety Engineering*, 14 October 2008.

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THE FIRE BEHAVIOUR OF GLASS AND ITS IMPLICATIONS FOR FIRE SAFETY ENGINEERING

Carl Sherwood, Danny Hopkin and David Charters

Fire and Security Group, BRE Global

SUMMARY

Most large and complex buildings are subject to fire engineering and one of the roles of a fire engineer is to optimise the fire strategy for a specific building. In many cases, this results in the replacement of high performance glazing systems with less expensive alternatives. As part of a coherent alternative fire engineering design solution this can be beneficial and provide an equivalent level of safety. This project provides information and guidance to designers, glass manufacturers and fire engineers on the:

- type of challenge that fire can present to glazing systems
- effect that glazing can have on the development of fire
- fire performance of different types of glazing system
- failure modes of different types of glass
- factors that affect the probability of failure.

BACKGROUND

Many of today's large complex buildings are subject to fire-engineered solutions, and one of the aims of the fire engineer is to optimise the fire strategy for a specific building. An increased knowledge of fire growth and smoke movement has led many fire engineers to specify more traditional and simpler forms of glazing, such as toughened glass for many atrium applications.

As part of a coherent alternative fire-engineering design solution this can be beneficial and acceptable. However, it is important to appreciate the nature of glazing and fire and in particular :

- fire performance of different types of glazing system
- the failure modes of different types of glass
- the factors that affect the probability of failure.

RESEARCH PROGRAMME

The objective of this project is to provide guidance to fire safety engineers, architects, building approvers and fire officers on the use of glass and glazing systems in the fire safety engineering of buildings.

Methodology

The project produced a guidance document using material collated from:

- a detailed review of the literature and analysis of different types of glass and glazing systems in fire (this included British Standard fire test results as well as the performance of glass in ad-hoc and experimental fires)
- knowledge of the way that architects would ideally like to use glass in design
- detailed understanding of the concepts and design methods used by fire engineers

Valuable advice was also provided by colleagues at the BRE Centre for Fire Safety Engineering at the University of Edinburgh on the review and the draft guidance document.

RESULTS

Effects of glazing (and its failure) on fire development, fire severity and smoke spread

Many practitioners believe that compartment fires and fires in atria subject the glazing system to the same or a similar time–temperature curve as the British Standard fire-resistance test curve. Fire modelling was undertaken for a range of compartments and fire growth rates so that they could be compared with the British Standard time–temperature curves.

Fire growth

In the early stages of a fire, the spread of flame depends on a range of factors including material factors (chemical and physical) and environmental factors. Therefore, the presence or failure of glazing is likely to have a relatively minor affect in the rate of fire growth.

If the fire continues to grow in size, the mass flow rate of volatilised fuel is likely to increase and so the fire will require increased oxygen for combustion. This oxygen is initially drawn from the air in the space of fire origin. As the fire grows it is also likely to draw air in through any openings or inlet vents.

Flash-over

If the air in the space of fire origin and/or the air drawn in through openings is sufficient, then the fire can become 'fuel controlled'. In some enclosures there may be sufficient fuel and ventilation for the fire to grow to the point where radiation from the hot smoke is sufficient to ignite all the combustible surfaces in an enclosure very rapidly: this phenomenon is known as flash-over.

Figures 1 to 3 show examples of the temperature–time curves in a range of enclosure sizes:

- *small:* 3 m high and 20 m² floor area
- *high:* 10 m high and 100 m² floor area
- *large area:* 4 m high and 250 m² floor area

for a range of fast, medium and slow fire growth rates.

The temperature–time curve for standard fire-resistance testing is included to show how much more severe it is than most pre-flash-over growing fires (with the possible exception of a fast fire (typical of a shop) in a small enclosure.

Initially, in some compartments, there may be insufficient ventilation opening for flash-over to occur.

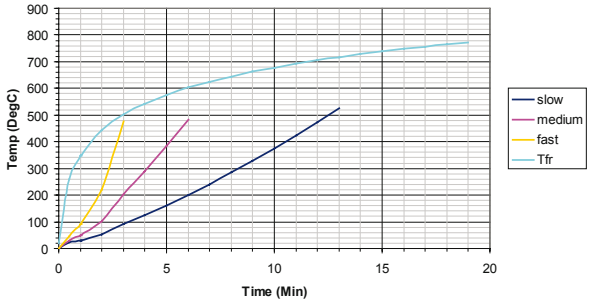

Figure 1: Time–temperature curves in a small space

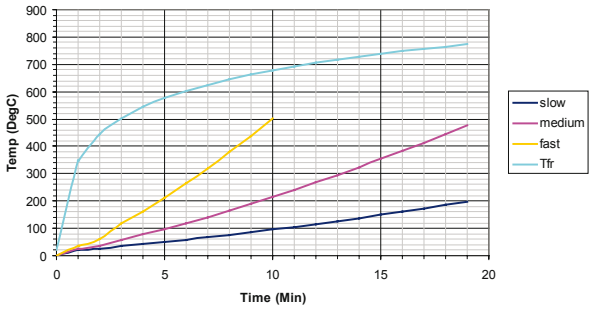

Figure 2: Time–temperature curves in a large area space

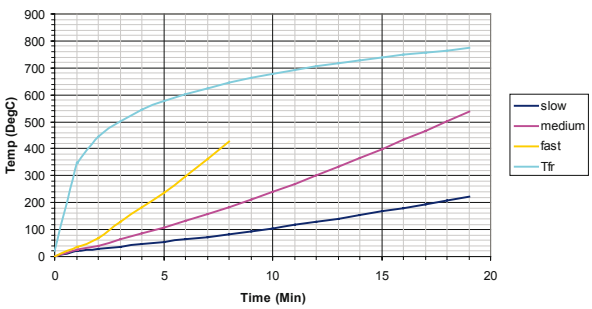

Figure 3: Time–temperature curves in a high space

However, if the temperature in the compartment increases sufficiently, this can increase the amount of ventilation available to the fire though the failure of the boundaries of the enclosure (including its glazing) such that flash-over can occur. Therefore, the performance of glass can be important to the prediction of flash-over.

Smoke spread

Irrespective of the dynamics of a fire in an enclosure, the presence or failure of glass can have a significant effect on the flow of smoke to spaces adjacent to the enclosure of fire origin, such as an atrium.

Figures 4 and 5 show examples of the temperature-time curves for an office atrium fire for a range of atrium heights. This analysis pessimistically assumes that the fire load on the atrium base is the same as adjacent areas, there is not suppression system and no heat loss from the atrium. Figure 4 shows the average temperature of the smoke in the atrium and Figure 5 shows the peak temperature of the smoke in the plume at that specific height.

The temperature–time curve for the standard fire resistance test is also included to show how much more severe it is than most atrium smoke temperature–time profiles.

Experimental observations and measurements of the behaviour of glass panels in fire

The project also reviewed a range of experimental studies. For example, we can see the result of the pane being under different states of stress in Hassani et al's initial observations; we notice the cracks initiate in the upper potion of the glazing and which do not propagate into the lower half for a considerable time. Strain gauges at the pane edges gave Hassani more information about

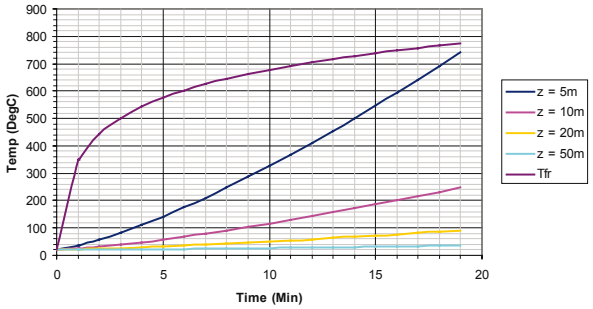

Figure 4: Office atrium plume temperatures

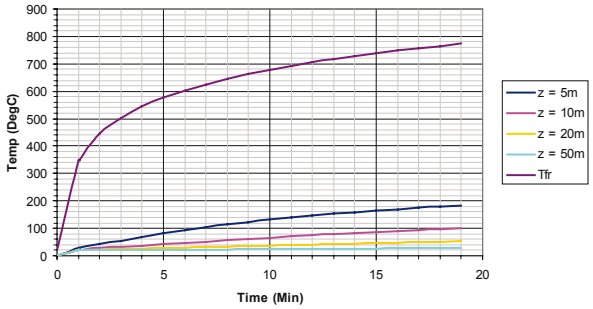

Figure 5: Office atrium average gas layer temperatures

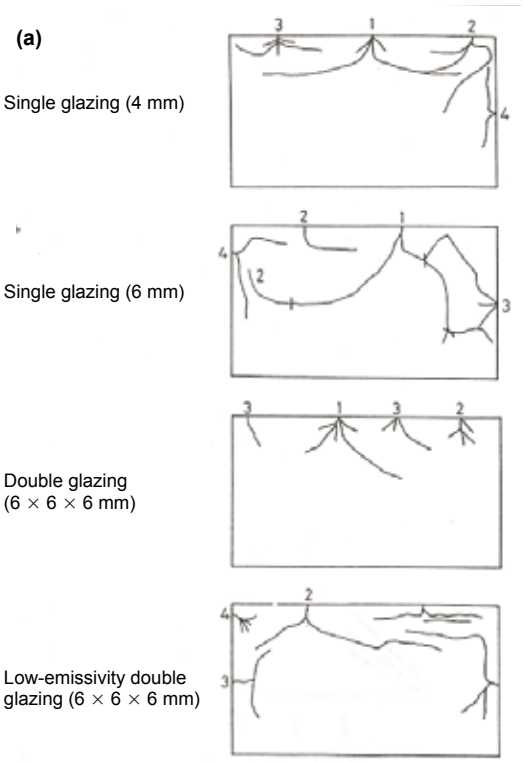

Figure 6: (a) Crack initiation sites and crack patterns in various glazing systems for normalised room construction [14], (b) Schematic stress field at the edge of window glass subjected to a descending hot gas layer (not scaled [14])

the thermally induced stress field. It was found that the lower edges of the pane were being put into a state of compression, and a complex stress field was prevailing through the pane as the hot–cold gas layer interface moved lower during the burn. It is suggested that this lends support to the view that glass cracks only occur in edges experiencing tension rather than compression.

In Hassani's experiments, the bifurication patterns created in the glazing types during the first 20 minutes did not lend itself to initiating fallout, in that cracks did not join to form an unbounded segment (Figure 6). The exceptions were the 6 mm single-glazed unit fitted in a lightweight structured enclosure and the 6 mm single-glazed unit in the normalised structure. Though in the latter the continuous bifurication route did not result in fallout, instead the segment remained in place. Hassani uses this to highlight that although bifurication is important in glazing fallout, it is not the only factor involved.

Thermal stress profiles within the glazing will be dependent on a number of factors which must be considered when attempting to predict edge stress and breaking. The compartment's temperature distribution (the hot and cold layer environment) is important, and as Hassani's tests found, is influenced largely by the thermal response of the enclosure with respect to the wall insulation and type of glazing itself. The siting of the glazing in relation to both the compartment and fire is important, and the degree of edge shielding to the pane.

CONCLUSIONS

The main conclusions of this study are as follows.

- Glazing systems are playing a increasingly significant role in the internal and external façades of large complex buildings.
- Glazing can have a significant influence on the development of a fire and the movement of smoke through its affects on:
  - fire growth rate by restricting/allowing ventilation in the room of fire origin
  - peak rate of heat release, eg is sufficient ventilation for flashover to occur?
  - fire severity and duration for a fully developed fire
  - smoke spread as part of compartmentation.
- These effects can have a significant impact on:
  - the available safe egress time (ASET) from the room of fire origin
  - whether a fully developed fire will occur
  - the stability of the building's structure
  - the extent and speed of spread of smoke within the building.
- The fire performance of glazing (and glazing systems) is usually measured in terms of standard fire resistance testing. That is, how long a glazing system will withstand a standard (fully developed fire) time–temperature curve in a standard furnace. This has several limitations in terms of fire safety engineering, including:
  - there is no indication of the fire performance on non-rated glazing systems
  - it gives little indication of the performance of glazing systems during the early stages of a fire

- standard fire-resistance ratings give little indication of the actual time to failure or the nature and extent of the failure and its mechanism(s),
- a single time–temperature curve does not represent the range of fire severities experienced in real fires.

There is relatively little full-scale experimental data on the behaviour of glass and glazing systems in scenarios representative of real fire. The majority of data is for small-scale experiments on single-pane float glass for which the mechanism of crack initiation is well understood. The concept of fallout, which is likely to be the governing criteria for both fire development and spread, is poorly understood and involves statistical probability-based analysis due to the glazing's brittle nature.

Important variables are far-ranging and are not always reported, these include glass composition, manufacture, quality (ie edge roughness), processing and after treatment, and installation. The failure of a glazing unit is likely to be situation-specific as external influences that cannot be controlled (such as damage during installation, workmanship defects) can have a major influence on behaviour.

There is relatively little research into double glazing (eg Shields et al has come to our notice). The models that exist to date are an extension of single-panel theory and basically work on the concept of some degree of radiant heat transfer to the second panel before failure of the first panes.

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FIRE RESEARCH TESTING WITH WATER MIST SYSTEMS FOR COMMERCIAL OFFICE BUILDINGS

Kelvin Annable

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SUMMARY

In the UK water mist systems are increasingly being used for the fire protection of buildings. However, systems designs vary widely and it may often be difficult for authorities having jurisdiction to determine the suitability of a system or otherwise for a particular risk. BRE Global have recently completed a three-year study investigating some of the parameters that affect the performance of a water mist system. The findings of the work will help those charged with assessing the acceptability of water mist system designs and those involved in developing British and international water mist standards.

BACKGROUND

In the UK water mist systems are increasingly being considered and used for the fire protection of buildings, including commercial premises and as an alternative to sprinkler systems. However, the impact of design variables in the application of such systems is often not well understood.

Water mist systems employ a spray of fine water droplets that can suppress a fire by cooling, wetting and displacing oxygen (by droplet conversion to steam). In a small compartment, such as a prison cell (3 m by 4 m and 3 m high) with a closed door, water mist has been shown to be very effective, both at suppressing the fire and improving tenable conditions. However, in larger spaces water mist may not be as effective because small water droplets are not contained in the vicinity of the burning fuel and air/fire dynamics can deflect droplets away from combustion gases. Hence, water mist system designs for larger spaces will often require greater water delivery rates and closer nozzle spacings.

For a water mist system to be accepted for use in a building it is necessary to undertake a full review of a particular system in the context that it will be used. One key part of this review is a requirement to demonstrate the systems effectiveness against fire performance tests that are appropriate to the real life application, because each water mist system is a bespoke system. Currently, there are only a very limited number of fire performance tests for different end use applications in the draft British Standard for commercial and industrial water mist systems.

A three-year experimental research programme to investigate the parameters that influence the performance of a water mist system has recently been completed. This work was commissioned by the BRE Trust and was supported by industry partners. The aim of the work was to investigate water mist system design parameters, investigate building/room parameters that influence suppression effectiveness and develop a fire performance test that could be applied to large open office areas.

RESEARCH PROGRAMME

Forty eight fire tests were conducted using low-pressure and high-pressure water mist systems. The commercial systems were provided by industry partners.

To assess the performance of water mist systems, three stages of experimental work were completed:

- parameter testing with crib fire tests
- development of a full-scale fire test protocol for open-plan office spaces
- testing with the full-scale fire test protocol for open-plan office spaces.

Tests were carried out under an open ceiling. Several compartment tests were also conducted.

Testing with the full-scale fire test protocol for open-plan office spaces

A series of tests were undertaken to assess the performance of industry provided water mist systems (both low- and high-pressure) and a sprinkler system against the BRE Global developed office fire test protocol. The test work was used to develop criteria for the determination of effective fire suppression.

RESULTS

All the systems, as a minimum, demonstrated temperature reduction at ceiling level and reduced fire damage, compared with the unsuppressed fire test. However, not all arrangements demonstrated effective fire suppression meeting the criteria for a successful test.

Figure 1: High-pressure water mist system in operation with BRE office fire test protocol

- A sprinkler and low-pressure water mist system (at 2.5 m by 2.5 m spacing) were successful.
- A low-pressure water mist system (3 m × 3 m spacing) was not successful.
- A high pressure water mist system (installed with various arrangements) was not successful.

CONCLUSIONS

Fire performance tests are necessary to demonstrate the effectiveness of a particular water mist system for specific end-use applications. In this work, the primary focus was on open-plan office areas.

BRE Global has developed a fire test protocol that can be employed for testing the effectiveness of water mist systems in this scenario. This stylised office fire test will be submitted to the relevant British Standards committee for their consideration to include as a new Part containing a fire test protocol for open-plan office areas in draft British Standard DD 8489.

Overall, the full-scale test results were of concern. Most water mist system arrangements were not able to provide expected levels of fire protection for the tested scenario (open-plan office areas with a high ceiling). Or, in terms of the design of the tested systems, the spacing between nozzles was too great and the quantity of water discharged too low, to provide effective fire suppression.

Critical for the successful operation of a water mist system is the system design details, in particular, nozzle type, nozzle spacing, water flow rate and building/room design details, in particular obstructions, ventilation, ceiling height, compartmentation and openings.

The general findings from this work are likely to be equally valid for other types of application and occupancy types. It is therefore advisable to always carry out fire performance tests to support the use of water mist systems in different applications.

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BRE CENTRE OF EXCELLENCE IN FIRE SAFETY ENGINEERING, UNIVERSITY OF EDINBURGH

Jose Torero

BRE Trust/RAEng Professor of Fire Safety Engineering

This year the Centre has celebrated its 5th anniversary with continuing growth and successes. The Centre's Director post, the BRE Trust/RAEng Professor of Fire Safety Engineering, was due to reach the end of its association with the Royal Academy of Engineering but given its recognized success has been extended for a further five years.

Research successes for 2009 resulted in the award of:

- the Best Knowledge Transfer Partnership in Scotland
- the Lord Ezra Award by the Combustion Engineering Association
- the publication of more than 20 peer-reviewed journal publications.

In November 2009 the Centre successfully organized the one-day 3rd Fire Seat symposium on the subject of *Fire & rescue in the 21st Century: How science and engineering support the fire service*. The symposium provided the occasion to deliver the Phillip Thomas H Medal to Dr Bjorn Karlsson, Head of the Icelandic Fire Authority and an eminent figure in Fire Safety Engineering.

The Centre graduated its first two PhD students funded by the BRE Trust:

- Dr Hong Liang for Development of an engineering methodology for thermal analysis of protected structural members in fire
- Dr Adam Cowlard for Sensor and model integration for the rapid prediction of concurrent flow flame spread.

It currently counts 28 other PhD students working in diverse areas of Fire Safety Engineering. The Centre has doubled its laboratory facilities adding to the Rushbrook Fire Engineering Laboratory a new state-of-the-art Structural Fire Engineering Laboratory in which the University has invested more than £300 000. This will expand the capabilities of the Centre to look into the behaviour of materials while simultaneously loaded and exposed to a fire. With the laboratory comes the recruitment of full-time technical support.

FIREGRID PROJECT

The main achievement of the year was the successful conclusion of the FireGRID project (www.firegrid.org). This project funded by the Technology Strategy Board brought together the efforts of BRE Global, the Centre and numerous industrial partners to develop a ground-breaking methodology to introduce information into fire emergency response.

The integration of sensors with computer models via a complex network of high-power computers and the GRID enables the super-real-time prediction of the evolution of a fire. The models are calibrated and accelerated with the sensors to generate predictions of the main variables associated with the fire. These predictions are delivered faster than the event. The information is digested by Artificial Intelligence Algorithms to provide an adequate and simple set of instructions that will enable Commanders to make a decision on the basis of direct information from the fire.

The project was completed with a large-scale demonstration in the Burn Hall at BRE where the FireGRID system was put to a test in the presence of the TSB Grant Manager and partners including the London Fire Brigade. The results were presented at a workshop in the presence of many of the industrial leaders and decision makers. FireGRID work continues through direct funding by the University of Edinburgh and through a Knowledge Transfer Partnership exploring applications of this methodology to the management of intelligent structures.

For further information on either of the projects that follow, contact Professor Jose Torero,
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SENSOR AND MODEL INTEGRATION FOR THE RAPID PREDICTION OF CONCURRENT FLOW FLAME SPREAD

Adam Cowlard

BRE Centre of Excellence in Fire Safety Engineering, University of Edinburgh

SUMMARY

This study aims to forecast fire growth by assimilating sensor data into fire models. It takes upward flame spread and develops a methodology for assimilating sensor data to calibrate a simple physical model that can predict fire spread faster than the event.

BACKGROUND

Fire safety engineering is required at every stage in the life-cycle of modern-day buildings. Fire safety design, detection and suppression, and emergency response are all vital components of structural fire safety but are usually perceived as independent issues. Sensor deployment and exploitation is now commonplace in modern buildings for means such as temperature, air quality and security management. Despite the potential wealth of information these sensors could afford fire fighters, the design of sensor networks within buildings is entirely detached from procedures associated with emergency management. The experiences of Dalmarnock Fire Test Two[1] showed that streams of raw data emerging from sensors lead to a rapid information overload and do little to improve the understanding of the complex phenomenon and likely future events during a real fire. Despite current sensor technology in other fields being far more advanced than that of fire, there is no justification for more complex and expensive sensors in this context. In isolation, therefore, sensors are not sufficient to aid emergency response.

Fire modelling follows a similar path. Two studies of Dalmarnock Fire Test One demonstrate clearly the current state-of-the-art of fire modelling. *A priori* studies by Rein et al[2] showed that blind prediction of the evolution of a compartment fire is currently beyond the state-of-the-art of fire modelling practice. *A posteriori* studies by Jahn et al[3] demonstrated that even with the provision of large quantities of sensor data, video footage and prior knowledge of the fire, producing a computational fluid dynamics (CFD) reconstruction was an incredibly difficult, laborious, intuitive and repetitive task. Issues of accuracy aside, these models demand heavy resources and computational time periods that are far greater than the time associated with the processes being simulated. To be of use to emergency responders, the output would need to be produced faster than the event itself with a lead time to enable planning of an intervention strategy. Therefore in isolation, model output is not robust or fast enough to be implemented in an emergency response scenario.

Fire fighting is therefore left as an isolated activity that does not benefit from sensor data or the potential of modelling the event. In isolation, sensors and fire modelling are found lacking. Together though, they appear to form the perfect complement. Sensors provide a plethora of information which lacks interpretation. Models provide a method of interpretation but lack the necessary information to make this output robust. Thus, a mechanism to achieve accurate, timely predictions by means of theoretical models steered by continuous calibration against sensor measurements is proposed.

RESEARCH PROGRAMME

The concept of super-real-time predictions steered by measurements is studied in the simple yet meaningful scenario of concurrent flow flame spread. Experiments have been conducted with poly (methyl) methacrylate slabs to feed sensor data into a simple analytical model. Numerous sensing techniques have been adapted to feed a simple algebraic expression from the literature linking flame spread, flame characteristics and pyrolysis evolution in order to model upward flame spread. The measurements are continuously fed to the computations so that projections of the flame spread velocity and flame characteristics can be established at each instant in time, ahead of the real flame. It was observed that as the input parameters in the analytical models were optimised to the scenario, rapid convergence between the evolving experiment and the predictions was attained.

Figure 1 shows the final stages of an upward flame spread experiment with the flow field around the flame being captured by a particle image velocimetry system.

Figure 1: Final stages of an upward flame spread experiment

RESULTS AND CONCLUSIONS

This work has demonstrated that prediction of concurrent flow flame spread and properties of the spreading flame can be performed accurately and rapidly (faster than the event itself) by using a combination of data from purpose-designed sensor techniques and 'simple' physical models that are representative of the processes being forecast. A methodology has been developed that performs this process using data from laboratory-scale experiments involving concurrent flow flame spread ignited from a single ignition source. As data was collected from the sensors, the predictions generated and the scenario-specific parameters optimised were seen to converge on accurate solutions. As the flame spread process evolved and the flame changed in nature, the output from the methodology re-converged to capture the new conditions and make fresh predictions based on them.

More globally, this work has demonstrated the potential for integrating modelling and sensing techniques to achieve rapid robust predictions of fire scenarios which would support fire fighters in mitigating an evolving fire emergency. Sensing techniques alone can provide huge quantities of data but lack appropriate interpretation. Models provide a method of interpretation but lack the information and data to make their output robust and reliable. Combining the two in the form of theoretical models steered by continuous calibration against sensor measurements will compensate for the deficiencies of the individual tools when used in isolation.

RESEARCH OUTPUT

Cowlard A, Auersperg L, Richon J-B, Rein G, Welch S, Usmani A & Torero J L. Sensor-driven prediction of upward flame spread. Turkish Journal of Engineering and Environmental Sciences 2007: 31: 403–413

Cowlard A, Jahn W, Abecassis Empis C, Rein G & Torero J L. Sensor-assisted fire fighting. Fire Technology: 2010 (in press)

REFERENCES

[1] Cowlard A, Steinhaus T, Abecassis-Empis C & Torero J L. Test Two: The 'controlled fire' (Chapter 4). In: Rein G, Abecassis-Empis C & Carvel R (eds) The Dalmarnock Fire Tests: experiments and modelling. Edinburgh, University of Edinburgh, 2007

[2] Rein G, Torero J L, Jahn W, Stern-Gottfried J et al. Round-robin study of a priori modelling predictions of the Dalmarnock Fire Test One. Fire Safety Journal 44 (4): 2009: 590–602

[3] Jahn W, Rein G & Torero JL. The effect of model parameters on the simulation of fire dynamics. Fire Safety Science, Proceedings of the 9th International Symposium, 2008, pp 1341–1352

DEVELOPMENT OF AN ENGINEERING METHODOLOGY FOR THERMAL ANALYSIS OF PROTECTED STRUCTURAL MEMBERS IN FIRE

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SUMMARY

A novel methodology has been developed to compute the evolution of steel temperatures in a fire. This methodology is based on a computationally efficient transfer of information from a three-dimensional field fire model to a structure. The efficiency is gained by making adequate simplifications on the way the structure is defined. Validation using fire resistance tests showed that the methodology can adequately predict the temperature of steel structural elements.

BACKGROUND

The ability to predict the temperatures in protected steel structures is of vital importance for the progress of fire safety engineering. Existing methods are limited in several respects, typically being computationally restricted and limited to examination of the performance of specific components. This project investigates a generalised computational fluid dynamics (CFD)-based methodology for thermal analysis of structural members in fire, developed to overcome these limitations.

RESEARCH PROGRAMME

A novel methodology has been developed, known as GeniSTELA (Generalised Solid ThErmal Analysis), which computes a 'steel temperature field' parameter in each computational cell. The approach is based on a simplified 1D model for heat transfer, together with appropriate corrections for 2D and 3D effects, to provide a quasi- 3D solution with a reasonable computational cost (Figure 1a). It accommodates both uncertainties in the input parameters, such as member emissivities, and possible variants to the specification (eg member size and protection material properties) by means of many simultaneous thermal calculations. A framework for the inclusion of temperature/time-dependent thermal properties (including the effects of moisture and intumescence) were established. Indicative values of intumescent material properties have been obtained by means of cone calorimeter testing. These are dependent on initial thickness and exposure heat flux. The corrections for 2D and 3D effects are based on simple physical considerations associated with different scenarios. Four cases where the precise nature of localised heating is important are treated in the quasi-3D model (Figure 1b):

- junction effect
- end effect
- heat sink effect
- axial temperature gradient.

By predicting temperature of 'virtual members' at every point in the computational domain, a fundamental limitation of existing methods is bypassed, and by performing simultaneous calculations which span the

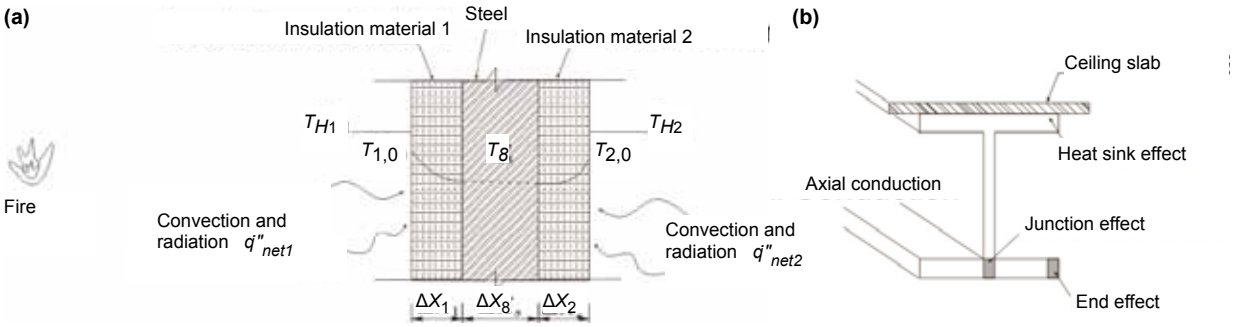

Figure 1: Schematics of the simplified heat transfer analysis

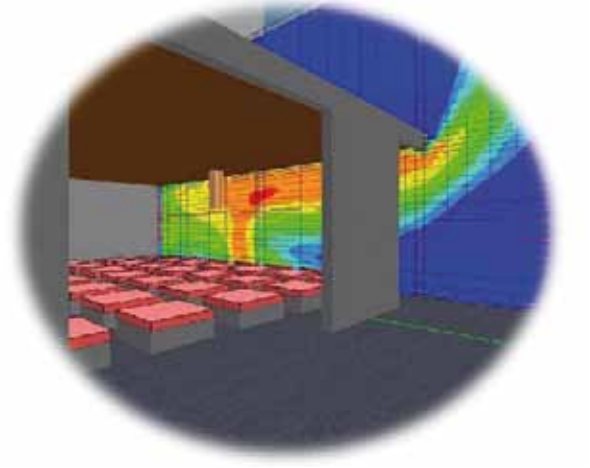

Figure 2: Numerical simulation of a compartment fire using wood cribs as a fuel source. A structural element is embedded in the fire

range of cases of possible interest, to provide a library of relevant solutions for any given fire scenario, the generality of the results is greatly increased.

GeniSTELA has been implemented as a submodel within the SOFIE RANS CFD code. The basic operation of the model has been verified and results compared with the empirical methods in Euro Code 3 (EC3), indicating a satisfactory performance. The role of the surface temperature prediction has been examined and demonstrated to be important for certain cases, justifying its inclusion in the generalised method. The models for 3D corrections have been verified and their significance assessed. The computational requirements are addressed considering a number of aspects such as the number of simultaneous parametric cases, the required frequency of GeniSTELA steel temperature field computation and, hence, the overall balance between fluid and solid-phase analysis. These confirm the practical utility of the tool in simultaneously running a large number of parametric variants.

Validation of the model is undertaken with respect to standard testing in fire resistance furnaces, examining the fire ratings of different practical protection systems, and the BRE large compartment fire tests (Figure 2), which looked at protected steel indicatives in full-scale post-flashover fires; in both cases, a satisfactory agreement is achieved. Model sensitivities are reported which reveal the expected strong dependencies on certain properties of thermal protection materials (Figure 3).

The intended operation of the generalised model is demonstrated in application to test scenarios, such as the hypothetical benchmark test scenario, with simultaneous computation of 72 parametric variants. The methodology is confirmed as a comprehensive, but practical, tool for structural fire design, providing far more flexibility in assessing the thermal response of steel structures to fire than has been available hitherto, with potential to improve the efficiency and safety of the relevant constructions.

Recommendations for further development required to consider a generalised structural response are:

- analysis of the importance of geometrical detailing in the predictions of the model
- benchmarking of the output of the CFD model
- large-scale experimentation for validation and verification purposes.

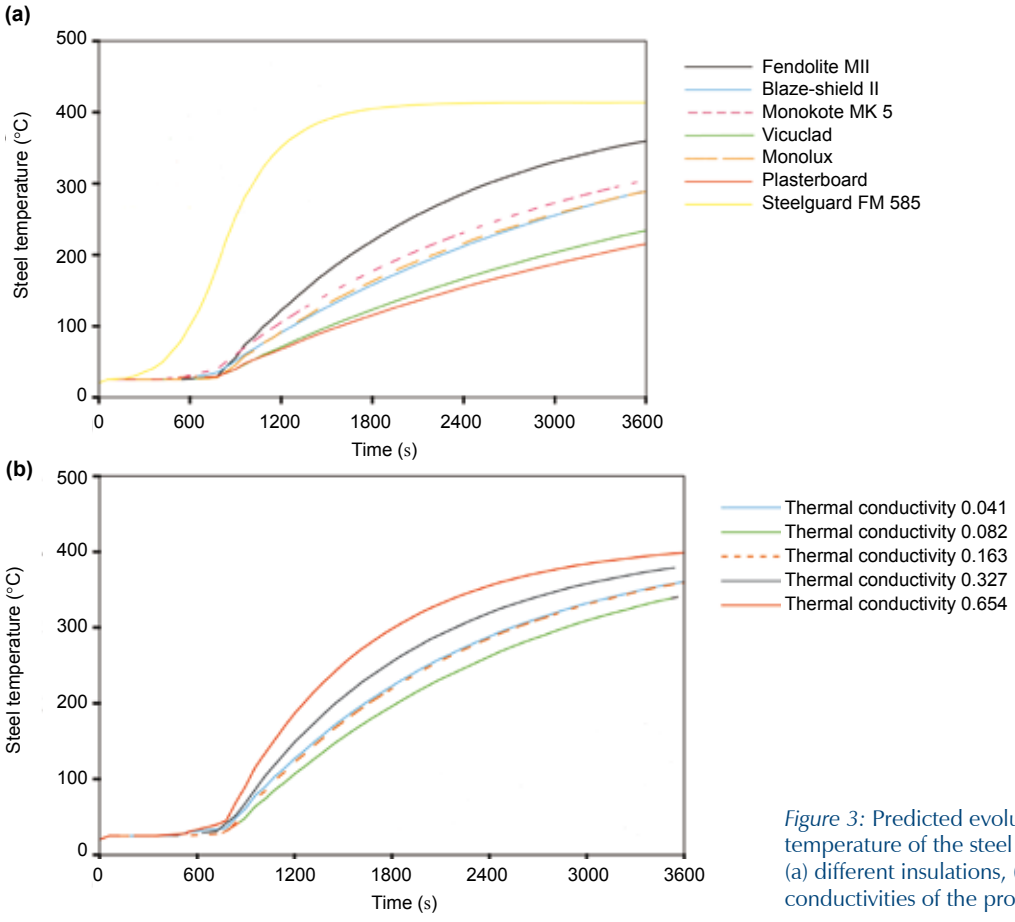

Figure 3: Predicted evolution of the temperature of the steel structural element for (a) different insulations, (b) different thermal conductivities of the protective layer

SUSTAINABILITY AND ENERGY USE

LESSONS LEARNT FROM APPLYING THE CODE FOR SUSTAINABLE HOMES ON THE BRE INNOVATION PARK

Christopher Gaze
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SUMMARY

When the Code for Sustainable Homes was published in 2006, four construction companies (ecoTECH, Hanson, Stewart Milne Group and Kingspan Offsite) undertook a challenge to design and build a Code-compliant house on the BRE Innovation Park. The lessons learnt by all parties during the process are significant.

BACKGROUND

Four houses built for the BRE Offsite07 exhibition in June 2007, just after the launch of the Code for Sustainable Homes[1] in Autumn 2006, were studied during construction. These were:

- the EcoTECH Organics™ Swedish closed panel timber frame house
- the Hanson factory-assembled panelised masonry EcoHouse™
- the Stewart Milne Group's closed panel timber frame Sigma® Home
- the Kingspan Offsite SIPs panel Lighthouse™.

The four houses are shown in Figure 1.

The results of reviewing the experience of the four constructors were published in 2008 in a four-part BRE *Information Paper* (IP 9/08). These *Information Papers* were not a last word on the Code (that is yet to be written) but they were a 'first word', highlighting some of the difficulties encountered and acting as an indicator for what the rest of the industry would have to do to meet the Code and future Building Regulations.

The four-part *Information Paper* covered the lessons learnt in the following areas:

- building fabric
- energy sources, overheating and ventilation
- water use, harvesting, recycling and drainage
- architecture, construction and material sourcing.

In 2010 these four Papers were combined into a single and updated publication, *Complying with the Code for Sustainable Homes: Lessons Learnt from the BRE Innovation Park*[2], to bring the material to a wider audience.

LESSONS LEARNT ABOUT BUILDING FABRIC

Traditionally, building fabrics have been specified for their U-value performance and sometimes their sustainability (or *Green Guide* rating[3]). However, for these sorts of houses other issues must also be taken into account: airtightness, thermal bridging, daylighting, solar gain and Secured by Design approval.

Good airtightness can be difficult to obtain and must be planned for in advance. If the team building the house has no previous experience, a good starting assumption would be 5 $m^3/h.m^2$@50Pa but even at this level site contractors and supervisors will need to be well briefed on jointing and integrity and what the check points will be. One such check point that is highly recommended is to test the building once primary airtightness has been achieved so that any remedial work can be carried out before further construction takes place. Simple house designs using large panels (with less joints) are easier to make airtight. The joints should be gasketed or taped, rather then relying on mastic or foam. And the whole house should be designed to have a robust primary air barrier including the floor zones within it.

Thermal bridging bypasses and cold spots, especially between each of the fabric elements and around windows and doors deserve special attention. For high performance applications consideration should be given to using window and door frames that incorporate a thermal break.

LESSONS LEARNT ABOUT ENERGY SOURCES, OVERHEATING AND VENTILATION

Energy

When designing developments one of the early questions needs to be whether renewables will be communal or micro (ie based on an individual dwelling). Renewables

Figure 1: (a) EcoTECH Organics™ house, (b) Hanson EcoHouse™, (c) Stewart Milne Group's Sigma® Home, (d) Kingspan Offsite's Lighthouse™

such as wind turbines, biomass boilers and CHP lend themselves to being communal.

If the micro-generation of electricity is chosen, photovoltaic panels are likely to be the most appropriate system to be adopted. Whereas micro-wind turbines are often ineffective in suburban and urban locations.

For the production of heat and/or hot water, gas boilers are still capable of giving good results up to Code level 5, although for low-energy housing most boilers will end up being oversized (though this will not normally affect their efficiency). Heat pumps may offer low-energy heating water provision but they need to be matched to appropriate building types and heating strategies. Solar thermal panels are a relatively cost-effective and popular source of energy and can be used to supplement many other systems. Whatever system is used, care must be taken to keep it simple for installation, maintenance and use.

Minimising overheating

Appropriate ventilation, shading and thermal mass can minimise overheating. Shading can be improved through external shutters, balconies and canopies. Thermal mass can be increased by using additional heavy panels, tiles and plaster skim onto blockwork. Consideration should be given to placing bedrooms downstairs.

Secure natural ventilation can be improved by the use of lanterns or louvered and meshed ventilation panels in windows. However, special care must be given to the specification and installation of lanterns.

Mechanical ventilation and heat recovery

When MVHR systems are specified it is important to look for an efficient one in SAP Appendix Q[4] and to install them in accordance with the Appendix Q checklist and the manufacturer's instructions if they are to work efficiently. As part of this, it is important that enough space has been allowed in floor and wall zones for the ducting. It is so important to get ductwork right that it may be worthwhile considering having it pre-fabricated offsite.

LESSONS LEARNT ABOUT WATER USE, HARVESTING, RECYCLING AND DRAINAGE

Minimising water use

Minimising water use is the best place to start when considering the Code through such things as aerated showers or low-water-use white goods that can be found on the Waterwise web site[5]. It is important that low-water-use systems are designed and risk assessed to check that they will not be potential environments for legionella and other similar bacteria.

Rainwater harvesting and greywater recycling

Rainwater from roofs needs to be taken directly to storage tanks without using open or grated gullies and all collection surfaces must be colourfast, non-rusting and free draining. Care must be taken to make sure that if the water is to be used in the washing machine then this is permitted by the manufacturer.

If greywater recycling is to be used, consideration should be given to using a communal system maintained by an outside contractor. There are however systems coming onto the market that offer single dwelling solutions. Whichever is specified greywater should never be taken from sinks.

Design maintenance

When installing systems provision needs to be made to allow space for the routing of pipes and the appliances and terminal fittings will need to be isolated individually and be accessible for maintenance.

LESSONS LEARNT ABOUT ARCHITECTURE, CONSTRUCTION AND MATERIAL SOURCING

When planning for daylighting putting kitchen and living areas upstairs can help. Rooflights are particularly effective for daylighting, but they will impact heat loss (and solar gain) for the dwelling.

The Robust Details web site[6] is a good source of information on separating wall and floor sound performance.

Low-energy white goods and lighting are becoming more easily available and more cost effective. Help with finding low-energy fittings can be found at the Lighting Association's web site[7].

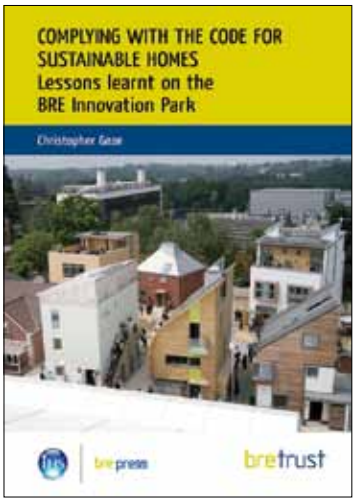
When specifying materials, chain of custody information should be obtained before orders are in place. When timber is specified for external use care should be taken to avoid staining surrounding surfaces.

RESEARCH OUTPUT

A BRE Trust report (FB 20), *Complying with the Code for Sustainable Homes*[2], draws together the practical experience of building innovative new homes on the BRE Innovation Park, and identifies key practical lessons for developers and housebuilders.

The report gives:

- valuable tips about achieving Code credits and attaining Code levels 3-6
- insight into this unique project on the BRE Innovation Park
- more than 60 photographs of the houses during and after construction



REFERENCES

[1] Communities and Local Government (CLG). The Code for Sustainable Homes: Setting the sustainability standards for new homes. 2008. Available as a pdf from www.communities.gov.uk/thecode

[2] Gaze C. Complying with the Code for Sustainable Homes: Lessons learnt from the BRE Innovation Park. FB 20. Bracknell, IHS BRE Press, 2009

[3] Anderson J, Shiers D & Steele K. The Green Guide to Specification. 4th edition. BRE Report BR 501. Bracknell, IHS BRE Press, 2009

[4] BRE. SAP 2005. [The Government's Standard Assessment Procedure for Energy Rating of Dwellings.] Available as pdf and software. www.bre.co.uk/sap2005 and www.sap-appendixq.org.uk

[5] www.waterwise.org.uk

[6] www.robustdetails.com

[7] www.lightingassociation.com

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RECOMMENDATIONS FOR DETAILED ENERGY PAYBACK RESEARCH FOR RENEWABLE ENERGY TECHNOLOGIES

Robin Wiltshire

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SUMMARY

This scoping study recommends that research on energy payback analysis focuses on deriving generic values for key renewable technologies: photovoltaics, solar thermal and wind energy.

BACKGROUND

The current and potential future impact of global warming, together with declining resources has led to emphasis being placed on carbon emission and primary energy factors. To do this comprehensively, it is important that embodied energy (principally that expended during manufacture) is included. However, the embodied energy during the manufacture of renewable energy equipment and in the equipment's subsequent installation, operation, maintenance and decommissioning is often overlooked.

RESEARCH PROGRAMME

This project examines the embodied energy issue by focusing on energy payback for renewable energy technologies. The purpose of this project is to set out recommendations for further work on energy payback.

In making these recommendations it is recognised that figures for energy payback are intrinsically case-specific. Product-specific considerations arise because the source of materials used and the nature of the process determine the energy consumed during manufacture. Payback times are actually site-specific because they depend on how quickly energy is gathered which in turn depends on location and quality of installation. It is, of course, not practical to expect authoritative figures for every circumstance, unless some obligation is placed on suppliers and/or installers to produce a figure for every installation.

However, the paucity of energy payback data means an important aspect of energy performance is often overlooked. Therefore, it is recommended that generic values should be derived for a number of key technologies. Inevitably, this will involve a number of assumptions that will be open to debate, but such an exercise would be of considerable benefit to our understanding of the overall environmental benefit of these technologies.

CONCLUSIONS

This scoping study has led to the following prioritised observations and accompanying recommendations for detailed work on energy payback.

- *Photovoltaics* (PV). There has been a significant amount of work carried out already. However, PV embraces several distinct technologies that will have quite different energy paybacks. It is therefore recommended that generic cases should be examined for each of these technologies. This is a high priority.
- *Solar thermal*. There is very little energy payback information for solar thermal, so for each generic technology type energy payback estimates should be carried out. This is a high priority.
- *Wind energy.* Some valuable work has already been done on wind energy but it does not comprehensively address all available types of wind generator and is limited in relevance by location. This is a medium-level priority.

In each case it is recommended that further work on energy payback analysis focuses on generic types with additional attention to key process issues (eg for PV the energy impact of melting silicon).

Such generic energy payback studies should preferably be accompanied by some observations on carbon payback. Important as such data would be, it should nevertheless be noted that this involves more difficult estimates than for energy payback because of the need to assume the carbon imprint of the delivered process energy.

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REGULATIONS AND DIRECTIVES LIKELY TO AFFECT THE ADOPTION OF INTELLIGENT BUILDING SYSTEMS

John Holden
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SUMMARY
This project reviewed the wide range of regulations and directives affecting, or likely to affect, intelligent buildings. Its objective was to identify those that could have an (inadvertent) adverse impact on the installation of intelligent building systems.

BACKGROUND
Some legislation applicable to buildings may inadvertently present barriers to the uptake of intelligent building systems. Therefore, traditional buildings systems that have previously been found to meet the relevant regulations and directives may be chosen in preference to potentially superior intelligent building systems. There is a need for the development of training and certification schemes for installers of intelligent building systems.

This project sought to review the wide range of regulations and directives affecting, or likely to affect, intelligent buildings and to identify those that could have an (inadvertent) adverse influence on their implementation. The requirements of the relevant legislation would be assessed and their potential impact on the uptake of intelligent buildings established.

RESEARCH PROGRAMME
Relevant regulations and directives were identified by reviewing publications (on web sites and in the trade press) from government departments responsible for legislation and by consulting with BRE colleagues and industry contacts.

Regulations and Directives affecting buildings
Intelligent buildings have the potential to provide many benefits to both owners and users. These include cost and energy savings during construction and throughout the life cycle of the building. They can also provide additional functions such as enabling the health service to care for patients more effectively in their own homes. In addition, the superior monitoring and control made possible through integrated systems facilitates compliance with certain legislative requirements.

There are many such regulations and directives that require compliance by intelligent building systems. While these apply equally to traditional building systems intelligent building systems may face barriers

Figure 1: Wembley Stadium is an example of an intelligent building
Courtesy of Quintain Estates and Developments plc

to implementation due to unforeseen and unintended consequences of this legislation. For example the Energy Performance of Buildings Directive requires the periodic physical inspection of boilers, this could undermine the benefit of an intelligent building system which monitors boiler efficiency and performance remotely on a continuous basis thereby identifying faults before any physical inspection.

Hence, when ensuring that legislative requirements are met, there is a temptation for those responsible for the selection and procurement of building systems to continue to use the tried and trusted products that they have used in the past in preference to less familiar, but possibly more effective, intelligent building systems. To overcome this potential barrier, independently verified information on the benefits made possible through the use of intelligent building systems should be made available. Stakeholder confidence, and the reputation of the intelligent building industry as a whole, could

Figure 2: The INTEGER House at BRE's Garston site which is an early example of an intelligent dwelling

also be improved through the appropriate training and certification of systems installers. In addition, the potential for intelligent systems to enhance the environmental credentials of buildings should be included in industry-leading environmental assessment tools such as BREEAM.

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RESEARCH OUTPUT

A two-part BRE *Information Paper* IP 11/08, *An introduction to intelligent buildings,* was published in December 2008.

ARE BUILDING USERS SABOTAGING THE MOVE TO LOW-CARBON BUILDINGS?

Mindy Hadi and Chloe Halfhide

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SUMMARY

With the advent of new technologies, buildings are becoming increasingly complex to operate both for the facilities professional and the end user. Designers of building systems and controls are not always aware of the impact of their decisions on the occupant. The findings of this research show that if users are uncomfortable they will adapt the building to meet their needs, even if this increases energy wastage and compromises safety.

BACKGROUND

New regulations and a drive to reduce energy bills and carbon emissions have meant that new buildings are being designed to be as energy efficient as possible and many use advanced, innovative technical systems to heat, cool and light the building. However, it has frequently been found that these new buildings are not meeting their proposed energy use targets.

On visits to schools, universities and other new buildings, BRE consultants observed that occupants frequently do not use the building as it was designed, and, in some cases, are inadvertently preventing the systems from working properly. It is thought that one of the main reasons for this is that the end users of the building do not understand the systems installed and do not know how to use the technologies. In fact, research has shown that building users frequently behave in ways that actually increase energy use above that expected, and that, occupant behaviour is a key determinant of energy consumption. Also, in many cases designers are not gving adequate consideration to occupant behaviour in the design of environmental systems and controls.

RESEARCH PROGRAMME

The objective of this BRE project was to outline and assess occupant behaviours that impact on the energy efficiency of buildings. This was achieved through a review of past research in this area and case studies carried out in eight buildings from a variety of sectors and regions over a 12-month period in 2008–2009. The buildings were selected based on their energy-efficient and sustainable design. The case studies investigated:

- the ways in which occupants actually use their buildings,
- whether they are used as they were designed to be used,
- the reasons why they are not used as they were designed to be used.

Each case study visit comprised interviews with the architect, building services engineer and FM of each building as well as focus groups with occupants and an observational walk-through.

The findings have been published as a BRE report (FB 21), *The move to low carbon design: are designers taking the needs of building users into account?* This guide for building designers, operators and users provides targeted recommendations for designers, facilities managers and building users as to how negative behaviours can be avoided and their impact reduced.

RESULTS

Lighting

All the buildings visited had been designed with energy-efficient, automatic lighting. However, in the majority of cases occupants had either experienced difficulties with controlling the lighting or were exhibiting inefficient behaviours, for example ‘blinds down, lights on’ scenario.

Temperature

In many of the buildings visited occupants were dissatisfied in some way with the temperature levels, resulting in the provision of additional back-up heating and cooling devices (fans, heaters, etc.). The location, quantity and operation of temperature sensors appears to be the overriding cause of temperature problems, exacerbated by lack of occupant or even facilities management control and understanding.

Ventilation

More often than not, occupants exhibited behaviours to increase ventilation, such as propping doors open with other furniture as they felt the building was too stuffy.

Water

Occupants generally had a good understanding of how to use and operate low-water-consumption sanitary fittings,

usually through personal experience or provision of information. However, this was not always the case and in one building visited a lack of clear instructions on the use of the dual-flush toilet had led to a number of blockages.

Provision of information

A recurring theme throughout the visits was the lack of information communicated to occupants about the technologies and systems installed. In one case, in particular, occupants were using the energy-intensive mechanical ventilation system rather than using the high-level opening windows and large opening doors which formed the natural ventilation strategy.

CONCLUSIONS

- Keep the design simple. Automation is not always the answer
- Give occupants control, or at least facilities management personnel
- Ensure systems are fully commissioned and operational before handover
- Ensure adequate and appropriate training for all building occupants. It is important that occupants understand not just how to control the building but why they are being asked to control it in a specific way that might be counter-intuitive.
- Carry out regular post-occupancy evaluation (POE) assessments with particular emphasis on end-user behaviour to check building performance in use.

RESEARCH OUTPUT

More information about the findings of this research project is given in a BRE Trust report (FB 21), *The move to low-carbon design: are designers taking the needs of building users into account?* The guide provides targeted recommendations for designers, facilities managers and building users, showing how negative behaviours can be avoided and their impact reduced.

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ZERO- AND LOW-CARBON NEW BUILD VERSUS UPGRADING EXISTING BUILDING STOCK
Costs and carbon savings

Christine Pout and Fiona MacKenzie
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SUMMARY
The UK Government has set a challenging target for reduction of greenhouse gases in which improving the energy efficiency of buildings will play a vital role. This project investigates whether improving energy efficiency and reducing carbon dioxide emissions of existing buildings can be done more cost effectively than constructing new buildings to the higher levels of energy performance needed to meet low- and zero-carbon targets.

BACKGROUND
The UK Government has stated its aim to reduce greenhouse gas emissions by 80% on 1990 levels by 2050. Carbon dioxide emissions from UK buildings accounted for 226 $MtCO_2$ in 2006 (approximately 40% of the total emissions in the UK, which amounted to 555 $MtCO_2$). Reducing carbon emissions from buildings will clearly need to play a key role if the Government's 80% target is to be met.

The Code for Sustainable Homes[1] was launched in April 2007 and provides a single national standard aimed at driving continuous improvement in the building of sustainable homes. While moving towards zero carbon for all new buildings can undoubtedly achieve a significant reduction in carbon dioxide emissions in the future, existing buildings will form the majority of the UK's building stock for many years to come. This is particularly true for housing, which accounts for around two-thirds of UK building emissions (Figure 1).

RESEARCH PROGRAMME
This project used existing data to explore the extent to which improving the energy efficiency of the existing UK building stock, both domestic and non-domestic, would be a more cost-effective route for achieving carbon dioxide savings than constructing new buildings to the higher levels of energy performance required to meet low- and zero-carbon targets.

RESULTS
This study indicates that, for the domestic sector, constructing new dwellings to Code level 2 and above is not yet a cost-effective means of reducing carbon emissions. However, constructing to level 5 of the Code is slightly more attractive, in terms of the cost per tonne of carbon dioxide saved, than constructing to levels 3 and 4, although it would not save quite as much carbon as a move to level 6 (saving of 23 million tonnes pa).

For the non-domestic sector, the results indicate that although none of the low-carbon new-build levels

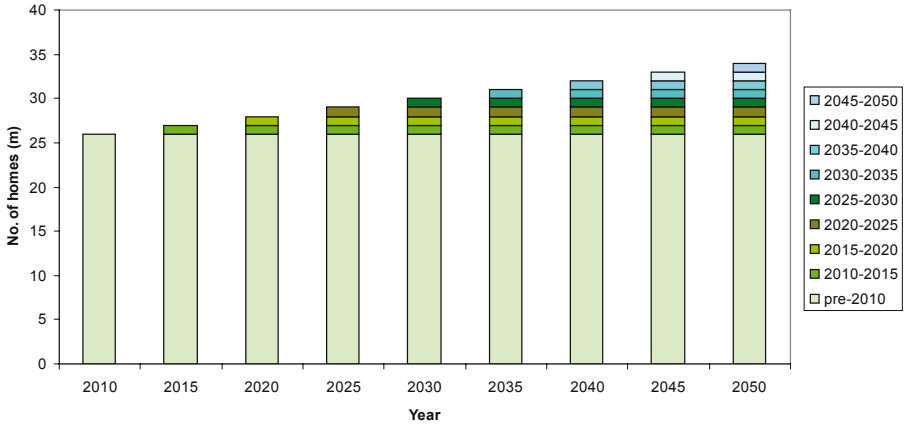

Figure 1: Age profile for domestic building stock

considered here* are cost effective, level 4 predictably has the greatest carbon savings (20 million tonnes pa). However, these savings are extremely non-cost-effective and the least cost-ineffective option (in terms of the cost per tonne of carbon saved) is level 3 rather than level 1 or 2.

In contrast to new build, the cost-effective potential for carbon savings in the UK building stock is very much greater at 96 million tonnes of CO_2 pa, the vast majority of which is in the domestic sector. Therefore, in terms of a conventional economic assessment, the results indicate that there are much more significant and more cost-effective carbon savings to be obtained by improving the existing building stock.

The costs per tonne of carbon saved and the total carbon saving that can be achieved are compared on a marginal cost abatement curve. Figure 2 shows data for non-domestic buildings and clearly demonstrates the higher relative cost of saving carbon (as a net annual cost per tonne of CO_2 saved) for different levels of low-carbon new-build compared with the potential for carbon savings that could be achieved through a range of refurbishment measures across the existing building stock where each block in the chart represents a different measure (eg increase level of roof insulation, install more energy-efficient lighting, etc.).

However, implementing cost-effective refurbishment of the building stock will not, on its own, be enough to achieve the 80% reduction target for buildings. It will also be necessary to move rapidly towards a requirement for low- and zero-carbon new buildings. Even with full implementation of both low- and zero-carbon new build and comprehensive refurbishment of the existing building stock there will be a shortfall of 50 million tonnes of carbon dioxide per annum (Figures 3 and 4) which would need to be addressed by other means such as decarbonisation of the electricity grid.

CONCLUSIONS

The Committee on Climate Change[2] and the most recent Government white paper[3] recognises several options and approaches for reducing carbon dioxide emissions, including energy efficiency improvements in buildings and industry, decarbonisation of the power sector, transport sector emissions cuts, heat sector decarbonisation and decarbonisation of industry. Because some of these approaches are still in the early stages of development (carbon capture and storage associated with power production from fossil fuels, for example, has not yet reached demonstration stage[4]), it appears even more vital to push forward improvements in both existing and new buildings as part of the overall solution to achieving an 80% reduction in emissions by 2050, particularly as other sectors may face greater challenges.

It should be remembered that this research project only represents one view of the future and the reality could be very different, and there are practical reasons why it might be necessary to build to intermediate levels of low-carbon new-build in the short term. Further research is recommended to:

- explore the embodied carbon associated with the construction of buildings and installed technologies
- assess the social cost of avoided carbon.

RESEARCH OUTPUT

More information about the findings of this research project will be published in a BRE Trust report, *Energy efficiency in new and existing buildings: comparative costs and CO_2 savings* in Spring 2010.

* As there is no equivalent Code for non-domestic buildings, four levels were defined for the purposes of this analysis and it was assumed that non-domestic buildings would not be expected to reach zero unregulated carbon (as opposed to the domestic sector for which level 6 represents zero regulated and unregulated carbon).

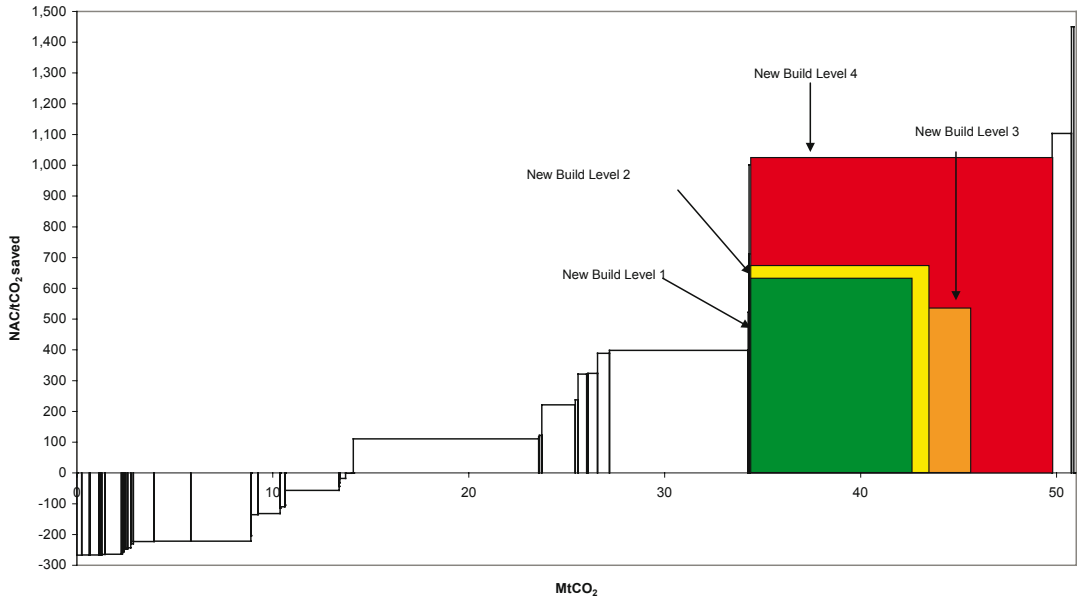

Figure 2: Cost effectiveness of carbon dioxide emission savings in non-domestic existing stock (new-build levels are also shown)

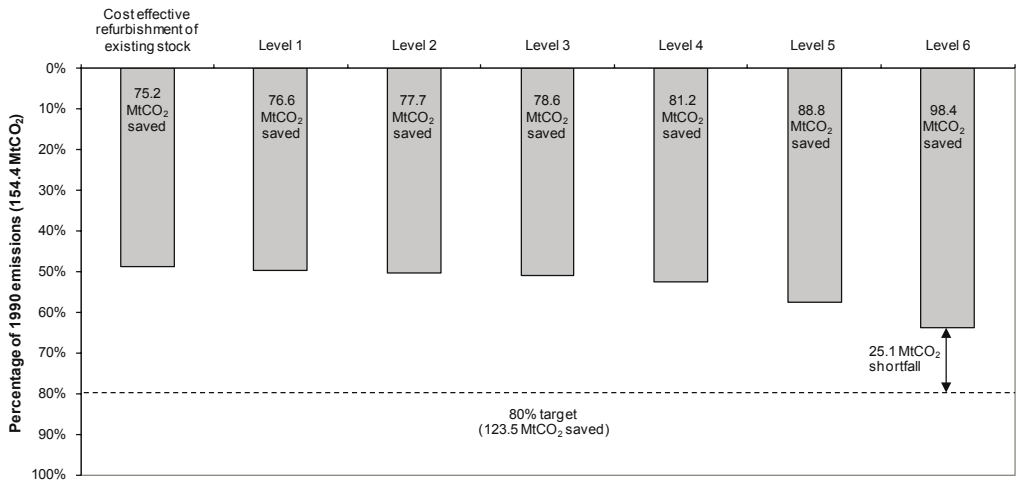

Figure 3: Carbon dioxide emission reductions from homes in 2050 relative to 1990 assuming that all cost-effective measures in existing buildings are undertaken and that new homes are built to 2006 Regulations or one of the 6 levels of the Code for Sustainable Homes

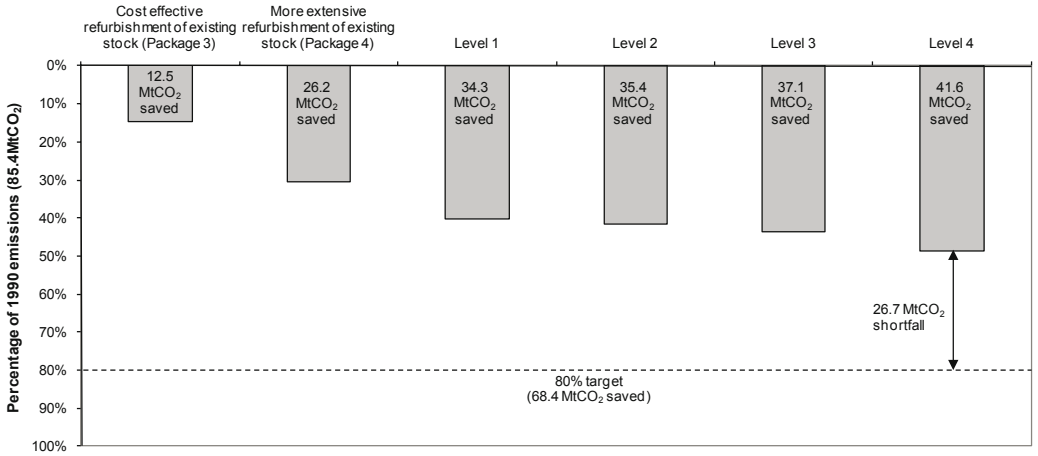

Figure 4: Carbon dioxide emission reductions in 2050 relative to 1990 for the packages and levels applied to non-domestic existing and new build respectively (includes the savings made between 1990 and 2006). Levels 1–4 include the savings from existing package 4)

REFERENCES

[1] Communities and Local Government (CLG). The Code for Sustainable Homes: Setting the sustainability standards for new homes. 2008. Available as a pdf at www.communities.gov.uk/thecode

[2] Committee on Climate Change. Building a low-carbon economy: the UK's contribution to tackling climate change. December 2008. Available to download at www.theccc.org.uk/reports

[3] Department of Energy and Climate Change (DECC). The UK low carbon transition plan: National strategy for climate change. London, The Stationery Office (TSO), July 2009

[4] Department for Business Enterprise & Regulatory Reform (BERR). Towards carbon capture and storage: a consultation document. June 2008. Available to download as a pdf at www.berr.gov.uk/files/file46810.pdf

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A GREENPRINT FOR HERTFORDSHIRE
Using BRE's GreenPrint tool as a dynamic planning framework for suburban growth

James Fisher
Sustainable Development Group, BRE

SUMMARY

This report summarises the GreenPrint analysis undertaken by BRE's Sustainable Communities Team at the Hertfordshire charrette. Led by Duany Plater-Zyberk, the charrette established and assessed growth and development models for the addition of future housing into Hertfordshire. During the week-long consultation, six growth models were assessed and BRE's masterplanning sustainability tool, GreenPrint, was used to assess the relative merits of each scenario. This report discusses the analysis and findings from this innovative project.

BACKGROUND

The Government Office of the East of England has proposed a growth allocation for the County of Hertfordshire to the year 2021. The Hertfordshire Charette was held from 24 June to 1 July 2008 and offered Hertfordshire residents and professionals the opportunity to work with a design team to develop sustainable growth strategies. The Charrette was funded by local and national sponsors including the County Council, the University, local landowners and a number of Hertfordshire-based organisations and companies. The results of the Hertfordshire Charrette, using BRE's GreenPrint tool to assess the sustainability of a range of scenarios, are published in *Hertfordshire guide to growth — 2021: How should the county grow?*[1]

GreenPrint, in its original version, is a BRE consultancy tool developed to help design teams to improve the sustainability of large development proposals. A bespoke assessment of the sustainability potential of the intended site and its context is conducted, following which a series of objectives and benchmarks is produced to guide the design team and client in creating their proposal. This forms the GreenPrint Framework. The aim is to help the masterplanning process to address sustainability weaknesses and maximise the sustainability opportunities of the site and its context.

RESEARCH PROGRAMME

The aim of this project was to develop up to six separate standard GreenPrint frameworks that could form the basis for the design scenarios to be used in the Hertfordshire Charette involving the University of Hertford, BRE, Turnberry Consulting and international urban designers, Duany Plater-Zyberk. The aim of these frameworks was to provide environmental standards for future urban extensions within Hertfordshire to accommodate its new housing allocation.

BRE considered that the GreenPrint methodology could be adapted to provide a sustainability assessment of the scenarios to provide a means of evaluating the strengths and weaknesses of each scenario, as well as considering which scenario performed best overall. This modification would produce a GreenPrint tool which could analyse the effects of mass, location and proximity on the sustainability of a settlement.

During the Charrette, the scope of the work changed, such that the six GreenPrint scenarios became a single flexible tool that could be applied to a variety of growth scenarios on the basis of size, location and relationship to any adjoining settlements. This was actually more flexible than the project's original intent since it meant that work from this project could be applied in other counties through the UK.

The six scenarios were not site specific. The design team proposed location types, design principles and methods for each one, and summarised their likely key economic, social and environmental outcomes, including acceptability to the wider community. BRE's modified GreenPrint was then used to assess their likely sustainability performance.

The Charrette approach is used in GreenPrint for masterplans, where a wide range of stakeholders are involved in shaping the sustainability framework for the development. The Charrette process proved useful in creating the GreenPrint for Growth Models, involving a range of politicians, specialists and interest groups. Discussions covering a wide range of issues relating to the region's character, context and current situation were

Figure 1: Design charrette estate layouts for future developments
Courtesy of Duany Plater-Zyberk

Figure 2: Design charrette future housing styles for Hertfordshire
Courtesy of Duany Plater-Zyberk

useful for informing many of the modifications made to the GreenPrint tool.

Scenario 1: Continuing the existing trends

This is simply to provide the additional housing requirement using the current growth trend for the county. Most growth at present is small-scale infill into small plots as they become available. This is the least planned approach, and is highly opportunistic. In most cases, opportunity sites are identified by local authorities or brought forward by developers. Often, they are the result of intensification of existing plots. The sites are somewhat random, and are chosen for their ability to accommodate dwellings rather than their proximity to facilities or public transport. It is piecemeal development, and uncoordinated with the infrastructure. The average scenario considered for the GreenPrint assessment assumed the creation of around 20 dwellings as infill or intensification, occasionally being sited on greenfield.

Scenario 2: Brownfield and greyfield sites

Growth is accommodated on medium-sized brownfield and greyfield (car park) sites in and around existing settlements. There are unlikely to be enough brownfield sites in Hertfordshire to accommodate all the growth required so brwonfield sites alone would only provide a proportion of the housing needs. Greyfield sites are more plentiful, but some of the car parking which is removed through redevelopment would need to be replaced through multi-storey car parks. Many of the greyfield sites are out of town, alongside retail and office parks. The scenario anticipated for the GreenPrint assessment was for developments with an average size of around 300 dwelling units. Sites would be of sufficient scale to offer some additional services either in the centre of the new community or on the periphery.

Scenario 3: Transport-orientated development

A field study of stations showed a number of rural stations which are still peripheral to both settlements and dwellings, and also opportunities to change the uses of existing retail and leisure developments close to urban stations to accommodate some of the growth Hertfordshire is required to take while increasing access to rail. This scenario faces the challenge of accommodating people and their cars in new settlements, while also enabling existing commuters to use the station. The scenario, situated in an urban location, is one of around 1500 dwellings, with some office and retail units. The size suggests that there may be more than one developer, and there would be opportunities to influence surrounding sites through the routing of pedestrian flows and creation of more permeable pedestrian and cycle routes.

Scenario 4: Settlement extensions

This scenario assumes that a number of existing settlements will take a share of the 'burden' of growth. New development takes place at the periphery of existing settlements, most likely to be attached to suburbs, office parks or shopping centres. Previous settlement extensions have tended to be single use, and often do not integrate into existing fabric and patterns. Perhaps counter-intuitively, well designed larger settlement extensions have a greater potential to improve existing settlements than might be expected as they can re-balance them and provide additional community facilities. Settlement extensions would be expected to occur on greenfield land and would by their nature be peripheral. If the distribution of the number of dwellings required in the regional spatial strategy is shared evenly across existing settlements proportionately to their size, the average number of dwellings added would be around 25. The post-charrette document shows examples of settlement extensions for a village, hamlet and town of varying sizes. Since smaller developments would be akin to that described in *Scenario 1,* the GreenPrint assessment anticipates a larger urban extension of around 1500 as part of a mixed-use development.

Scenario 5: Satellite (Garden) villages

This scenario envisages the creation of new Satellite Villages, each of which is close to an existing town or village and relate to it, but is separated from the town or village by a Green Belt. This Green Belt is not so large that it cannot be traversed by bicycle or on foot so that residents of the new village can access facilities in existing settlements. However, the new villages have

the characteristics of walkable neighbourhoods: when combined with the edge of the neighbouring settlement they contain all the daily facilities that people need together with some commercial and office space.

An interesting variant on this scenario is the creation of Garden Villages, where local food production is prioritised. Each dwelling would have an area for food growing. The size of the food-growing plot increases with the distance from the village centre, moving from allotments in the centre of the village to smallholdings on the periphery. Duany Plater-Zyberk suggest that if the garden village is properly designed, it could increase the economic productivity of agricultural land to compensate for that lost to provide the new village. Food growing and related processing would also provide employment opportunities.

Scenario 6: Stand-alone Garden City

This scenario proposed a city which takes the lessons from Garden Cities and new towns, and also addresses the challenges of environmental efficiency. A Garden City is a larger settlement which could be more self sufficient in terms of employment, leisure and accommodation while being connected to the national rail network. It would be developed on a greenfield site. For the purposes of the GreenPrint analysis, a town of around 50 000 dwellings was anticipated with a rail station at its centre. There is at least one suitable location within Hertfordshire for this kind of development, but this scenario could be difficult to deliver in the current planning process where allocations are split between different local authorities.

RESULTS

In terms of the overall GreenPrint ranking, the scenarios scored as given in Table 1.

Table 1: **Ranking of the six scenarios assessed in the Hertfordshire Charette using BRE's GreenPrint tool (1 = highest)**

Ranking	Scenario
1	Transport-orientated development
2	Stand-alone Garden City
3	Satellite (Garden) villages
4	Settlement extensions
5	Brownfield and Greyfield sites
6	Continuing the existing trends

REFERENCE

[1] University of Hertfordshire, BRE, Duany Plater-Zyberk. Hertfordshire Guide to Growth — 2021: How should the county grow? Hatfield, University of Hertfordshire. Available as a pdf from www.herts.ac.uk/fms/documents/events/herts-charrette-guide-to-growth_02-12-2008.pdf

FURTHER READING FROM BRE

BRE Sustainable Communities Team. A guide to GreenPrint: understanding the benefits for sustainable masterplanning. BRE Information Paper IP 6/10. 2010

Watson C. Masterplanning science and technology parks: a BRE guide. BR 505. 2009

BRE publications are available from www.brebookshop.co.uk or from IHS BRE Press: tel 01344 328038 or email brepress@ihs.com

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CARBON REDUCTION
A scoping study

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SUMMARY
This project identified that the UK needs to develop a standardised method for accounting for the carbon saved from carbon reduction projects. This would enable an assessment of the value-for-money of government programmes and facilitate increased capital investment in projects to reduce carbon emissions in the UK.
A domestic carbon offsetting scheme is not viable. Rather, a new type of funding mechanism needs to be developed to support the considerable desire from corporates to invest in UK-based carbon reduction projects.
The demand for regulatory and voluntary carbon reductions from UK-based projects is likely to exceed 10 million tonnes per year.

BACKGROUND
This research assessed the feasibility of creating a funding mechanism for carbon reduction projects in the UK. The research was commissioned by the BRE Trust in response to strong demand from BRE's clients to be able to support UK-based carbon reduction projects instead of, or in addition to, traditional international carbon offsets. The primary hurdles to the creation of a specific mechanism to finance carbon reduction projects within the UK are:

- the Government has decided against creating a formal offsetting system as part of its Kyoto carbon accounting system
- the complex policy environment in the UK, including regulatory obligations and financial and fiscal incentives to fund carbon reduction projects.

These two factors make it much harder for a domestic UK-based project to demonstrate that it complies with the following two principles which apply to traditional offset projects.

- *Additionality.* Does voluntary funding really pay for carbon reductions if a project also benefits from government incentives or regulatory requirements?
- *Double-counting.* If a project receives both voluntary and regulatory funding, will the same single emission reduction be counted more than once?

RESEARCH PROGRAMME
Within this context, the study investigated:

- current and future expected demand for carbon reductions from UK-based projects (In light of the multiple government programmes to fund carbon reduction projects, the research was not restricted to projects to be funded on a voluntary basis only)
- the possible supply of such projects from various sectors of the economy
- the best way to overcome the regulatory hurdles summarised above.

RESULTS
The need for a standardised method of accounting for carbon reduction projects
There is an urgent need to create a standardised method of accounting for all project-based carbon reductions in the UK, whether they are funded to meet regulatory requirements or on a voluntary basis. Creation of a standardised method would have the following benefits.

Enable assessment of value-for-money of government programmes: Existing programmes different methods to calculate carbon reductions. Future programmes may not use methods consistent with current programmes. The volumes of investment from these programmes will run into billions of pounds. Standard accounting methods would enable evaluation of value for money across different programmes.

Facilitate increased capital investment in projects to reduce carbon emissions in the UK: Project-based reductions currently happen sporadically as required by organisations to meet a particular requirement. We urgently need to speed up and increase the volume of investment.
A 'common currency' across the whole range of government and voluntary programmes would encourage organisations to invest the capital needed to finance emission reduction projects knowing that there is demand for the reductions achieved.

Enable companies and individuals to support UK-based carbon reduction projects on a voluntary basis: Creation of a standardised carbon accounting method would enable UK-based companies and British citizens to make a voluntary contribution to helping the UK to meet its international carbon reduction obligations.

The need for a new type of funding mechanism rather than a domestic carbon offsetting system through which tradable carbon credits are issued

Although there are many proponents of a domestic carbon offsetting system, this is not helpful for the following reasons.

The UK Government is strongly opposed to domestic offsets. Domestic carbon offsetting has negative impacts for the UK's Kyoto compliance including increased costs and complexity of the UK's carbon accounting and making the UK's target harder to achieve.

The binary nature of carbon offsetting (ie one either receives a credit or not) does not reflect the complexities of carbon reduction projects in the UK. The wide range of regulatory requirements and fiscal incentives available for UK carbon reduction projects means that issues such as additionality and double-counting cannot be addressed in an 'all-or nothing' approach. Instead, a comprehensive reporting framework which recognises different standards of project is envisaged. This would enable different programmes or funders to determine the standards they wish to meet while remaining within a universal, recognised framework. Likewise, project developers can determine the standards they wish their projects to meet, based on cost and likely demand.

There is no need for project funders to take ownership of tradable instrument. Organisations required to fund carbon reduction projects on a regulatory basis via, for example, the CERT scheme or to meet planning regulations, do not currently need to take ownership of a tradable carbon credit to meet their obligations. This also applies to organisations that wish to fund UK projects on a voluntary basis. Our research indicates that these organisations want to fund projects that meet rigorous, recognised, transparent standards but that they have little interest in taking ownership of a tradable instrument.

The term offsetting has many unhelpful connotations which are a barrier to engagement on the part of regulators, non-governmental organisations (NGOs) and potential funders. Offsetting has become associated with replacement of domestic measures to reduce carbon emissions, such as becoming more energy efficient in our homes or transport, with cheaper efforts of questionable efficacy in developing countries. While we do not accept this characterisation of good quality carbon offsetting, it is also clear that investment in carbon reduction projects in the UK would not be subject to the same ethical challenges or worries about effectiveness.

Carbon reduction projects in the UK

All companies interviewed that were committed to offsetting expressed the following views.

Support for fulfilling at least part of their offsetting commitment by funding UK carbon reduction projects. The degree to which companies were willing to switch all or part of their offsetting to UK-based projects was correlated with the proportion of customers and supply-chain outside the UK.

Pricing of UK projects was not the crucial issue expected. Pricing was more significant for companies that paid for the offsets themselves rather than passing the cost on to customers. Most surprisingly, several companies stated that the value of supporting local projects was so strong that they would prefer to set a fixed budget for emission reductions in the UK and offset fewer tonnes of emissions instead of offsetting all of their emissions from international projects.

A recognised standard for UK projects would be required. All of the companies interviewed would need to be able to demonstrate to their their customers and stakeholders that adequate quality assurance procedures had been applied to the projects they were supporting. The most important quality criterion for such a standard would be endorsement by an NGO that would be recognised by their customers.

Demand from regulatory and voluntary sources

The demand from regulatory and voluntary sources for carbon reductions from UK-based projects is likely to exceed 10 million tonnes per year. The CERT and CESP programmes are expected by the Government to deliver annual net carbon savings of 5 million tonnes of CO_2 per year. It is estimated that 'allowable solutions' will generate emission reductions of around 3 million tonnes of CO_2 per year. From our research, we conservatively estimate voluntary demand to be 1 million tonnes of CO_2 per year. Other potential sources of demand are:

- local planning requirements for developers to offset the emissions from new developments,
- the carbon reduction commitment (CRC),
- the renewable heat incentive
- the Government's Environmental Transformation Fund.

Cost-effective CO_2 abatement in the UK

There is a potential supply of at least 110 million tonnes of cost-effective CO_2 abatement in the UK, much of which can be achieved on a project basis:

- 90 million tonnes of abatement could be achieved cost-effectively within the housing sector
- 13 million tonnes of annual emissions abatement could be achieved within non-domestic buildings covered by the CRC (including refurbishing social housing or public buildings such as schools)
- 6.4 million tonnes of CO_2 equivalents could be abated cost-effectively from the agricultural sector.

CONCLUSIONS

In response to these findings, BRE is proposing to develop a comprehensive framework for the reporting of UK-based carbon reduction projects. The framework would be comprehensive in that it would be designed to accommodate all types of carbon reduction project in the UK. To ensure widespread adoption, BRE is building support from:

- a wide range of stakeholders including government agencies
- respected NGOs
- commercial organisations.

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BRE CENTRE OF EXCELLENCE IN ENERGY UTILISATION, UNIVERSITY OF STRATHCLYDE

John Counsell
Professor, Energy Systems Research Unit

The University of Strathclyde's BRE Centre of Excellence in Energy Utilisation has been established as an integral part of the Energy Systems Research Unit (ESRU) which has over 30 years' experience in modelling, simulating and designing advanced energy systems for the built environment and renewable power generation. The Centre, now in its third year has eight PhD students receiving part-funded scholarship funds from the BRE Trust.

In addition to the platform research of the PhD projects described in the following articles, the centre has built up a critical mass of knowledge exchange with the buildings' industry. Example projects are:

- a EPSRC CTA post-doctorate secondment working with BRE Scotland,
- a Technology Strategy Board-funded project BIEN-RPG to develop innovative Green IT networks with Siemens SIS
- a partnership with Arup and India's IIT Bombay to research the feasibility of autonomous buildings, ie buildings that power themselves.

This year, the Centre is establishing Knowledge Transfer Partnerships (KTP) programmes to facilitate knowledge exchange of the research results with the buildings' industry as whole, the first programme established being with BARR Limited. Finally, the Centre has progressed so rapidly, it is now actively seeking patents and potential spin-out company activities in partnership with BRE Ventures Limited.

The core platform of PhD students consists of projects grouped in the following key research themes in energy utilisation for the next decade. These are:

- Energy demand reduction to reduce CO_2 emissions and inflationary pressure on economies
- Electricity demand power management to reduce the number of power stations and sustain economic electricity distribution
- Advanced modelling and simulation methods and tools to assist building regulation compliance methods such as the standard assessment procedure (SAP) and the simplified building energy model (SBEM)
- Novel conceptual design methods and tools to assist architects in the design of leading-edge buildings and systems that will assist the first two themes above

The projects in these themes draw on the core research science and software tools of the ESRU team, which are:

- internationally recognised dynamic simulation of buildings and communities using the tool, ESP-r
- power demand-side and power supply matching using the tool MERIT and methods used to develop the CELECT-type heating standard in SAP
- advanced controls for buildings using methods used in flight systems
- nonlinear symbolic modelling for buildings and their systems to greatly simplify dynamic simulation tools for use in regulation and the conceptual phase of building design.

The following articles provide an overview of final-year and second-year PhD projects and a brief introduction to new PhD projects.

For further information on any of the projects included in the articles that follow, contact Professor John Counsell, Tel: 0141 548 3986, Email: john.counsell@strath.co.uk

CO_2 EMISSION ASSESSMENT METHODOLOGIES FOR INFORMATION AND COMMUNICATION TECHNOLOGY EQUIPMENT IN BUILDINGS

Alastair Scott

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SUMMARY

This project has developed dynamic models for the simulation of both electricity consumption and heat emission of typical information and communications technology devices commonly used in the home and offices. These models are now being used on a number of real-life case studies to help validate the models and predict the impact on the total energy performance of homes and buildings.

BACKGROUND

Information and communication technology (ICT) has become a focus for energy-efficiency measures as the UK moves towards its 80% CO_2 emissions reduction target.

The potential reduction in energy consumption from devices has side-effects. ICT does not exist in isolation and contributes to the thermal profile of any building.

Thermal comfort of occupants is becoming an increasing problem in offices that have intensive use of ICT equipment. The project uses a holistic approach through fully integrated dynamic modelling of the ICT devices, the building and its systems. This allows thorough assessment of total energy consumption and thermal comfort in the building.

RESEARCH PROGRAMME

The project has developed a number of software tools.

- An Excel-based tool to enable an ICT-intensive organisation to estimate their equipment's energy consumption based on the Frauenhofer Institute's equipment usage study and manufacturers' data on power consumption.
- A dynamic simulation model of different types of ICT devices. Figure 1 shows an example of power input and heat output from devices.
- A fully integrated dynamic simulation model consisting of models for the building, devices and the thermal and ventilation systems of the buildings.

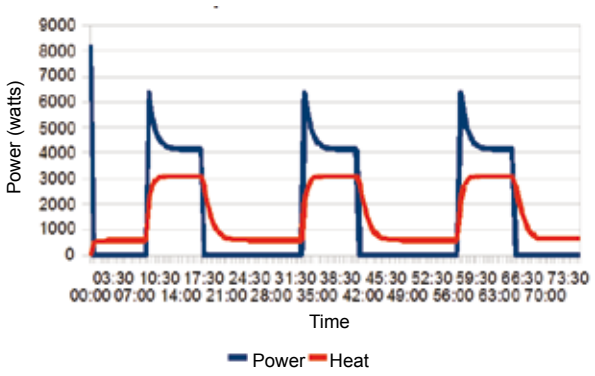

Figure 1: Heat profile for 25 devices

Table 1: IT carbon share profile: electricity usage. Data from a typical local authority (LA)

Item	Number (000s)	Pre-policy % of IT	Pre-policy % of LA	Post-policy % of IT	Post-policy % of LA
Desktop	10	44.27	4.04	23.84	1.08
Laptop/ Tablet	2	2.54	0.23	5.37	0.24
Monitor	11	32.75	2.99	27.55	1.25
Inkjet/MFD	1	0.22	0.02	0.47	0.02
Laser	2	5.29	0.48	11.18	0.51
Server	0	14.92	1.36	31.58	1.43
Total		**100.00**	**9.13**	**100.00**	**4.53**

RESULTS

A case study was carried out in collaboration with the Carbon Trust at a typical local authority. Initial results illustrated in Table 1 indicated that procurement of efficient equipment such as LCD displays and laptops could save nearly 50% of the power used by desktop IT equipment and bring about reductions of over 1000 tonnes CO_2 per annum.

A case study is now being carried out with a Scottish local authority to validate the fully integrated model using existing data for energy use and building environmental conditions. The validated model will be used to predict the impact of leading-edge low-powered ICT equipment alternatives on the energy efficiency and thermal comfort of the building.

CONTROLLABILITY AND ADVANCED CONTROL OF CLIMATE-ADAPTIVE BUILDINGS

Yousaf Khalid

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SUMMARY

This project presents a methodology for assessing the controllability of a building and its building services (eg heating, lighting and ventilation) applying processes used in the design of aircraft flight control systems (Figure 1). The project has established methods and simple tools that can be used by architects in the early stages of conceptual design, for example to predict whether the building will be easy or difficult to control. The tool is also useful in assisting control engineers in the design of more advanced control algorithms and strategies.

RESEARCH PROGRAMME

The project has developed a holistic approach to the modelling of the nonlinear and linear dynamics of the integrated building and its systems. These models are symbolic not digital/finite element in nature. Thus they can be used to analyse the controllability of the building using Nonlinear Inverse Dynamics controller design methods originally developed in the aerospace and robotics industry over the last 20 years.

RESULTS

Initial results have demonstrated that the controllability of a building has to be divided into two distinct assessments:

- Will the system be stable around a desired set point?
- Will the system have enough power to keep tracking a desired set point?

Results have shown that the stability of the system is dominated by the thermal response of the heating system and the time delay that exists between measuring a change in temperature in response to a change in heat input. Thermal mass of the building has no effect at all on stability. That said, window area, thermal mass, U values and the power of the plant have a complex relationship to determine if the control system can track the desired set points. This project has determined this relationship.

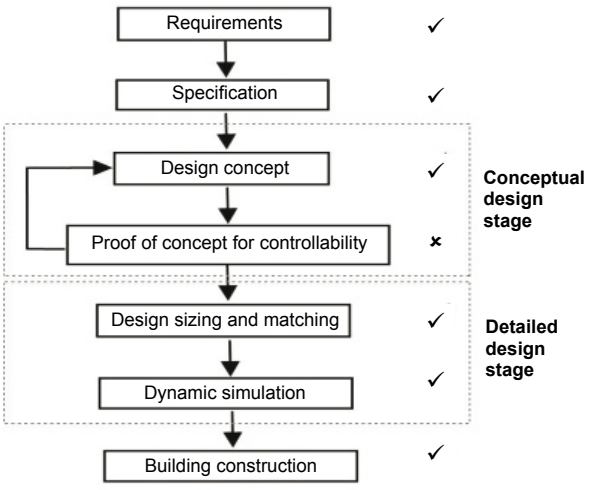

Figure 1: Simplified design process for building design adapted from aircraft systems design

Case study

The project collaborated with SMC Parr Architects to assess the controllability of a school in Scotland, designed with a Climate Adaptive Building (CAB) philosophy. The school in Figure 2 has been designed to have an under-floor heating system. The assessment showed that the controllability of this building would be difficult, but proposed a solution to the problem by suggesting that the temperature control system required a rate of temperature feedback system.

RESEARCH OUTPUT

Counsell J & Khalid Y. A holistic analysis method to assess the controllability of commercial buildings and their systems. Paper presented at the 3rd International Conference on Sustainable Energy and Environmental Protection (SEEP 09), Dublin, August 2009

Figure 2: Example of a school designed with a climate-adaptive philosophy. © Archial Architects

DEMAND RESPONSE AND BUILDING-INTEGRATED RENEWABLE ENERGY SYSTEMS

Matthew Stewart

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

SUMMARY

The project has successfuly optimised the performance of DC power-generating building-integrated renewable networks for the DC power distribution to small power devices (< 25 watts) found in homes and offices. In particular, the use of the IEEE Power over Ethernet standard in conjuction with a robust and smart control philosophy allows this novel system to maximise the use of the renewable power generated to prevent the need for low financial return and inefficient export of power to the external power supply grid.

BACKGROUND

Building-integrated and urban renewable energy systems are becoming more popular as part or a total solution for corporations and private parties to contribute to carbon reduction commitment (CRC) targets. However, current building-integrated renewable power generation systems are limited to either being grid-connected or stand-alone so the potential cost/carbon value of full and independent ownership is not realised. This project has researched and developed, in collaboration with a Technology Strategy Board project, a novel solution to achieve the full value of independent ownership.

RESEARCH PROGRAMME

As a primary case study in local generation and local use of urban renewable energy, the concept Building Integrated Ethernet Network with Renewable Power Generation (BIEN-RPG) project represents an entirely new class of renewable system between classical descriptions of grid-connected and stand-alone systems. The design demonstrates a topology which operates as stand-alone at times, but has the security of supply offered by dynamic grid back-up capability.

The topology of this system allows demand-side control of the electricity demand by taking active control of battery energy storage in the network's devices. By controlling the devices in a unique way, the network demand is tuned simultaneously to achieve maximum power point tracking for a renewable micro-generating DC source such as photovoltaic (PV) panels and also minimise the chance that grid back-up will be required. Hence this minimises the CO_2 emissions from the system as a whole. The system consists of a unique DC power supply unit and distribution system that interfaces a power-over ethernet midspan with the PV panels as illustrated in Figure 1.

Figure 1: Schematic representation of the BIEN-RPG system

RESULTS

The system and the sophisticated control systems have been modelled using the European Space Agency's simulation language ESL. Initial results estimate that the novel system could save as much as 30% in CO_2 when compared with a conventional system consisting of DC to AC invertors and AC to DC transforming power supplies for the devices. Furthermore, the far less complex wiring requirements by having a single CAT5 cable to provide power and data to the device can significantly reduce new-build costs for information communication technology intensive offices.

Case study

The prototype system developed in this project is now part of pilot study plans with Siemens SIS to trial in Wales and Scotland.

RESEARCH OUTPUT

A patent has been filed via BRE Ventures Limited.

MODELLING EMERGING TECHNOLOGIES IN BRE'S STANDARD ASSESSMENT PROCEDURE

Gavin Murphy

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

SUMMARY

This project aims to develop methodologies and tools to assist in the process of introducing new technologies into the standard assessment procedure (SAP) procedure. With the renewed sense of urgency to reduce carbon emissions in new and refurbished homes, it is vital that new technologies can be readily included in SAP without delay and be given a fair rating. Existing and new dynamic simulation of homes and their systems are being utilised to create a new framework to speed up SAP method approval for new technologies.

BACKGROUND

The drive to reduce UK carbon emissions directly associated with dwellings and to achieve a zero carbon home dictates that Renewable Energy Technologies will have an increasingly large role in the built environment. Created by the Building Research Establishment (BRE), the Standard Assessment Procedure (SAP) is the UK Government's recommended method of assessing the energy ratings of dwellings.

The SAP methodology used to assess the energy performance of buildings is based on simple physical equations and empirical evidence. The project has many facets which are underpinned by initial research of the current SAP methods and techniques, currently used to assess the relative performance of existing systems and building solutions. An examination of BRE's SAP related methodologies, such as RdSAP and BREDEM has been conducted. Research with SAP and the SAP derivatives are being used to highlight areas where SAP could be updated for new technologies such as building integrated micro-renewable generation and other new energy system technologies.

Statistical comparisons will be made between the calculated results from the SAP Methodology and detailed numerical simulation systems. Dynamic and detailed modelling of dwellings will be valuable in determining the effectiveness of SAP in assessing emerging technologies.

RESEARCH PROGRAMME

The project presents an ideal opportunity to bridge the gap, as illustrated in Figure 1, which currently exists between the advanced approaches of dynamic simulation and those of semi-empirical and validated models such as BREDEM.

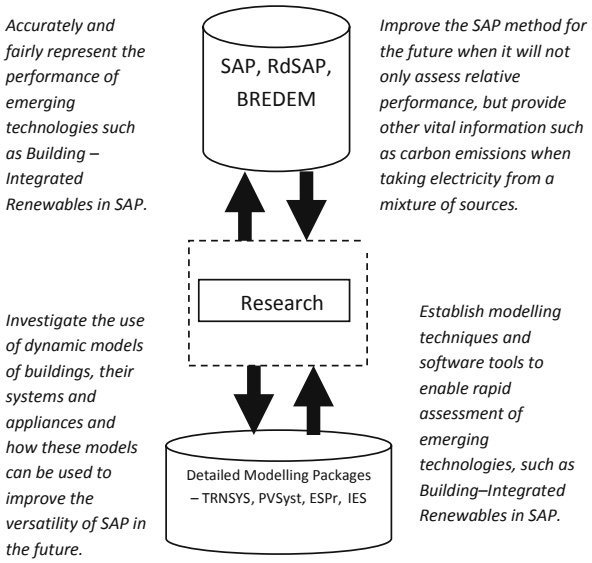

Figure 1: Bridging the gap between SAP and dynamic simulation methods

RESULTS

Initial studies have established how dynamic simulation tools such as PVSyst and TRNSYS can be used to create statistical based models for incorporating in the existing SAP format. Perhaps more exciting is that the project has now established the feasibility of creating a simple nonlinear symbolic dynamic model that can be implemented in Microsoft Excel and could provide an effective means to incorporate many of the advantages of dynamic simulation within the existing SAP framework, this research work continues.

ADVANCED NON-LINEAR CONTROL FOR AEROSPACE AND ENERGY SYSTEMS

Joseph Brindley

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

SUMMARY

This project has focussed on the use of non-linear controller design method Variable Transient Response to supersede traditional controller designs such as PID in building systems. It is a well-known fact that the higher the responsivity of a system, then the more energy-efficient the system is. This is clearly demonstrated in the BREDEM calculation for energy consumption of heating systems in the home. The difficulty is that the responsivity of a system in a highly insulated building is limited by the stability constraints of the control system. VTR enables the maximum response without stability concerns.

BACKGROUND

Flight control systems of high-performance aircraft are the most challenging control problems. They demand the highest level of understanding of the system's physics and the use of the fastest-acting and most powerful technologies.

This project aims for ultimate performance from such systems by driving the actuation systems safely at their maximum power levels at all times. Fast-acting systems, if safe, can bring about benefits in energy efficiency and quality of performance through far more accurate control. The project aims to provide a knowledge-exchange activity that will look at applying these techniques to Building Energy Management Systems (BEMS).

RESEARCH PROGRAMME

The novel non-linear controller design methods of Variable Transient Response (VTR) and Robust Inverse Dynamics Estimation Plus (RIDE Plus) have been developed. These methods use flight systems' state-of-the-art methods of non-linear inverse dynamics (NDI) as a foundation. Analysis demonstrates that VTR in conjunction with NDI dynamically alters the system's transient response characteristics, such as damping and natural frequency, resulting in a more efficient, non-linear response. The RIDE Plus design method unlike previous NDI designs commands a rate of change of the system's actuator input. This functionality allows actuator rate limits to be compensated for in the controller design to significantly speed up the dynamic response and tighten the tracking of a set point.

Figure 1 illustrates how VTR works. When the demand is a high output, the controller increases the closed-loop systems frequency and reduces the damping ratio. As the amplitude demanded reduces, the system reduces the frequency of response to provide an ideally damped system response.

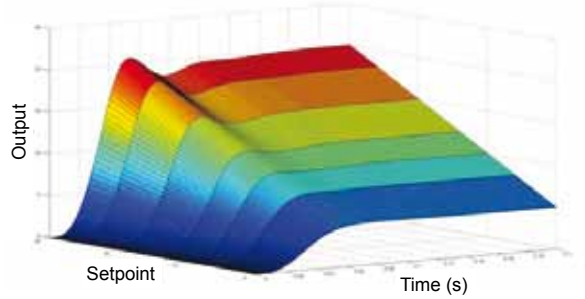

Figure 1: How variable transient response (VTR) works

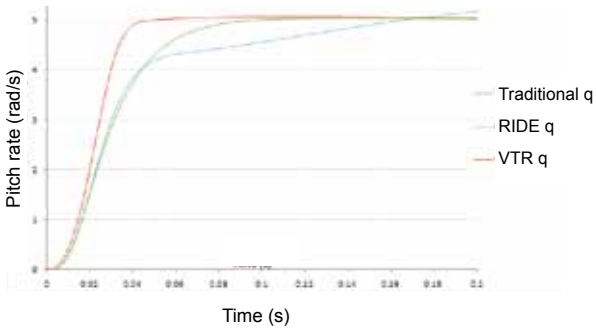

Figure 2: Examples of transient response of traditional, Ride and VTR designs

Case study 1

The first case study[1] was an unmanned aircraft pitch rate autopilot which illustrates the enormous improvement gained in performance of the system versus other traditional and state-of-the-art RIDE autopilot designs (Figure 2).

Next stage

The technique is now being applied to temperature-control systems for buildings designed with a climate-adaptive philosophy. The improved accuracy and response time is estimated to save up to 10% in energy consumption. This will both improve the energy certification of the building and also improve the thermal comfort of the occupants as thermal comfort has proved to be problematic in this type of building when employing traditional control methods such PID control.

REFERENCE AND RESEARCH OUTPUT

[1] Counsell J M, Brindley J & Macdonald M. Non-linear autopilot design using the philosophy of variable transient response. Paper presented at AIAA Guidance Navigation and Control Conference, Chicago, 10-13 August 2009

FIRST-YEAR PhD PROJECTS

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

THE DEVELOPMENT AND TESTING OF ENERGY CODE COMPLIANCE SOFTWARE IN THE NON-DOMESTIC SECTOR

David Kellock

Objectives

This project is focused on the continuing development of the Simplified Building Energy Model (SBEM). The aim is to bridge the gap between SBEM and programs that use dynamic simulation methods (eg ESP-r) while still maintaining a user-friendly interface. The project will use the science developed in the dynamic simulation field of 'sensitivity analysis' to investigate the most important modelling parameters that have an impact on the energy performance of the buildings and its consequent SBEM rating.

AUTONOMOUS BUILDINGS

James Johnston

Objectives

The project aims to establish the feasibility across world locations for the design and build of near or totally autonomous buildings. In the main, this means independent of any electricity and/or gas supply. Water supply and waste services are of less concern in the definition of 'autonomous' in this project. The project is in partnership with BRE, Arup and the IIT Bombay in Mumbai, India deliberately has an international dimension as it looks at the feasibility of this radical building design concept on a global basis. It aims to demonstrate the concept to the industry by using a mobile building of the future (Figure 1).

DESIGN METHODS FOR CONTROLLER DESIGN OF COMPLEX FLUIDIC BASED SYSTEMS

Obadah Zaher

Objectives

The aim of the project is to develop a design procedure which incorporates CFD for optimised controller design. The general design process will include creating a detailed CFD model of a system, reducing this model to a simplified model which retains all of the important characteristics and dynamics and finally using this model for the design of the control system. The project will focus on two areas of application to demonstrate the effectiveness of the design method:

- domestic hot water systems which can obtain heat from several sources at any one time
- the design of unconventional aircraft systems, such as unmanned vehicles.

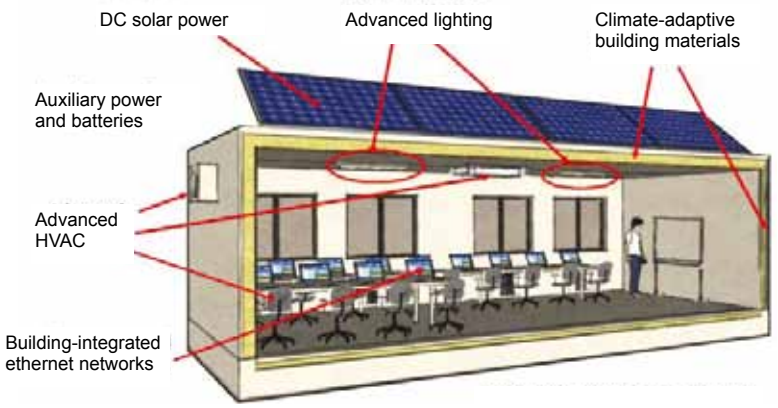

Figure 1: An off-grid education unit

BRE CENTRE OF EXCELLENCE IN BUILDING SYSTEMS AND INFORMATICS, UNIVERSITY OF CARDIFF

Yacine Rezgui

Professor, Building Systems and Informatics

The construction industry is renowned for its complex project-based structure, reflected in its virtual enterprise-like *modus operandi*. It is currently facing some major societal and environmental challenges in terms of climate change and sustainability, including the need to reduce greenhouse gas emissions from existing and new build. This is reflected in increasingly complex regulations (environmental, energy, waste, etc.) that must be assessed and addressed by specialists to satisfy planning consents and public concerns[1].

Moreover, the construction industry is facing a paradigm shift: a move from simple 'physical' components towards extended IT-aware products embedding various forms of 'intelligence'. Buildings should have the ability to be context-aware (including environmental aspects) and learn from user behaviours and lifestyle patterns, and thus be adaptive to change[2].

From a building conceptualisation perspective, ongoing Building Information Modelling (BIM) efforts have shown limitations reflected in their static representation of a building and its environment. Further developments are required to provide a dynamic representation of a building necessary to provide real-building performance (including energetic) accounts, while ensuring the building has lifelong adaptability to its usage and environment[3].

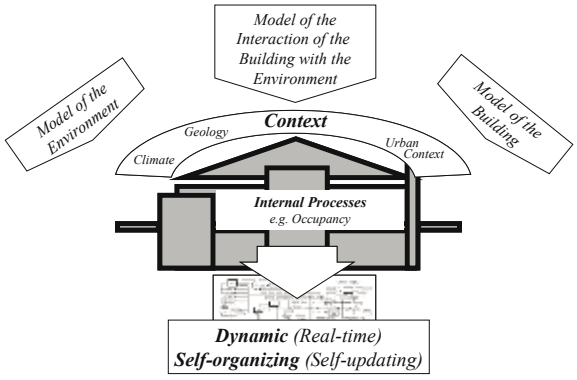

Figure 2: Dynamic and self-organizing building information model

There is an urgent need to re-think and pave the way to a built environment adapted to the challenges of the 21st century. This is the mission addressed by the new Building Systems and Informatics Centre supported by the BRE Trust. It adopts multi-disciplinary and multi-faceted methodological interventions that factor in: people, process and technology issues.

The Centre was established in April 2009. It is led by Professor Yacine Rezgui and includes

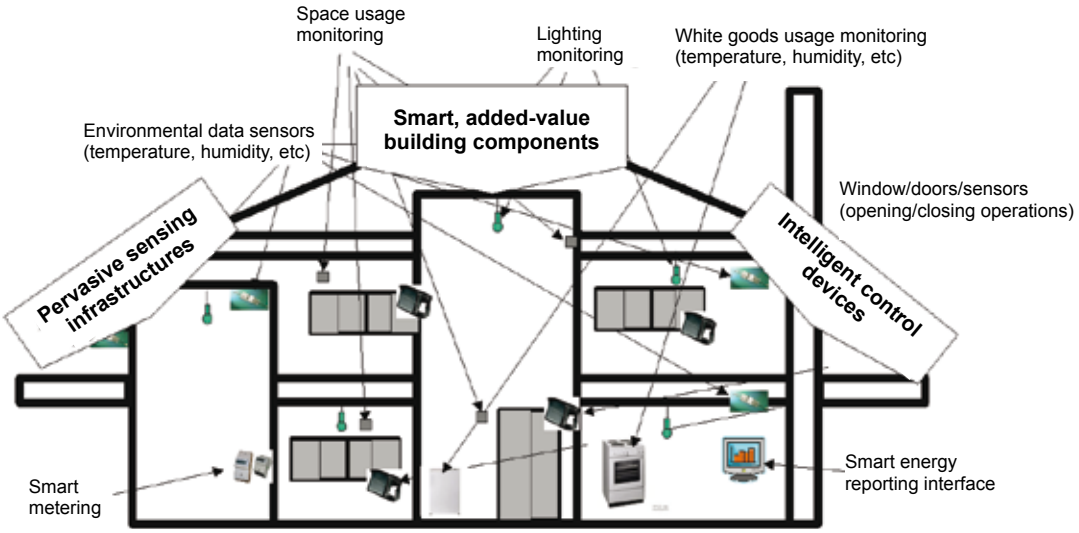

Figure 1: Smart building enabled by digital technologies

Dr Christina J Hopfe, Dr Alexandra Koj, Dr Alan Kwan, Dr Haijiang Li and Professor John Miles. More detailed information will be included in the *BRE Trust Review 2010*.

REFERENCES

[1] Rezgui Y & Zarli A. Paving the way to digital construction: a strategic roadmap. Construction Engineering and Management: 2006: 132 (12): 767–776

[2] Rezgui Y, Zarli A & Hopfe C J. Building information modeling applications, challenges, and future directions. Journal of Information Technology in Construction: 2009: 14: 613–616

[3] Rezgui Y, Boddy S, Wetherill M & Cooper G. Past, present and future information and knowledge sharing in the construction industry: towards semantic service-based e-construction. Computer Aided Design: 2009: Elsevier 10.1016/j.cad.2009.06.005

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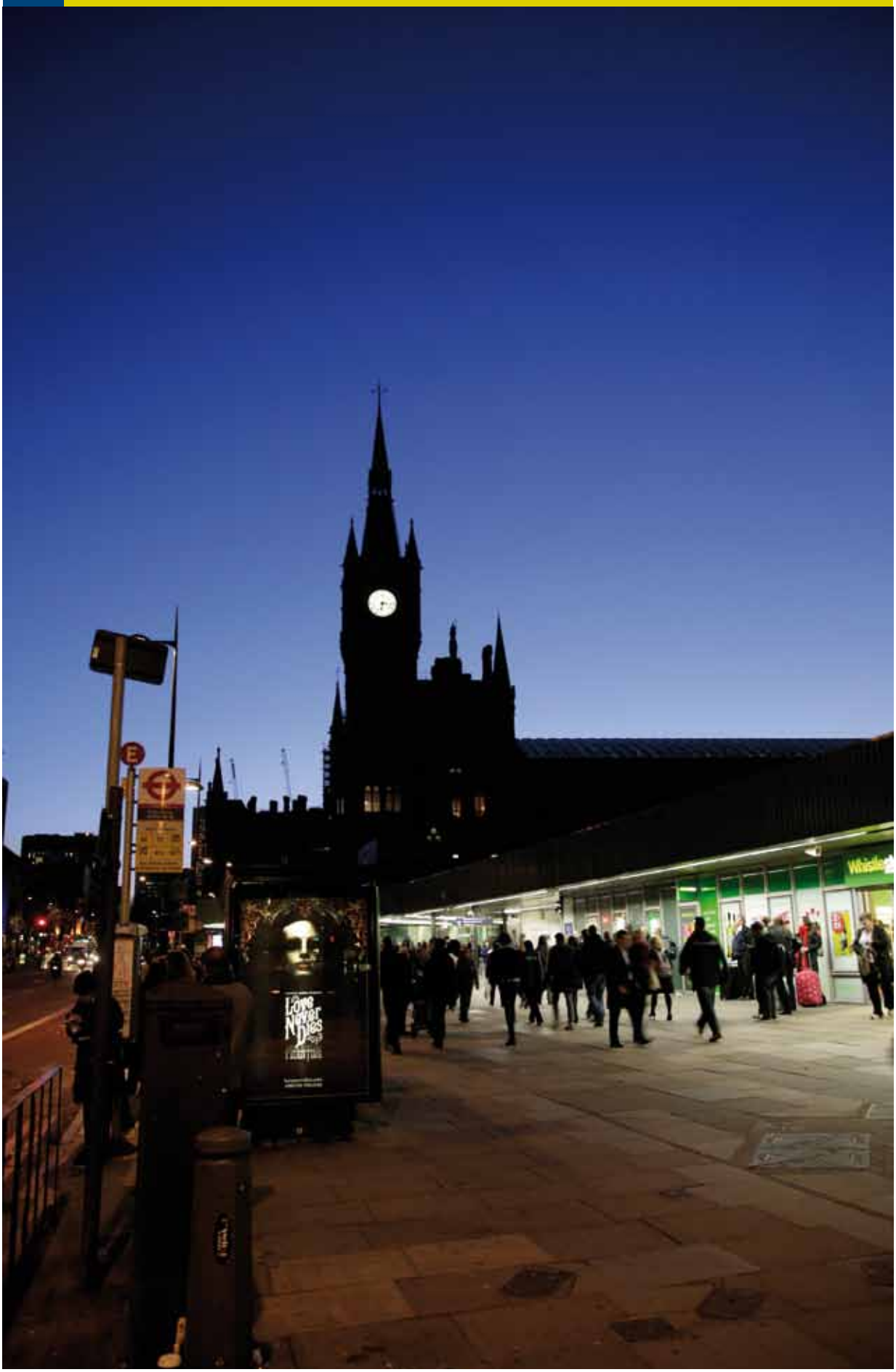
SOCIAL ASPECTS OF HOUSING AND THE BUILT ENVIRONMENT



SAFE AND SECURE TOWN CENTRES AT NIGHT

Sharon Monahan

Housing Group, BRE

SUMMARY

This project assessed the issues involved in managing the night-time economy and alcohol-related violence in town centres. This included Crime Prevention Through Environmental Design (CPTED) surveys, interviews with key stakeholders, steering group meetings, three case studies, participant observations and literature reviews.
A toolkit was developed as a method of assessing the management of town centres at night. It provides comprehensive coverage of all the issues involved in alcohol-related violence and disorder and explains how they can be used by stakeholders in their decision-making processes to reduce crime and disorder in the night-time economy.

BACKGROUND

Alcohol-related violence and disorder are significant problems in the night-time economy. The British Crime Survey estimates that there were just over two million violent incidents against adults in England and Wales in 2008/09; in nearly half of these, the victim believed the offender to be under the influence of alcohol.
The night-time economy brings revenue to a town, provides employment and attracts visitors. However, the combination of large numbers of people and a high concentration of licensed premises can be related to higher levels of violence and disorder. It is difficult to strike the right balance between constructing vibrant town centres with inclusive forms of entertainment, and at the same time creating places that are safe and free from drunkenness and anti-social behaviour. Those responsible for managing night-time economies require tools to help them to get that balance right.

Box 1: Consequences of alcohol-related violence and crime

Alcohol-related violence and crime issues can have an impact on many areas of the community, including:

- the health services:
  - high levels of assaults and alcohol-related incidents increase demands on health services, and
  - health service staff are vulnerable to attack by patients under the influence of alcohol
- the police service:
  - the additional police required to deal with alcohol-related crime and disorder places pressure on police resources and diverts policing away from other areas
- the local authorities:
  - costs such as street cleaning of vomit, urine, litter and the results of vandalism
- the owners of licensed premises and other night-time venues:
  - for example, damage to premises
- the local residents and day-time businesses:
  - for example, noise, vandalism and damage to property

RESEARCH PROGRAMME

The aim of this research was to produce a problem-solving tool to assist practitioners to prevent, tackle and reduce crime and disorder and create safe and secure town/city centres at night.

The methodology included:

- a literature review
- an analysis of crime and disorder data
- steering group meetings with key crime reduction experts
- three case studies of town centres at night, including:
  - Crime Prevention Through Environmental Design (CPTED) surveys of the town/city centre plus the main access and dispersal routes and taxi ranks, car parks, walking routes, etc.
  - semi-structured interviews with major stakeholders in the night-time economy. Interviewees included representatives from:
    - the police, at both a strategic and operational level
    - the Community Safety Partnership
    - town centre management
    - Licensing Officers
    - licensees
    - residents
  - night-time participant observations
  - identification of examples of good and bad practice

RESULTS
The toolkit

The toolkit is split into 13 categories which are listed in Box 2. These cover all aspects of the night-time economy known to affect crime levels and alcohol-related violence. Within each category, there are a number of actions that can be taken. These actions have different levels of importance, as illustrated by the colour band and dot rating shown in Box 3. Hence, the actions at the beginning of each category are considered to be more important than those lower down the list.

Each of the actions need to be considered to determine whether they have been:

- already implemented, with evidence to support that implementation
- considered and intending to implement
- considered but not applicable
- not considered.

The actions need to be applied with careful consideration as there are no generally applicable solutions; what works in one town centre may not work in another. It is essential therefore to consider the context and the unique characteristics of the locality. However, the scoring method at the end of the form can provide a starting point for responsible stakeholders to assist in tackling the issues involved in alcohol-related violence and disorder in town centres at night through appropriate action.

The toolkit is intended to provide stakeholders in the night-time economy with a structure for measuring the issues involved in alcohol-related violence and disorder in town centres at night, identifying priorities and taking action to deal with them. The toolkit provides a benefit to managers of the night-time economy by supplying a framework for evaluating policies and procedures.

Box 2: Issues covered in the toolkit

- Partnership working
- Data and information sharing
- Licensed premises
- Policing strategies
- Capable guardians and street welfare
- CCTV
- Lighting
- Under-age drinking
- Transport
- Offenders and victims
- Visual cues
- Fast food outlets and access routes
- Space allocation

Table 3: Levels of importance for actions

• • • Essential	These actions are essential and urgent. Immediate action is required to implement them.
• • Important	These actions are important and should be considered as soon as possible.
• Desirable	These actions are desirable and are a bonus if implemented.

Through implementation of the suggestions included in the toolkit it should also provide benefit to users of the night-time economy by allowing them to have a safer night out.

RESEARCH OUTPUT

The toolkit, which has been approved by the Home Office, is available as a pdf via the BRE website at:

www.bre.co.uk/safetowncentresatnight

and is also available via the Home Office web site where it is reported to have received a lot of interest.

More information about the findings of this research project is given in a BRE *Information Paper* IP 10/08, *Safe and secure town centres at night*.

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PERSONAL SAFETY AROUND TRANSPORT INTERCHANGES

Joan Oxley
Housing Group, BRE

SUMMARY

The need to interchange, for example to change from train to tube or tube to bus, during a journey can be a key factor in deciding when and if people use public transport. Interchanges tend to increase passengers' feelings of insecurity and perceptions of risk. Transport planners, operators and providers need to take a whole-journey approach that integrates transport interchanges and their services with their surroundings, and makes the journey more convenient and safer and a generally more pleasant experience.
This project has helped in the development of tools to enable transport providers to understand the risks associated within and around their property and highlight the necessary changes to reduce these risks.

BACKGROUND

For many members of the public, personal security is an important factor when considering the use of public transport and when changing from one method of transport to another. Feelings of insecurity deter many passengers from using interchanges at certain times of the day or at certain locations. In fact, the need to interchange between transport systems tends to increase the public's perception of the risks involved.

It is essential that underground stations are integrated with other methods of transport either within or just outside the immediate environs of the station through transport interchanges. This necessitates that transport planners, operators and providers view transport interchanges within a broad definition, in order to improve the integration of their facilities and services with their immediate surrounding environments. In addition, by adopting a whole journey approach and by making that whole journey a safer, more pleasant experience, many people could be encouraged out of their cars and onto public transport, providing a positive impact on climate issues and sustainability.

Some schemes that are concerned with the security of railway stations, such as the Secured by Design 'Secure Stations' scheme normally used for station assessments, cover only the station itself. Yet, for the travelling public to continue their journey as pedestrians, or to transfer to an alternative means of transport, they may have to leave the 'safety' of the station building.

There was clearly a need for a security toolkit to assess interchanges, their immediate surroundings, as a whole and for the risk factors which might lead to crime or personal injury. Such a toolkit would enable transport interchange providers to understand the risks associated within and around their property and would highlight the necessary changes to reduce these risks. This should result in changes to these environments which in turn would ensure safer travelling experiences for passengers.

RESEARCH PROGRAMME

Objectives

This project was devised for the development of a Personal Security Around Transport Interchanges toolkit. Such a toolkit could be used to assess current transport interchanges across London and the public transport needs for the forthcoming Olympics. It would also be applicable to transport interchanges elsewhere across the UK.

The aims were to identify:

- security and usage problems from the travelling public's point of view
- the travelling public's perceptions of risks
- specific physical or operational features that increase passengers perceptions of risks

- how perceptions of risks vary with time of day
- precautions taken by customers, including changes to transport choices.

Methodology

- Comparison of results of previous BRE consultancy work on five London Underground transport interchanges with similar research on other interchanges carried out by other organisations and interest groups
- A gap analysis to highlight what other issues should be considered
- Review by experts at steering group meetings

A partnership approach was adopted during the course of the toolkit development through participation in steering groups. Partnership members included Transport for London, British Transport Police, Metropolitan Police Authority, Local Authority departments and passenger groups.

RESULTS

This research assisted in the development of a set of tools that will be of benefit to local authorities and transport providers and members of the public by allowing:

- assessment of the factors which increase the risk of crime and the fear of crime at transport interchanges
- suggestions to changes to these environments, which may lead to public perception of safer travel
- more consistent levels of security across the London transport area and possibly, in the long term, the wider national transport network
- London transport interchanges that will be designed and managed in a manner that will reduce crime for all user groups and will improve the 'whole journey experience'
- increased partnership working between London transport providers, user groups, Metropolitan Police, BTP, Local Authorities, GLA, GoL etc
- positive impact on future design, build and maintenance of transport interchanges
- a significant positive impact on the environment (ie cleaner, safer, greener) as more members of the public are encouraged to use public transport rather than motor vehicles.

The results will be sustainable as physical opportunities for crime and fear of crime will be removed from crime generators. In the short- to medium-term this will lead to a reduction in crime rates. In the medium- to long-term this will be seen by the travelling public who will gain confidence in an environment that looks and feels safer.

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AN ASSESSMENT OF EXISTING CORPORATE SOCIAL RESPONSIBILITY TOOLS

Stuart Blofeld* and James Fisher+
Housing Group* and Sustainable Development Group+, BRE

SUMMARY

Corporate social responsibility (CSR) means that organisations are expected to take responsibility for the impact of their activities on customers, suppliers, employees, shareholders, communities and the environment in all aspects of their operations. Customers are increasingly placing pressure on companies to demonstrate that they are fulfilling their 'social' obligations as well as their business ones.
To demonstrate their good business citizenship, companies can currently report in accordance with a number of CSR reporting guidelines or standards. BRE conducted an analysis of these tools that suggests that the tools are incomplete, not demanding enough on the standards that they require and missing impact areas that perhaps they should focus on.

BACKGROUND

Corporate social responsibility (CSR) is a concept whereby organisations consider the interests of society by taking responsibility for the impact of their activities on customers, suppliers, employees, shareholders, communities and the environment in all aspects of their operations. This obligation is seen to extend beyond the statutory obligation to comply with legislation and sees organisations voluntarily taking further steps to improve the quality of life for employees and their families as well as for the local community and society at large.

CSR is currently coming into sharp focus for many large organisations. There is an increasing pressure being placed on companies by their customers to demonstrate that they are fulfilling their 'social' obligations as well as their business ones. This is particularly true where environmental considerations and the wider palette of sustainability issues are concerned. To demonstrate good business citizenship, firms can currently report in accordance with a number of CSR reporting guidelines or standards.

Early analysis of these tools suggests that the subject areas they cover are wide-ranging and diverse, although none covers all topic areas. In particular, they seem to be remiss of actual measurable improvement standards (ie targets and benchmarks). They seem to focus on actual reporting rather than improvement performance.

RESEARCH PROGRAMME

The objective of this project was to assess the tools and indices currently used in the business arena to measure and report on corporate social responsibility (CSR) performance. The project investigated the extent of coverage of these tools to see to what degree they measure the true sustainability of a business.

RESULTS AND CONCLUSIONS

The scope of the schemes researched were found to be wide-ranging and diverse, with different intended applications and target audiences. The scheme types varied from:

- investment-based sustainability indices such as the FTSE4Good, and Dow Jones Sustainability Index which specifically target the investment community,

to schemes like:

- the Business in the Community CR Index aimed at the organisations themselves to help record progress, bench mark performance against others, and identify areas for improvement in managing their CSR.

Other scheme types included:

- sustainability reporting frameworks (AA1000 Assurance Standard and GRI Reporting Framework)
- management standards (Green Globe Company Standard and ISO 14001)
- CSR guidelines or principles such as the UN Global Compact.

What was interesting from the research undertaken regarding scheme type is that only one scheme could be described as a performance standard, setting minimum performance levels that any organisation seeking certification against the standard must meet.

The verification methods employed by the schemes varied considerably from those that require self-declaration at one end of the spectrum to those that

require third-party certification at the other. The majority of schemes researched sat somewhere between these two methods favouring a combination of different methods including self-assessment and second-party assessment.

What was evident from the data collection techniques explored is that few schemes, especially the sustainability indices, use any kind of primary monitoring or auditing of companies' practices as a means to assessing an organisation's sustainability performance or ranking. To compensate for this lack of first-hand information, scheme operators gathered company information using multiple methods and sources to provide a better chance of balance.

With regard to the scope of those schemes researched, common areas of convergence and/or areas felt to lie at the heart of the schemes were identified. As a result, 10 core areas were identified that can be described as forming a fundamental part of the schemes in question.

Taking account of an organisation's environmental performance for example was the most common element across the schemes researched. However, closer examination of the schemes' assessment criteria revealed that often the requirements in relation to environmental performance tended to focus on little more than the implementation of an environmental management system, as outlined in the ISO14001 standard.

While this approach seems eminently sensible (why 'reinvent the wheel' when there already exists a recognised international standard) one needs to understand the limitations of standards such as ISO14001 if they are incorporated into major indices as a means of assuring an organisation's environmental credentials. In short, the presence of an environmental management system (EMS) cannot guarantee improved environmental performance, and therefore it is questionable if an EMS should be used as a key determinant in assessing an organisation's environmental credentials.

Another observation from the research conducted is that for organisations even to be considered on the major sustainability indices they must be among the top 500 companies in the world by value. The reason for this is that these investment-based indices are specifically targeted at the investment community to manage their sustainability portfolios. However even those schemes that are not traditional investment indices such as the AccountAbility Rating and Business in the Community CR Index seek participation in their schemes by inviting companies listed on economic indices such as the Global 500 or FTSE350.

One other area identified through this research is the large absence of minimum performance criteria in the scheme requirements. Only three schemes researched contained what could be loosely described as minimum performance requirements, and this didn't include any of the major sustainability indices that we are particularly interested in.

Beyond excluding certain industry sectors such as nuclear energy, arms or tobacco sectors, the sustainability indices researched do not set a minimum performance level that all organisations must achieve to be listed on the indices. It could be viewed that the minimum performance level in these indices is self-setting by the very fact that the lowest ranked organisation featuring in a particular index will effectively set the minimum performance level. And over time the minimum performance level will increase as organisations' overall performance and awareness of sustainability improves.

The problem with this approach is that there is little transparency over what such a ranking means in terms of a company's sustainability performance, ie what is the organisation actively doing to reduce its total impact. Instead they focus on a company's environmental and social reporting rather than measurable performance improvement.

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THE REAL COST OF POOR HOUSING

Mike Roys*, Maggie Davidson*, Simon Nicol*, David Ormandy+ and Peter Ambrose#

Housing Group, BRE*, University of Warwick+, University of Brighton#

SUMMARY

The relationship between poor housing and poor health has been recognised for a long time, but until recently it has not been possible to estimate its cost to society. Although the problems of disease associated with slum living have largely been eradicated in England, a significant number of health and safety hazards in the home remain.

This project highlights weaknesses in existing models of the housing stock and proposes a new model which overcomes them. The model uses data obtained from the English House Condition Survey to illustrate the effects of various scenarios and repair options. It clearly demonstrates that money invested in improving poor housing could have a significant impact on improving health and reducing the financial burden on the NHS.

BACKGROUND

There is a long established, recognised relationship between poor housing and poor health. In Victorian times diseases such as tuberculosis, cholera and typhus were known to be associated with insanitary, cold, damp and overcrowded housing conditions. This led to various public health acts and eventually to the Housing of the Working Class Act, 1890 which was the first attempt to consolidate the law relating to housing. The first national definition of homes that were 'unfit for human habitation' appeared in the Housing Act of 1954 and this remained (with various changes) as the minimum standard of housing in England and Wales until 2006 (the last version, following the 1989 Housing Act, is still applied in Northern Ireland).

Many studies have investigated the relationship between housing and health but, because of the number of intervening variables, it is difficult to demonstrate clear and measurable cause/effect relationships. Nevertheless there is a large and growing body of evidence linking systematically adverse health effects with poor housing conditions. These conditions include dampness, the effects of living in a cold home, household accidents, noise, insecurity, overcrowding and fire safety.

RESEARCH PROGRAMME

This project shows the background information and assumptions made in generating a new interactive spreadsheet model to calculate the costs and benefits associated with the main building-related hazards found in homes in England.

All values used are the best estimates that could be found at the time of the model creation. The model is, however, designed to be flexible so that more up-to-date or accurate values could be used. The conclusions based on these values are therefore likely to be underestimates of the real current day costs, and are at best only representative of the large range of potential costs associated with each hazard.

Objectives

The key objectives of the project were to:

- review current literature and research on the relationship between hazards in the home and health
- examine the availability and coverage of data sources on housing and health
- review current literature and research on the cost to society of poor housing
- quantify the national risk (England) under the 29 hazards of the Housing Health and Safety Rating System (HHSRS), in terms of extreme, serious and severe health hazards
- estimate the cost of making the existing English housing stock healthy and safe (to an acceptable level) through analysis of the latest English House Condition Survey (EHCS) data
- produce 'cost to society' averages for key HHSRS hazards using Department of Works and Pensions (DWP) data, insurance data, EHCS and other sources.

Method of estimating the cost

The basic stages are listed as follows.

- Use EHCS data to identify the number and profile of homes where the HHSRS rating score has a hazard score of 1,000 or more.
- Use EHCS data to estimate how far the above properties could be improved (eg to an 'average' level for the stock as a whole or an 'average' level for properties without significant hazards) and the costs of the building work required to achieve this.
- Use HHSRS statistics on the spread of health outcomes to estimate how many of the dwellings stated in point 1 above are likely to fall into the four outcome categories (extreme, severe, serious and moderate) given current conditions and after improvement works.
- Use data from other sources on the average total costs to society of each type of outcome to estimate the benefit gained from improving these homes and compare this with the costs of building work itself.

Figure 2: This staircase presents a Category 1 safety hazard

An improved model

An existing model considering HHSRS hazards had previously been created for the Chartered Institute of Environmental Health (CIEH). However, this previous model had a number of limitations. An improved model was therefore required to take account of all these issues. The model was developed in Excel and used the EHCS derived data for five hazards.

While the developed model is more complicated than the previous CIEH model, the flexibility it provides makes it more applicable to practical applications since it is possible to change all the following:

- the hazard to be considered
- the scenario to be applied (all up front, annual payment, no change)
- the number of properties that can be repaired
- the proportion of properties to repair (all, cheapest 20%, cheapest 50%)
- flexibility in value of costs and benefits
- different discount rates for net present value (NPV) calculations.

Figure 2 shows the cumulative costs and benefits over 25 years for the hazard 'Falls associated with stairs and steps', where the scenario allows the cost of repairs to be spread equally over 10 years. When considering all the homes with a Category 1 hazard of this type in England, the chart shows that there is a positive cumulative payback after 15 years. The repair costs, to repair 1.7 million homes with this type of hazard, average out to £1084 per house, with a total cost of £1.9 billion. There is a further cost to the NHS for treating injuries in homes where the repairs have not been carried out. The cumulative excess cost to the NHS in this example is over £1.6 billion. Even with an NPV calculation, with an interest rate of 7%, the hazard has a payback period of 21 years.

Total cost of poor housing

The data obtained from the EHCS and the HHSRS model can provide an initial estimate for the total cost of poor housing. The number of dwellings with Category 1 hazards is just over 4.7 million. This is multiplied by the

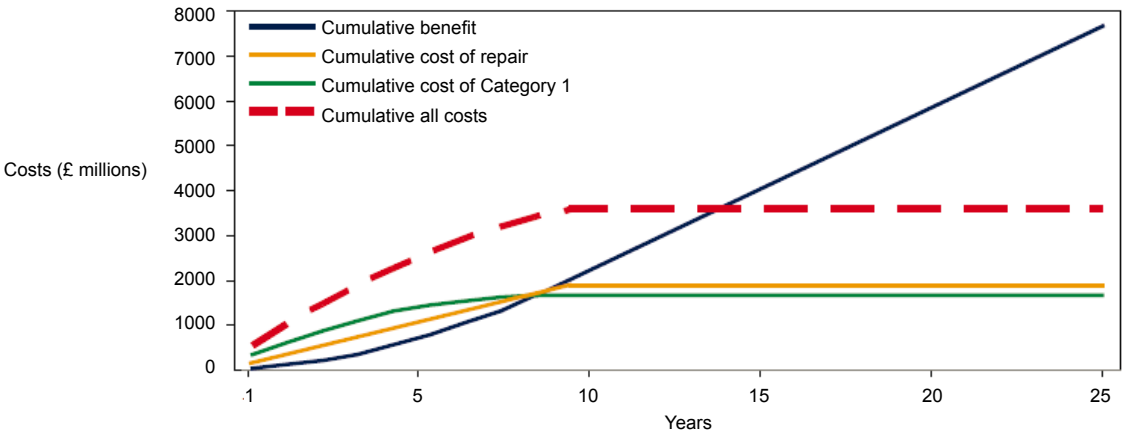


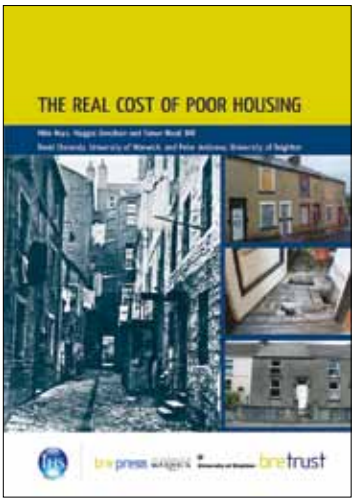
Figure 2: Cumulative costs and benefits over 25 years for the hazard 'Falls associated with stairs and steps' with annual payments over 10 years

estimated total cost to repair from the EHCS data, which implies that it would cost in excess of £17.6 billion to remove all the Category 1 hazards from dwellings in England. For the hazards that were fully measured, we have a value for the average likelihood of Category 1 hazard scores (scores over 1000). For all the other hazards the likelihood band that just provides a Category 1 hazard has been used with the average spread of harms. This implies a minimum likelihood, rather than the average for each hazard, underestimating the average risk of harm. Using the difference between this likelihood and the average likelihood for the whole stock an estimate for the total annual benefit to the NHS can be calculated, which in this case is just over £600 million. Put another way, this is the cost to the NHS each year if the repairs are not made.

This model is currently poor at estimating the costs associated with the hazard 'Excess cold' since the estimated average for the country is very similar to the minimum required to achieve a Category 1 hazard. It is highly likely that the actual risk associated with Category 1 excess cold is much higher than this estimate, improving the cost–benefit analysis. By removing excess cold from the calculation, we find that the total direct cost of poor housing to the NHS is £580 million and the payback period to cover all repairs would be just over 10 years. Since the direct cost of poor housing, is at most 40% of the total cost to society, the total cost is likely to be nearer £1.5 billion, reducing the payback period, for all hazards except excess cold, from 10 years to just four.

RESEARCH OUTPUT

More information about the findings of this research project is given in a BRE Trust report (FB 23), *The real cost of poor housing*. This report examines the evidence for links between housing and health, defines 'poor housing', highlights weaknesses in existing models and proposes a new model that overcomes those shortcomings.



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PERCEIVED QUALITY OF SOCIAL HOUSING
Does it encourage tenant responsibility?

Kathryn Rathouse*, Mindy Hadi+ and Andrew Gemmell*

Housing Group* and Sustainable Development Group+, BRE

SUMMARY

This research investigated housing association tenants' attitudes to their kitchens and kitchen furniture. The first stage looked at the types of fittings that are perceived as 'good quality' and determined the key factors that influenced users' opinions. The second stage investigated the role of choice in influencing tenants' attitudes to their new kitchens, their level of satisfaction, perception of durability and subsequent treatment. The findings suggest that there is a relationship between provision of choice and satisfaction both immediately after installation and 18 months later.

BACKGROUND

Housing associations are becoming increasingly aware of the need to consider whole-life costs when refurbishing or developing new homes. They can draw on a large body of research on technical issues but there has been less research exploring the social issues that impact on whole-life costs, ie how to ensure that tenants take good care of their homes thereby reducing repair and maintenance costs. This project, carried out in association with Guinness Trust, looked at the relationship between:

- the amount of choice tenants were given in the selection of kitchen furniture,
- the perceived quality of kitchens,
- how well tenants take care of them.

RESEARCH PROGRAMME
Objectives and methodology

The research was carried out in two stages.

- A series of facilitated focus groups was carried out with a sample of Guinness Trust tenants to ascertain what types of kitchen were perceived as 'good quality'. Feedback was obtained on a variety of kitchen fittings from a range used by Guinness Trust in their homes (cupboard doors, drawer fronts, and handles) in terms of which participants would like best in their home, perceived durability, ease of cleaning and overall quality.
- Two questionnaire surveys, 18 months apart, of Guinness Trust tenants living in new or refurbished properties in two Guinness Trust regions, the South East and the West.

The aims of the questionnaires were to:

- assess Guinness Trust tenants' level of satisfaction with the amount of choice offered and to ascertain whether the amount of choice tenants have over their new kitchen affects their rating, usage and subsequent treatment of the kitchens.
- ascertain whether Guinness Trust tenants living in Section 106 acquired properties, who had not been given any choice over their fittings, perceive, rate, and subsequently treat their kitchens differently from tenants living in Guinness refurbished properties.
- assess what factors are important in predicting tenants' rating, usage and treatment of the kitchens.

The first questionnaire provided a baseline measure of tenants' attitudes to their new kitchens:

- how satisfied they were with the level of choice offered,
- how they used their kitchen
- how they rated the kitchen and the individual components.

The survey was repeated after 18 months when the tenants had had the opportunity to live with their kitchens for some time to ascertain:

- how durable tenants have found their kitchens to be,
- how much damage they reported
- how tenants' ratings, usage, and general perceptions had changed 18 months after installation.

RESULTS

Focus groups

The focus group findings indicated that on the whole, kitchens were important to people of all ages and genders. They are seen as the centre of the household and a meeting place both within the family and also for visitors. Cupboards played a key role in determining whether people liked or disliked their existing kitchens. The type of cupboard was important but so was the condition of the cupboard, the amount of cupboard space and the height of the cupboard.

Although participants had different views about colours and finishes, wood and wood-effect doors were generally the most popular. They were believed to suit most people and blend in well with other fittings. In contrast, white laminate doors were not widely liked; they were seen as cheap, plain and difficult to clean, and reminded people of 1960's council housing.

Handles were the most popular form of door-opening device although there was considerable variation as to style preference: C-shaped metal handles (Figure 1a and b) were most popular as they were robust and easy to grip.

Metal handles were much preferred to plastic ones as the latter were seen as much more easily broken and metal was viewed to be better looking. Knobs (Figure1 c and d) were disliked as they were seen as a safety hazard because they stuck out and could fall off easily if knocked.

Tenants generally reported that they would take better care of better-quality kitchens as they felt more incentive to do so and also felt that they preferred some element of choice. This finding was supported in the questionnaire results.

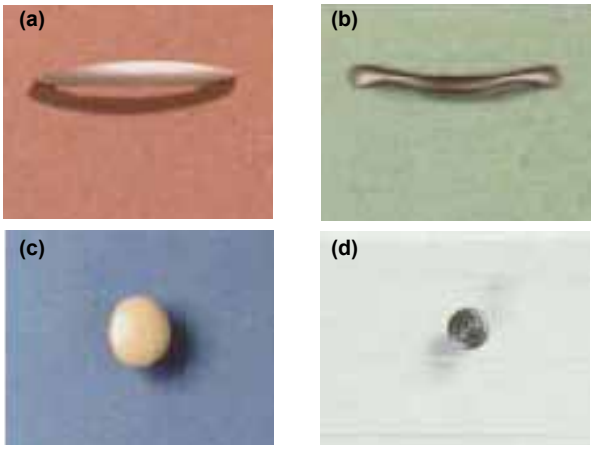

Figure 1: Kitchen cupboard and drawer (a), (b) handles, (c), (d) knobs

Questionnaires

Respondents were generally very happy with their new kitchens and were proud of them. Those who were given some choice over the colour and design of their kitchen components were generally satisfied with the amount of choice they were given and happy with the selection they were given to choose from.

The findings of the two questionnaires showed that on average, respondents from Guinness Trust refurbished properties, who were given some choice, rated every aspect of their kitchens as higher quality than respondents from Section 106 acquired properties who had no choice.

The differences between the two types of property were found to be even greater 18 months after installation than in the baseline questionnaire findings. Tenants who lived in Guinness Trust refurbished properties also rated the durability of their kitchens as higher and reported that their kitchens sustained less damage and required fewer repairs. Unfortunately, due to changes in policy and other factors, the kitchen ranges actually used were from different manufacturers, so it was not possible to say if the differences were due to actual differences in the kitchens themselves, the amount of choice offered or other factors influencing tenant perceptions of the kitchens.

Tenants' satisfaction with the amount of choice they felt they had had over their kitchen as a whole was found to be an important predictor of how much tenants liked their new kitchen and how much pride they felt in their kitchen. In addition, tenants who were more satisfied with the amount of choice they had over their kitchen, generally rated their kitchens as more durable and tended to report less damage had been sustained since installation.

CONCLUSION

It is not possible to say that offering choice actually causes tenants to be proud of their kitchens, to look after them or to perceive their kitchen as more durable. However, this finding is in line with the view, widely supported by social science research, that suggests that offering choice, even a limited choice, in decisions about their living environment gives people some feeling of control and has an influence on feelings of ownership, satisfaction and general psychological well being.

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BRE CENTRE OF EXCELLENCE IN SUSTAINABLE DESIGN OF THE BUILT ENVIRONMENT, UNIVERSITY OF CARDIFF

Christopher Tweed

Professor, Sustainable Design of the Built Environment

The BRE Centre of Excellence in Sustainable Design of the Built Environment (SuDoBE) is based in the Welsh School of Architecture (WSA) at University of Cardiff. The Centre was established in 2007 with the appointment of its Director, Professor Chris Tweed. The Centre continues and extends a successful partnership with BRE established through funded studentships and projects such as the Modern Methods of Construction project (led by the School's Design Research Unit) and the ongoing research and development of the next generation design tool, *Climate Lite* (Figure 1).

The main focus of the Centre's current research lies at the interface between people and built environment technologies. Its overriding aim is to develop a better understanding of how people perceive, experience and operate these technologies so that we can develop design tools and create a built environment that enhances people's lives and yet reduces our impact on natural systems. Research carried out in SuDoBE recognises the need for a holistic approach to sustainable design, embracing social and economic aspects of sustainability as well as the more conventional environmental concerns. The underlying premise is that if we are to reduce carbon dioxide emissions and reliance on energy consumption then it will require an imaginative approach to developing new solutions to persuade people to abandon the 'business as usual' attitude that is still prevalent.

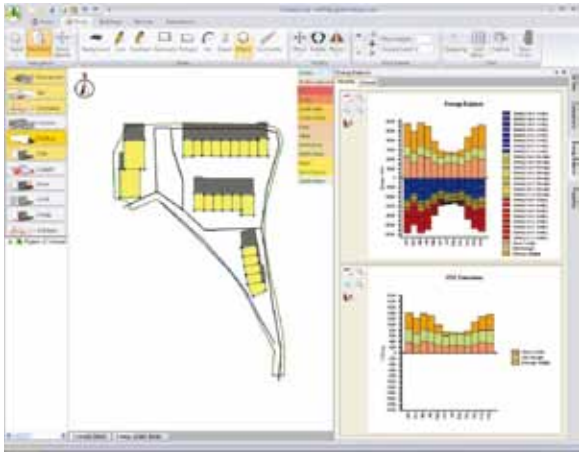

Figure 1: Climate Lite is an assessment tool to help architects and others evaluate design proposals at an early stage

Figure 2: Testing for the air tightness in dwellings built to Passivhaus standard

The Welsh Assembly Government funded an initial study of the Passivhaus standards as the basis for future low-carbon housing in Wales. This project was carried out in collaboration with BRE Wales and has made an important contribution to the move towards a low-/zero-carbon agenda for new buildings in Wales by 2011. The results from this research were disseminated as an invited keynote presentation to the Passive and Low Energy Architecture (PLEA) conference in 2008. BRE Wales is continuing to investigate the potential of Passivhaus in Wales using different meteorological data sets to reflect differences between the German and Welsh climates, as well as differences in microclimates across Wales.

Building on this early success, the Centre has attracted funding from the EPSRC (Engineering and Physical Sciences Research Council) and E.On for a major research project, *Carbon, Control and Comfort: user-centred control systems for comfort, carbon saving and energy management (CCC),* to investigate the relationship between occupants' behaviour in social housing, comfort and energy consumption. This collaborative project will monitor environmental conditions, energy consumption and lifestyles to inform the design of new control systems that will be installed and evaluated in real homes during the project. As part of this research, the team in Cardiff is monitoring environmental conditions in social housing in the Merthyr Tydfil area to find out what occupants consider comfortable and to relate this to energy consumption within the dwellings.

Figure 3: The EPSRC/E•On funded CCC project will investigate the impact of occupant behaviour on energy consumption in the pursuit of comfort

Figure 4: The UK has many buildings with thick stone walls that will be addressed in the SUSREF project

The Centre has recently started a project funded under the European Framework Programme 7 (FP7), *Sustainable Refurbishment of Building Facades and External Walls (SUSREF)*. SuDoBE is working with BRE Wales, Sustainable Gwynedd Gynaladwy and other European partners to investigate ways of improving the hygrothermal performance of hard-to-treat external walls, including the thick solid stone walls found in many older buildings in the UK. Many such buildings require a sensitive approach to refurbishment to avoid upsetting the delicate distribution of temperature and moisture that protects the construction from biodegradation. Many are listed buildings and therefore not amenable to 'standard' solutions. Refurbishment poses greater challenges for buildings on the western fringe of Europe where they are exposed to the persistent moisture-laden winds off the Atlantic Ocean. The research will involve intensive physical monitoring of existing properties before and after different treatments are applied.

The interest in retrofitting existing stock is reflected in the Centre's role in the Technology Strategy Board's (TSB) Retrofit for the Future programme. SuDoBE conducted the social survey and liaised with tenants during the selection of design alternatives. This project has now been selected for implementation in the final phase of the programme.

The Centre has benefitted from the success of the WSA in leading the new Low Carbon Research Institute (LCRI). This places the School at the heart of the research needed to support the move to a low-carbon future for Wales. SuDoBE and BRE Wales are contributing to this programme of work through participation in the Low Carbon Built Environment project, which will be funded as one of the LCRI projects.

The School has been awarded studentships from the BRE Trust in the past and the Centre now provides a focal point for future students. Three studentships have recently been awarded:

- Shiyu Jiang for a project on *Understanding the impact of occupant behaviour on energy consumption within existing homes*
- Gabriela Zapata for a project on *Learning from low-carbon design: designing and constructing buildings to emerging standards*
- Kate Knowles for a project on *Developing effective strategies for design interventions to improve sustainability in existing urban communities*

In all cases, these connect to projects that are either underway or about to begin in collaboration with BRE. The research, therefore, should benefit from, and contribute to, a synergy that will strengthen ties between the Centre and BRE. They further define the central theme of SuDoBE research which aims to address the interface between people and built environment technologies.

The Centre is currently awaiting the outcome of funding applications that will support research into the important junction between human activity and built environment technologies. The Centre has partnered with Manchester, Lancaster and Exeter Universities as well as the French electricity company, EDF, on a proposal submitted to EPSRC under the *People, Energy and Buildings* initiative. The Centre contributed to a proposal submitted under the EPSRC's *Sustainable Urban Environments* programme.

Other applications are in preparation, all of which are driven by the need to understand how to design (and re-design) the built environment to enhance people's lives using the least resources and minimising the impact on the planet. Developing this understanding is the Centre's highest research priority.

For further information on any of these projects or the article to follow, contact Professor Christopher Tweed, Tel: 02920 876207, Email: tweedac@Cardiff.ac.uk, Visit www.cardiff.ac.uk/archi/sudobe

THE POTENTIAL FOR SOLAR THERMAL TECHNOLOGIES AND THERMAL ENERGY STORAGE TO REDUCE THE ENERGY USE FROM WELSH HOUSING

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SUMMARY

This research deals with the potential contribution that state-of-the-art solar thermal systems enhanced by thermal energy storage technologies might have in reducing the energy use in Welsh dwellings: the share of the conventional energy currently consumed for thermal comfort and hot water that could be replaced by solar energy harvested by water-based solar systems with storages. Using the TRNSYS simulation engine, 12 typical Welsh dwellings were modelled and the solar thermal potential was investigated both via the mismatch of energy demand and availability and with the use of typical solar combisystems for Europe.

BACKGROUND

There is an impression, shared even among architects and designers, that there is insufficient solar energy in the UK for solar thermal (ST) systems to achieve solar fractions which would bring significant energy savings and carbon reductions, within economically feasible solutions. In addition, the lack of supporting policies at a national level and the poor reputation that ST systems gained in previous decades are responsible, to a large extent, for the limited installed ST capacity in the UK, compared with the rest of Europe. In general, it is usually the low-energy buildings that these technologies are considered for. When it comes to retrofit scenarios, it is expected that all other 'passive' measures are first implemented, resulting in a low space heating (SH) load to be (partially or fully) met by the ST system. With Wales being among the highest energy consumers in the world, and with an aging housing stock, one of the questions arising regarding the energy demands in existing Welsh dwellings is whether there is a realistic potential for energy savings and carbon reductions from the use of the solar energy incident on sloped roofs.

RESEARCH PROGRAMME

The focus of this work lies in the share of the overall amount of conventional energy currently consumed for thermal comfort and hot water preparation that could be replaced by solar energy harvested by active, water-based, solar systems. Twelve typical Welsh dwellings drawn from a recent survey and considered as representative of the Welsh housing stock were modelled (Figure 1), and the collectors' yield for different orientations and tilts was predicted. The subject was investigated with computer simulations using the TRNSYS simulation engine. The methodology dictates at first prediction and analysis of the thermal energy demand profiles of 12 × 4 case studies using average (smoothed) and actual (warmer) weather conditions (see Meteonorm tmy2 and METsite WSA data in Figure 2), continuous and intermittent comfort maintenance. Next, the ST potential is estimated considering solely a maximum

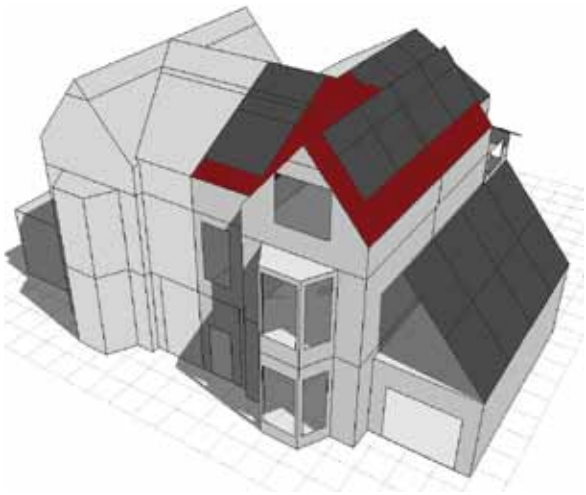

Figure 1: The 1850–1919 semi-detached house, one of the 12 models used in this study

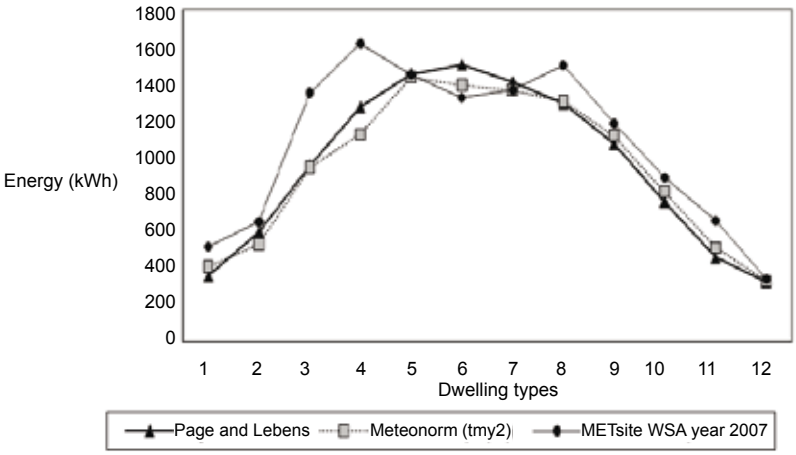

Figure 2: Monthly incident total (direct and diffuse) solar energy (kWh) falling on 10 m² south-facing 45° tilted collector area predicted with three weather datasets for Cardiff (two average and one actual data)

Key to Figures 2 and 4

Met = METsite weather data (recorded in 2007 from a weather station located at the roof of the Welsh School of Architecture)

tmy2 = average weather data Cardiff provided from the weather library of TRNSYS in tmy2 format. The tmy2 average year is built in **Meteonorm** and in the case of Cardiff is based on measurements from a local weather station (TRNSYS, 2006). See also Figure 2.

Cont Comf = continuous comfort maintenance (24/7)

Int Comf = intermittent comfort maintenance (comfort is maintained only when occupants are present in the house)

(0.7) and an average (0.4) overall system efficiency and no other technical part for the ST system (modelling approach), to investigate the mismatch of energy demand and availability and the thermal energy storage (TES) contribution. The performance characteristics of some representative European ST systems (short-term TES only), as derived from the IEA SHC Task 26 FSC method[1], are then applied to the simulations to reveal the potential with realistic losses and parasitic energy consumption included (applied only to five compatible models).

RESULTS

As a result of the simulations, a range of possible thermal demands for space heating and cooling in Welsh dwellings were predicted (Figure 3) and are listed as follows.

- The nominal space heating (NSH) requirement as calculated with average weather data for 24/7 use of the SH system ranges between 43 kWh/[m².a] and 242 kWh/[m².a].
- The NSH requirement for intermittent and constant thermal comfort in the case of actual 2007 weather conditions ranges between 16–92 kWh/[m².a] and 24–172 kWh/[m².a] respectively.
- For the predictions of the year 2007, a maximum cooling demand of 49 kWh/m² is calculated for the continuous comfort scenario.

The modelling approach showed that ST systems could contribute to thermal savings of between 9–34% solely with direct utilisation of the collected energy (Figure 4). In general, when warmer than average actual weather

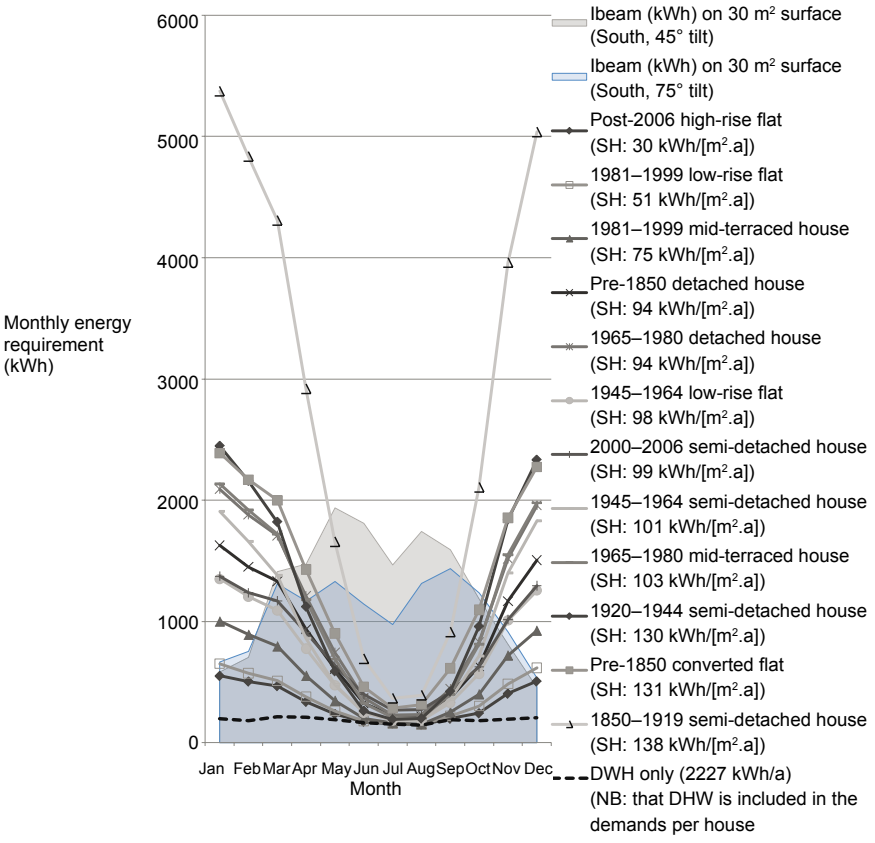

Figure 3: Predicted thermal requirement for hot water and space heating for the 12 case studies and incident beam solar energy on 30 m² south-facing surfaces with 45° and 90° tilt (for intermittent comfort and average weather conditions)

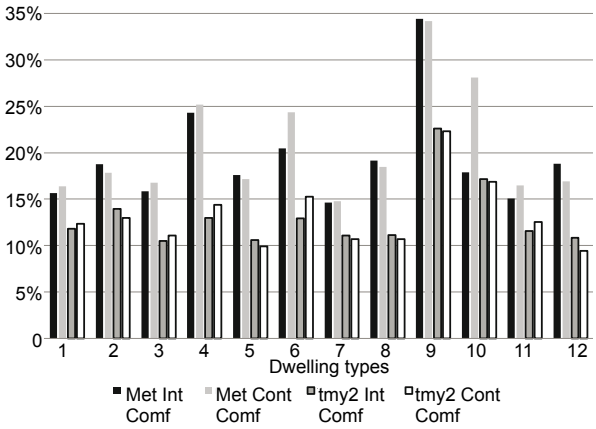

Figure 4: Percentage of total annual thermal energy requirement met by direct use of the collector yield (predicted for two weather and two comfort conditions) per house type

conditions were tested the ST potential predicted was found to be significantly larger than that of average weather conditions. It was also found that although at an annual basis the potential appears to be greater for intermittent than continuous comfort system strategies, the direct solar utilisation in a 24/7 comfort maintenance scenario might be higher than that of an intermittent usage, depending on the thermostat settings and of course on the absorbers' orientation. It is thus highlighted that due to the fluctuating nature of the solar availability in the UK climate, a solar system has to work as a receptor of the 'free' energy at any time of the day, and be able to utilise it in an effective way. A strategy designed to feed the house with the available energy when this becomes available without being tied to a scheduled demand, could be the preferable choice.

Furthermore, for most cases, if stores of a reasonable size are used (up to 300 kWh TES capacity) then the solar contribution to the overall thermal energy consumption, in the most favourable conditions, would be around 42–58%. Only a couple of models appear to have a lower potential, mainly due to lack of sufficient absorber areas. It was further shown that a clear threshold on the required collector capacities exists for each house type and this effect follows the 'law of diminishing marginal returns' (Figure 5). Absorber areas larger than a certain size would not contribute to higher energy savings or smaller TES sizes. However, for reaching the highest end of expectations for certain house types (up to 54% with the average and up to 100% with warmer weather conditions) inter-seasonal storage would be required. In this case, the justifiable storage capacities predicted correspond to large store volumes, revealing that these are currently not feasible options, as sensible heat storage is still the state-of-the-art for TES. Use of innovative storage types identified by the literature survey, that would only be available in the future, are required to achieve high solar contributions, considering space limitations in Welsh dwellings.

The results of the FSC method show that for the five models the use of solar energy would bring thermal energy savings of around 41–47% if the best system is employed compared with a conventional system, while if parasitic (electric) energy consumption is considered the expected energy savings could be as low as 10%. The actual ST potential is analysed and is found to be in between the two approaches, as both methods have advantages and limitations and complement each other (Table 1).

CONCLUSIONS

The results show that all these house types are possible candidates for effective ST applications, assuming that economies of scale would allow for large absorber areas in the near future. Most importantly, this work highlights that it is worthwhile discussing solar thermal systems in the UK so more attention should be given to solar thermal technologies, especially with regards to the current targets for energy savings and carbon reduction in the built environment. The focus of further research in this area should be on the particular characteristics of the appropriate solar thermal system(s) per house type, including the thermal energy storage component of the installation.

REFERENCE

[1] Weiss W. Solar heating systems for houses: a design handbook for solar combisystems. London, James & James, 2003

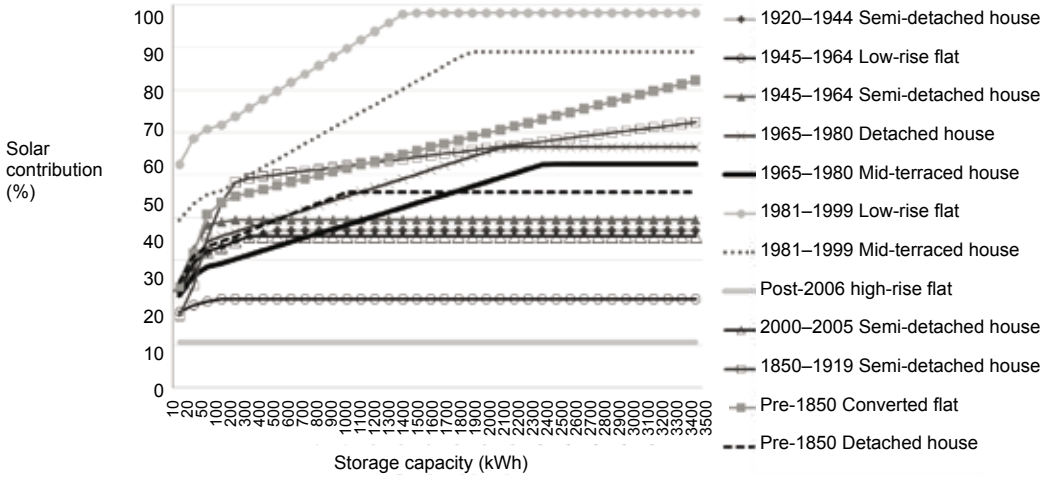

Figure 5: Solar contribution for different storage capacities for the 12 houses with actual 2007 weather data for Cardiff and intermittent comfort maintenance

Table 1: **Summary of the results by dwelling type**

House no.	House type/ era	No. of collector units, tilts and azimuths	Roof % covered	Range of results for 2 comfort (intermittent and continuous maintenance) and 2 weather (actual 2007 and average) conditions. System losses ignored			Maximum solar contribution and respective store requirement predicted a ST system with overall efficiency at 0.4			
				NSH demand (kWh/m². a)	Annual collectors' yield / Annual overall demand (%)	Direct use of collectors' yield (hourly intervals) (%)	Int Comf Met		Cont Comf tmy2	
							(%)	(kWh)	(%)	(kWh)
1	Pre-1850 detached house	5 S (35° tilt)	72	62–131	39–98	12–16	56	1100	22	100
2	Pre-1850 converted flat	6 S (46° tilt) 7 E & 7 W (34° tilt)	78	91–242	41–191	13–19	100	5600	34	1800
3	1850–1919 semi-detached house	2 E (28° tilt), 2 S (28° tilt), 4 E (26° tilt), 12 S (50° tilt), 6 S (31° tilt)	74	92–227	54–137	10–17	100	10300	45	7000
4	1920–1944 semi-detached house	3 NW & 3 SE (38° tilt), 4 horizontal	81	88–237	27–82	13–25	47	500	16	300
5	1945–1964 low-rise flat	2 W & 3E ⁻10° (90° tilt)	54	65–138	20–54	10–18	31	100	11	10
6	1945–1964 semi-detached house	6 S (40° tilt)	85	66–176	32–87	13–24	50	200	18	20
7	1965–1980 detached house	8 S (29° tilt)	89	61–151	42–116	11–15	67	2200	24	400
8	1965–1980 mid-terraced house	4 W & 4 E ⁺5° (26° tilt), 3 horizontal	59	66-158	41–110	11–19	63	2500	23	800
9	1981–1999 low-rise flat	4 W & 4 E (14° tilt)	68	32–83	70–180	22–34	98	1400	54	700
10	1981–1999 mid-terraced house	4 W & 4 E ⁺5° (29° tilt)	82	46–109	70–159	17–28	89	1900	40	900
11	2000–2006 semi-detached house	4 S (46° tilt)	63	72–145	33–80	12–17	46	300	19	50
12	Post-2006 high-rise flat	2 NW & 2 NE (90° tilt)	62	16–43	20–32	10–19	21	10	11	20

ABOUT BRE TRUST

BACKGROUND

BRE Trust is a charitable company whose objectives are through research and education, to advance knowledge, innovation and communication in all matters concerning the built environment for public benefit.

BRE, along with BRE Global Limited and FBE Management Limited, are wholly owned subsidiary companies of the Trust. This ownership structure enables BRE to be held as a national asset on behalf of the construction industry and its clients, independent of specific commercial interests and protects BRE's impartiality and objectivity in research and advice.

Profits made by BRE and by the other subsidiary companies are passed to the Trust and used by it to promote its charitable objectives.

The Trustees meet in Council four times a year to provide strategic direction and to oversee and guide developments of the charity and of its subsidiary companies. The Trustees ensure that the charity pursues its objectives of 'for public benefit' research and education and that the assets owned by the Trust, namely its subsidiary companies, are used in a way that will contribute to the Trust achieving its objectives.

The Trust is the largest UK charity dedicated specifically to research and education in the built environment.

CONSTITUTION

BRE Trust is a company limited by guarantee Company number 3282856 and is registered as a charity in England and Wales (no 1092193) and in Scotland (no SCO39320). It is governed by its memorandum and articles of association.

Its registered office is Bucknalls Lane, Garston, Watford, Herts WD25 9XX.

TRUSTEES AND OFFICERS OF THE CHARITY

The Trustees serving during 2009 are as given in Box 1.

The Trustees delegate the day-to-day management of the charity and management of its subsidiary activities to BRE Group's Chief Executive, Martin J Wyatt, and Finance Director, Russell Heusch.

***Box 1:* Trustees serving in 2009**

Chairman
Sir Neville I Simms FREng

Professor John B Burland CBE, FREng, FRS
John Callcutt CBE
Mark Clare (from 5 August 2009)
Professor Leslie A Clark OBE (until 26 November 2009)
Steven Evans (from 5 August 2009 to 13 November 2009)
Mark Farrar (from 5 August 2009)
Hugh Ferguson (from 5 August 2009)
Richard Gillies (from 5 August 2009)
Richard B Haryott FREng
Peter Lobban OBE
John R Pike (until 8 January 2010)
Ian Stewart (until 5 May 2009)
David J Szymanski (until 21 October 2009)
Williams R Treen
Hugh W Try CBE
Geoffrey H Wright (until 26 November 2009)

Secretary
Russell Heusch

GOVERNANCE

Trustees are invited to become a Trustee because of the merit of their skills, and because their general expertise would be of benefit to the Trust and represent the wider interests of the built environment.

The Council has five committees reporting to it:

- Finance and Audit Committee
- Research Committee
- Publications Committee
- Business Development Committee
- Site Development Committee.

Management

The Trustees are expected to:

- give strategic direction to the work of the BRE Trust and group companies
- have an input into the strategic business plans of the group companies
- extend the scope of BRE Trust's charitable activities and seek funding

- develop research and education objectives for the charity and prioritise expenditure against such objectives
- act as ambassadors for the work and objectives of the Trust and its group companies
- benchmark the activities and achievements of the Trust and group companies
- ensure the excellence of scientific standards within the BRE group of companies.

All other day-to-day decisions have been delegated to the boards of directors of the subsidiary companies.

The Council of Trustees meets quarterly. The directors of subsidiary companies and senior staff are invited to the meetings to report on operational and business performance.

The activities of the trading subsidiaries are:

- Building Research Establishment Limited provides independent advice and information on building performance, construction and fire safety in the UK
- BRE Global Limited carries out research, testing and certification of materials and products, and certification of personnel, buildings, processes, systems and supply chains
- FBE Management Limited manages research work and carries out consultancy and research for the European Commission and provides technical support for the Construction Products Directive.

BRE TRUST REVIEW 2009

The BRE Trust Review 2009 presents a summary of the year's activities and achievements. The main focus is on short papers from BRE, BRE Global and the five BRE Centres of Excellence, summarising research projects funded by BRE Trust in 2009. These papers demonstrate the breadth and scope of the research that is being supported by the Trust.

BRE TRUST TITLES PUBLISHED BY IHS BRE PRESS

VACANT DWELLINGS IN ENGLAND: The challenges and costs of bringing them back into use
FB 24, 2010

THE REAL COST OF POOR HOUSING
FB 23, 2010

BUILDING-MOUNTED MICRO-WIND TURBINES ON HIGH-RISE AND COMMERCIAL BUILDINGS
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COMPLYING WITH THE CODE FOR SUSTAINABLE HOMES: Lessons learnt on the BRE Innovation Park
FB 20, 2009

AUTOMATIC FIRE SPRINKLER SYSTEMS: A guide to good practice
FB 19, 2009

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