ROYAL ACADEMY OF ENGINEERING

SMART BUILDINGS
people and performance

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1. Introduction


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Recent advances in data gathering and analysis are opening up new possibilities for smart building technology. For the first time, building management systems (BMS) have the capability to learn and even anticipate their occupants' needs and preferences for light, temperature and other services – saving energy through targeted supply. The ongoing expansion and upgrading of wireless networks and leaps in computing power mean that today's smart building designers possess the tools to use data to make the built environment more comfortable while reducing our carbon footprint.

In March 2013, the Royal Academy of Engineering held a roundtable meeting to consider potential applications for smart building technologies and to identify possible challenges. Consensus rapidly emerged that smart buildings will be crucial to maintaining quality of life as urban populations rise and natural resources dwindle. However, this would be predicated on an environment of supportive policymaking and improved research funding for the construction sector.

Arup Global Research Director Professor Jeremy Watson FREng, who chaired the meeting, used the occasion to call on engineers, architects and technologists to create "inspiring, transformative proposals" that will attract funding and support for the smart building sector. The roundtable proposed to:

- Encourage holistic, systems thinking in the design of buildings
- Introduce a vector of value in building design that takes in wellbeing, maintenance and productivity
- Consider the bigger picture of service, security and future-proofing of a building, and to develop business models which promote this approach
- Extend the temporal and spatial systems boundaries to take in the whole building life cycle.

For the first time, building management systems (BMS) have the capability to learn and even anticipate their occupants' needs and preferences for light, temperature and other services

"The rate of increase in resource consumption means that business as usual is not an option. I believe that the only solution to this challenge is improving and rolling out digital infrastructure and digital services."

Mike Perry, principal consultant at BRE

CASE STUDY

EDF Energy smart meter roll-out

By 2019, EDF Energy aims to have installed smart meters in 100% of the homes and small businesses it provides energy to. The kit will include gas and electricity meters, an in-house display and a (non-internet) connected communications hub that allows customers to view data on other devices and link with the supplier systems. At the point of installation, EDF Energy plans to offer energy advice and explain how to take advantage of the meters. It will also make customers aware of other energy-saving devices on the market.

EDF Energy will offer time-of-use tariffs to manage demand, with smart meters offering the ability to analyse consumption and automatically control load.

The government and energy suppliers are setting up an infrastructure to administrate the network. This will include a regulated national centralised data and communications monopoly that will be subject to licence. A smart energy code will govern the system's participants and its administration, while new regulations will protect customer data as well as ensuring all customers are treated fairly.

Smart metering has been mandated for energy suppliers. However, customers may opt out completely – as customers will have in-home displays which will allow them to choose the amount of data going back to the supplier.

2. Tools and technologies for 'smartness'

Sensors and the internet of things

By 2020, there will be an estimated 50 billion networked appliances and sensors worldwide, constituting a vast global network of data-generating devices such as sensors and their URLs, known collectively as the 'internet of things'.

Sensors are increasingly being installed in buildings to gather data about movement, heat, light and use of space. This information allows building management systems (BMS) to make reactive – and even anticipatory and personalised – real-time alterations to a building's environment to suit its occupants. Data from sensors can also be analysed as part of post-occupancy evaluations to inform the design of subsequent buildings and systems. Such information may ultimately be incorporated into 'real-time Building Information Modelling (BIM)', enabling live data to be held in the data structures used to describe building design.

While there are applications across all building types, the healthcare sector promises particularly interesting opportunities for internet-connected sensors. For instance, sensors could extend the length of time that elderly people can remain in their own homes by allowing remote monitoring of health through blood pressure and heart monitors that note behaviour patterns and highlight any change that might indicate a problem, offering improvements to their quality of life and generating savings for the NHS.

However, we need to find an affordable way of sending data from sensors to the internet if their mass rollout in public and private buildings is to happen.

"The solution needs to be incredibly cheap and ubiquitous and ideally should be global to achieve economies of scale", says Neul Chief Technology Officer Professor William Webb FREng. He sees the likely solution in 10-year battery-powered long-range (up to 5km) wireless sensors that bypass congestion with local ICT network signals and avoid the need for expensive wiring.

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Smart meters and smart grids

Smart electricity meters use sensors to record energy use, feeding information to the provider as well as the building occupant, to help regulate energy use and lower bills. Smart meters are set to become a strong presence in UK households and business premises following a government mandate issued to energy suppliers in 2011 to distribute them to 100% of customers by end of 2019.

The government estimates that, over the next 20 years, the rollout of smart meters will deliver £7bn in net benefits to consumers, energy suppliers and networks by creating more accurate billing and lower bills by increasing customers' control of electricity usage and broadening the choice of payment methods.

This pioneering attempt to create a national smart utility network is intended to "create a platform from which energy and other service suppliers can innovate," says Head of Industry, Regulation and External Affairs for Smart Metering at EDF Energy Ashley Pocock. He adds, "Interconnectivity with smart appliances will be an important part of the programme and provide a bridging point with smart buildings".

Smart meters are the first step to creating a national smart grid, where electricity will be delivered to customers on the basis of responding to dynamic demands using data. This is a long-term model with a five-year rollout and a 20-year business case. "We don't really know what the smart grid will look like yet, although policies that will shape it are starting to emerge now," says Pocock.

CASE STUDY
Cookham Wood

Cookham Wood young offenders' institution in Kent was the first project to use BIM, in the construction of a 180-room, two-wing, three-storey extension.

The first data drop entailed stakeholders meeting to share information to create a design. The second focused on the creation of detailed 3D modelling of the structure, while the final two data drops involved sharing information on construction, operations and maintenance.

"It took a lot of hard work and pre-planning, which may be where BIM gets its value – in the amount of effort put into getting the customer to thoroughly work out what they need from the project," says Professor Tim Broyd FREng, Professor of Built Environment Foresight at University College London.

Building information modelling

In May 2011, the Cabinet Office published the Government Construction Strategy, with a timeline for publicly-funded building projects to use BIM. The paper specifies "full collaborative 3D BIM by 2016".

Through 3D computer modelling, BIM is an information repository for the geometry, spatial relationships, quantities and properties of the whole building and its components, allowing architects, engineers and designers to work on the same platform. The spatial relationships defined can then ensure that there are no clashes between services and new elements can be produced and replaced easily and accurately.

The government's goal for BIM is to reduce construction costs by 20% by organising a project's plan of work around a series of shared 'data drops', thereby avoiding costly duplication of information between the teams working on the construction.

BIM is also a platform to provide data for the user. It is a way of looking at a building as a system, a method that has been used in manufacturing for decades where interoperability of elements allows for adaptability in processes.

It is how BIM is used that demonstrates its value as a smart building tool. The digital plan of work should also include the user's requirements in the system loop that feeds useful data back to the model, so that performance of the building can be checked against those requirements and improved.

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3. Smart data

Data and energy use

Big open data and social media are creating opportunities for the world's first smart applications. "Until very recently, we have only been able to interpret data by putting it in a very specific format and running it through a supercomputer," says Through Architecture Director Paul Fletcher. He adds, "The magic of big data is finding synergies by putting massive, disparate, non-formatted datasets through standard computers."

The use of algorithms to analyse huge amounts of data in near real-time helps energy companies take decisions about supply. There are ambitious visions about how this data could be used, if city service systems were integrated. Mike Perry envisages linking healthcare and energy systems, among others, so that "when elderly Mrs Smith, apprehensive about her energy bills, spends three consecutive winter days without the heating on, the local healthcare agency is alerted to check on her, possibly preventing a case of hypothermia."

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Data and building use

Data-enabled machine learning creates a smart building, whose defining feature is the ability to be proactive in making appropriate changes to services on behalf of its users. Andrew Eastwell, Chief Executive of the Building Services Research and Information Association, described smart as "equal to self-awareness plus the ability to react".

In the hope of creating more productive workplaces, Paul Fletcher envisages data-informed smart systems that "allow you to query a large building about what space you should use for a particular activity, and have it make a suggestion".

Data and structural design

The collection of finely-grained data relies on employing sensors to monitor the building and its occupants' behaviour to inform post-occupancy evaluations. Underlining the pre-eminence of sensors, Bennetts Associates Director and Architect Simon Erridge believes the true definition of smartness "lies not in the provision of services but in the collection of post-occupancy data".

Big data's full potential can only be exploited when shared openly with the construction community in order to create a feedback loop that enhances the design of future buildings.

> "It is not all about high-tech digital design technologies; an intelligent building has to include other low-tech approaches such as passive environmental control."
>
> Professor Derek Clements-Croome, University of Reading

4. Smart buildings and smart people

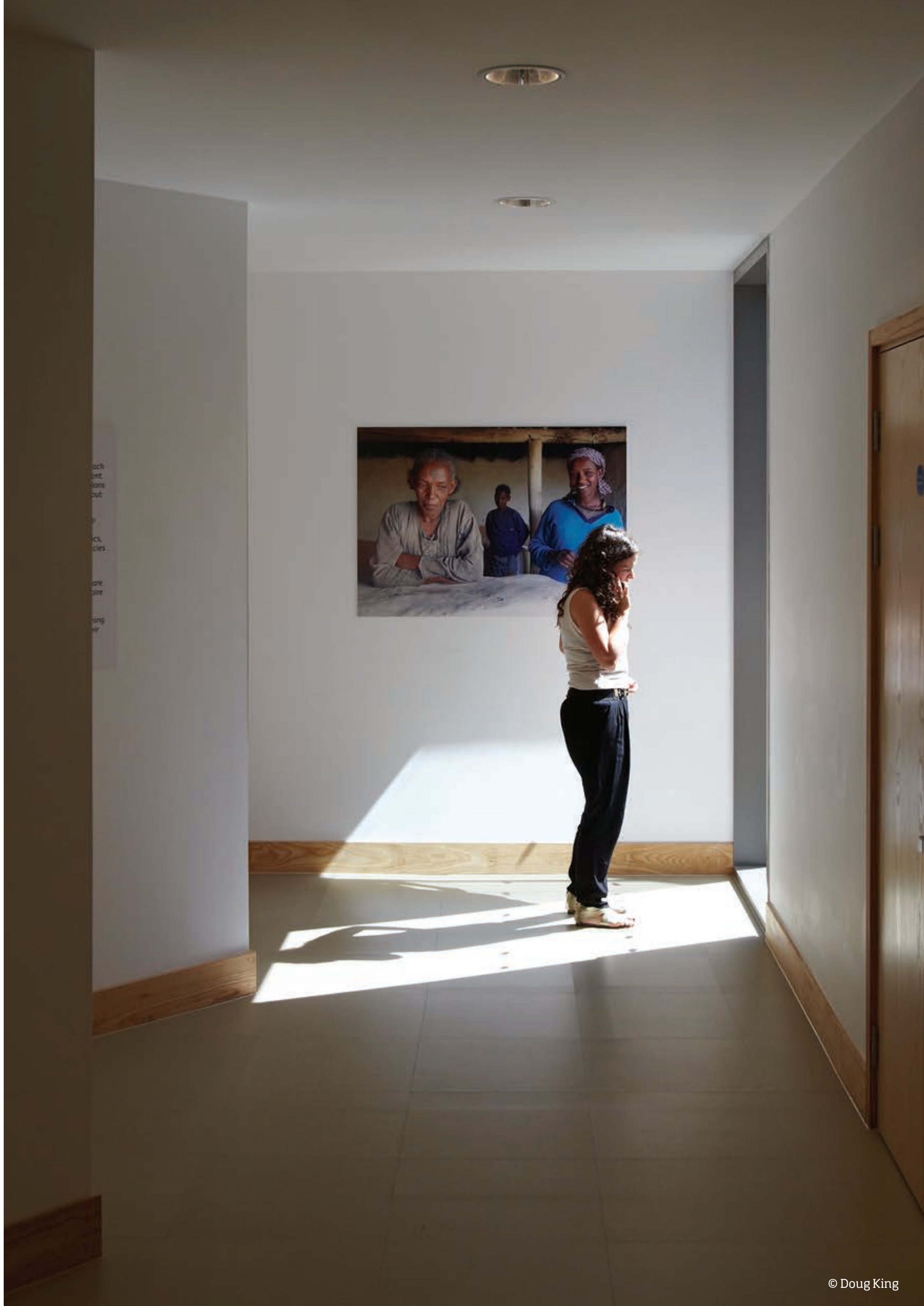
The living building – buildings as sociotechnical systems

Buildings should evolve and adapt to accommodate their users. It is therefore important to incorporate the user into the design of buildings and allow them control over their environment. Smart buildings should be responsive to their inhabitants in order constantly to improve living conditions.

William Webb observes that, although the concept of the smart home has been around for at least 40 years, "it has been messed up every which way, with misaligned objectives between end users and those who design the smart system". He suggests that architects and smart technologists resist anticipating the needs of users, instead consulting with them at the start of the design process.

Close observation of the behaviour of occupants is important when retrofitting smart technologies to existing buildings in order to provide appropriate services. Simon Erridge also recommends that architects and installers remain mindful of the human need to feel in control of the immediate environment. "People want to engage with the controls rather than feel at the mercy of a technological hand of God", he says.

As well as soliciting the opinions of users, building designers should embrace their role as service providers and collaborate more closely and creatively with clients to create innovative buildings.



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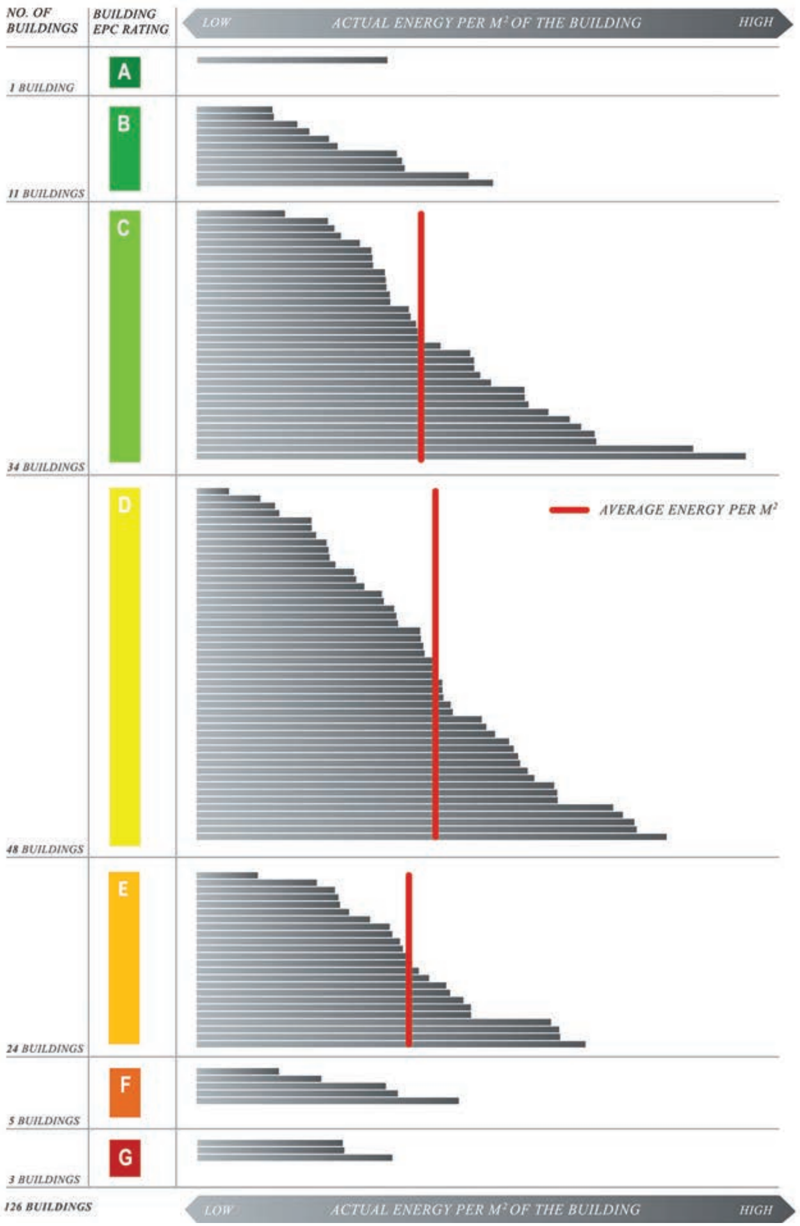
Actual energy use of more than 100 BBP member offices grouped by their EPC rating



Source: *A Tale of Two Buildings*, Jones Lang LaSalle / Better Building Partnership, 2012
www.betterbuildingspartnership.co.uk/download/bbp-jll---a-tale-of-two-buildings-2012.pdf

"I can guarantee that what we assumed would happen in a building when we designed it, now isn't happening. There is all too often a tendency to blame the occupiers for that. We need to focus on people and get buildings to be reactive to human needs, not the other way round."

Paul Fletcher, Director of Through Architecture

CASE STUDY

Romero House – design for productivity

Some buildings are structurally designed to help people behave more smartly. Aid agency CAFOD's headquarters in Romero House in London lacks data-driven smart technology, yet helps its occupants to work more creatively, reduce energy use and even stay fit.

With the lifts tucked discreetly away, the default behaviour of CAFOD staff is to use the stairs. The stairwell features offset mezzanines with coffee points, toilets and meeting rooms, rather than the facilities being located on the office floors. Staff must choose between two alternative destinations for coffee and thus cross paths, facilitating interdepartmental knowledge-sharing.

Within weeks of the charity moving into Romero House, an aid team solved what they had considered an intractable problem after a chance conversation over coffee revealed that a team working on the other side of the world held a key piece of knowledge which unlocked the solution.

"All we can do is try to make buildings that permit people to use them in any way they want to, in ways we may not imagine," says consulting building engineer Professor Doug King FREng.

CAFOD's Romero House design team: architect – Black Architecture, structural engineer – WSP, service engineer – King Shaw Associates.

Smart systems and the user

Building occupants, with higher priorities such as work and family, may lack the time, knowledge or inclination to create optimally efficient environmental conditions. This is where smart building technology can step in, learning and anticipating user preferences, and altering conditions to meet user needs more precisely and flexibly than we ourselves can. However, the human tendency to abandon technology when it fails to be more attractive than a tried-and-trusted low-tech solution offers smart technologists a formidable design challenge.

While most people rapidly come to rely on trustworthy and prevalent new technologies, some groups struggle to adapt. The guiding principle of inclusive design, which dictates that products and services should be designed to serve their most vulnerable users first, may be considered in the creation of smart building system interfaces – especially for premises that lack a resident technician.

By extension, the undesirability of every smart building having its own set of instructions raises the need for a standardised interface that would enable the inexpert or semi-skilled user to master a new building management system fast and instinctively.

To survive, smart building systems need to accommodate individual occupants' contrasting preferences for heat, light, cooling, entertainment, video conferencing and other services. A possible solution could be for building

> "Smart is about the building beginning to anticipate your needs – it is about living in a machine that cares about you."
>
> Professor Jeremy Watson FREng, Director of Arup Global Research

users to be identifiable to the BMS networked system and possess their own set of identifying cookies to help the system configure the best solution for all occupants at any one time.

Education and cultural change

Establishing public trust in smart buildings demands the design of reliable systems and instinctive interfaces. But achieving the prerequisite buy-in for the technologies will require communication of their benefits to clients with non-technical backgrounds such as local authorities and property developers. Using accessible language to describe the systems is key to winning the support that will carry smart technology into our buildings.

Similarly, non-technical education about how to use smart technologies should be provided. Consultant engineer Professor Doug King FREng claims that the average lifetime of a domestic energy meter is two battery changes, "after which the novelty wears off because we don't really know the benchmark against which to compare our statistics – it is just data noise". We must also bear in mind 'contrary' and 'rebound' behaviours in response to energy meters – for example people initially taking an interest in their energy use but gradually shifting back to their previous usage patterns.

A cultural shift is also necessary within the construction and technology sectors to open lines of communication between them. One urgent challenge that will require unprecedented cooperation arises from the contrasting lifespans of physical buildings and digital technology.

Towards a new construction paradigm

The lifespan of a building is currently around 50 to 100 years, while digital technology changes over a dramatically shorter two- to five-year cycle. The possibility that buildings may have to become 'evolvable' offers an opportunity for imaginative thinking, viewing the building as a core infrastructure into which 'applications' can be plugged. The structural frame holds half the embodied energy of a building, making retrofitting essential to introduce smartness while managing carbon emissions.

There are parallels in the relationship between smartphones and their apps, and buildings and their smart systems. A smartphone can be disaggregated

> "Behavioural science tells us that we are intuitive beings. This technology should not be about taking our decisions away, but about enhancing our decision-making."
>
> Paul Fletcher, Director of Through Architecture

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as a collection of sensors, such as GPS, software in the form of apps, and outputs such as the screen and speaker. The elements in a building can be disaggregated in the same way to separate basic structure from the services hosted by the building.

The design of commercial aircraft offers another potential model to learn from. The average working life of a Boeing 747 is approximately 50 years, during which time it is refitted about six times. The necessity of making frequent upgrades to its electronic, communications and other systems requires that the design allows old technology to be rapidly removed and replaced with minimal disruption to the fabric of the plane.

Buildings could be conceived as similarly upgradeable as technology changes, with elements added in such a way that they can easily be changed as technology and the building's use develops. Architect Paul Fletcher expands on the idea, looking at the use of disruptive technologies for supporting this continual remodelling, suggesting "installing a 3D printer in the basement to create modular workspaces as they are needed, which are then dissolved ready for reuse".

> "The advance of technology is bringing new threats. The advent of superfast broadband means there is a considerable amount of damage that can now be done from a home computer."
>
> Hugh Boyes, Cyber Security Lead at the Institution of Engineering and Technology

5. Risks and challenges

Privacy and the security of data

The growing availability of data produced by social media, smart devices and the internet of things raises concerns about privacy, data ownership and security. Users' willingness to provide or share personal information and use applications increasingly depends on whether they trust the data processor to protect their privacy and to use the data in a fair, legal and accountable manner. Loss of user confidence or trust has implications for application usage and the quality of data provided.

Hacking causes serious reputational damage to major institutions such as banks and retailers, a fact which requires us to improve the trustworthiness of software and to endeavour to 'design out crime' from data systems. Preventing security breaches will require government to work with commerce and engineering to create regulatory and legal frameworks as well as software engineering and maintenance standards that can protect both organisations and individuals. Recent experiments by security specialists found that 90% of test phishing attacks launched on the staff of large corporations succeeded. While risks arising from these attacks may be partially mitigated by improved user awareness and training, the experiments demonstrate the need to develop more resilient systems.

Where in the past the cyber security threats were primarily hacking and viruses, the advent of malicious software like the Stuxnet worm and the use of botnets to deliver denial of service attacks means that the systems supporting smart buildings are exposed to a wide variety of threats. The systems in a smart building will need to be engineered to minimise the impact of such threats and to allow changes over their life cycle to address emerging threats.

Development of smart buildings involves the integration and interaction of a range of building, corporate and third party systems. The creation of these complex 'systems of systems' will introduce new management challenges relating to the continuity and security of operations as processes and data across organisation boundaries. For example, if building management systems (BMS) operated by the facilities team are connected to corporate systems operated by the corporate IT team, there needs to be clarity about who takes responsibility for protecting the security of the BMS, which has the characteristics of a control system rather than a typical enterprise computer system. This could also allow building performance information to be available via an 'enterprise dashboard' which can provide a visual understanding of the key performance indicators and metrics.

In multi-occupancy or multi-use buildings, the complex business models of building ownership and tenancy can also result in confusion about who should take responsibility for building security. This needs to be addressed in the design and operation of any shared infrastructure or applications, particularly where they affect individuals' health and safety or the security and availability of the building[1].

[1] The Institution of Engineering and Technology has recently published a briefing document on these issues [http://www.theiet.org/cyber-buildings].

CASE STUDY
The BRE Environmental Building, Watford

The Building Research Establishment (BRE) Environmental Building features external louvred shades that were programmed to adjust automatically to changing light and heat conditions. However, about six years after the building was completed, the mechanism controlling the louvres failed, leaving them in a horizontal position. To keep out solar glare, the building's occupants installed blinds. Today, the louvres remain static, the system has been entirely abandoned and the blinds are rarely raised even when light levels fall. "What was commissioned as a smart building became dumb," says Doug King. "If we don't provide the service, then no amount of machine smartness can overcome the inventiveness of the human users. People are very good at making decisions and weighting them on criteria that machines cannot replicate."

Maintaining systems

Integrating digital, electronic and mechanical systems to create a smart building promises great benefits, but only if the BMS is well-maintained.

As building service networks become more integrated, they also become prone to cascade failures that impinge on the comfort and productivity of building occupants and at worst endanger their safety. Preventing such failures is likely to become the joint responsibility of IT and facilities departments and will require continuous investment on the part of the building owner or tenant.

The expertise to safeguard BMS systems from attack belongs to smart building system engineers, installers and maintainers, bringing a need for scrupulously drafted and monitored industry standards.

"Whatever 'smart' is, it comes at a maintenance penalty."

Professor Tim Broyd FREng, Professor of Built Environment Foresight at University College London

6. Making smartness work

Understanding human behaviour in buildings

Since smart building technology is intended to serve human needs, software engineers and architects could gain valuable insights by talking to behavioural psychologists about the design of BMS systems. More research needs to be done in order to understand users' reaction to smartness. Living demonstrations and the post-occupation evaluation (POE) of a building will also be important to ensure that buildings meet the needs of their occupants.

Making the most of BIM

Establishing exemplars of BIM good practice and ensuring that standards are in place to guarantee BIM fulfills its potential will be important to progressing smart building technology.

BIM was introduced to save money on the design and construction process, but there is an appetite for it to serve social as well as financial ends. Paul Fletcher suggests that a post-occupancy evaluation of Cookham Wood that not only measures cost savings but also takes in comparative data about reoffending rates among inmates of the new wings would be useful in informing the design of young offenders' institutions. This approach may eventually save money at both ends of the building process. "The purpose of Cookham Wood is to rehabilitate young offenders: that should be the driver of the economies in this project," says Fletcher.


© Doug King

Openly sharing information gathered during the post-occupancy stage is in the spirit of – and key to – maximising the usefulness of BIM, benefiting building projects in general, says Erridge. "If post-occupancy evaluations reveal poor performance, smart building architects are duty-bound to release information about the event, regardless of the risk of legal action against them. We need to share data about failures without prejudice."

Collecting and using the 'right' data

The relative novelty and sheer scale of big data are contributing to a lack of confidence about how to identify the 'right' data and then gather and interpret them. While an abundance of information exists about the choices people make in the consumer product and services realm, the as yet small-scale use of sensors within buildings means that there is relatively little data about our use of the built environment. But even once gathered, some doubt remains on how important data are to modelling building use.

"We assume the more data, the more accurately we can model a building, but that's not quite true," says Dr John Counsell of Advanced Control Partnerships. "Systems models are not very good at predicting energy use. We have all this data but we don't understand how to use it."

Finally, BRE Trust Director Nick Tune urges engineers, architects and suppliers to remember that "ultimately, it is about service not gadgets, and it is not about the data itself, but about how we exploit the data to create better living and working environments".

7. Roundtable participants

Name	Organisation
Professor Jeremy Watson FREng (Chair)	Arup
Dr John Counsell	Advanced Control Partnerships Limited
Simon Erridge	Bennetts Associates
Mike Perry	BRE
Nick Tune	BRE Trust
Saviour Alfino	BSI Smart Cities Standards Strategy
Andrew Eastwell	Building Services Research and Information Association
Professor Derek Clements-Croome	CIBSE – University of Reading
Tony Williams	Cube Controls Ltd
Professor Doug King FREng	Doug King Consulting Ltd
Ashley Pocock	EDF Energy
Professor Will Stewart FREng	IEEE
Hugh Boyes	IET Cyber Security
Andrew Cooney	IET Standards
Dr Martyn Thomas CBE FREng	Martyn Thomas Associates
Professor William Webb FREng	Neul – Weightless
Dr Damien McDonnell	Perseus Global UK
Paul Fletcher	Through Architecture
Professor Tim Broyd FREng	UCL
Professor Campbell Middleton	University of Cambridge
Dr Chengzhi Peng	University of Sheffield
Beverley Parkin	The Royal Academy of Engineering
Dr Natasha McCarthy	The Royal Academy of Engineering
Sahar Danesh	The Royal Academy of Engineering

Report prepared by Emily Pacey

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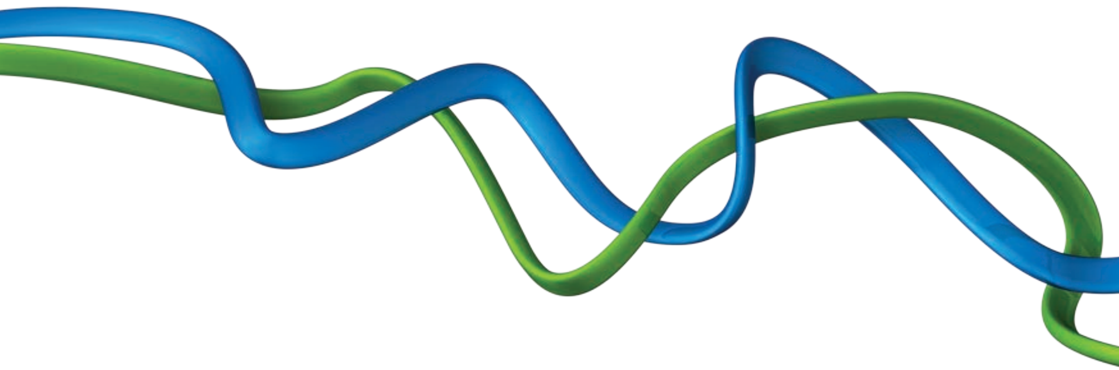
Foster better education and skills

Lead the profession

Promote engineering at the heart of society



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