SUSTAINABLE BUILDING DESIGN AND REFURBISHMENT IN SCOTLAND

CARBON TRUST: DELIVERING THE FUTURE TODAY
INSULATION AND SOLID MASONRY WALLS
GREYFRIARS COMMUNITY PROJECT
THE REDEVELOPMENT OF THE NATIONAL MUSEUM OF SCOTLAND
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If you need funding for your innovations, find out more about Innovation Vouchers scheme managed by Interface.

More on pages 16-17

Carbon Trust Scotland presents a few case studies that demonstrate how good internal environments can be created and carbon emissions reduced through careful design.

More on pages 18-29

Donald Simpson of Gareth Hoskins Architects presents Greyfriars Community Project in Edinburgh whose completion is due in December 2012.

More on pages 38-45

Architect Bern Balfe shares his experience on insulation of solid masonry walls and tells a cautionary tale.

More on pages 34-37

Gordon Gibb of Gareth Hoskins Architects presents the redevelopment of the National Museum of Scotland, Chambers Street, Edinburgh

More on pages 46-53
What is CIC Start Online?

- A three-year project of seven Scottish universities funded by European Regional Development Fund and Scottish Government’s SEEKIT programme

- AIM: To embed sustainable building design and refurbishment into practice

- OBJECTIVE: To support academic/industry collaboration in developing and testing innovations, and to disseminate the outcomes in order to facilitate the application of innovations in practice

- WHY?
  - To reduce CO₂ emissions and other negative environmental impacts from buildings
  - To reduce fuel poverty and improve indoor climate
  - To create jobs and support competitiveness of Scottish construction industry through innovation
  - To remove the barriers to the application of innovation in practice

- HOW?
  - Through competitions for academic/industry feasibility studies and for 10-days free academic consultancy on sustainable building design and refurbishment
  - By testing innovations at the testing facilities of the project partners’ institutions
  - By publishing guidelines for the application of innovations in practice
  - By developing and publishing database of design solutions for sustainable refurbishment
  - By providing assistance and advice on sustainable building design and refurbishment to Scottish small to medium sized enterprises
  - By disseminating the project outcomes through the project website, seminars, interactive webinars, webcasts and three whole-day online events that will include an exhibition, a conference and networking facilities
  - By publishing information on products and services for sustainable building design and refurbishment offered by Scottish small to medium sized businesses registered with CIC Start Online.

BENEFITS OF FREE MEMBERSHIP

- Publish information on your company’s products or services for sustainable building design and refurbishment
- Receive a set of headphones with a microphone, monthly E-News and quarterly Innovation Review
- Ask for advice/assistance

Please click here to access the registration page at the project website

www.cicstart.org

PROJECT PARTNERS

Funded by

Scottish Funding Council
Promoting further and higher education
Welcome to the tenth issue of Innovation Review!

We are happy to announce that the membership of CIC Start Online has reached over 1,300 members. Most of them are based in Scotland, but the online outputs of the project are seen by the members in many countries (see above).

By January 2012, the project has initiated 50 feasibility studies and 20 academic consultancies. As the project target for this activity has been reached and available funding allocated, the competition scheme is now closed. An overview of themes and sub-themes of the studies demonstrates the range of knowledge developed and information provided through the project, see pages 6-7.

The outcomes of completed studies will be disseminated in forthcoming months through free interactive webinars and in the Innovation Review. Information on the published video recordings of our recent webinars is available on pages 8-10 and on five forthcoming webinars on pages 11-13.

Our first live conference Build Tight, Ventilate Right: Air Quality in Housing attracted over 70 delegates and seven exhibitors at the event held in the Lighthouse on 2nd February, see pages 14-15. Its programme was developed by The Glasgow School of Art.

The second live conference, Green Deal and Sustainable Refurbishment of Traditional Buildings, will be hosted at Glasgow Caledonian University on 29th February. This conference is sponsored by Historic Scotland.

Our third live conference, Micro-generation of Energy for Buildings and Transport: Deliverables and Barriers, will be hosted by Edinburgh Napier University on 18th April. The conference programme will be published in due course.

In this edition, we publish information on Innovation Vouchers scheme available to Scottish small to medium size enterprises through Interface (pages 16-17), and the support provided by Carbon Trust (18-29) and BSRIA (30-31) for sustainable building design.

A team of four quantity surveying students from Glasgow Caledonian University have won the Chartered Institute of Building (CIOB) Student Challenge (Scotland) centred on the Scottish Government’s ambitious target for reducing carbon emissions by over 40% by 2020, pages 32-33.

Gareth Hoskins Architects present their new project Greyfriars Community Centre in Edinburgh, pages 38-45.

We look forward to receiving articles on other sustainable building design and refurbishment projects in Scotland. You are welcome to send the articles to me by 15th May for the next edition.

Branka
Competition for 50 feasibility studies and 20 academic consultancies is now closed as the awards have been given and funding allocated. Please access the links to see the titles of all the studies and who is undertaking them.

Our Knowledge Base contains outputs of CIC Start Online: webinars, conferences and articles in Innovation Review. Key words from these outputs indicate the range of themes addressed through the project. They also show the scope of knowledge developed and made available, some to date and other through our forthcoming webinars, conferences and Innovation Reviews on sustainable building design and refurbishment.

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### SPATIAL ISSUES
- land use
- rural and urban settlements
- resilience to flooding

### BUILDING AGE
- pre-1919
- post 1919
- new

### BUILDING USE
- domestic
- non-domestic

### INTERVENTION OR DESIGN APPROACH
- Refurbishment
- Retrofit
- PassivHaus
- zero carbon buildings

### DECISION MAKING TOOLS
- environmental modelling
- energy simulation
- dynamic simulation
- BIM

### RENEWABLE ENERGY
- hot water solar panels
- photovoltaics
- photovoltaic-thermal systems
- roof mounted wind turbines
- air-source heat pumps
- CO₂ heat pumps
- ground source heat pumps
- biomass
Testing of a method for insulation of masonry and lath walls in Existing Domestic Scottish Construction

Dr Amar Bennadji, Robert Gordon University
Michael Levie, Craigie Levie

The main aim of this research project was to develop and test the feasibility of a method of insulating an existing historic listed building whilst maintaining its original architectural features. The success of the project is conditioned by the avoidance of any damage of the inner lath plaster wall leaf.

The application of the feasibility study involved a trial off site to make sure the process won't bring any harm to the building. Despite these precautions, alterations of the method took place during the trial due to onsite discoveries related to the building's age and condition.

Please click on the image to access the video recording.
The main focus of this study was to explore the possibilities of improving the energy efficiency of the apartment’s fabric and energy for space and water heating. The apartments in question are owned by Lanarkshire Housing Association and are located in the town of Bellshill near Motherwell.

This feasibility study addressed options and elements in which the apartments can be thermally improved and to also explore the improvement of heating services which at present have become difficult to maintain and are costly for the tenant.
Researchers from the School of Architecture, University of Edinburgh worked with Research Officers at IES Glasgow to develop a version of the IES-VE environmental analysis programme, tailored to the needs of undergraduate Environmental Design teaching.

The relevant parts of the existing IES–VE programme dealing with Climate and Location, aspects of Lighting, and Thermal analysis were selected and written into a student worksheet for teaching principles of environmental physics and its assessment within building models.
Our series of seminars and online webinars disseminate the outcomes from our feasibility studies and academic consultancy projects that have taken place with the assistance provided by CIC Start Online partners.

Our online platform provides a live video feed, alongside the presentation slides, and offers opportunity to interact in a Q&A session as part of the webinar. Online attendance is free of charge to CIC Start Online members. Seminar attendance is £70 per delegate, reduced to £50 for members.

**ATTEND IN PERSON**

A buffet lunch will be provided before the event, providing opportunities for networking with fellow delegates and the seminar speakers. Lunch and registration starts at 12:00, with the seminar commencing at 12:30. Please book your place at [www.cicstart.org](http://www.cicstart.org) on the event page.

**ATTEND ONLINE**

All CIC Start Online members will be invited to attend the online webinar and will receive an email with the meeting link. To attend online, use the “attend online” link in our E-News email – sent to all members on our MAILING LIST. You can subscribe to our mailing list at [www.cicstart.org](http://www.cicstart.org)
Thursday 8th March 2012

David Jenkins (Heriot Watt University) and Bob Barnham, Stuart Hay (Changeworks)

Thursday 22nd March 2012

Julio Bros-Williamson (Edinburgh Napier University) and Leanne Evans (Solas Scotland)

Thursday 29th March 2012

Dr Paul Baker (Glasgow Caledonian University) and Bruce Newlands (Kraft Architecture)
Friday 13th April

Anila Ahmed (Fairfield Housing Co-operative)
Masa Noguchi (Glasgow School of Art)
Prof Tariq Muneer (Edinburgh Napier University)

Thursday 19th April

Julio Bros-Williamson (Edinburgh Napier University)
John Stephen (SA Estates)
# Build Tight, Ventilate Right: Air Quality in Housing

**Conference hosted by The Glasgow School of Art**

2nd February 2012

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Photographs from the Conference
Support available for Scottish businesses looking to grow and innovate

Businesses are being urged to consider tapping into the world class expertise and funding opportunities available on their doorstep to help overcome the challenges they face in the current economic climate.

The Scottish Funding Council (SFC) has recently issued a call for applications for its successful Innovation Voucher Scheme. Initially launched in 2009, the scheme was set up by the SFC to encourage small to medium sized enterprises to access the expertise, skills and research facilities within Scottish HEIs (Higher Education Institutes). The scheme offers awards up to £5,000 to offset the cost of the academic time to collaborate with the company.

The scheme is administered by Interface – The knowledge connection for business, a national programme offering a central point of access for industry to Scotland’s universities and research institutes. Interface offers a free, face-to-face service to businesses wishing to engage with academia from business schools to physics, from social scientists to chemistry to address challenges such as increasing competitiveness, developing new products or exploiting new market opportunities.

More recently a pilot follow on Innovation Voucher Scheme has been launched by the SFC.

In particular all of the voucher schemes should encourage a longer, sustained relationship between companies and HEIs rather than just offset the costs of the business purchasing a service from a HEI.

Donna Kudarenko of Interface commented, “Scotland’s universities and research institutions are home to a wealth of talent which often companies are unaware of. The SFC Innovation Voucher Scheme presents a fantastic opportunity for businesses looking to ‘test the water’ and trial working with an academic institute whilst getting strategic projects off the ground!”

Many companies have already benefited from collaborating with academia including GamesAnalytics which identified an opportunity to apply social network analysis (SNA) into gaming to act as a hub around which online game players would associate, leading to a greater understanding of player’s behaviour. Full information is available here.

Visit our website to view additional success stories www.interface-online.org.uk/2064

To find out more, contact Donna Kudarenko, donna@interface-online.org.uk or visit www.interface-online.org.uk.
Games Analytics

Change the Game

Collect

Predict

20-30% Increase

Engage

Measure

Player Satisfaction

www.gamesanalytics.com
There is mounting significant evidence indicating that most buildings commissioned today provide poor working conditions, are unnecessarily expensive and complex to run and fail to account for the projected effects of climate change in their design. This is the case in both the public and private sectors, as is widely observed by the Carbon Trust as well. We are still not learning the lessons for the design of new buildings, making it even more difficult for refurbished buildings that have further limitations on options, even though the underlying principles are the same.

The Audit Scotland report, “Improving the School Estate” from 2007, investigated how effective the new and refurbished schools are and how well the Scottish Government and the councils were managing the improvements. Although it identified a general level of satisfaction with the design quality, it noted that when assessed against best practice the schools could be better designed. In particular, two areas were identified where improvements could be made:

- Environmental conditions such as the balance between day lighting, ventilation and temperature are often unsatisfactory and;

- Environmental sustainability can be inadequate. It became apparent that these features were only considered where their inclusion did not significantly increase the overall capital costs.

Furthermore, extensive evidence indicates these failures re-occur across all building types. Such problems are not restricted to Scotland. A National Audit Office report on the UK Government estate noted that of the projects that they examined, 80% failed the required sustainability standards.

**Case Study 1 - Seaview Primary School**

Figure 1. Angus Council’s Seaview Primary School won the Carbon Trust Scotland’s Low Carbon Building Award for a New Building in 2010.

They used an in-house team to manage the development process consisting of architects, interior designers, mechanical and electrical engineers, quantity surveyors as well as staff from the Council’s energy and maintenance teams.

Natural ventilation by automated high level windows is controlled by the BEMS based on inside and outside temperatures and CO₂ levels. Where mechanical ventilation is required, heat recovery is used to temper the incoming air.

The school optimises its use of daylight using clerestory windows and skylights combined with artificial lighting controls based on occupancy detection and daylight dimming.
Productive environment

One of the issues identified in the Audit Scotland report was the unsatisfactory environmental performance of the new build and refurbished school buildings. This problem can have a significant detrimental effect on the productivity of the individuals in a building. Looking at it from the other side, the function of a building is to provide a more productive environment than standing out in the cold, wind and rain. So what do you need from a building to make it most productive for its occupants.

Issues with temperature, daylight, ventilation and acoustics may result in productivity losses. Dealing with them once the building is in operation is often expensive and results in decreased energy efficiency. For example, solving an acoustics problem by fitting acoustic panels to the ceiling or walls could mask the thermal mass of the building. Where the design of a building addresses such matters from inception, then such problems do not arise; however avoiding all of the potential issues may be costly.

Thermal comfort

The temperature that individuals find acceptable will vary according to a number of factors:

- The outside temperature; on warm days individuals are likely to accept a higher internal temperature than on cold days
- The company clothing policy
- How active they are
- What temperature they are used to at home and in the car.

A number of temperature-related problems can occur:

- Trapped warm air at ceiling level; the ceiling will radiate the heat back down causing occupants to sense a sizeable vertical temperature differential. People generally prefer a temperature difference of no more than 3°C from floor to ceiling. Hot air needs to be able to escape at high level.

Figure 1. Hot air trapped at the ceiling due to poor window design, only the middle and bottom panes can be opened preventing hot air from escaping
• Wholly or partially naturally ventilated buildings may be uncomfortable if ventilation air is not tempered.
• Large glazed areas can radiate cold and spill cold air. People’s perception of temperature is based on a combination of the air temperature and the radiant heat from walls and windows. A large window can result in an area feeling colder despite a reasonable air temperature. Cold spill is caused by air coming into contact with the inside of a cold window and falling owing to convection, which then draws more warm air to the window, creating a draught.

Many buildings have a “Monday morning” problem caused by improperly controlled heating/cooling systems or the installation of an incorrectly sized heating plant, resulting in an unacceptable temperature for the building on a Monday morning.

One of the problems most frequently encountered is overheating, through excess solar gains, internal gains such as computers or poorly controlled heating. The latter is more an issue in spring and summer but can occur at any time of the year if a building is not correctly designed or controlled.

There are a number of studies investigating the relationship between temperature and performance. Generally it is acknowledged that performance drops by 2% for every °C above 25°C although this is dependent on the clothing being worn.

To design out overheating problems, it is most important for Clients to know how much the internal temperature will be above the external temperature, taking into account all internal heat gains as well. A good specification in Scotland would be not to exceed the external temperature at any time during the day.

Daylight

Achieving high levels of daylight results in a reduced requirement for artificial lighting and has been proven to result in improved performance of its occupants.

These improvements in performance are thought to result in:
• Improved visibility due to more consistent illumination levels, better distribution of light and better colour rendition
• Avoidance of seasonal affective disorder and suppression of melatonin production
• Improved mood, alertness and behaviour.

Badly designed daylight schemes can have a detrimental effect on performance. Typical problems include:
• Glare, causing occupants to look away
• Lack of brightness uniformity
• Inadequate integration with artificial lighting.

Wide-ranging research into the effects of day-lighting on productivity in schools, offices and shops has been carried out in California.

It found that in schools, students with the most day-lighting in their classrooms progressed 20% faster on maths tests and 26% faster on reading tests in one year than those with the least.

It also found that some office workers’ performance deteriorated by up to 21% when they were subjected to glare.
To achieve the desired level of daylight it is essential to use a computer simulation of the daylighting scheme. Standard tools only use “daylight factor”, which ignores the affects of sunlight and brightness variation during the day.

Figure 2. Splayed window reveals, white mullions, astragals and light ceilings and walls reduce glare, making the most of the daylight
The low carbon impact is obviously that if there is good daylighting, then the artificial lighting can be switched off. For a Client it is therefore more important to know how much artificial light will be replaced by daylighting during the year.

**Ventilation**

Inadequate ventilation rates can result in a reduction of cognitive function, increased odours and raised levels of volatile organic compounds (VOCs).

Exeter University has conducted extensive research into the impact of ventilation on cognitive function. Research in a primary school showed a 5% loss of cognitive function when CO₂ levels had a mean of 2,900 ppm compared to normal levels of 1,000 ppm.

High ventilation rates or drafts can also cause problems. Any airflow greater than 0.3 ms⁻¹ can cause discomfort.

Natural ventilation is often the preferred low carbon means of ventilating a building however this can often result in lower ventilation rates than those desired. Natural ventilation schemes can be successful provided a detailed analysis of the proposed design takes place. Using natural ventilation for narrow buildings is more likely to be successful.

Many designs now use mechanical ventilation with heat recovery to decrease this risk. Where this is used, installing large ducts, short runs and clever control can be a lower energy option, but needs careful modelling to actual operating and non-operating hours.

**Impact on low carbon design**

For a productive workplace, the building elements and systems are likely to include good daylight levels, high insulation values and low summer solar gains as stated above. These can all contribute to a low carbon building if designed right.

Good daylight levels only reduce energy demand if the lights can be switched off when light levels are appropriate. High insulation levels mean lower heat demand in winter, but could also mean a significant cooling load in summer if not appropriately designed.

![Figure 5. Excessive light levels in a corridor. Half the lights would still exceed minimum standards.](image)

Ventilation rates determine a significant part of the heating requirements in winter, so increased levels that are continuous will result in higher heat losses. To make it low carbon, the ventilation should be controlled using, for example, CO₂ level control. High daylight levels will often lead to more sunlight that will cause blinds to be lowered, thereby increasing artificial lighting loads. Daylight from north and easterly directions, and coming from high clerestorey lights is a better all round solution.
Figure 6. The high clerestorey lights provide the majority of daylight. The low windows face north so there is no glare, and good uniformity of light. The clerestorey lights also open to let hot air escape when needed.

**Challenging the users**

With the need to minimise carbon emissions and reduce energy costs some organisations are choosing to change employee’s expectations of what an acceptable working environment is.
The specification gap

Avoiding the design flaws that undermine employee productivity as outlined above demands a new approach to building design and specification. Typically, few targets are given to building designers. Organisations procuring buildings, whether new build or leasehold, tend to specify one or two headline targets and then rely on compliance with building regulations to deliver an acceptable level of energy performance.

As the table shows, the Building Standards provide a minimum standard for some of the necessary factors that influence energy performance. However there are still a considerable number of elements that are unregulated or at the discretion of the building users and operators.

For the building specifier it is important to be familiar with what Building Standards include and exclude, so that a comprehensive specification can be provided to the designers that will minimise energy in use and give Best Value, whilst providing a productive environment.

The minimum standards set by the Building Standards are set to increase over the next few years aiming to reduce carbon emissions. The new section 7 enables organisations to set higher measurable targets for the design of buildings to achieve silver or gold sustainability label, however this is still based on the design of the building and does not govern how the buildings can be operated in practice.

Further advice on the specification gap is in the Carbon Trust publication Closing the Gap - CTG047.

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Figure 7. Some of the regulated and unregulated aspects of building energy use. The green boxes represent the items influenced by building regulations and the red boxes are within the specification of the client organisation.
For example, the Building Standards specify an initial minimum level of luminaire lumens per circuit watt and the control systems that are acceptable in different scenarios. However, there are a number of other factors that need to be specified to ensure that the building minimises its operational lighting load:

- Minimum daylight levels and uniformity
- Blinds to be located where they do not obstruct the windows when open
- How much artificial light will be displaced by daylight
- Brightness levels of walls and ceilings
- The maximum acceptable level of lumens in a room from artificial light
- Acceptable level of degradation of a luminaire over its life
- Acceptable range of colour rendering and colour temperature.

Incorporating as many of these measures as possible should ensure that the lighting design is carried out in sufficient detail that it is suitable for purpose and low energy in operation.

**Case study 2 - Whitecross School in Herefordshire**

Whitecross School in Herefordshire is a good example of what can be achieved when low carbon is addressed in a systematic way early in the project life. It was built under a PFI arrangement by Stepnell, and uses around 110 kWh/m² per annum of floor area, about half of what many new schools are using. However, it has an excellent internal environment in the classrooms with good levels of daylight, high thermal comfort, well controlled ventilation and comfortable summer temperatures. Since it opened there have been hot summer days where the majority of local schools have had to close due to excessive temperatures and Whitecross has remained open and pleasant to work in.
Operational Targets
The introduction of operational design targets can assist design and construction teams to deliver a building that operates in an energy efficient manner.

An issue that is sometimes highlighted by design teams is lack of guidance on detailed environmental design requirements provided by clients. Design teams are normally provided with the user requirements for room layouts, furniture and physical adjacencies but environmental conditions or building service requirements tend to be minimal with no distinction of room types. To help designers ensure that a building is fit for purpose, further guidance is required describing the internal environment required for the building. This will normally take the form of an overarching technical brief and detailed room data sheets with supporting schedules.

On the other hand, operational targets should not be a straightjacket for designers. A blanket approach that does not allow flexibility or discussion between a prospective design team and the users has often led to a building that becomes unnecessarily expensive and more complex to operate.

Case Study 3 - New South Glasgow Hospital
Use of operational targets in this project has changed the way the project team discuss options. Both cost and the carbon impact are now considered when design changes are proposed.

Operational targets are measures of building and equipment performance that are easily defined without ambiguity, are measurable and should be enforceable. One of the challenges with targets is to ensure that responsibility for delivering the target is clearly defined. The overall operational target should be what the building will consume in energy once in operation. The only way to control this during the design process is to use a Dynamic Model in operational mode, rather than in design mode, as has been done for some NHS projects. The greater the level of specification at the beginning of the project, the more likely that they are to end up with a building that provides a productive workplace and is cost effective to run. In order to achieve a higher level of specification, the procurement team needs to have a wide range of skills available to them. Frequently knowledge gaps exist within procurement teams in the following areas:

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<th>Skills and Knowledge</th>
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| Architectural | • Passive design  
|            | • Thermal mass  
|            | • Air tightness  
|            | • Day-lighting and brightness to reduce artificial lighting  
|            | • Design for low summertime overheating  
|            | • Facade Modelling  
|            | • Space planning and massing  
|            | • Allowing for appropriate internal heat gains  
|            | • Ceiling shapes that give good acoustics  |
| M&E      | • Interaction with architects to improve the fabric design  
|          | • Interpretation of daylight modelling  
|          | • Thermal & ventilation modelling  
|          | • Seasonal operational efficiency of heating and cooling plant  
|          | • How building services are controlled with their integral controller and BMS to minimise energy use  
|          | • User appropriate BMS systems  |
| Finance  | • Whole life costing  
|          | • Single action – multiple benefit  |
Where these skills are not present in the client team it can result in dependence on external advisers who are responsible for delivery of the building and who therefore may not have their interests fully aligned with the clients.

If a knowledge and skills gap analysis is carried out at the start of the process of procuring a building, any training needs or external advisers’ requirements can be identified. Where external advisers are used to fill these knowledge gaps, it is beneficial to ensure that they are independent of the building delivery team.

Similar knowledge and skill gaps occur within design teams as is evidenced by the variations in quality of Scotland’s newer building stock. A knowledge and skills gap analysis can be used during the selection process to ensure that the design team is competent to deliver the required building.

Cost Implications
There is a range of estimates that have been published on the capital cost impact of achieving a low carbon building. There is evidence from the schools building programme that significant operating cost savings have been achieved with minimal capital cost implications:

- The Angus Council Seaview Primary School project discussed in Section 2 achieved a 49.8% saving for no capital cost premium
- Whitecross school in Herefordshire has an energy consumption of 50% of typical new build secondary schools for a 0.7% cost increase
- Inverclyde Council has recently built four schools that encompassed many of the principals discussed in this document. They incurred a 4% increase in capital and expect to achieve a 30% reduction in operational energy usage.

Most of these projects have in common that decisions on the design and value engineering were made in favour of productivity and low carbon at the expense of other aspects.

Whole life costing
ISO 15686 Part 5 (12) describes a comprehensive method for calculating whole life costs for a building. The process involves evaluating all costs involved in:

- **Acquisition and Construction**
  - In house costs
  - Surveys of existing buildings
  - Decanting costs

- **Operation and Maintenance**
  - Maintenance and replacement costs
  - Cleaning and minor repairs
  - Carbon costs

- **End of Life Costs and Residual Value**
  - Inspection costs
  - Decommissioning costs
  - Recycling costs
  - Disposal costs

Conclusion
There is considerable scope for improving the quality of the buildings that will be built over the next few years to ensure that they have a good internal environment and are affordable to operate. This will require changes to the procurement process, in house and external team member skills and construction techniques.

This article has highlighted a wide range of problems including:

- High operating costs
- Overheating
- Glare
- Acoustics issues
- Ventilation problems.

A number of exemplar buildings have also been identified where an excellent working environment and low operating costs have resulted from the use of an appropriately skilled team and a well-planned design.
The problems can be avoided by following a few simple steps. The Carbon Trust has created a suite of guidance documents and tools to assist this process. These include a project owner’s guide; a project manager’s guide; tools to help evaluate team members’ and bidding parties’ skills, knowledge and experience; templates for agendas and meeting report and documents to assist in the detailed specification required.

Figure 10. Acharacle school has natural ventilation with external shading screens when very bright, still giving good daylight in the room and allowing lights to be off
Figure 11. Potterow Informatics Building for Edinburgh University - a building that can attract high calibre postgraduate students in the international arena, without the heavy energy penalty
This updated guide replaces Condition Survey of Building Services AG 4/2000 and is aimed at those who have the responsibility for maintaining buildings.

Maintenance is vital to ensure a building can operate in accordance with its core function and also plays an important role in reducing carbon emissions from buildings. A condition survey will document and assess the state of each individual item of a building’s assets.

Condition Surveys and Asset Data Capture outlines the benefits of having a good knowledge of assets and describes how by having a greater understanding of their condition, they can be maintained in a more efficient and economical way. Regular condition surveys and asset data capture will help the maintenance and facility management staff plan for future maintenance, replacement and refurbishment needs. The knowledge gathered will enable staff to identify and prioritise future works and assess the financial commitments required over a set period of time.

The guide delivers practical advice on the most suitable type of survey, takes you through how to do the survey, undertake non-destructive testing and grading.

Chapters cover:
- The value of asset data
- Level of survey
- How to do a condition survey
- Non-destructive testing
- Grading
- Survey toolkit

Hard copies of Condition Surveys and Asset Data Capture (BG35/2012) will shortly be available to order until 27th January at pre-launch price of £25 (full price or £30) to BSRIA members or £50 (full price £60) to non-members. A pdf will also be available at £60 full price or free to BSRIA members. Checklists in word format are attached to the pdf and can be downloaded from the BSRIA website.

Contact
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Email: Catherine.england@bsria.co.uk
Web: www.bsria.co.uk/goto/conditionsurveynonmems
A weather louvre is a passive device, essentially a grille fixed over an opening, designed to let air through whilst restricting the entry of rain.

It is designed to perform both these functions simultaneously and its suitability for a particular application is determined by how effectively it achieves these functions in combination. Subtleties of blade profile and pitch (distance between blades) are among the design features that affect performance.

This guide has been compiled to help system designers and specifiers of weather louvres to achieve optimum performance.

Failure to understand and clearly express the performance requirement at the design or procurement stage increases the risk of the product not being fit for purpose. The end user may experience unwanted water penetration or wasted energy, both of which represent unnecessary cost. Improved efficiency of louvre design not only saves money but may assist with building regulations compliance and contribute to an improved energy rating for a building.

The guide explains:

- how to understand weather louvre requirements
- how to minimise whole-life costs through system design and louvre selection
- which terms to use to ensure that performance data are consistently stated when sourcing products from suppliers
- how to minimise risks associated with overstated performance claims
Glasgow Caledonian University wins CIOB Student Challenge (Scotland)

Halbert Mills, Glasgow Caledonian University

A team of four quantity surveying students from Glasgow Caledonian University have won the Chartered Institute of Building (CIOB) Student Challenge (Scotland) held at Perth Racecourse in January. The team of Lauren Brown, Lauren Meldrum, Eve Mallon and Craig Wright are final year students.
Universities and Colleges around Scotland are invited to send teams to compete annually in this challenge with the winning team going forward to the CIOB National Final in March at the CIOB Headquarters near Ascot.

This year, the project based challenge centred on the Scottish Government’s ambitious target for reducing carbon emissions by calling for reductions of over 40% by 2020 – Climate Change (Scotland) Act.

As new homes are already highly energy efficient by the very nature of materials and building techniques employed, the focus of this challenge was towards improving the energy efficiency of existing housing stock by a retrofit programme for Scotland’s 2.4 million homes.

The teams were tasked to advise the Scottish Government on why a retrofitting programme for existing homes should be promoted and the importance of adopting a coordinated initiative. They were to identify a range of measures to be implemented and the problems which may be encountered. Finally they were to suggest routes to finance the measures and advise what part the Scottish Government should play.

The exercise involved preparing a word processed report in 2 hours followed by a PowerPoint presentation after lunch. Teams had access to a number of published documents and also internet access throughout the day.

The team recommended the following measures to be implemented:
- Various types of insulation both in walls and roofs
- Window replacement
- Upgrading heating and hot water systems with new efficient boilers
- Education of the public in understanding how to become more energy efficient and this would involve a marketing strategy to be adopted.

Problems were identified which included the unique house styles, expense of some schemes, convenience and they concluded there was simply no quick fix.

As one may expect financing the scheme is a difficult task and the team recommended various mechanisms such as ‘Green Deal’ and various grants for Government, Energy Suppliers and Local Authorities.
As a sole practitioner involved mostly with domestic alteration work, the last decade has seen me move from a position of advocate for improved insulation and energy saving measures to cautious adviser on the feasibility of the extensive measures that my clients are now all extremely keen to implement. A few years ago there was much talk of eco-awareness going mainstream, rather than being an area of specialist interest. This has certainly now happened, but are we altering our building techniques too rapidly, leaving tried and tested solutions behind in the rush to bring existing housing stock up to acceptable levels? Old buildings have much value, they embody not just energy but cultural values; they are a window into other times.

In my experience insulating old buildings is not simple. In essence, with modern insulation materials you are attempting to turn a slow response building into a fast response building. We live fast lifestyles nowadays – houses are often unoccupied for long periods of the day. It’s not surprising that people expect instant heat on demand since most of their other needs are satisfied in this way – but solid masonry houses were built in the time when things still happened more slowly and an awareness of this is a big help in understanding them. An old house takes time to get up to a comfortable temperature. Current methods of insulation generally involve a significant reduction in breathability and this can cause a lot of problems in old masonry walls. A huge proportion of energy input is lost in ventilation and the focus is now moving towards savings which can be made in this area, which causes problems for the fabric of traditional buildings.

Insulation grants for this type of solid wall building are currently limited to loft spaces; this is sensible as these areas are relatively easy to insulate without doing too much harm. However my clients are now looking for a full house upgrade and are anxious to persuade me that this is entirely possible. There is a huge amount of advice available on the internet and in the media generally encouraging people to protect the environment (and reduce their fuel bills) by insulating their houses. When you read between the lines there are some embodied warnings/caveats in the advice, but the subtlety often escapes the enthusiast. In many of the houses I work on I find that my clients have already embarked on their chosen DIY measures, with internet search engines rather than architects as their guide. The Energy Saving Trust website offers the following advice on internally insulating solid walls:

**Internal wall insulation is done by fitting rigid insulation boards to the wall, or by building a stud wall filled in with mineral wool fibre.**

- **Internal wall insulation:**
  - is generally cheaper to install than external wall insulation
  - will slightly reduce the floor area of any rooms in which it is applied (the thickness of the insulation is around 100mm)
  - is disruptive, but can be done room by room
  - requires skirting boards, door frames and external fittings to be removed and reattached
  - can make it hard to fix heavy items to inside walls – although special fixings are available
  - needs any problems with penetrating or rising damp to be fixed first.
This all sounds relatively easy and the last warning point is easily glossed over; indeed can often be difficult to establish as most walls are damp but breathing. It is the bit that remains unsaid which may cause difficulties in the end. The applied internal insulation will change the temperature differential across the construction, causing the wall to be much colder and introducing a risk of condensation within the construction, probably on the inside face of the (now much colder) stonework where it will remain undetected. A vapour control layer placed on the warm side of the insulation will prevent moisture from the inside penetrating the wall, but will also prevent any water within the construction from escaping. Solid walls are designed to get damp and dry out easily, a little like the way some modern wicking outdoor clothing works. The designers went back to the principle of a wet dog that stays warm while drying, as an alternative to the early days of high performance raingear which attempted to keep the rain out completely. Anyone who has gone walking in a nylon jacket will be aware of how the inside can become quickly wetter than the outside as your body breathes.

Stone walls in Scotland were traditionally either left unclad or rendered with lime externally – allowing them to breathe to the outside – they got a bit damp in rainy weather and dried out in dry windy weather. Internally they were normally strapped with lath and plaster with a ventilated gap being left behind the lining, ideally running from a solum to an attic void, so that a current of air was generated. You can often put your hand into this void and feel the strength of the air movement; the building quite literally breathing.

One of the worst insulation situations I have come across recently was in an old cottage dating from the 1870s which had been upgraded and refurbished several times since then. A 450mm solid brick wall had its original lath and plaster lining replaced with a new internal lining consisting of mineral wool, held in place by tongued and grooved timber lining boards on timber battens, over clad with two layers of staggered foil backed plasterboard forming a complete and effective moisture vapour barrier. When a flashing overhead failed, water entered the unventilated timber lined cavity unbeknownst to the owner, was unable to escape and the result was a spectacular outbreak of dry rot, with, by the time it was discovered, nothing much left of the timber lining boards bar the varnish and some serious damage to adjacent floor and roof joists embedded in the wall. This illustrates the damage that a sealed vapour barrier can do when applied to an old wall, and it is not unusual for a flashing to leak, even in a well maintained house. It is actually very difficult to guarantee that a solid wall will remain dry at all times – a fact which the dry rot guarantee companies do not fail to exploit. If the original permeable linings had been left in place, at least some of the moisture would have been able to escape; at any rate it would not have gone undetected for so long.

Even after this experience, the owner was keen to apply insulation to the walls, so we experimented with a ventilated void as in the best traditional practice, but in this case used pre-warmed air from a small slate roofed attic space to a ground floor lean-to. This was insulated at ceiling level and, by installing roof vents at high level we created convection current to keep air moving within the concealed void. We left access panels at critical points for regular monitoring.

The air current is certainly there and appears to have cured the problem, although the wall will need to be regularly monitored for a number of years to come. It’s not perfect – there are no vents at ground level for example, where there is a solid floor so we rely on whatever draw there is from above, and the building has a cement external render, which needs to be constantly checked for hairline cracks. It does appear to be providing an improved level of insulation although it’s impossible to be certain about this in the absence of any scientific form of measurement.
Pre-warmed air introduced into the construction through solid masonry wall.
There is clearly a pressing need to comply with the global agenda to reduce CO₂ emissions, and we need to search for ways in which this can be done. Vapour permeable insulation may offer some possibilities, but there is still a lot of research needed to find materials with adequate breathability. The performance of old solid walls must surely differ greatly as a consequence of the porosity of the masonry, the degree of exposure, the ratio of mortar to stone, the composition of the mortar etc.

Perhaps we should accept the possibility that we may not be able to do this effectively and consider whether there is a case for some controls to be introduced on insulation procedures to prevent damage to the existing housing stock. In any case some definitive guidance is sorely needed, based on careful research and analysis. The budget is not always available to provide a tailored solution for an individual house – but perhaps alternatives could be developed for houses of similar construction with guidance on how the performance could be measured and analysed before solutions are proposed.

There are stringent controls now being placed on ventilation, as it is now one of the largest components of heat load but there seems to be a lot of wishful thinking on the subject. Most householders don’t understand the measures enshrined in the building regulations to preserve a healthy indoor atmosphere. I regularly come across blocked up air vents, adjustable trickle vents which have remained in the closed position since they were first installed, fan extracts which are making plenty of noise but are connected to a duct run the length of which far exceeds their capacity and are therefore largely decorative. Often these measures are poorly understood by householders because no-one has explained how they should be used.

These measures, intended to reduce indoor humidity levels, are often not working and this, combined with the increasing number of product salesmen and other advisers who maintain that construction vents just waste heat and are no longer required, could result in a lot of damage to building fabric as well as the health of their occupants before too long.

Insulation is important; energy conservation is important; but buildings must be designed above all to enhance people’s lives. Modern building techniques may work in theory but do they work as well in practice, outside a factory controlled situation? The solution of factory made buildings has been suggested many times but I suspect that people will always treasure a unique home, and will always desire to adapt it to their own specification.

We have made a great deal of progress in the last century, and have many more materials and techniques at our disposal, but these relatively simple buildings have stood the test of time, which after all is an essential aspect of sustainability. Our climate is no less damp now than it was when they were designed and built; should we not bear this in mind alongside our current need to save energy if we are to find the right solutions?

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Greyfriars Kirk has been supporting disadvantaged citizens in the Grassmarket area of Edinburgh since its formation in the 17th century. In recent times the Kirk has facilitated the provision of services for homeless people through its ownership of the Kirkhouse at the foot of Candlemaker Row (by the northern entrance to the Kirkyard). In association with the charitable organisation, the Grassmarket Mission, food, shelter and advice was provided to people experiencing homelessness and deep social exclusion. These operations have outgrown the Kirkhouse where facilities have developed to incorporate a training kitchen, wood workshop (for the reconditioning of redundant wooden church pews) and textile weaving looms. As well as the provision of services for the homeless the Kirkhouse, like so much of the city is occupied by a theatre group for the duration of the Fringe Festival generating vital income.

SITE
The development site is situated behind the Kirkhouse immediately to the north of the grade ‘A’ listed Greyfriars Kirkyard which is within the Edinburgh Old Town World Heritage Site and conservation area. The site is landlocked on three sides with the short Candlemaker Row frontage offering the only opportunity for access and egress. The southern boundary is formed by the 16th century Kirkyard retaining wall, the wallhead of which is approximately 8m above the ground level of the site (image 1). Tenements to the north and George Heriot's school buildings to the west prevent access from elsewhere and limit views out towards the old town back courts.

In 2004 Hillcrest Housing Association expressed an interest in developing the site (including the kirkhouse) for rentable flatted accommodation. This lead to a joint venture being formed with the Kirk to develop two floors of social enterprise accommodation providing sufficient height for the flatted accommodation to sit above the Kirkyard wall. The scheme was developed by Gareth Hoskins Architects but the tricky site and buoyant economy at the time lead to high tender returns and the residential element failed to secure grant funding. This ensured the land was deemed unviable for social housing and was transferred into the full ownership of the Kirk January 2010 to enable them to develop the site on their own.
The Kirk’s requirement for continuous provision of services to their vulnerable user group ensured a phased approach to developing the site was essential. Phase 1 saw a refurbishment of the Kirkhouse in 2010 comprising vital repairs and upgrading of the interiors to form the new wood workshop and a small training kitchen. Phase two is due on site imminently which involves a new extension to rear of the kirkhouse providing additional accommodation for the users including a larger training kitchen with adjoining dining room, as well as dedicated classroom space. The main focus of the new extension is the community hall, a multi purpose venue for rent to provide a valuable income stream to fund the social enterprise activities.

**INITIAL IDEAS**

This initial developments were based around the location of the main hall as a response to the site constraints. A clear path towards a strong contemporary solution was sought as the site is visually isolated from the historic fabric of the old town and can be seen as a more backland building away from the main street and hidden from the Kirkyard.

The initial image conceived for the building was seen as an extension of the Kirkyard greenery over the accommodation punctured with the monolithic form of the rooflights (image 2).
The basic strategic arrangement of spaces has evolved during the design process to reflect the developments of the client’s requirements. The hub space is at the centre of the proposals with the other activities, grouped loosely into two categories - the industry (wood workshop, weaving workshop) in the kirkhouse and the art (performance hall, classrooms) in the new extension.

The series of diagrams (image 3) show:
1 - The cleared site with the Kirkyard wall head approximately 8m from the existing level of the site.
2 - The double height volumes (hall and hub) have been placed adjacent to the high Kirkyard wall - allowing light and ventilation from above. The hub extends across whole site with all other spaces accessed from here including the main entrance.
3 - Two storey block of accommodation runs alongside north-western boundary. Lower level comprises service accommodation (kitchen / plant etc) adjacent to service lane. Upper level comprises lettable, sub-divisible classroom accommodation.

LAYOUT (images 4, 5, 6)

The building is organised carefully to make the most of the limited views out and to bring natural light and ventilation into the landlocked internal spaces.

The facade to the courtyard off Candlemaker Row presents a simple smooth glass wall spanning between the rough rubble tenement walls. A timber colonnade sits in front of this emphasising the new entrance (drawing visitors away from the original entrance to the kirkhouse which will no longer be used).

Behind the facade sits the main double height hub space, all visitors and users of the building enter via this space and all functions/spaces are visible from this central point (including the link to the existing Kirkhouse). The intention is to increase user awareness of the activities promoted by the Kirk (for example: where a visitor going for a yoga class in the hall could spend some time watching weavers work on the looms). A large rooflight above the hub allows natural light in which is filtered by the canopy of the mature trees in the Kirkyard and provides a visual focus. This hub space also has the potential to spill out into the courtyard during the busy festival periods where it is envisaged it will be used as a cafe.

The main double height hall runs parallel with the Kirkyard wall directly behind the hub and because of the enclosed site it also employs a series of rooflights to provide a view up to the mature trees in the Kirkyard while allowing light in. Flexibility is achieved partially via technical means with the ability for blackout conditions as well as complete sound isolation from the rest of the building.
Surrounding the hall on the North and Western boundaries is the single storey service accommodation with the main block of classroom accommodation above on the first floor. A series of windows along both facades take advantage of the limited views out from the site towards the historic fabric of the Old Town. The single run of classroom accommodation is sub-divisible into two separate areas, with each separate entrance to the large room marked by an internal window looking back into the hall from first floor level.
The building’s location tucked in behind the Kirkhouse and the Kirkyard wall make it very much a ‘back court building’ with only a small strip of facade visible from the main thoroughfare of Candlemaker Row and the projecting rooflights above the Kirkyard wall. To this end the Kirkhouse becomes an important element in projecting the ethos of the Kirk and Grassmarket mission to the wider public. The activity of the workshops within will help to provide animation to the frontage and a large display window at the front entrance can be used to show of the products of the creative industries within.

CONSTRUCTION/MATERIALS/SUSTAINABILITY (image 7)

Too often vulnerable citizens are forced into the worst buildings in the worst locations in a city which do not assist with their health or wellbeing. The client’s aim was for a building with a high quality robust finish with minimal toxins and low running costs.
Timber lined walls and stone flooring to the public areas together with Fermacell wall coverings covered with low VOC paint aim to achieve this (image 8). The large rooflights or triple glazed windows provide natural lighting to all the habitable rooms. A floating ground floor provides a plenum for air movement deep into the plan to naturally ventilate the hall. Warm air is extracted at high level (fan assisted in the hot summer months) with equipment contained within the cheeks of the rooflights (image 9).

**SOCIAL SUSTAINABILITY**

As well as the building sustainability there is also a social sustainability element to the project and there is the intention to use on site wood workshop and the skills learned by the woodworking team to produce some of the new decorative timber lining for the interiors.

**project budget** £1.4m

**start on site** - February 2012

**expected completion** - December 2012
Image 9. Section through rooflights

Project team

Architect: Gareth Hoskins Architects
Structural Engineer: David Narro Associates
Mechanical Engineer: Max Fordham Partnership
Quantity Surveyor: Morham and Brotchie Ltd
Construction Design Management Coordinator: AECOM
The re-opening of the museum in July 2011 marked the completion of the second phase of a £70 million masterplan by Gareth Hoskins Architects, representing the museum’s most significant overhaul in over a century.

The National Museum of Scotland is home to an internationally important collection of objects that span the fields of Science & Technology, Art & Design, World Cultures, the Natural World and Scotland.

Image 1. New entrance hall
This phase of work has included a comprehensive upgrading of the Victorian building through a series of major architectural interventions and the formation of new public spaces to create a clear and open setting for the museum. The project was delivered on time and on budget at a total cost of £47.4 million which was funded by the Heritage Lottery Fund (£17.8 million), the Scottish Government (£16 million) and £13.6 million from private sources.

The client’s aspirations for the masterplan were that it create a world-class attraction, providing a cohesive visitor experience that brought to the fore many previously unseen wonders of the collection. There was to be improved access for all, dramatic new displays and significantly enhanced visitor facilities. Working with National Museums Scotland, Gareth Hoskins Architects’ approach was to collaborate across all disciplines to ensure the Grade A listed building was returned to its original Victorian grandeur as part of an integrated and coherent museum experience.

The project began with an enabling phase of works that included the building of new off-site storage facilities to accommodate the million objects to be decanted from the museum cellars and a new stair and lift core that allowed the west wing of the old building to remain open to the public throughout the redevelopment. This phase of work also afforded National Museums Scotland the opportunity to reassess the entire collection and the lessons learnt then informed the architectural and exhibition design process.

The spectacular vaulted cellar spaces, previously hidden from public view beneath the museum, have been sensitively excavated to form an impressive new entrance hall (Image 1).
This ‘Window of the World’ feature sits either side of another major architectural intervention – the newly opened double-height Treasures Gallery which provides a north/south connection through the museum and enables direct access up to the new Special Exhibition Gallery (Image 3). The project team have also re-imagined the main hall as the museum’s primary orientation space. This ‘Grand Gallery’, a beautiful birdcage structure designed by Captain Francis Fowke and inspired by Paxton’s Crystal Palace, now houses key large objects from the collection to further signify the themes and stories contained in the atria galleries beyond (Image 4).
Inclusive Design and Accessibility for all

Before redevelopment the museum failed to provide appropriate equality of access. From Chambers Street the entrance was via an imposing stone staircase and these steps were seen as difficult, off-putting or impossible to use by many visitors, especially the elderly, those with mobility or visual impairments and those with push chairs. Level access was provided only via a dislocated “back door” or via the tower entrance of the 1998 extension building and entering from these points presented significant orientation difficulties for visitors.

Although not solely concerned with the provision of level access one of the major architectural interventions was to create an entire new public floor in what was previously the basement of the museum. A clutter of services and storerooms were cleared, the floor level was reduced by a metre and a major supporting spine wall was removed and replaced with steel beams and columns all requiring delicate and extensive engineering works. Access to the new Entrance Hall is via two large but subtle openings created in the existing building plinth (Image 5).

Previous visitor studies showed there to be serious issue with orientation and route finding within the old museum, only 10% of visitors ever left the ground floor and only a poor 4% ever making it to the second floor. In response to this Gareth Hoskins Architects’ scheme centres on the creation of clear routes through the building to up open links across the collection. Two centrally located scenic glass lifts are arranged either side of the impressive new north/south route where escalators climb to the upper levels (Image 6).

This route is opened up to aid orientation and link to future phases of masterplan development on the second floor and on the galleries to the west of the escalators.

In addition to the scenic lifts giving access to all gallery levels there are 3 new stair/lift cores, each lift being installed with audible descriptions of the galleries, and increased provision of accessible WCs on all levels. Work to the auditorium sees level access and wheelchair spaces provided, improvements in acoustic performance and the introduction of an induction loop.
Sustainability

Improvements to the energy performance of the building fabric of large historic buildings such as the National Museum are generally very difficult to achieve.

To enhance the thermal performance or airtightness of the grade-A listed facades would have been prohibitively expensive, and in many areas of this building practically impossible.
An important task during the early design stages therefore was to assign functions to each space in a way that made the best use of energy, building form and structure. For example the Special Exhibition Gallery and Environmentally Controlled Store both house very sensitive artefacts that are vulnerable to changes in temperature and humidity. These controlled zones are housed in bespoke sealed 'boxes' deep within the building plan - protected from daylight and closely controlled with new air-conditioning systems. By contrast the traditional open balconied galleries, with natural daylight and fresh air ventilation, are used to display more resilient items from the collection and the new interactive exhibits (Image7).

New air conditioning plant incorporates very high efficiency 'thermal wheel' heat recovery systems. These devices capture heat from exhaust air then recycle this energy to heat incoming fresh air. This is particularly important in the Special Exhibition Gallery and Environmentally Controlled Store - where conditions have to be kept stable to protect the sensitive artefacts.

Prior to the refurbishment, there was little or no control of the heating system in the galleries. As part of the project(4,4),(996,992) the heating distribution and control system was fully updated. The strategy allowed the original architectural cast iron radiators to be retained, while making significant improvements in control of energy use. Gallery heating circuits can now be monitored and controlled individually to reduce overheating and energy use.

The lighting scheme makes use of the latest low energy technology, including LEDs and high efficiency fluorescent lamps. Light levels in the galleries are kept as low as possible - primarily to protect sensitive objects, but this also helps to minimise energy use.

An integrated gallery control system operates both the exhibition lighting and the audio visual systems.

Lighting, interpretation panels, projectors etc. are automatically switched on and off each day.
This prevents these systems using any excess electricity. This control system is flexible and adaptable, which will allow the client to add new galleries to the scheme in future (Image 8).

With a new centralised energy metering system in place, museum staff can monitor and improve energy consumption in each of the galleries and in the extensive storage and support spaces behind the scenes.

**Conclusion**

The ambitious programme of work undertaken was strongly focussed on improving the use of museum and encouraging movement through the entire museum complex. The intention was to seamlessly integrate the collection displays with the architecture and visitor facilities in order to make the visitor experience a more enjoyable and memorable one. The incredible visitor numbers achieved since opening, now over 1.4million suggest this aim has been successfully achieved and work has begun on the next phase of the masterplan – new Science & technology and Art & Design galleries as well as a scheme to dramatically improve the public realm of Chambers Street.

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**Project Team:**

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<th>Company</th>
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<tr>
<td>Client</td>
<td>National Museums Scotland</td>
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<tr>
<td>Architect</td>
<td>Gareth Hoskins Architects</td>
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<tr>
<td>Structural Engineer</td>
<td>David Narro Associates</td>
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<tr>
<td>Services Engineer</td>
<td>Max Fordham</td>
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<tr>
<td>Quantity Surveyor</td>
<td>Gardiner and Theobald</td>
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<td>Exhibition Designer</td>
<td>Ralph Appelbaum Associates</td>
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<td>Lighting Design</td>
<td>DHA Design</td>
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<td>Fire Consultant</td>
<td>Buro Happold FEDRA</td>
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<tr>
<td>CDM Coordinator</td>
<td>Turner Townsend Project Management</td>
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<td>Main Contractor</td>
<td>Balfour Beatty Construction</td>
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<td>Exhibition Contractor</td>
<td>Beck Interiors</td>
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