Surveying Historic Buildings
Valuing Sustainability in Places of Worship

Magdalini Makrodimitri, James Campbell

University of Cambridge, UK

0263

The Asian Conference on Sustainability, Energy & the Environment 2013

Official Conference Proceedings 2013

Abstract

Historic buildings contribute positively to all aspects of sustainable development. They are more than an environmental and cultural asset; they are an important driver for economic development and delivering social objectives.
In the first instance this paper looks at the factors that need to be considered in order to assess the sustainable performance of listed buildings. There is an increasing awareness of the necessity of balancing comfort with energy efficiency. In order to be sustainable historic edifices, including places of worship – which account for a large part of the cultural heritage in the UK– need to willing to adapt to modern comfort requirements but the question is how to do so without risking damaging the historic fabric and exactly how far it is right to adapt these structures at all rather than adjust our ideas of comfort.
Historic buildings provide particularly difficult challenges to manage environmentally both because alterations have to avoid destroying the historic character of the building and because changes in the internal environment can easily have adverse effects on that historic fabric.
The results of detailed survey of four case-studies, including monitoring, and building thermal simulation and comfort surveys applied to historic church buildings are used here to generate conclusions on the thermal efficiency, performance and risks associated with changing micro-climatic conditions of places of worship.
This paper suggests broadening existing sustainability criteria for such edifices in order to include the wider range of factors that affect sustainability in the historic built environment.

Keywords: historic buildings, thermal comfort, sustainability, conservation, energy

INTRODUCTION

Historic buildings by definition consist of structural elements and artworks that are uniquely valuable and laws are formulated in most countries to afford them protection against demolition. However, the rising expectations of thermal comfort constitute an additional threat to the preservation of these edifices (Camuffo et al., 2007). Even in the heritage sector, the needs of modern society cannot be entirely ignored. And to a certain extent it can be argued that the structural materials and elements that make up all existing buildings, including those of historical importance, which constitute natural resources in themselves, should be preserved where possible to achieve sustainability (Meryman, 2005).

Improving the performance of the building envelope is often the first action to be considered when starting any sustainable retrofit of a building. In the modern structures this is typically achieved by insulating, sealing and draught-proofing the building envelope, which reduces heat losses in walls, ground floors, roofs and through loose windows fittings. However, the materials that make up or are found in older buildings require higher rates of ventilation and much of this required ventilation was provided in the past by fortuitous air leakage- the buildings' "leakiness" (Heritage, 2008). It has become increasingly apparent that sealing and draught-proofing historic buildings can cause significant deterioration of the internal fabric and the artifacts they contain and can also have a negative impact on indoor air quality and the occupants' health. This research paper looks at the environmental performance of historic churches, whose construction typology - high ceilings, massive un-insulated masonry walls, decorative finishes, etc. - provides particularly difficult environmental challenges. It provides key insights into sustainability in the historic built environment and the factors contributing to the sustainability of historic structures; it highlights and presents a review of the most significant issues of revising sustainability rating systems in order to include the whole range of factors that affect sustainability in the historic built environment.

SUSTAINABILITY, CLIMATE CHANGE AND CONSERVATION

Conservation and sustainability are related in a broader ecological sense (Rodwell, 2007). English Heritage's "Regeneration and the Historic Environment Heritage as a catalyst for better social and economic regeneration" (2005) highlights the benefits of using existing buildings rather than constructing new ones. In the words of another paper: "The greenest building is the one that's already built" (National Park Service. U.S. Department of the interior, website, 2012). One important reason for retaining any exitsing building including those of histroic importance is that any new building will involve considerable embodied energy (Jackson, 2005). The carbon released in building construction has already been long expended in an existing building. Reusing buildings limits the need for new building materials and reduces the structural waste from demolition work (English Hertiage, 2005). At the same time, conservation is considered to be the most cost-effective form of preserving energy in the built environment, since it appreciates the value of existing structures and thus embodied energy (Sedovic and Gotthelf, 2011).

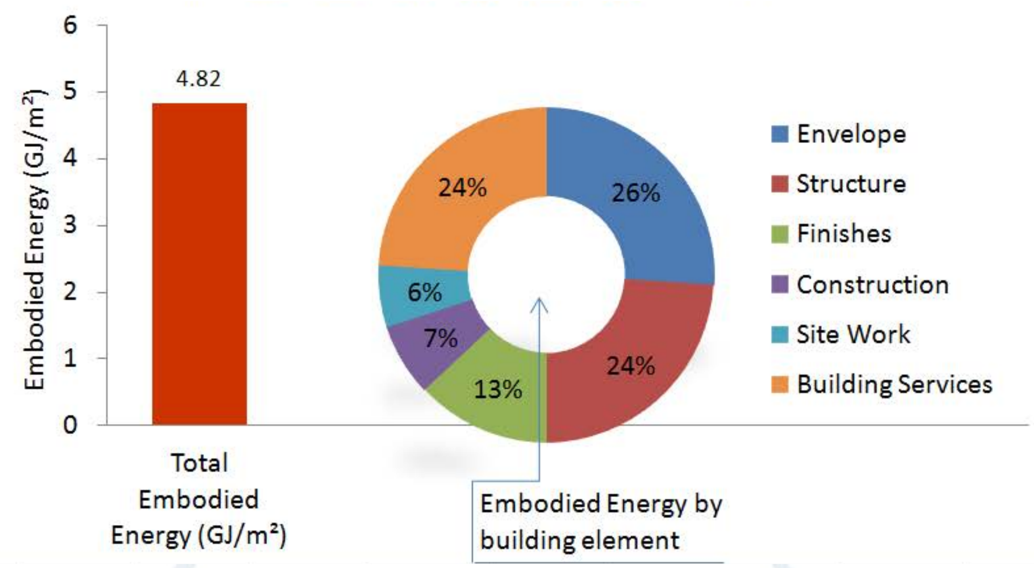

Figure 1 Embodied energy- note that 24% spent wasted on buildings services, a figure than can be substantially reduced by passive energy design
(Cole and Kernan, 1996).

Although, the majority of historic buildings have been constructed with local materials which tend to enclose low embodied energy, the total amount of energy possessed by both materials and the labour to construct the buildings is enormous (Figure 1) (Sedovic, 2003).

Sustainability needs to be seen in its broader sense and not just in terms of carbon emissions (Technical Preservation Services, 2004). There are economic and social aspects of sustainability. On the social level, the sense of *place* is often dependent on the retention of key buildings and landscapes. In England older buildings generally have a greater economic value than new ones of similar uses. Areas with a rich historic legacy have been show to have strong senses of local identity, and historic continuity is an important local educational resource. Historic buildings and other historic assets of urban environment promote community spirit and are often selected as places to host local social events (wedding, funerals, celebrations etc). Moreover historic buildings provdie a physical record of the past, the destruction of which reduces our knowledge irreversibly. Few historic buidlings used much energy for heating or lighting when originally constructed. Where they are inefficent it is modern adapttations have made them so. In the past levels of comfort expected of building were far lower than today. Extensive research has shown that historic buildings can be more environmentally sustainable and their environmental performance can be, as good as, new-build projects (Pickard, 2004). On the economic side, conservation and revival of historic environment creates jobs and thus assists the growth of local economies (English Heritage, 2002) and there is no doubt that an environment of high quality positively affects the performance of any business or community activities. However any scheme needs to be aware of the risks of additions to historic building. It is not simply a matter of adding heating to existing buildings. Siome heating can even be beneficial in certain climates, but poorly-designed heating or cooling systems can cause deterioration to fabric and artworks, as they cause variations of temperature and humidity beyond the limits required for conservation (Curteis, 2008).

SUSTAINABILITY AND CONSERVATION

Historic environment conservation is closely connected to sustainable development and regeneration. In the UK, government statements praise the relationship between the historic environment sector and sustainability (Pickard, 2004). It is recognised that a building can be valuable simply because it represents the social and cultural attitudes of local people. Conservation needs to aim at preserving the character and fabric of the historic building while meeting the needs of people who use them (Pearce, 1989). J. Douglas in his book *Building adaptation* (2002) goes further, suggesting that all conservation work should be combined with regeneration work to improve people's lives in ways that include the quality of local environment. English Heritage has long stressed that existing structures can be adapted to modern needs when required. Indeed there are countless examples where this has been carried out. Sensible alterations or the addition of existing buildings contribute to the sustainability of the urban environment as this can offer people a sense of the familiar along with the excitement for the new (English Hertiage, 2005). Harvey (1972) warns however that it is difficult to decide how far it is possible to alter a historic building without losing its architectural and historic qualities. In all historic buildings including church buildings which are the focus of this paper, special attention to building requirements and implementation of sustainable measures is essential. Places of worship are recognised to constitute a unique type of building and thus normal conservation or environmental design methods recommended for towns and other traditional structures are often not applicable to them (DEFRA, 2009).

ENVIRONMENTAL PERFORMANCE OF HISTORIC STRUCTURES: THE CASE OF ENGLISH CHURCHES

Churches constitute a signifcant part of the heritage of Western Europe. Whatever their size and religion, from cathedrals to chapels, churches in the UK have always been seen as vitally important by the majority of locals, congregations and visitors alike (Taylor, 2010). Unfortunately over the last few decades many churches in the UK been abandoned (Bird, 1959). In England congretgations have been falling and clergy seeking to expand them are often qucik to blame cold and draughty churches. Most historic churches remain in use for worship but with aging and dwindling congregations. Worship is churches' primary and main purpose, and as a rule historic buildings are best used for their intended purpose. Alternative (conversion to housing, offices etc) tend to be espcially damaging to the special architectural or historic interest of the building and thus not always a sustainable choice (Kelleher, 2003).

Securing sustainability of church buildings therefore means maintaining the building structure and contents and while achieving a welcoming environmental conditions for participants. Ecclesiastical buildings are challenging case studies; given that churches represent a large part of the historic built environment in the UK (Over 30,000 churches are listed in the UK, while Church of England is caring for over 13,000 listed places of worship). As energy costs increase and congregations reduce cutting energy use is a necessary aim for the church. On a smaller scale, church buildings also pose particular challenges to achieve an environmentally sustainable performance because they are complex structures; their large volume creates additional difficulties in managing heating and air movement internally to achieve satisfactory comfort conditions; being occupied infrequently sets hurdles to the decision-making of installation of mechanical equipment and in parallel achieve energy conservation and acceptable comfort; and lastly as they are often buildings whose preservation is mandated by law any environmental adaptation needs to be done with the minimum interruption to physical fabric and contents.

COMPARATIVE ENVIRONMENTAL PERFORMANCE OF CASE-STUDIES

This study focuses on four case studies which have been used to test and challenge current thinking on the performance of specific heating methods with regards to building behaviour and formation of specific microclimatic conditions; and the on-site measured values of Temperature and Relative Humidity. Among other conclusions, the research has shown that long-term monitoring can be a successfully employed approach for analysing the microclimate of historic buildings and churches in particular. However, the identification of any thermal stratification inside the enormous volume of church buildings is particularly difficult due to access limitations. A plethora of factors may affect the environmental conditions at the upper levels of the building, such as intermittent occupancy, non-specific schedule for windows and doors opening, instantaneous operation of heating or even occasional failure of the building envelope.

It is important to remember that in England most older churches were originally constructed without any heating provision, heating being uncommon until the late nineteenth century. Retaining the original microclimate conditions by avoiding changing heating, ventilation or other mechanical service operations, maintains a state of equilibrium is achieved between the moisture in the building structure and that in the air (Curteis, 2004). Among all possible influences, heating has been proven to affect the church microclimate most intensively, especially in the case of heating use for thermal comfort provision for short time periods which usually causes environmental distress to the building structure and is likely to become the source of deterioration of plaster, stonework and other historic material.

The following study is based on monitoring of Great St Mary’s, St Botolph’s, All Saints church and Queens’ College chapel in Cambridge, UK, which employ representative heating methods and mechanical equipment. Each case employs a different combination of heating system and strategy that causes particular variations in the building environmental response.

Despite the different methods employed, the Temperature per month in all case studies shows remarkably homogenous conditions at both the lower occupied levels and in upper parts of the buildings. (Figure 2) The buildings with constant heating strategies (Great St Mary's and All Saints) maintain rather high temperature conditions (average 15°C throughout the year). The intermittently-operated localised heating system in St Botolph's church has little influence on the internal microclimate of the church which generally follows the fluctuation patterns of the external conditions; however the building still acts as a buffer zone that maintains the indoor Temperature at approximately 5°C above outdoor Temperature level. Furthermore the lack of heating at the generally heated Queens' College chapel during out-of-term time within the heating period provides significant differences in the thermal conditions in the chapel.

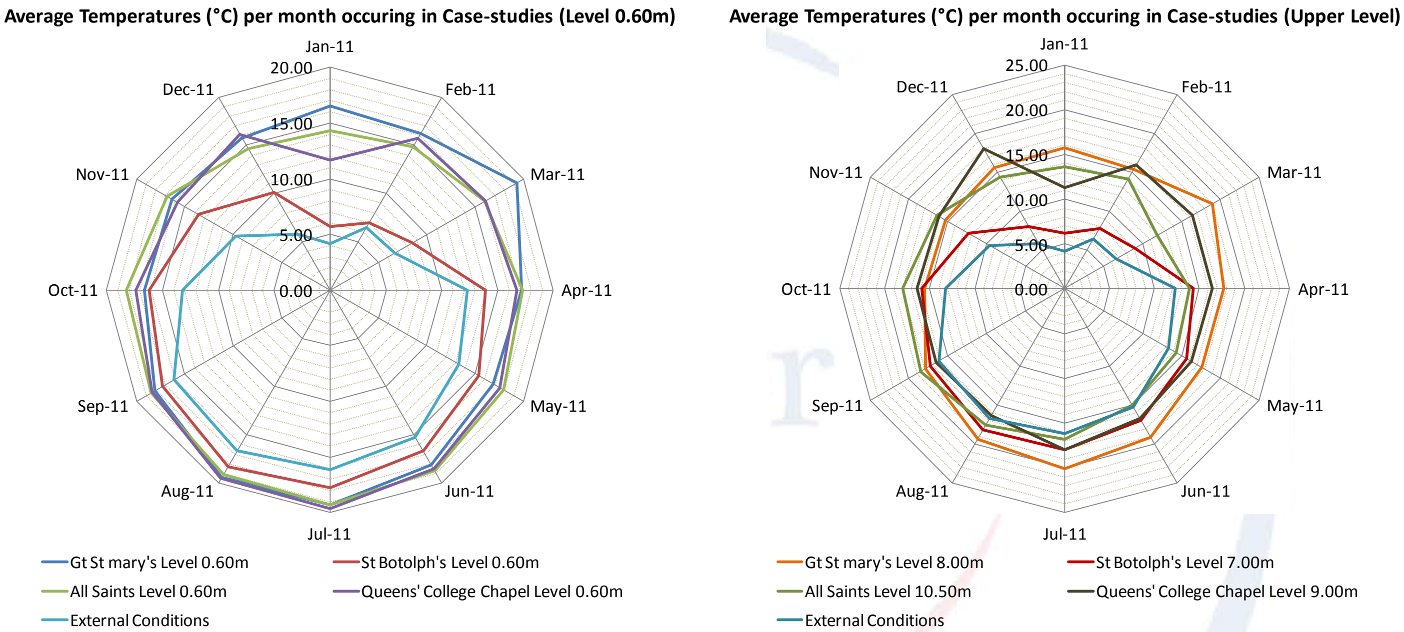

Figure 2: Average Temperature per month occurring on the occupancy level and upper building part in all case-studies.

Detailed analysis provides more interesting results. The regressed temperature against relative Humidity values on a typical Sunday when services took place in all case-studies, show concentrated values at the occupied level in all case studies. (Figure 3) However the regression analysis reveals more varied results in the upper parts of case-studies, most significantly at St Botolph's church which is heated intermittently. The heating systems used in three out of four cases (Gt St Mary's, All Saints and Queens' college chapel) produce their effect by radiant means (and convective means in some auxiliary spaces of Gt St Mary's) which do not introduce any further particles into the internal microclimate. However, in the case of St Botolph's church, which is heated only for limited hours per week, the church is using both radiant local heating method through heating panels on pews and portable gas flame heaters. The gas heaters are very efficient in producing fast and relatively low cost heat, however they have the huge disadvantage that the main combustion product of Liquid Petroleum Gas (LPG) is water, each 1kg of gas burned producing about 1.5kg water (Curteis, 2004). The result is that using gas heaters in a large church for only one or two hours, causes dramatic rises in absolute humidity, resulting in condensation, immediately after they are turned off. Thus, RH in St Botolph's church fluctuates rapidly compared to other intermittently heated cases, such as Queens' college chapel when the heating is radiant and it operates for much longer periods before it is switched off. This is important because high levels of humidity and particularly condensation, are detrimental to pictures, timber, paintwork and plaster and also, through mould growth, to human health. The conclusion is that general low level constant heating is better for the building. This however is not necessarily the most energy efficient solution, nor the most comfortable.

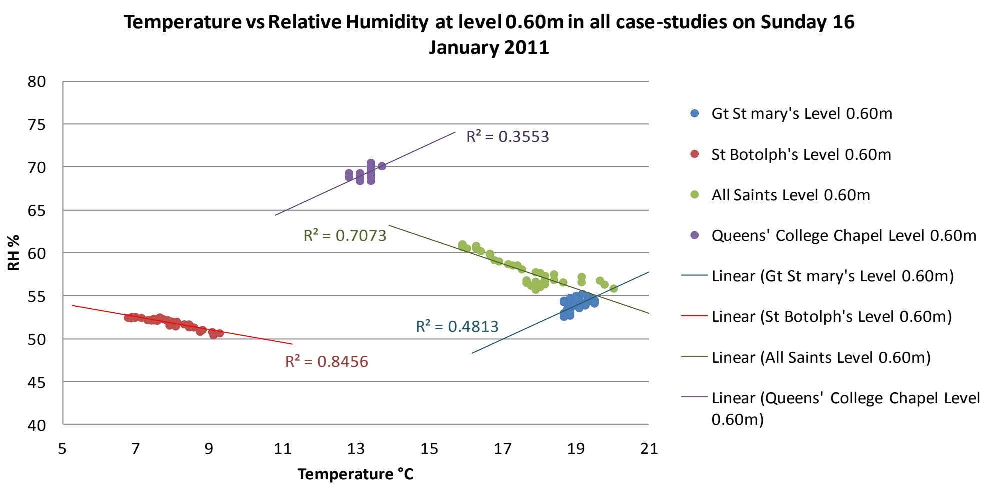

Figure 3: Temperature and RH correlation on occupancy level (0.60m from floor) in case studies during a typical one-day period.

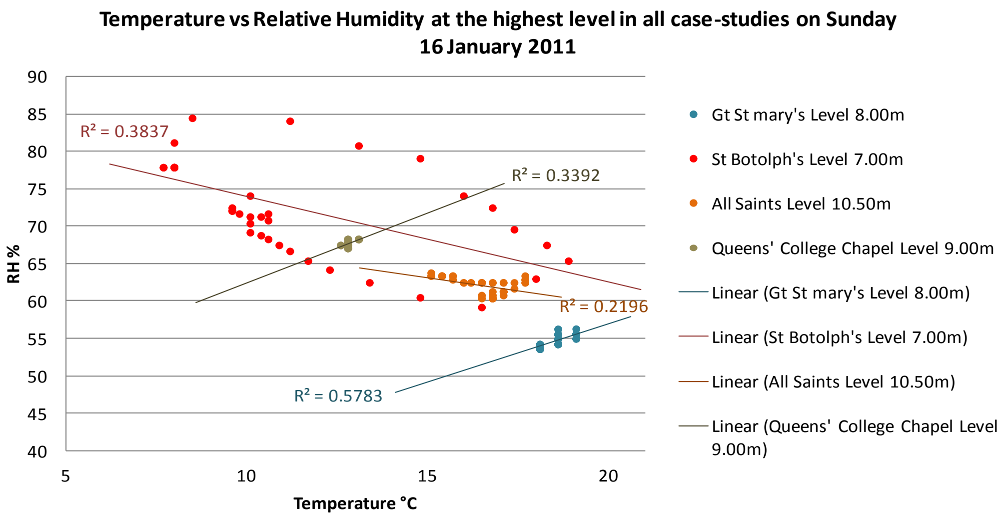

Figure 4: Temperature and RH correlation on upper part of case studies (average of 8 m from floor) during a typical one-day period.

ENERGY CONSUMPTION IN PLACES OF WORSHIP

The energy consumption of a church varies with size, age, heating type, weekly occupancy and the community use of the buildings (CofE, 2008). Managing and reducing energy consumption can have significant benefits for everyone. Reducing energy consumption reduces costs, and helps reduce the volume of harmful greenhouse gases being released into the atmosphere (CofE, 2008). Church of England has undertaken surveys of church halls and other ecclesiastical buildings in order to estimate the energy consumption in its premises with the intention of producing general guidance in due course on energy saving measures. 60 church buildings within the Diocese of London and Westminster were inspected as part of the Church of England's environmental audits during 2009 and 2012. Those series of audits were part of the Diocese of London's response to the church of England's environmental campaign, named "Shrinking the Footprint", which aims to reduce carbon emissions of the whole organisation's premises by 80% by the year 2050 (CofE, 2008). The aforementioned environmental audits examined the churches' energy use and carbon footprint as a result of fuel and water consumption, waste and recycling. It was found that fossil fuels constituted the largest source of carbon dioxide emissions. The survey has also revealed that approximately 43% of churches use natural gas and 21% use oil for space heating. In addition comparison between a rural and urban church revealed that the two types of church varied in terms of energy use patterns. The rural church used the majority of total energy consumed for space heating (79%) and lighting (17%), while the urban church used only 53% of total energy consumption for heating (CofE, 2008). In many cases, in the urban churches, especially the ones that are in constant operation, energy usage can be attributed to other uses (i.e. kitchens, cafés, offices, etc) which made up a considerable percentage of the total energy consumption. Figures 5 and 6 illustrate findings of the survey conducted in a rural and an urban church that hosts community actions.

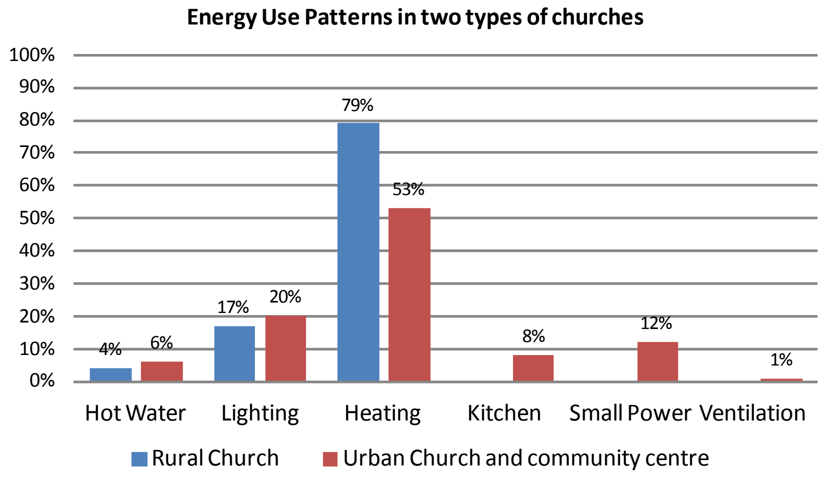

Figure 5 Energy use patterns in a Rural and Urban church.

It is evident that the majority of energy used in both cases can be attributed to space heating. However the average energy consumption of a rural church is estimated to be less than a tenth lower than the annual energy consumption in an urban church. (Figure 3-2) It is clear that occupancy patterns play an important role in church buildings energy use; rural churches have limited occupancy periods compared to urban churches and use almost all the energy they consume for space heating during church services.

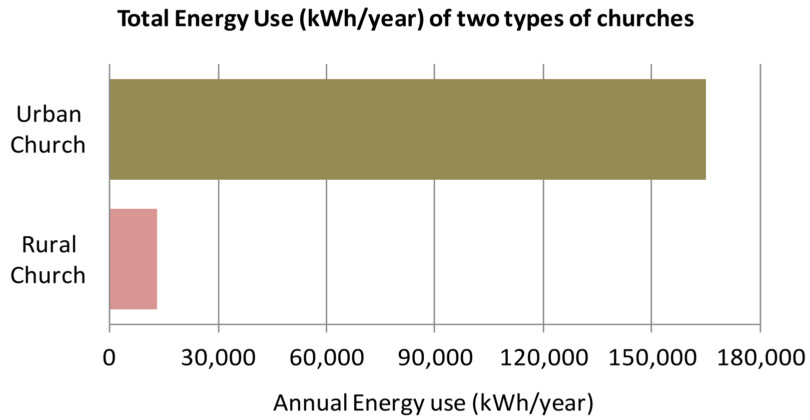

Figure 6 Total Annual Energy use of Rural and Urban church with community use.

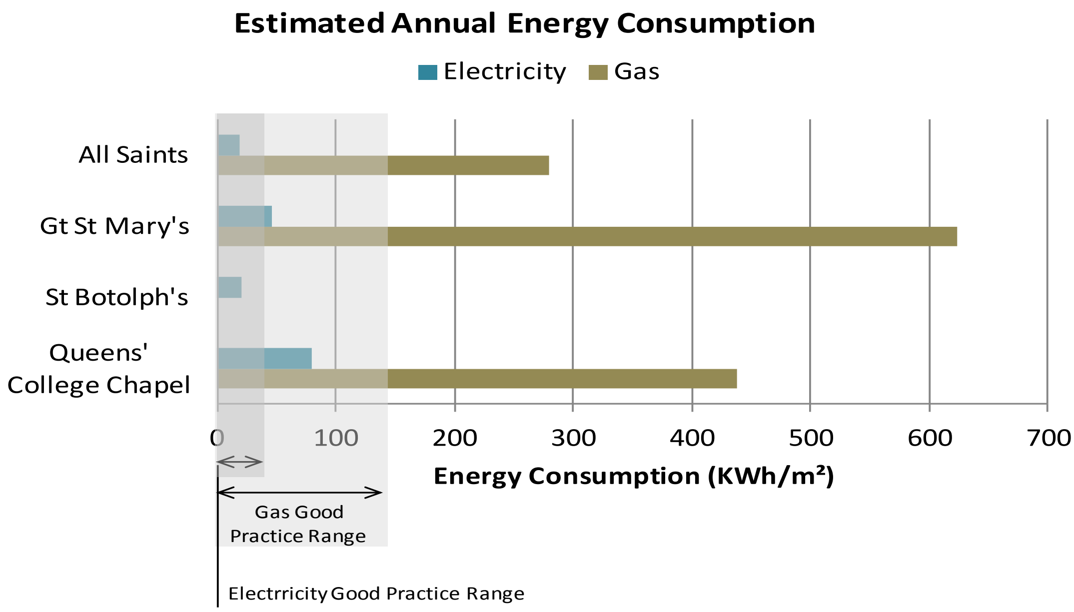

Figure 7: Estimated Annual Energy Consumption in four churches in Cambridge.

MEASURES FOR ENERGY CONSERVATION IN CHURCH BUILDINGS

Carbon dioxide emissions from churches arise from a limited number of activities. Mainly emissions come from energy used when heating and lighting a church but at larger sites other activities like hot water generation, kitchen and catering activities and office energy use will also contribute. It should be noted that using energy, whether it is electrical energy or fossil fuels like gas, oil or coal, will generally result in the release of carbon dioxide emissions into the atmosphere (CofE, 2008). Small scale wind generation or solar power are generally not viable for most churches in the UK. Table 1 presents a summary of suggested energy saving actions that church building managers and users could undertake in order to achieve specific potential savings on their utilities bills (see). These measures can be of low, medium or high cost and would include:

- Establishing a schedule for energy conservation by empowering energy saving considerations to building users:
  - Inform and consistently educate users about benefits of building energy conservation and methods of reducing energy demand in their building.
  - Conduct regular monitoring of building energy consumption by either manual meter readings or via installation of specialised monitoring equipment, e.g. energy meters with pulse output transmitters (if affordable). This is the simplest method of energy-monitoring a church without need to install any extra hardware since regular meter readings and bills are kept to compare performance annually against benchmarks (Diocese of London, 2011).
  - Map the energy use patterns within the building through observation of energy end uses in order to identify activities that use excessive energy.
  - Introduce energy benchmarks to building users and provide them with regular feedback in order to understand the impact of particular activities or behaviours on energy consumption of their church.

- Effective settings and control of heating in churches can save up to 80% of energy use (Diocese of London and Carbon Trust, 2011). Measures to improve heating controls can vary:
  - Adjust temperature set-points to match requirements for heating levels in church environments.
  - Set appropriate time schedule controls to avoid waste of energy during long period when the building is not occupied.
  - Consider creating zones within church building according to use patterns.
  - Take advantage of the high thermal capacity of historic churches thermally heavyweight structure.

- Investing in energy efficient plant equipment and controls can lead to significant reduction of energy demand:
  - Low energy lighting lamp technologies and controls, e.g. Task/Ambient Lighting Schemes.
  - Low energy space heating systems in combination with creation of microenvironments for occupied zones, e.g. Floor-warming, pew heating.
  - Insulation of hot water pipework.

- Although often constrained because of heritage characteristics of church buildings that require conservation, particular fabric improvement options may prove to be robust and offer long term benefits to energy demand reduction:
    - Add insulation where the heritage fabric allows, e.g. roof voids, but ensure ventilation to minimise the risk of condensation.
    - Check completeness and improve the condition and of roof insulation.
    - Improve air tightness through repairing building envelop failures, such as sealing penetrations and joints in walls that may form unwanted air-paths, joints of walls to roofs, cladding panels and where services penetrate.
    - Check and improve condition of windows, grouting seals, closing mechanisms to minimise air leakage paths.
    - Consider high performance glazing for replacements with argon filled voids and special coatings to reduce the U value to less than 2.0 W/m2K including frame.
    - Secondary Glazing with high performing glass thin gap double glazing has been used successfully in heritage building refurbishments.
    - Check seals around doors, repair or replace as necessary.
    - Consider the fitting of draught lobbies to minimise the heat loss through external doors used continuously by public or building occupants.

- Micro generation equipment as soon as it is not visible from important view points and does not damage historic fabric. However, since installation of renewable energy technologies entails high investment costs with long payback periods, Low and Zero Carbon Technologies (LZCT) should be considered once procedural and demand reduction measures have first been put in place. Then LZCT would offer potential for major carbon reductions.

Table 1 Suggested energy conservation action for churches based on sources:(Diocese of London and Carbon Trust, 2011).

Suggested Primary Action	Suggested follow-up options/actions	Potential cost implications	Estimated savings on annual fuel bills (% of total utility cost per annum)
Establish a schedule for energy saving	Inform/educate users about benefits of building energy conservation and methods of reducing energy demand in their building	Zero or low cost	5% - 15%
	Regular monitoring of building energy usage	Zero or low cost	5% - 15%
	Monitoring and mapping of energy use patterns within the building to identify activities that use/waste too much energy	Zero or low cost	5% - 15%
	Provide feedback to building managers and users	Zero or low cost	5% - 15%
Improve heating controls	Check temperature set points	Zero or low cost	5% – 10%
	Check time schedule of controls	Zero or low cost	5% – 10%
	Check the zoning of heating and ventilating systems according to use patterns.	Low or medium cost	10 – 15%
	Take advantage of historic churches' thermal mass properties.	Zero or low cost	10 – 15%
Suggested Primary Action	**Suggested follow-up options/actions**	**Potential cost implications**	**Estimated savings on annual fuel bills (% of total utility cost per annum)**
Energy efficient systems and controls	Low energy lighting	Medium cost	Up to 50%
	Low energy space heating and controls according to occupation patterns	High cost	Up to 20%
	Insulation of hot water pipes.	Low cost	Up to 5%
Fabric improvements	Insulate where heritage fabric allows but ensure ventilation to minimise the risk of condensation.	Medium or high cost	Up to 10%
	Improve air tightness to establish better control of air movement through the building.	Medium or high cost	1% - 10%
Low and Zero Carbon Technologies	Photovoltaic Panels: Electricity Production	High cost	Up to 76% reduction of electricity (mains) consumption
	Solar Thermal Panels for Domestic Hot Water (DHW) provision	High cost	Potential for 100% offsetting of gas (mains) use for DHW
	Biomass heating	High cost	Up to 56% reduction in carbon emissions (gas consumption may be 0 if gas boiler is not used as back up to heating and hot water system)
	GSHP (Ground Source Heat Pumps): Space heating	High cost	Up to 34% (GSHP) would displace gas used for heating but with additional electricity use and would have longer payback period than biomass boilers.

Regular meter readings were made in 2010 of the four church buildings in Cambridge in order to estimate the energy consumption per month (Figure 7). The survey was conducted in four representative churches with different types of heating strategies:

- Great St Mary's church, Cambridge: Constant Central (Trench) heating

- St Botolph's church, Cambridge: Intermittent Local (Electric Panels on Pews) heating
- All Saints church, Cambridge: Constant Central heating, Thermostatically controlled to keep the church at conservation temperatures (11.5°C -12°C)
- Queens' College Chapel: Central heating with water pipes on windows level.

Queens' college chapel and Great St Mary's church consumed large amounts of gas (m^3/m^2) and electricity (KWh/m^2) due to regular use, compared to All Saints and St Botolph's church. The case-studies that used gas for heating space consumed much more fuel (KWh/m^2) than the 'good practice' quantity suggested by the benchmark - $151KWh/m^2$. The electricity consumption per annum seems to be closer to the suggested values (CofE, 2008). St Botoph's has been shown to perform poorly in conservation terms, leaving the question of whether All Saints provides adequate thermal comfort.

THERMAL COMFORT IN PLACES OF WORSHIP

One of the evident purposes of the Building Research & Information special issue 'Comfort in a Lower Carbon Society' (Shove, 2008) was to underscore how cultural and historical context has a significant impact upon the techniques of achieving human comfort deemed appropriate at the time. This undertaking is useful because it challenges assumptions that are often otherwise made about the ambient conditions with which we should provide people when these assumptions could easily lead towards certain undesirable outcomes. Supplying the same immediate environmental conditions to people scattered across the varied local climates around the world would require enormous amounts of energy. The effect of these assumptions might also mean many people could quickly become so used to specific ambient conditions that they turn their backs on the varied benefits that often follow the decision to spend time outdoors (Shove, 2008).

Creating thermal comfort with background heating and local supplementary warmth should more often be considered as a heating strategy in churches. Aside from technical upgrades of the building fabrics and services to address thermal comfort, this strategy can easily complement such upgrades and achieve better savings (Humphreys, 2011). Studies of thermal comfort in churches have shown that the operative temperatures that churchgoers consider thermally neutral have varied greatly in different cultures (de Dear, 1998, Humphreys, 1976).

To enable comparison of perceived thermal comfort levels occurring in all four case studies, responses obtained from the thermal comfort questionnaire survey that took place in all churches have been plotted in graphs that have expressed results in percentage of total answers obtained from each case.

Figure 8 reveals that the constantly heated churches (All Saints and Gt St Mary's) with trench LPHW heating system are more likely to offer thermally comfortable environments in comparison to St Botolph's and Queen's College chapel whose answers are distributed towards the cool range of perceived thermal comfort graph. Although in both later churches responses present a rather normal distribution, large percentage of respondents indicated cool and slightly cool feeling, due to lack of constant heat inputs and thus low radiant temperatures expected to occur in these cases.

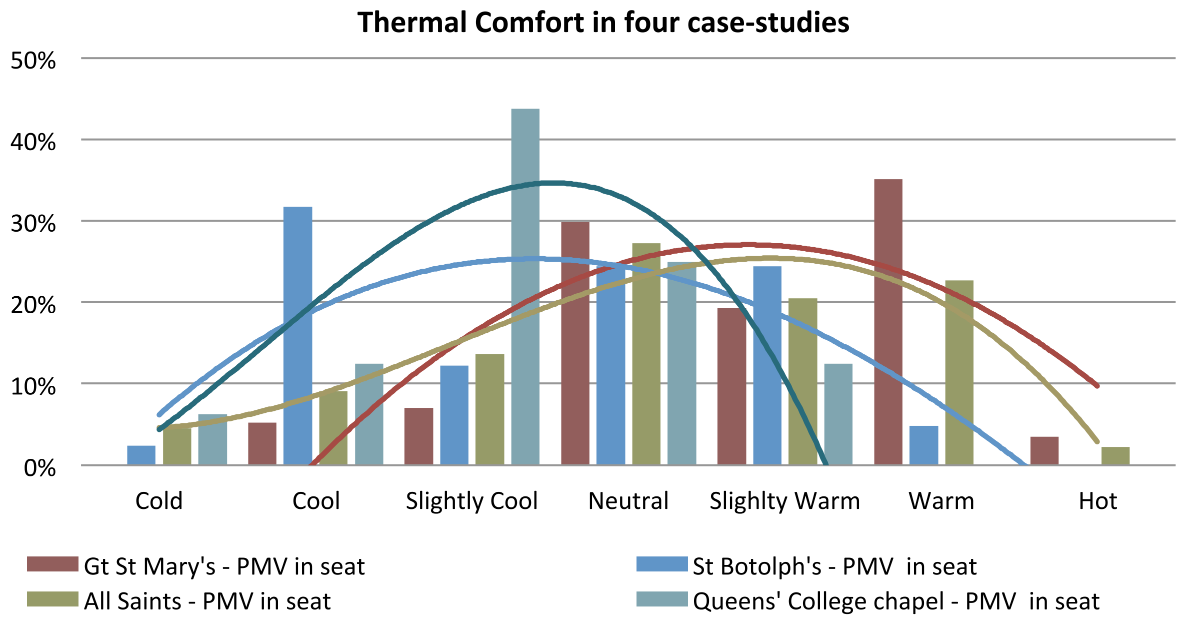

Figure 8 Perceived thermal comfort levels inside all four case-studies.

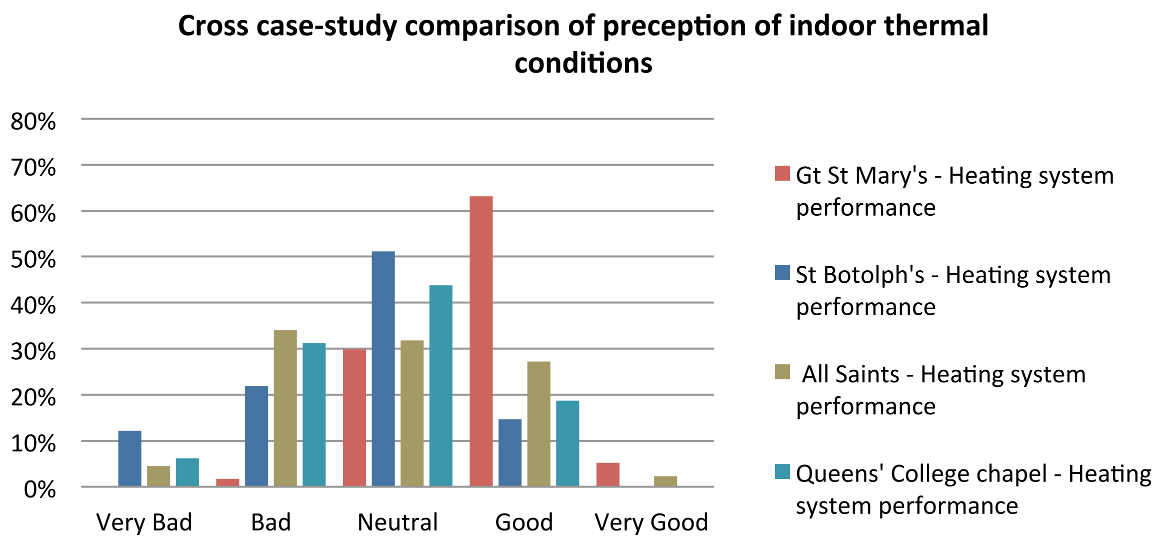

Figure 9 Rating of overall thermal conditions occurring inside all four case-studies as indicated by questionnaire survey respondents.

CONCLUSIONS

It is key to improve energy and environmental management of historic buildings with minimal intrusion. As in all other sectors, sustainable development in the historic built environment becomes a necessity. It is imperative for historic structures to reduce their footprint too. However, to achieve this, from an environmental performance point of view, buildings need to satisfy three key elements:

- **Energy efficiency**

Historic buildings and especially church buildings can often be found on exposed sites; structures are often massive, porous and damp. Due to the heritage value of their fabric and artefacts they contain, there are significant constraints on the type of environmental adaptation measures which can be used to upgrade their efficiency. For example, thermal insulation can be installed in roofs but is very difficult to incorporate in walls without significant effects on the building's appearance. Most improvements focus on renewing or upgrading existing building services, mainly heating systems in historic churches. However, building services are often difficult to select appropriately thanks to limited knowledge of the mechanisms that affect building fabric conservation and occupants' satisfaction; and due to restrictions on budgets to run them.

- **Conservation of historic fabric**

To maintain usability and increase interest in historic buildings, in is important to conserve fabric and conserve in vigorous and economical ways. However historic structures, such as church edifices pose more serious difficulties in applying effective and appropriate control of the environment than other building types. Best practice scenarios and principles are essential.

- **Human factor**

Although general guidance for design criteria for comfort exists, these need to be re-assessed. The research undertaken in four case studies in Cambridge, has proven that existing conditions should be further investigated to take into account human perception as well, rather than simply using predicted comfort models. Very often requirements of people, objects and fabric, appear to be in conflict; however this research suggests that it is possible to combine occupant satisfaction, conservation and energy efficiency.

Nevertheless, it is imperative to achieve better communication among key stakeholders, including practitioners, such as architects, conservators, building services engineers, building managers and curators, in order to achieve effective exchanges of knowledge that can balance the requirements of each party and thus benefit a wider public audience and society. Interdisciplinary thinking can result in better solutions.

Most of the adaptation solutions already exist and do not require of very complicated and technologically advanced equipment. The most important requirement is having a comprehensive insight into the environmental requirements of occupants, historic elements and the energy saving options available. It is often said that the "best is enemy of good", often analysis shows that trying to improve rather than reach some notional ideal may be the best and most practical solution for interventions in the historic built environment.

REFERENCES

BIRD, P. 1959. Churches, Artists, and People. *Studies in Conservation,* 4 **(**2).

CAMUFFO, D., PAGAN, E., SCHELLEN, H., LIMPENS-NEILEN, D., KOSLOWSKI, R. & BRATASZ, L. 2007. *Church Heating and the Preservation of the Cultural Heritage. Guide to the Analysis of the Pros and Cons of Various Heating Systems. Results of the European project Friendly Heating (EVK4-CT-2001-00067),* Brussels, European Comission.

COFE 2008. Shrinking the footprint, The Church of England's National Environmental Campaign, Guidance on Energy Efficient Operation and Replacement of Plant and Equipment. *Deliverable D9 Carbon Management Programme.* London: Church of England.

CURTEIS, T. 2004. Environmental Conditions in Historic Churches: Examining their effect on wall paintings and polychrome surfaces *Transactions of the Ecclesiastical Architects and Surveyors' Association,* 5 36 - 46.

CURTEIS, T. 2008. The survey and identification of environmental deterioration. *The Building Conservation Directory.* London: Cathedral Communications Ltd.

DE DEAR, R. J., & BRAGER, G.S. 1998. Developing and adaptive model of thermal comfort and preference. . *ASHRAE Transactions,* 104 **(**1).

DEFRA 2009. Waste Strategy, Annual Progress Report 2008/09. London: Department for Environment, Food and Rural Affairs.

DIOCESE OF LONDON 2011. Options, Challenges, Solutions, Limitations. *Environmental Challenge.* London: Diocese of London.

DIOCESE OF LONDON AND CARBON TRUST 2011. Generic Building Solutions. *In:* ARUP (ed.).

DOUGLAS, J. 2002. Building adaptation. Oxford: Butterworth-Heinemann.

ENGLISH HERITAGE 2002. Heritage Dividend 2002. Swindon: English Heritage.

ENGLISH HERTIAGE 2005. Regeneration and the Historic Environment. Heritage as a catalyst for better social and economic regeneration. London: English Heritage.

HARVEY, J. 1972. *Conservation of Buildings,* London John Baker.

HERITAGE, E. 2008. Energy conservation in traditional buildings. London: English Heritage.

HUMPHREYS, M., NICOL, F., & ROAF, S. 2011. Keeping warm in a cooler house creating thermal comfort with background heating and local supplementary warmth. *Historic Scotland Technical Paper 14.* Scotland: Historic Scotland.

HUMPHREYS, M. A. 1976. Field studies of thermal comfort compared and applied. *Journal Inst. Heaing. & Ventilation. Engineering* 44 5-27.

JACKSON, M. 2005. Embodied Energy and Historic Preservation: A Needed Reassessment. *APT Bulletin,* 36 **(**4): 47-52.

KELLEHER, S. (ed.) 2003. *New Work in Historic Places of Worship,* Swindon: English Heritage

MADDEX, D. & NATIONAL TRUST FOR HISTORIC PRESERVATION IN THE UNITED STATES 1981. *New energy from old buildings,* Washington, D.C., Preservation Press.

MERYMAN, H. 2005. Structural Materials in Historic Restoration: Environmental Issues and Greener Strategies. *APT Bulletin,* 36 **(**4): 31-38.

PEARCE, D. 1989. Conservation today. London.

PICKARD, R. 2004. The Role of Historic Buildings in Urban Regeneration: Eleventh Report of Session 2003–04. *House of Commons ODPM: Housing, Planning, Local Government and the Regions Committee.* London: The Stationery Office Limited.

RODWELL, D. 2007. *Conservation and Sustainability in Historic Cities,* Oxford, Blackwell publishing Ltd.

SEDOVIC, W. 2003. History's Green Genes. *The second International conference on Sustainability (GreenBuild), 12-14 November 2003.* Pittsburgh, PA: Green Building Council.

SEDOVIC, W. & GOTTHELF, J. H. 2011. Paradox to Paradigm. Sustainability & Performance of Heritage Buildings. *Proceedings of Energy Management in Cultural Heritage conference, 6-8 April 2011.* Dubrovnik, Croatia.

SHOVE, E., CHAPPELLS, H., LUTZENHISER, L., & HACKETT, B. 2008. Comfort in a lower carbon society. *Building Research & Information,* 36 **(**4): 307-311.

TAYLOR, J. 2010. Listed Places of Worship. *The Building Conservation Directory.* London: Cathedral Communications Ltd.