Sustainable Energy Strategy for Historic Churches and Cathedrals in the UK

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Abstract

The Church of England (CoE) has been activity involved with environmental concerns and has launched an environmental campaign to reduce the carbon footprint of its properties by 80% by 2050 in line with the UK government carbon reduction targets. The CoE has published a guidance document on energy efficiency and different dioceses have carried out independent surveys to identify the most effective approach in reducing their carbon footprint. However, research suggests that the measures taken by the CoE are insufficient in achieving an 80% reduction by 2050.

Development of a sustainable energy strategy for historic churches and cathedrals in the UK is a complex process. First of all, most of these churches are listed which severely limits the scope of refurbishment work that can be carried out. Moreover, the rapid decline of church membership in the British Society poses a great challenge for the CoE whose income is, to a great level, dependent on the donations and financial support of its members. In addition, the secularisation of the British society presents questions with respect to future function of historic churches.

The research uses an energy reduction hierarchy to investigate the effectiveness of various energy reduction measures using Lichfield Cathedral as a case study. The hierarchy firstly focuses on low cost solutions such as behavioural changes and energy management measures which could result in up to 15% reduction of overall energy consumption. In addition, technological solutions which require higher investment are discussed and examined. It is recommended that for churches with intermittent services and infrequent use, the application of local heating methods such as pew heating could result in significant savings. Moreover, building fabric improvements including insulating the roof and improving windows should be considered by all churches before moving toward more expensive refurbishment options. Finally, using under-floor heating systems and low carbon technologies should be studied further as a long-term solution if the financial means are available.

Nevertheless, no unique solution could be presented for all historic churches and the individual characteristics of a church and its future function should be taken into consideration whilst devising a sustainable energy strategy.

Acknowledgments

I would like to thank my mom and dad and my brothers whose love and support made this possible. Also, I would like to pay gratitude to Dr. Mark Gaterell, Dr. Marwa El-Cheikh and Dr. John Bridgeman for their help and support as my supervisors. Finally, I would like to thank Archdeacon Chris Liley of Lichfield Cathedral for his help in completing this work.

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Chapter 1: Introduction

1.1 Background

Exploitation of natural resources to achieve rapid economic growth has significantly damaged the environment in the past decades (Son et al, 2009). Sustainable development and the necessity of protecting the environment along with social and economic growth could be considered as a response to such difficulties. However, the definition of the concept and what it entails has been the subject of numerous discussions since its introduction and continues to date. The built environment is a major source of energy consumption and carbon emission; it accounts for about 40% of carbon emissions in Europe and over 50% of carbon emissions in the UK (Clarke et al, 2008). As a result, the built environment plays a pivotal role in the shift toward more sustainable practices.

By introducing The Climate Change Act (2008), the UK is the first country with a legally binding document by which the government is committed to reduce carbon dioxide emissions by 34% of the 1990 level by 2020 and 80% by 2050 through investment in energy efficiency and clean energy technologies (DECC, 2009). In summer 2006, the Church of England (CoE) launched an environmental campaign to reduce its CO_2 emissions in line with the government's target. Although other Christian organisations such as the Catholic Church have preached about the significance of environmental issues and taken isolated initiatives, the CoE's campaign is the only systematic approach with specific CO_2 reduction targets for the entire building stock of a major religious institution. However, research suggests the feasibility of the CoE's strategy in achieving its target is uncertain; the heart of the CoE's strategy is reducing the energy demand in their buildings but such demand is linked to the use to which a building is put. The increasing secularisation of UK society raises significant questions as to the long term use of CoE buildings for mainly faith-based activities and therefore the kinds of energy efficiency measures that can be adopted. Consequently, any decisions to invest in energy measures are beset with uncertainty; they must not only help meet CoE carbon targets today but remain efficient and effective over the whole life of the buildings. In addition, due to historic nature of many CoE's churches and cathedrals, the scope of refurbishment work which could be carried out is limited. Therefore, achieving a sustainable energy strategy for historic churches and cathedrals is a complex process which requires a thorough examination of the existing energy reduction measures with respect to the specific characteristics of a given church.

1.2 Aims and Objectives

The overall aim of this research is to investigate the feasibility of various sustainable energy strategies and provide a systematic sustainable approach toward energy efficiency and reduction of carbon dioxide emissions for historic churches and cathedrals in the UK. The key objectives have been defined as:

- Understanding the concept of sustainable development and its implications within the historic built environment
- Investigating the feasibility of the Church of England's environmental campaign in achieving an 80% cut in its carbon footprint by 2050
- Examining the effectiveness of the existing energy reduction measures for historic churches and cathedrals (behavioural solutions, technological solutions and building fabric improvements)
- Developing a case-study and investigating the impact of implementing energy reduction measures on the building's carbon emission and overall energy consumption

1.3 Structural Layout of the Thesis

Chapter 2: This chapter provides a historical background on the concept of sustainable development and explores its implications in the built environment. Furthermore, the historic built environment and how it can be associated with sustainable development are discussed in this chapter along with the relevant policies and legislations of the UK government on the subject.

Chapter 3: This chapter discusses sustainable development in the framework of the historic built environment and the Church of England's environmental campaign. It reviews the response of the church to the current ecological crisis and discusses the CoE's environmental campaign. In addition, similar environmental initiatives undertaken by various Christian organisations are briefly reviewed.

Chapter 4: This chapter reviews the existing solutions with respect to reduction of energy consumption and carbon emission and their feasibility in the historic built environment. These solutions vary from technological solutions such as heating systems to the potential impact of increased public awareness and education on reducing energy consumption and carbon emissions.

Chapter 5: This chapter introduces an energy reduction hierarchy and investigates the implementation of various measures on Lichfield Cathedral through developing a computer model of the cathedral using Integrated Environmental Solutions (IES) software. In addition, this chapter provides a discussion on the result and an analysis of the CoE's environmental campaign. Finally, this chapter reviews the available measures and provides recommendations in each area.

Chapter 6: This chapter provides a summary of the research

Chapter 2: Sustainable Development

2.1 Overview

This chapter provides a historical background on the concept of sustainable development and explores its implications in the built environment. Furthermore, the historic built environment and how it can be associated with sustainable development are discussed in this chapter along with the relevant policies and legislation of the UK government on the subject.

2.2 Background

Since 1850's and following the industrial revolution, extensive consumption of natural resources led to an unprecedented economic growth in the developed countries (Halliday, 2008). This economic growth was achieved through a development model which called for peace, economic development, human rights and supportive national governance; however, that approach failed to eradicate poverty and deterioration of the environment and sustainable development adds a significant fifth element that is protection of environment. The devastating impact of unsustainable practices on the environment resulted in increased concentration of greenhouse gases in the atmosphere causing climate change, depletion of the ozone layer, 10% deforestation only since 1900 whilst the remaining forests are decreasing at an accelerated rate and disturbing the earth's equilibrium and pollution of air and water supplies (Langston & Ding, 2001).

Carson's 'Silent Spring', a book published in 1962 is widely recognised as a turning point in understanding the relationship between environment, economy and social well-being. The book was a landmark ecological text which helped to found the modern environmental movement and is claimed to be the main reason behind most of the anti-pollution legislations of the 1970s. Carson (1962) argued that we are subjecting ourselves to slow poisoning by the misuse of chemical pesticides and asserted that one of the most basic human rights must surely be "the right of the citizen to be secure in his own home against the intrusion of poisons applied by other persons". Carson (1962) correctly pointed out that human beings are a part of nature rather than in control of it and asserted that the post-war culture of science that claimed domination over nature was the philosophical root of the problem. It can be argued that Carson (1962) presented a system view of the nature where all elements are interdependent and the health of one section is dependent on the others.

Another essential text is Hardin (1968) 'Tragedy of the commons' where he argued free access and unrestricted demand for a finite resource ultimately reduces the resource through over-exploitation. Hardin (1968) points out that "each man is locked into a system that compels him to increase his herd without limit in a world that is limited" and therefore the human-kind faces a dangerous situation created not by malicious outside forces but by the apparently appropriate and innocent behaviours of many individuals acting alone.

As more scientific evidence illustrating the ecological crisis began to emerge in 1960's and 1970's, the environment gradually became a central policy issue in the developed world. In 1972, the first environmental conference of the United Nations was held in Stockholm to transform environment into a political matter of international significance; in the same year, an international group of decision makers called "the Club of Rome" published "Limits to Growth" which emphasised the dangers of economic growth and raised concerns regarding the long-term impact of pollution and degradation of natural resources on humankind well-being (Levallois, 2010). The report asserted that economic growth could not continue indefinitely due to limited availability of natural resources such as oil.

The concept of sustainable development received international attention when it was endorsed by the World Commission on Environment and Development in 1987. In their report (Our Common Future), sustainable development was defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development, 1987). According to this definition, an economic activity is sustainable only if natural resources are not depleted or degraded and there is no adverse effect on the global environment which will be inherited by future generations; for instance, if the green house gases continue to build, the ability of future generations to support themselves will be compromised due to degradation of soil quality, pollution of air and water and exhaustion of natural resources (Langston & Ding, 2001).

In 1992, twenty years after the first UN environmental conference, the United Nation Conference on Environment and Development (UNCED), also known as Earth Summit, was held in Rio de Janeiro to assist governments in rethinking their economic development strategies and halt the depletion of irreplaceable natural resources (UN, 1992). The conference led to adaptation of 'Agenda 21' which set out a wide-ranging blueprint for sustainable development world-wide. In addition, two agreements were signed by the members; United Nation Framework Convention on Climate Change and the Convention on Biological Diversity (Halliday, 2008). The Conference Secretary General, Maurice Strong, pointed out that although Agenda 21 was weakened by compromise, it was still the most comprehensive programme of action sanctioned by international community and the summit was a historic moment for humanity (UN, 1992). The progress of the agenda was reviewed ten years later in Johannesburg during the 2002 World Summit on Sustainable Development which encouraged further development of renewable energy sources. Today, the UN Division for Sustainable Development (DSD) continues to promote sustainable development through technical cooperation and capacity building at regional, national and international levels and their main goals are listed as: (UN, 2011)

- Integration of the social, economic and environmental dimensions of sustainable development in policy-making at international, regional and national levels;
- Wide-spread adoption of an integrated, cross-sectoral and broadly participatory approach to sustainable development;
- Measurable progress in the implementation of the goals and targets of the Johannesburg Plan of Implementation which calls for promoting the integration of economic, social and environmental pillars of sustainable development and recognises poverty eradication, protection of natural resources and changing unsustainable patterns of production and consumption as essential requirements for sustainable development

2.3 Defining Sustainability and Sustainable Development

Generally, sustainable development remains poorly understood and the source of continuous debates and discussions (Halliday, 2008). Giddings et al (2002) argue that sustainable development is a contested concept due to various interpretations of the term by people and organisations worldwide which in turn influences how the issues are formulated and actions proposed. The UN Conference on Environment and Development (1992) affirmed the integration of environmental factors in any progress model and defined sustainable development as "*socially responsible economic development that protects the resource base and the environment for the benefit of future generations*" (UN, 1992). This definition provides a better understanding of the concept of sustainability and introduces 'economy', 'environment' and 'social' elements as the three pillars of sustainable development usually illustrated as three interconnecting circles (Figure 2.1).

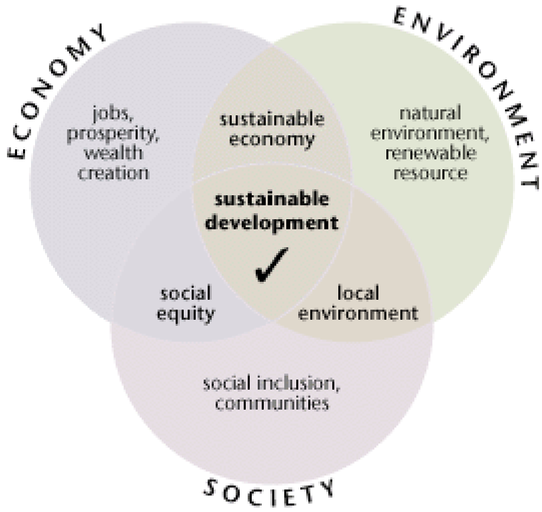


Figure 2.1: Three Pillars of Sustainability

Source: Forestry Commission UK (2011)

However, the current three-pillar model of sustainable development, regardless of the discussions over its exact definition, does not satisfy some critics. Publications by some researchers and institutions point out that the current model is not capable of reflecting the complexity of modern societies and culture must be included in the model. Hawkes (2001) explores the subject and proposes the inclusion of culture as the fourth element of sustainability. He argues that culture is an invaluable tool which could provide an improved theoretical model and has been greatly ignored as a key element of sustainability. Nurse (2006) argues that sustainable development in developing countries is largely influenced by western notions that creates new dependencies and raises questions about whose agenda is being served. As a result, culture is not only a fourth element but should be used as a basis for interrogating the meaning of sustainable development (Nurse, 2006).

The classic definition coined by Brundtland report (1987) 'meeting the need of present without compromising the ability of future generations to meet their needs' has been criticised as an ambiguous definition designed in order to gain widespread acceptance (Wackernagel and Rees, 1996). The World Business Council on Sustainable Development (WBCSD) comprise of members from different backgrounds from oil and gas industries, banking, drug and bio-technology to environmental groups such as Green Peace; Sustainable development is therefore defined, used and interpreted in various ways by different groups to suit their own goals (Redclift, 2005).

Regardless of varied definitions, sustainability recognises the intricate relationship between humankind and the natural habitat and realises that if humankind is to survive and flourish, nature and its resources must be preserved. In fact, the concept of sustainability emerged as the devastating impact of degradation of natural resources on the future well-being of humankind became more apparent through scientific research (Hopwood et al, 2005).

Whilst sustainable development promotes a harmony between economic, social and environmental elements, it can be argued that different perspectives may appoint a higher priority to a one or the other element (Carter, 2007). One area of debate is between the views of weak and strong sustainability where the main debate is over substitutability between the economy and the environment or natural capital and manufactured capital (Ayres et al, 1998). Weak sustainability considers the natural and manufactured capital to be interchangeable and economic growth can substitute for depletion of natural resources (Hopwood et al, 2005). Therefore, the proponents of weak sustainability define it as maintaining the nation's portfolio of capital at a constant level and allowing for unlimited substitution between man-made and natural capital (Ayres et al, 1998). On the other hand, the proponents of strong sustainability theory heavily criticise the weak sustainability theory and argue that man-made capital cannot substitute the loss of natural resources (Hopwood et al, 2005). They argue that essential elements to human well-being such as bio-diversity and the processes vital to human existence such as water cycle could not be substituted with man-made technologies such as genetic engineering (Hopwood et al, 2005).

Clearly providing a single definition for sustainable development that could be accepted by all is not possible; however, any definition should in its essence recognise the dependency of humans on the environment and promote the possibility to achieving economic growth whilst protecting the environment. In summary, in order to avoid a 'silent spring' where all the birds are dead, man-kind should realise its position as a part of the natural system and understand that harming the environment will eventually result in devastation and suffering for the entire eco-system we are a small part of.

2.4 Sustainability and the Built Environment

Arguably, nowhere is the complexity and importance of the relationship between interdependent forces of society, environment and economy more evident than in relation to the built environment as constructed facilities are the humankind's most significant economic, social and environmental investment (Langston & Ding, 2001). According to Sev

(2009) both the existing buildings and the addition of new infrastructures have several environmental, social and economic impacts.

According to statistics, the construction industry is a major contributor to unsustainable development and its environmental and economic impacts; it consumes 40%of total energy production, 40% of all raw materials and 25% of all timber and is responsible for 16% of all water consumption and 35% of carbon emissions (Son et al, 2011). On the other hand, over 40% of carbon emissions in Europe are due to the energy use in buildings and the EU has committed to reduce the current levels by 20% by 2020 (Young, Perry & Manson, 2009).

In the UK, the built environment accounts for 40% of the total energy consumption and arguably more than 50% of the total UK carbon emissions could be attributed to energy use in buildings (Clarke et al, 2008). Furthermore, the construction industry in the UK provides 8% of the UK's gross domestic product or £100 billion a year and employs around 3 million people (HM Government, 2008). It is responsible for over 25% of all industry- related pollution incidents. Moreover, construction and demolition waste accounts for 19% of UK waste (Halliday, 2008). The energy used in extracting raw materials, transporting, constructing, operating, maintaining and demolishing buildings is responsible for about 50% of the UK's greenhouse gas emissions (Clarke et al., 2008).

According to Dahl et al (2005), sustainability measures should be undertaken during the entire life cycle of construction because the industry generates environmental damage over the entire course of a project. The main social, economic and environmental impact of the construction industry is summarised in Table 2.1 (Sev, 2009).

Table 2.1: Main Impact of Buildings and the Construction Industry

	Environmental	Social	Economic
• Raw material extraction and consumption, related resource depletion	*		*
• Land use change, including clearing of existing flora	*	*	*
• Energy use and associated emissions of greenhouse gases	*		*
• Other indoor and outdoor emissions	*		*
• Aesthetic degradation		*	
• Water use and waste water generation	*		*
• Increased transport needs, depending on site	*	*	*
• Waste generation	*		*
• Opportunities for corruption		*	*
• Disruption of communities, including through inappropriate design and materials		*	*
• Health risks on worksites and for building occupants		*	*

Source: Sev (2009)

Considering the significant level of energy consumption and carbon emissions in the built environment, implementing more sustainable measures is essential in minimising the long term risks to the environment, society and the economy. Brown et al. (2005) point out that although the built environment consists of various structures, different end-uses, multiple stake holders and different ways of contributing to emission of green house gases; it also contains numerous opportunities which may be utilized by implementing an effective integrated approach.

Boyle (2005) argues that although the concept of sustainability has noticeably developed since its introduction, it is still poorly defined with regards to buildings and much of the focus remains to be the use of energy in buildings. Kohler (1999) explained that the objective should not be qualitative improvement of the building stock but to improve functional quality and durability without growth through development of techniques to maintain, refurbish and adapt existing buildings to new requirements.

Various steps could be undertaken to significantly reduce the energy consumption and carbon emissions of existing buildings. Clarke et al (2008) summarise the required actions as:

- Increasing public awareness on the significance of energy saving
- Using new efficient domestic appliances
- Implementing modern building technologies in various areas such as heating
- Legislation quantifying building plant performance
- Improved building regulations to include installed plant
- Adaptation of small-scaled renewable technologies
- Flexibility in legislation and energy saving initiatives

Continued use of such improvements is likely to result in significant energy and carbon savings in the long run (Clarke et al, 2008). The important point with regard to existing buildings is that there is no single solution; every building is different and requires a different approach in order to maximise its energy saving potential. However, actual achievement of the above objectives is often faced by certain barriers. Kua and Lee (2002) argue that the barriers to the promotion of intelligent practices can be grouped as the lack of:

- Financial resources and confidence to undertake new and 'untested' technologies;
- Professional capacity to incorporate and manage intelligent technologies;

- Knowledge of developers and owners on the environmental impact of inefficient buildings;
- Information on opportunities presented by intelligent technologies;
- Institutional structures to encourage and support uptake of such technologies

Therefore, members of construction industry should regularly update their knowledge of environmental issues and intelligent technologies in order to implement the most efficient solutions for a given project. Sev (2009) considers the aim of sustainable built environment is the minimisation of environmental degradation and resource use whilst ensuring health and comfort for the occupiers in contrast with the traditional design model which focused on cost, performance and quality concerns.

2.5 The UK Government and Sustainable Development

Sustainable construction is a subset of sustainable development which aims at the integration of environmental, social and economic elements into construction business strategies and practices; it therefore is concerned with application of the principles of sustainable development to the entire life-cycle of a construction project from the extraction of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste (Tan et al, 2010). According to Sev (2009), sustainable design and construction add the issues of minimisation of resource consumption, environmental degradation and the creation of a healthy and comfortable built environment. Sustainable construction principles can be differentiated according to the three dimensions of sustainable development, which are environmental, social and economic; therefore, sustainable construction must rely on three basic principles: resource management, life cycle design and design for human and environment as illustrated in Figure 2.2 (Sev, 2009)

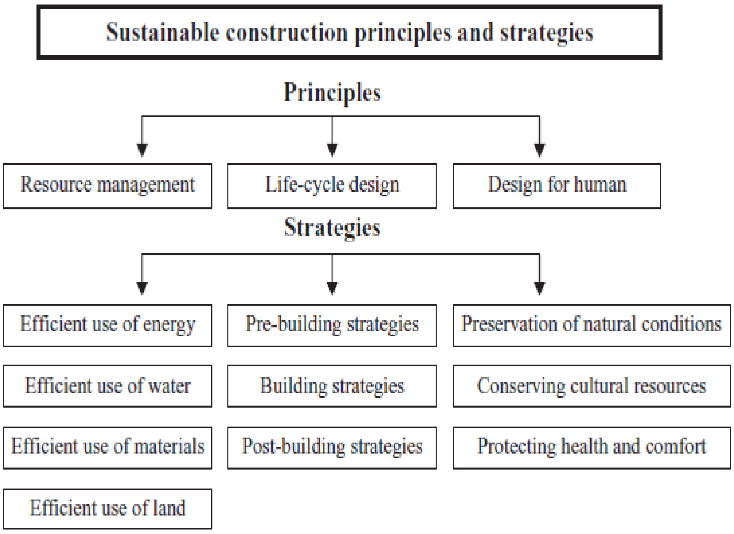


Figure 2.2: Principles of Sustainable Construction

Source: Sev (2009)

Since the 1992 Rio summit, the UK government has produced many reports outlining sustainable construction principles in the UK; in 1994 a strategy for sustainability was produced and in 1996 a list of sustainability performance indicators was published followed by the government's effort in 1997 to set a target for communities to develop a local 'Agenda 21' sustainable strategy by the year 2000 (Hall & Purchase, 2006). In 1998, the UK government launched 'an opportunity for change' initiative to enquire about people's opinions on what a new sustainability policy should include and based on the responses, the government prepared a new strategy, *A Better Quality of Life: a Strategy for Sustainable Development in the United Kingdom* followed by the publication of the first progress review that highlighted areas for future focus (DEFRA, 2002). The report highlighted priorities for the UK sustainable development strategy of particular relevance to construction including:

- More investment in people and equipment for a competitive economy;
- Achieving higher growth whilst reducing pollution and use of resources;
- Sharing the benefits of growth more widely and fairly; and
- Improving towns and cities and protecting the quality of the countryside

According to Hall and Purchase (2006) whilst the progress review made certain changes, the core of the UK government's strategy remained the same and is based around four key elements all of which have implications for the construction industry:

1- *Maintain stable economic growth and employment*; the UK construction industry accounts for 7% of the GDP whilst it has relatively small profit margins and is vulnerable to an unstable economy
2- *Provide effective protection of the environment*
3- *Ensure prudent use of natural resources*
4- *Encourage social progress that meets the needs of everyone*; the £3 billion allocated for the development of social housing is a prime example of the role that construction plays in encouraging social progress (Hall & Purchase, 2006).

The strategy was later reviewed and updated and the new version titled 'Securing the Future: Delivering UK Sustainable Development Strategy' was published in 2005. Figure 2.3 illustrates the updated guiding principles adapted by the UK government in 2005.

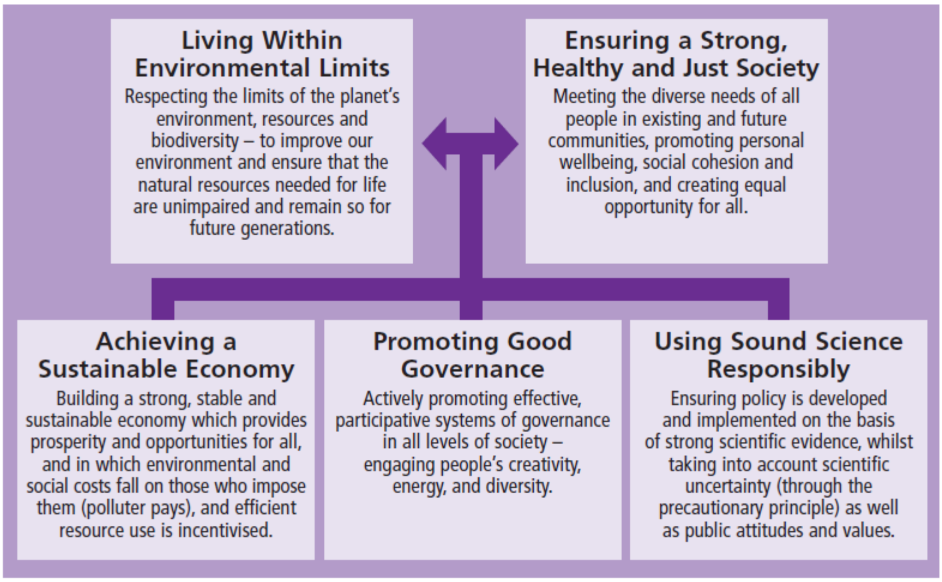


Figure 2.3: Guiding Principles of Sustainable Development in the UK

Source: DEFRA (2005)

The new strategy takes account of the developments and new policies since 1999 both domestically and internationally; it highlights the renewed international push for more sustainable practices following the UN 2002 meeting in Johannesburg and places a greater emphasis on delivery at regional level and the new relationship between government and local authorities (DEFRA, 2005).

In 2006, the government published ‘Review of Sustainable Construction’ with two aims: to document the current main strands of Government policy and industry initiatives related to Sustainable Construction and to encourage industry to respond positively and propose its own targets (Department of Trade and Industry (DTI), 2006). In 2008, a strategy for sustainable construction was launched as a joint government/ industry initiative and identified specific collaborative actions and commitments by both the industry and the government to deliver sustainability in the construction sector (HM Government, 2008).

Whilst implementing these principles and planning policies for new building designs is likely to result in significant reduction of energy and carbon emission, it must be noted that the around two thirds of the building stock that will be present in 2050 has already been built (HM Government, 2008). As a result, ensuring sustainability in the existing stock through system and fabric upgrades is essential in helping the UK government achieve its long-term sustainable development strategy. In addition, the following regulations and agreements are directly or otherwise linked to energy consumption in buildings and although they may not be all applicable to historic buildings, a brief of the main related documents is provided below:

1- Climate Change Act (2008)

The Department of Energy and Climate Change (DECC, 2011) calls the act ‘the world’s first long-term legally binding framework to tackle the dangers of climate change’ where the government is required to make at least a 26% reduction of CO_2 by 2020 and an 80% reduction of all green house gases by 2050 against 1990 levels. However, the act is a general legislation intended to improve carbon management and a transition to a low carbon economy and is not specific to buildings.

2- The Energy Performance of Building Directive

As a member of the European Union (EU), the UK is also legally obliged to abide by the European energy performance of Building Directive (Directive 2002/92/EC) which implements the following requirements most of which are applicable to historic buildings (English Heritage, 2010):

- The application of minimum requirements on the energy performance of new buildings;

- The application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;

- Energy performance certification of buildings;

- Regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old;

- Requirements for experts and inspectors for the certification of buildings, the drafting of the accompanying recommendations and the inspection of boilers and air-conditioning systems.

3. Part L of the Building Regulations

This is arguably the most important regulation with regard to energy and carbon management directly related to buildings. Approved Documents L1B and L2B (2010) provide the requirements for fuel and power conservation of all domestic and non-domestic buildings respectively although the upgrading of energy saving measures is only required for elements which are to be significantly replaced or renovated or if there is a change in use (English Heritage, 2010). According to the latest version of the Part L (2010), the following actions are considered to be some ways of demonstrating compliance:

- Propose improvements which can be economically validated and have a specific pay-back period
- Ensure U-values of thermal elements comply with the requirements
- Show compliance using approved computer modelling process
- Confirm compliance of thermal bridges and minimise air leakage
- Justify reduced standards using set period payback criteria
- Specify efficient boilers, pipe-work
- Perform duct leakage and fan performance testing

However, special attention is required when it comes to historic buildings as some of these actions may damage or risk the historic fabric of the place. English Heritage (2010) identifies two principal areas of risk with regard to renovation of historic structures:

- ‘Causing unacceptable damage to the character and appearance of historic buildings’
- ‘Causing damaging technical conflicts between existing traditional construction and changes to improve energy efficiency’

As a result, the Part L of Building Regulations (2010), contain certain exemptions for historic buildings and for circumstances where special considerations should be applied. The exemptions are described in Regulation 21.2 (c) and 21.3 and include

- Listed Buildings at Grades I, II* and II
- Building in conservation areas
- Scheduled ancient monuments

Based on these regulations, the majority of historic churches will be exempt from strictly following the Building Regulations in terms of fossil fuel energy consumption. However, this exemption is not absolute as the document states:
"For these buildings the exemption applies only to the extent that compliance with the energy efficiency requirements would unacceptably alter their character or appearance*".*
Therefore, even the historic buildings should be renovated or upgraded according to the requirements described in Approved Documents L1B and L2B (2010) but not necessarily beyond that point or where the relevant alterations become unacceptable with respect to preservation of the historic fabric of the structure. However, the Approved Document L1B (paragraph 3.6) mentions that special consideration should be applied to historic places of worship and "*...buildings of this type often have traditional, religious or cultural constraints that mean that compliance with the energy efficiency requirements would not be possible."*
According to English Heritage (2010), the main reason behind the extra exemption levels for historic places of worship is the fact that it is impossible to efficiently heat these usually large spaces which are used occasionally and carrying out the alterations would be both expensive and potentially damaging to their significance and character.

2.6 Sustainability and the Historic Built Environment

2.6.1 What Constitutes a Historic Building?

The historic environment is a unique and invaluable resource from which a large section of the nation derives inspiration, enjoyment and instruction (English Heritage, 2006). The UK historic building stock is a rich and precious inheritance that could teach the new generations how their ancestors lived, worked and worshipped. This great collection therefore, must be preserved and protected in a sustainable fashion and be passed on to the next generations.

There is no singular specific definition of what constitutes a 'historic building' and the official criteria may vary from one country to another. According to Feilden (2003), a historic building has architectural, economic, social, archaeological, aesthetic, political and symbolic values and gives a sense of wonder to people. If a building has the mentioned characteristics along with cultural significance, being considered a part of national heritage and has survived hundreds of years of usefulness, it deserves to be called historic. This definition however may exclude a considerable number of places that are considered to be historic as they may lack one or more of the criteria Fielden (2003) deems necessary. In the UK, many buildings which are considered to be of 'special architectural or historic interest' are listed by the government and receive certain protection from unauthorised alterations. According to the Department for Culture Media and Sport (DCMS), the following criteria are used when the Secretary of State assesses whether a building is of special interest and should be listed: (DCMS, 2010)

- Architectural interest: importance in the building's design, decoration, craftsmanship or buildings displaying technological innovation or virtuosity
- Historic interest: the building must be of national social, economic, cultural or historic importance; in addition, buildings associated with important figures are considered for listing

In terms of age and rarity the following general principles are used: (DCMS, 2010)

- Before 1700: All the buildings constructed prior to 1700 and still contain significant proportion of their original fabric are listed.
- From 1700 to 1840: most buildings constructed in this period are listed.
- After 1840: considering the high number of buildings erected and higher numbers which survived to date, progressively greater selection is required.
- After 1945: Particularly careful selection is carried out.
- Past 30 years: The buildings are listed only of outstanding quality or under threat.

For the purpose of this research, listed buildings and churches are considered to be of a historic nature. Based on the DCMS (2010) principles summarised above, even new buildings that are of outstanding technological or architectural quality may be listed; however, a breakdown of the listed buildings in the UK demonstrates that more than 95% of them have been constructed more than 100 years ago. Figure 2.4 illustrates the breakdown with respect to the buildings' age (English Heritage, 2011).

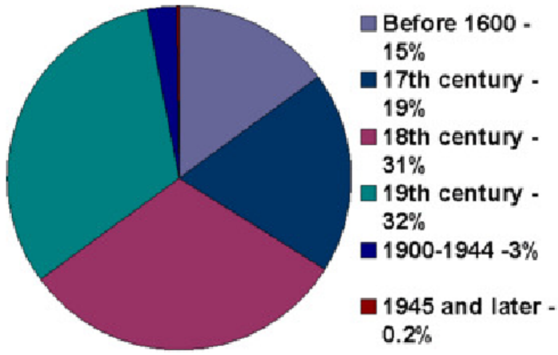


Figure 2.4: Age Range of Listed Buildings in the UK

Source: English Heritage (2011)

Each listed building falls in one of the following three categories: (English Heritage, 2011)

1. Grade I buildings: this is the highest category with regard to the significance of the structure; Grade I buildings are of exceptional interest and some of them are considered to be internationally important. Only 2.5% of the listed buildings in the UK fall into this category
2. Grade II* buildings: buildings of more than special interest fall into this category and many historically or otherwise important listed buildings which account for about 5.5% of the listed buildings are of Grade II*.
3. Grade II: the majority of listed buildings (92%) which are of special interest and or are nationally important are Grade II buildings

Although listing a building creates a presumption in favour of preservation, it does not necessarily rule out the possibility of alteration or even demolition in rare cases. What the listing guarantees, however, is that if alteration is contemplated or necessary, the decision makers take into account the desirability of preserving the structure and any special feature it may possess (English Heritage, 2003). As a result, any major alteration to a listed building requires going through a few steps to ensure all the necessary precautions have been taken and the required permissions have been obtained.

2.6.2 Historic Buildings: Burden or Opportunity?

It is difficult to develop a clear definition of sustainability for historic buildings which are generally considered to be inefficient in terms of energy use. Power (2008) argues that the century-long debate over renovation or demolition of old buildings has been further intensified with Government's Sustainable Communities Plan (2003) that proposed large-scale clearance and buildings. It must be noticed that the focus of such arguments have mainly been on older homes and not necessarily all older buildings or churches. However, this raises questions regarding the inherent sustainability of historic structures. Generally, the question is whether historic buildings present a burden or opportunity with regard to sustainability. Cassar (2005) points out that with so much focus and discussion about new sustainable communities, some perhaps are forgetting that the historic environment has been sustaining older communities for generations and has provided them with opportunities to work and play near home. According to English Heritage (2010), historic buildings constructed prior to the industrial age, were by definition 'sustainable buildings'; the primary power for construction and use of the building were human and animal power and the biomass of locally grown timber and the buildings were technically sustainable and zero carbon. Therefore, there is no inherent conflict between the renovation of historic buildings and the concept of sustainability. However, the patterns of work and life-styles are considerably different in modern societies and historic buildings may not only be used in new capacities but must be able to meet the new performance requirements that the society demands. Therefore, in order to argue against demolition, it must be demonstrated that preserving historic buildings promotes sustainable development and successful re-use of these structures results in reduction of carbon emissions. Trusty (2007) points out that whilst renovating and refurbishing historic buildings has environmental merit, it is not easy to prove without access to appropriate tools and data. This is mainly due to uncertainties regarding the cost of rehabilitation because of the unknowns inherent in the process which makes it difficult sometimes to justify the cost if the environmental benefits are not quantified; therefore, it is necessary to take steps such as comparing the embodied environmental effects of renovation (such as the resultant carbon emissions) against a benchmark value to justify the refurbishment (Trusty, 2007).

The discussion over the superiority of demolition or renovation is not directly within the scope of this research; this is mainly due to the fact that historic churches in the UK are often listed and therefore not under the threat of demolition purely because of inefficient energy use.

In addition, the dominating factors in argument against the demolition of buildings with historic significance are their cultural and social importance for a community. This especially applies to historic churches and cathedrals in the UK which have existed for many centuries and served their communities in various ways. Moreover, communities benefit economically from preservation and renovation of such historic buildings by attracting visitors and tourists.

The historic environment is an irreplaceable source of inspiration, joy and knowledge which informs us of our heritage and is a window to the lives and culture of past generations. In addition, historic buildings provide communities with a unique sense of character. According to English Heritage (2006), “they are a living record of our social, economic and artistic history, as well as being powerful contributors to our sense of place and to feelings of local, regional and national identity.”

Therefore, the arguments regarding renovation or demolition mainly apply to older homes and structures whilst there is a consensus that buildings with historic or cultural significance must be preserved for future generations regardless of their compliance with new standards.

However, the arguments regarding the sustainability of older homes often apply to majority of older and historic structures including churches.

Therefore, prior to reviewing the application of sustainable measures to historic buildings, it is necessary to understand the merit of renovation compared to demolition purely based on their impact on environment and carbon emission.

The Environmental Change Institute at Oxford University have argued that if the government is to reach its carbon emission targets by 2050, more than 3 million demolitions are necessary (Boardman, 2006). They argue that the current rate of demolition (about 0.1%) is very low and there is a need to replace older buildings with inefficient energy use with new more sustainable buildings. However, this has been criticised in the literature for the following reasons: (Power, 2008)

- The required number of demolition has been based on a complex model and applying small changes provides considerably different results
- The embodied carbon cost including and not limited to volume of new materials and the energy for producing and delivering concrete and other construction materials have not been taken into account.

In fact, the significance of embodied energy of historic structures has not received the attention it deserves with respect to environmental concerns. Jackson (2005) defines embodied energy as "the sum of all energy required for extracting, processing, delivering and installing the materials needed to construct a building". He points out that the historic environment is a great resource that should be conserved and made efficient for the environmental challenge of 21st century and the combination of preservation and embodied energy concepts provides a strong argument for re-use of historic buildings. The required embodied energy in terms of materials, transport and construction for replacing an existing building with a new one is equivalent to five to ten years of energy consumption for heating and lighting the building (English Heritage, 2004).

In addition to the overall energy savings, Power (2008) lists the following benefits of renovating old/historic buildings:

- Renovation saves the structure of the property and retains the existing infrastructure
- It attracts investment as it sends the signal that the neighbourhood is worth investing in
- It involves a shorter and more continuous building process
- It has a wider positive social impact on the neighbourhood

Therefore, to answer the question raised earlier in this section, it could be argued that historic structures provide an opportunity with regard to sustainability rather than being a burden. As discussed above, applying sustainable measures to historic structures is beneficial not only with regard to energy efficiency and consequently environmental aspect but also with regards to social and economic elements and the combination of these elements are necessary to illustrate sustainable development. In addition, most of the sustainability measures discussed in section 2.4 such as system and fabric improvements that have proven to result in significant energy and carbon emission savings could be applied to historic structures if the historic fabric is not damaged. In fact, it could be argued that even if historic buildings were not listed or protected from demolition, it would still be more sustainable to renovate rather than demolish such structures. The opportunities for applying sustainable measures to historic buildings in the UK vary based on the building characteristic and what listed category, if any, it may fall under. Therefore, it is necessary to understand the building regulations relevant to historic buildings.

2.6.3 Applying Sustainable Measures to Historic Buildings

According to Kua and Lee (2002), modern living standards, which can be achieved by intelligent technologies and healthy conservation of historic buildings, may not always be easily compatible. Achieving sustainability could be a complex process due to inherent differences of such structures with modern buildings and the limitations of working in historic environment. The basis of the current conservation engineering practice in the UK was developed in the late 20^{th} century from several landmark projects including St Paul's Cathedral, Ely Cathedral and more recently Windsor Castle. Forsyth (2008) argues that the critical assessment of these projects and monitoring their performance over a number of decades have led to

- Recognition of the necessity of developing analytical and assessment models which acknowledge the considerable differences in behaviour between traditionally used materials (masonry and timber) as opposed to current ones (reinforced concrete and steel)
- Increased awareness of the vulnerability of historic structures to natural hazards and the need for damage mitigation strategies that will ensure the conservation of the original building fabric

Historic structures in the UK which are considered to be of historic or architectural value become listed which considerably limits the scope of renovation for such structures. In addition, listed churches are exempt from strictly following the Part L of Building Regulations which covers the energy efficiency and carbon management. However, there is a range of viable sustainable measures which could be applied to historic structures in order to enhance their energy and environmental performance whilst preserving the fabric of the structure.

Implementing such measures is recognised in the in planning policy where it is explained that "*listing should not prevent sympathetic adaptation and innovative solutions may be appropriate providing the special interest of the building is protected*" (Planning and the Historic Environment, 2008). Forsyth (2008) proposes that all structural interventions for historic buildings should be governed by four maxims of conservation which were first introduced by The Society for Protection of Ancient Buildings (SPAB) and consist of:

- Conserve as found
- Minimum intervention

- Like for like repairs
- Reversibility of interventions

These are also in line with the current position of English Heritage on conservation of historic buildings and embedded at the core of British Standards 7913: 1998 A Guide to the Principles of Conservation of Historic Buildings. In addition to the SPAB's four maxims, special attention should be given to localised repair of historic structures from both a physical and aesthetic point of view and similar principles form the basis of most historic building legislations in Western Europe (Forsyth, 2008). Generally, enhancing energy efficiency in historic buildings could be achieved through a range of sustainable options such as building fabric improvements (glazing, insulation), enhanced heating regime, application of low carbon and renewable technologies and behavioural changes through education and awareness. The extent to which such measures could be used within the historic built environment heavily depends on the type of structure, listing status, function, pattern of use and compliance with the existing laws and legislations. However, with regards to historic buildings, conservation of the historic fabric of the place should be regarded as the key issue before devising any enhancement strategy.

2.7 Summary

This chapter provided a historical background on the concept of sustainability and its implications with respect to the built environment. The global community is taking a stronger stand on sustainable development and the necessity of preserving the environment for future generations. Since over 40% of the carbon emissions in Europe and over 60% of energy use in the UK are contributed to the buildings and construction industry, the built environment is a key player in achieving sustainable development. The focus of this research is sustainability of historic churches and cathedrals in the UK and as discussed in this chapter, the majority of such structures are listed in the UK which considerably minimises the scope of refurbishment work. However, the review of the relevant legislation indicates that energy efficiency measures could be implemented in historic churches as long as they do not alter the historic character or appearance of the building. Therefore, there is no unique solution for all historic churches and the energy saving measures should be determined based on the specific characteristics of a given church and the needs of the users.

Chapter 3: Sustainability of Historic Churches and Cathedrals

3.1 The Church of England

The Church of England (CoE) is the established Christian church in England and the largest Christian denomination in the country; In addition, the CoE is the mother church of the Anglican Communion which is active in more than 160 countries worldwide (Church of England, 2008). Moreover, the CoE is an established church with a certain range of privileges and responsibilities and the Monarch is the supreme head of the church which links the church and the state. The CoE is organised in two provinces; the northern province led by the archbishop of York and the southern province led by the archbishop of Canterbury and together they cover England, the Isle of Man, the Channel Islands, the Isles of Scilly and a small part of Wales (Church of England, 2011). Each province is built from dioceses and each diocese is divided into a number of parishes led by a parish priest also known as vicars; currently, there are 43 dioceses in England as illustrated in Figure3.1 (Church of England, 2011).

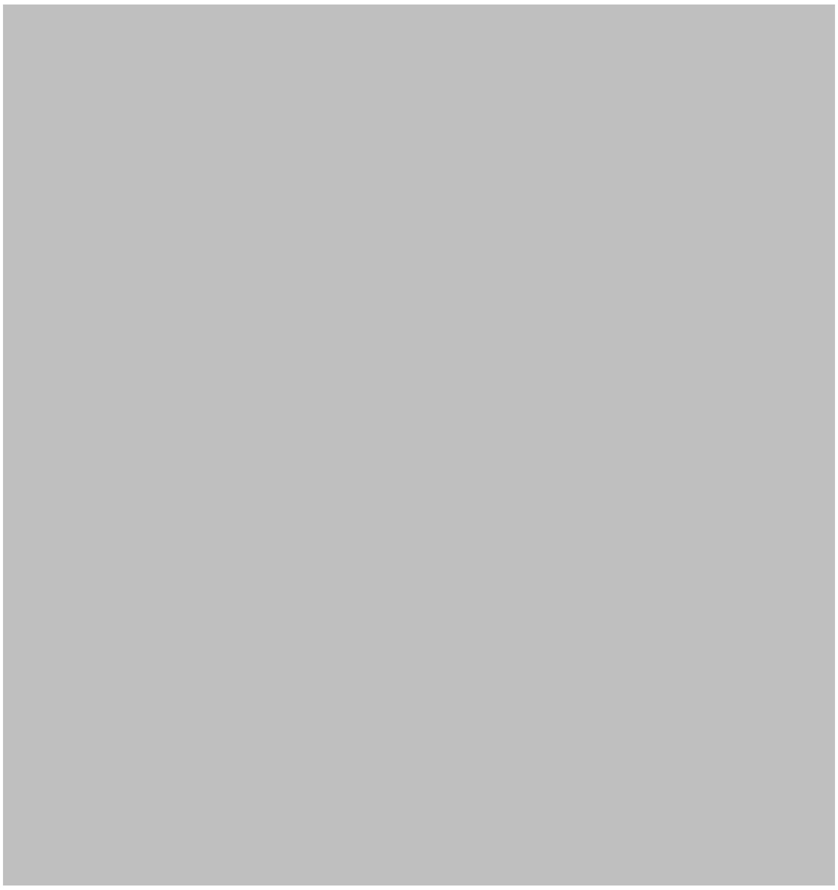


Figure 3.1 CoE Diocese of England

(Church of England, 2011)

According to the church statistics (2003-2009), the CoE remains the largest Christian denomination as well as having more followers than any other faith in England. Approximately, 1.7 million people take part in various church services each month, 3 million participate in Christmas day or Christmas eve services and 85% of the population visit a church each year for a variety of reasons ranging from attending religious services to social events such as weddings or just to find a quiet place (Church of England, 2011). In addition, one in four primary schools and one in sixteen secondary schools belong to the CoE educating more than one million pupils in more than 4,700 CoE schools (Church of England, 2011). According to English Heritage (2010), the CoE carries a major burden of responsibility to efficiently manage the CoE's large estate of buildings. The CoE owns (Church of England, 2008):

- 16,200 churches
- 43 cathedrals
- 100 offices
- 13,000 clergy homes
- A significant number of other buildings

However, like many other religious institutions, the CoE faces a number of unprecedented challenges in the secular society including and not limited to decline in church attendance, ordination of women and homosexuality. A more detailed account of such challenges and the CoE's response will be discussed in further sections of this chapter.

3.2 The Church of England and the Environment

The CoE's involvement with environmental issues goes back a few decades as illustrated in figure3.2; however, the church seems to have taken a much more proactive role toward the subject of climate change in the past five years. The CoE's Public Affairs Council published "Sharing God's Planet" in 2005 introducing a Christian vision for a sustainable future. The book explores the human engagement with environment in Western Europe and investigates how human activities have systematically harmed the environment (Foster, 2005). In his forward to the book, Dr. Williams, the Archbishop of Canterbury, suggests that ecology should be regarded as a matter of justice and calls upon the church to undertake an ecological audit. The CoE seems to understand the significant role it could play in building a more sustainable future and the church authorities try to build a biblical and spiritual case for a more environmentally friendly approach toward every day activities. In 2005, the General Synod debated "Sharing God's Planet" and called upon the entire Church to be actively engaged with the issues of energy consumption and climate change (Church of England, 2005). In June 2006, on world environment day, the CoE launched their environmental campaign called 'Shrinking the Footprint (StF)', led by the Bishop of London, in an attempt to cut its current carbon footprint. All church parishes were invited to carry out an energy audit in order to establish an original benchmark (Church of England, 2006). In June 2008, the Mission and Public Affairs Council published a new report (Climate change and human security, 2008) to describe the CoE's environmental agenda and covered the following:

- The impact of climate change on poor and vulnerable communities
- The progress made in mitigation and adaptation techniques and the international responsibility to climate change
- Making practical suggestions on how the CoE should respond to these developments

The general synod debated the report in 2008 and voted to endorse the recommendations presented in the report. In 2009, the CoE published "Church and Earth (2009)" which outlines the church's seven year plan on climate change and the environment. The book outlines the devastating impact of the current ecological crisis and emphasises the necessity of safeguarding the nature's habitats and wildlife and provides a Christian theological basis for caring for God's creations. In addition, the book explores what has already been done by different parishes and discusses the future plans for further reduction of the CoE's carbon footprint.

Milestones in the Church of England's engagement in environmental issues

1978	The Lambeth Conference passes resolutions calling for fresh approaches to economic well-being and livelihood and for a move away from wasteful forms of growth.
1986	The General Synod receives the report '*Our Responsibility for the Living Environment*'.
1988	The Lambeth Conference formally adopts Five Marks of Mission, one of which is "to strive to safeguard the integrity of creation and to sustain the life of the earth."
1990	'*Christians and the Environment*' is published and circulated at General Synod.
1995	The Church of England is represented at the congress marking the 1900th anniversary of the Revelation to St John the Divine, when the *Religion, Science and the Environment Symposium* is launched by the Ecumenical Patriarch of Constantinople.
1998	The Lambeth Conference draws up a theology of the environment, and resolves to establish a global Anglican Environment Network.
2003	Bishop James Jones's pioneering book on '*Jesus and the Earth*' is published.
2005	General Synod passes a resolution endorsing the message and recommendations of the report '*Sharing God's Planet*'.
2006	Launch of the Church's *Shrinking the Footprint* campaign.
2007-2008	Continued work on *StF*, including auditing of Church's carbon footprint with Carbon Trust and AECOM Consultants. Publication by Church House of handbooks by Claire Foster and David Shreeve on Church action to reduce environmental impacts: '*How Many Lightbulbs Does it Take to Change a Christian?*' and '*Don't Stop at the Lights*'. Significant contributions by the Bishops of London and Liverpool to the House of Lords debates on the Government's Climate Bill.
2009	On 11th June over 100 delegates from nearly every diocese gather for the Church's 'Milestone' Conference reviewing progress with *StF*. A comprehensive website and set of online guides for energy and carbon management in churches is launched for the *StF* programme – www.shrinkingthefootprint.org. Launch of the *Climate Justice Fund* for climate change adaptation.

Figure 3.2: CoE's involvement with environmental issues

Source: Church of England (2009)

3.3 Shrinking the Footprint (StF) Environmental Campaign

3.3.1 Background and Objectives

In June 2006, the CoE launched their environmental campaign called 'Shrinking the Footprint (StF)', led by the Bishop of London, in an attempt to cut its carbon footprint. Originally, the main objective of the campaign was achieving a 40% reduction in the current carbon footprint of the CoE properties by 2050 (Church of England, 2008). In 2008, the church commissioners increased the target cut for bishop's houses and offices to 60% in order to correspond with the UK government's 'White Paper' policy which aimed for a 60% cut by 2050 (Church of England, 2009). The target was modified a final time following the debates in the parliament calling for an 80% reduction by 2050; as a result, the current target is an 80% carbon footprint reduction of the CoE properties by 2050 with an interim target of 42% by 2020 (Church of England, 2009).

In order to identify the main sources of energy consumption and CO_2 emissions for each CoE property type, a national audit was carried out in 2006 (Church of England, 2008). The audit outlined the sources of CO_2 emission for the cathedrals, churches, offices and clergy homes belonging to the CoE. In addition, the Carbon Trust carried out an energy survey of 24 churches and 6 cathedrals from seven dioceses; the surveys identified the main sources of CO2 emissions for each property, offered specific energy saving measures and provided an estimate of potential energy and CO_2 savings. Moreover, the Parsonage Sustainable Energy Project (2008) was conducted by Marches Energy Agency with the support of the Energy Saving Trust; the project investigated energy saving opportunities for clergy homes and investigated the changes required to make them more energy efficient (Church of England, 2008). A guidance document was then published on the official website of the StF campaign; the document is aimed at people in charge of energy consumption, carbon footprint or the environmental aspects of various CoE building properties (Church of England, 2008). The document outlines the current trends of energy consumption and provides a set of recommendations for each building type to become more energy efficient.

3.3.2 Essential Findings and Recommendations of the StF Guidance Document

The CoE emits approximately 330,656 tonnes of CO_2 annually and a breakdown of the CO_2 emissions by source is illustrated in figure 3.3 (Church of England, 2008).

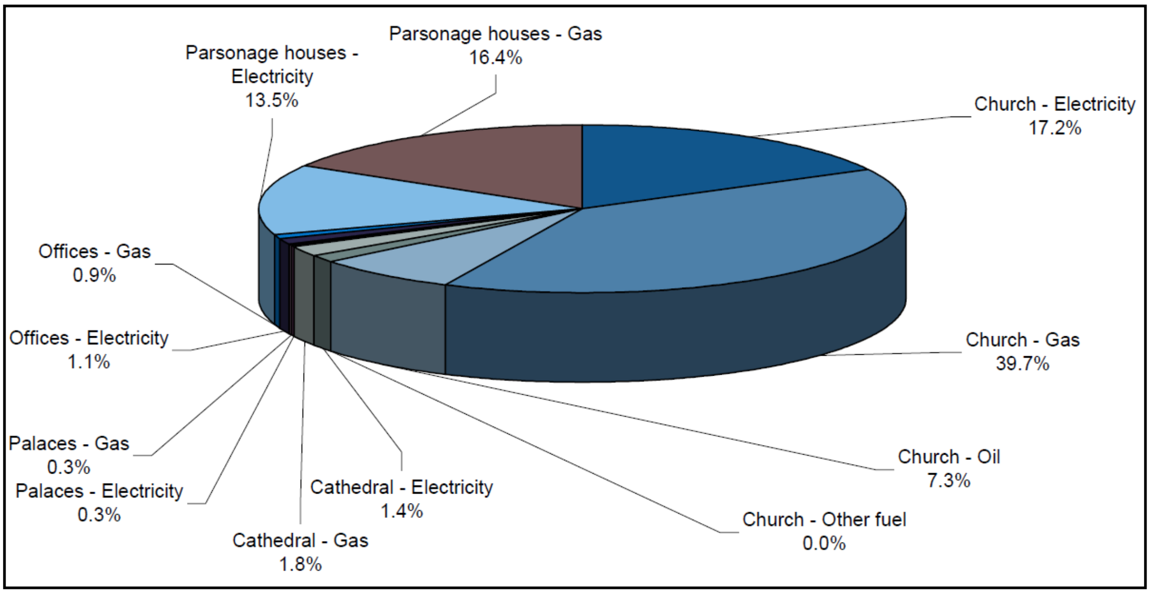


Figure 3.3: CoE's CO_2 Emissions by Source

Source: Church of England, 2008

16,200 churches of the CoE emit approximately 215,000 tonnes of CO_2 annually which constitutes 65% of the entire CoE's CO_2 emissions (Church of England, 2008). The energy consumption varies according to the size of the church, age, heating type and occupancy patterns. Figure 2.2 illustrates the difference between energy consumption patterns of a rural church with that of an urban/suburban church with a community centre.

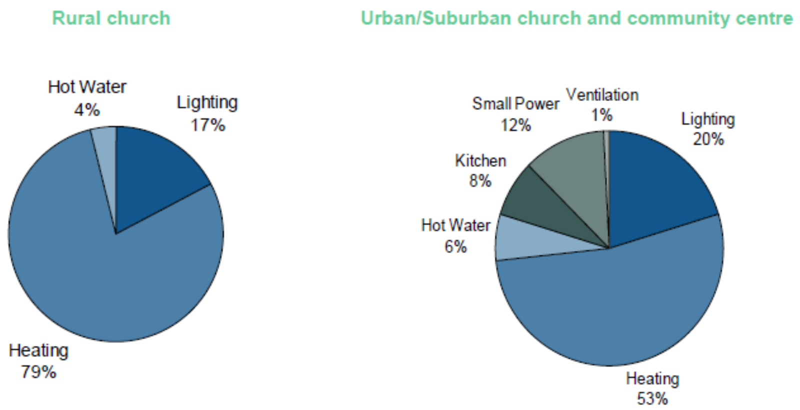


Figure 3.4: Energy Consumption Patterns of Rural and Urban/Suburban Churches

Source: Church of England, 2008

On average, urban/suburban churches (average consumption of 165,000 kWh) use up to ten times more energy in comparison with rural churches which consume 13,000 kWh of energy per year. This is mainly due to higher levels of activities and occupation patterns in urban churches compared to less frequent services that serve less population in suburban churches. In addition, activities that use electricity contribute more to the carbon footprint of a building in comparison with the ones using fossil fuels (Church of England, 2008). On the other hand, the 43 cathedrals belonging to the CoE emit approximately 10,000 tonnes of CO_2 per year equivalent to the emissions of 1800 average homes (Church of England, 2008). The main source of energy consumption is heating (36%) followed closely by lighting (31%).

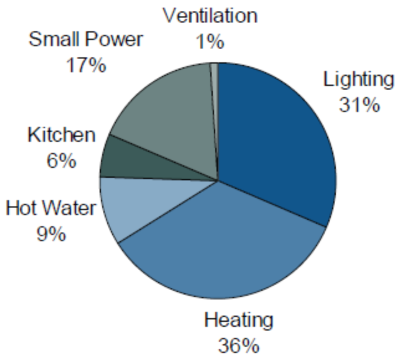


Figure 3.5: Carbon dioxide emissions from a cathedral

Source: Church of England, 2008

Although limited scope of refurbishment exists with regards to cathedrals because of their historic value, savings of up to 25% are possible through routine energy saving measures and using energy efficient equipment (Church of England, 2008).

The guidance document is divided into five sections covering all the main types of CoE's properties; churches, cathedrals, schools, offices and clergy homes; it focuses on a number of general improvements for each identified building type and recommends taking the following steps:

1. Assess your current Carbon Footprint and audit activity
2. Use energy more efficiently
3. Switch to green energy
4. Generate your own renewable energy
5. Support the Climate Justice Fund (Supporting Anglican churches in developing countries to cut their carbon footprint)
6. Review - take another look at your footprint and start again

The document also provide tables identifying the range of energy savings possible from implementing specific improvements for churches, cathedrals and clergy homes such as: insulating pipework, draught proofing, installing more efficient boilers and lighting and upgrading controls. In addition, indications of the initial cost and annual savings (both financial and CO_2) are included (Church of England, 2008).

3.4 Analysis of the StF Guidelines

The StF guidelines focus on a range of general improvements for various building types owned by the CoE (Churches, cathedrals, offices, clergy homes and schools). In addition, the guidelines provide data with regard to the expected savings in energy use and carbon emission associated with each specific improvement such as insulation or installing high efficiency boilers (Table 3.1)

Table 3.1: Important Actions and Potential Savings for Cathedrals

Description	Capital cost	Energy saving %	Average annual cost saving £	Average annual CO2 saving (tonnes)
Begin routine of energy saving^	None	5% total	£1,850 total	12.5 total
Insulate hot water pipes	£10-30 per metre	3% heat	£900 - £1,800 heat	4.2 heat
Install draught proofing	£400-£1,500	2-9% heat	£300 - £1700 heat	3 - 13 heat
Upgrade lighting controls	Approx £1,000	1.5 – 30% electric	£250 – £5,700 electric	33 electric
Install efficient boiler controls	£1,500-£4,000	5 – 10% heat	£900 - £1,800 heat	7 – 14 heat
Install energy efficient lighting	£1,500 - £100,000	5 – 50% electric	£950 - £9,500 electric	5.5 - 66 electric
Upgrade Boiler	£10,000 - £100,000	10-15% heat	£1,800 - £2,760 heat	14-21 heat

total = this is a total energy saving
electric= this is a saving from the electricity consumption
heat = this is a saving from the heat consumption

Source: Church of England (2008)

In general, the guidelines are designed to start the process of implementing more energy efficient strategies in order to reduce the carbon footprint of the CoE properties. In addition, the official website of the StF campaign provides links to other advisory organisations such as Carbon Trust to help each diocese form their own strategy.

The progress made in each diocese with respect to reduction of energy consumption and carbon footprint varies depending on the actions undertaken in that area. The case study selected for this research is Lichfield Cathedral. Specific details regarding the cathedral and actions undertaken to reduce its carbon footprint are provided in chapter 5. However, it was estimated that if all the energy saving solutions outlined in the StF guidelines and additional measures proposed by independent parties (Carbon Trust and MEA) were implemented, savings of up to 17% in carbon emission could be achieved in Lichfield Cathedral. On the other hand, the latest report by the head of the environmental campaign in the diocese of London indicates that savings of up to 12% were achieved during 2005-2008 but was partly cancelled out by a rise of 9% in 2009 resulting in a 4% net drop in consumption during 2005-2009 (Cuthbertson, 2011). Clearly, these ranges of savings are far from the main objective of the campaign which is an 80% reduction of carbon footprint by 2050.

3.5 Future function of the church

The Church of England has made it clear that they have a strong commitment to systematically reducing the carbon footprint of its properties by 2050 due to environmental and spiritual reasons. However, the success of their strategy depends on a variety of uncertain future elements mainly the future function of the church and the impact of climate change. As a result, the way the Church of England will respond to such challenges is a key element in determining how successful they will be in achieving their goals. In addition, the historic churches and cathedrals of the Church of England have no defined life time; therefore, it is essential that any energy strategy takes into account the future uncertainties and addresses the implications of potential scenarios. However, none of these concerns are addressed in the Church guidelines which casts a shadow on their feasibility and effectiveness in the future.

Prediction of demand is of high significance in devising any energy strategy. Forecasting future demand is a key element in any decision regarding energy strategy along with growing demand for energy, the impact of new technologies and identifying alternative energy strategies. However, there is no mention of demand forecast in Church guidelines; this is unreasonable since there are significant uncertainties with respect to future function of such buildings that need to be addressed in order to device a sustainable energy strategy. For instance, if churches and cathedrals significantly expand their services beyond mainly religious functions the energy demand of the structure and the suitable energy strategy will change accordingly.

3.5.1 Decline of Faith

The greatest challenge of the church is undoubtedly the rapid decline of faith in British society. According to Crabtree (2007), the decline of Christian faith in Britain has been immense since the 1950's and all indicators point to a continued secularization of society in future.

Percentage who:	1964	1970	1983	1992	2005
'belong' to a religion	74	71	55	37	31
do not 'belong' to a religion	3	5	26	31	38

Figure 3.6: Decline of Faith in Britain

Source: National Centre for Social Research (2006/7)

Comprehensive research in 2006, which involved 7000 UK adults aged 16 or over, found that two third of the people have no connection with any religion or church in the UK. The report also stated that "*this secular majority presents a major challenge to the Church*" (Ashworth & Farthing, 2007). In earlier research, Monica Furlong (2000) showed that the Church of England has suffered a 27% decline in membership between 1980 and 2000. She also explained that the children who do not come from Church-going homes are mostly ignorant of Christian ideas and even university-educated people find it difficult to comprehend the basic principles of Christianity.

The figures are even more alarming with respect to church attendance. Only ten percent of the population attends church services on weekly basis and the number grows to 26% for those who attend at least yearly while 59% never attend any services (Ashworth & Farthing, 2007). Moreover, while the attendance figures are declining, the average age of the people who attend is noticeably increasing which shows the lack of faith in the younger generation.

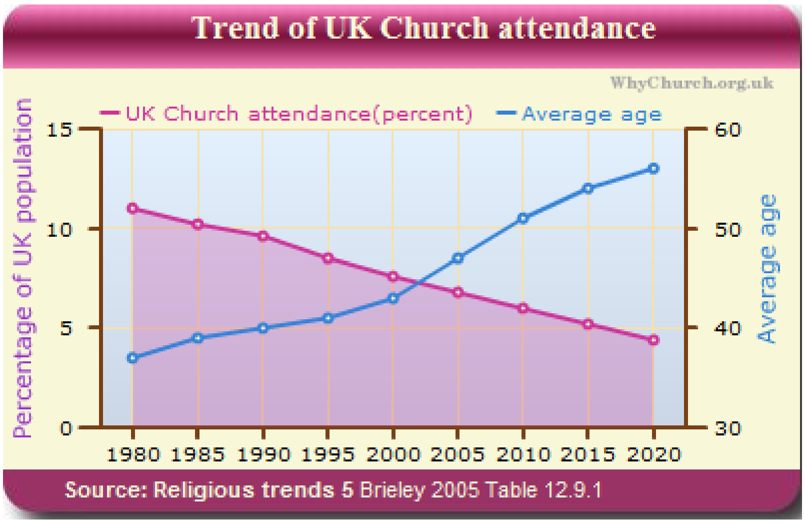


Figure 3.7: UK Church Attendance

Source: Brierley (2005), Religious trends

On the other hand, According to a comprehensive study of religious trends in UK, the number of Muslims attending mosque will be greater than the Church attendance within a generation and even Hindus will come close to outnumbering the Christian church goers by 2050 (Gledhill, 2009). The decline of Christian faith is recognised by the high church officials as a main challenge for the Church of England in near future. Revd Michael Scott-Joynt, Bishop of Winchester and one of the most prominent figures in the Church of England, in his speech about the future of the Church of England stated that "*'non-faith' is fast bf becoming the assumed, the fashionable, the 'default' position, de facto the 'established' religion, of English culture and English politics*" (2009).

3.5.2 Finance

The annual amount for running the Church of England, its 13,000 parishes and 43 cathedrals is over £1 billion a year and around three quarters (£750 million) of that money comes from donations of worshippers to local parishes, around fifteen percent comes from Church Commissioners who manage assets of £4.8 billion on behalf of the church and the remainder is financed through income on reserve on parishes and the fees for services such as weddings or funerals (Church of England, 2009b). The rapid decline of church goers in British Society, therefore, poses a great challenge for the Church of England whose income is, to a great level, dependent on the donations and financial support of its members. According to Gledhill (2009), if the current trend continues, the Church of England along with many other Christian denominations will be soon financially unviable and there will not be sufficient funding to support the infrastructure or pay the pensions for the ministers and other church staff.

In addition, according to their latest report, the church lost over £1.3 billion in asset value after the financial crisis and their portfolio has fallen to £4.4 billion, the lowest since 2004. If the current trend continues, the adverse effect of falling church membership on the financial viability of the church suggests that at least certain churches may have to introduce new functions in order to attract more financial resources. A significant change in the function of the church, on the other hand, may impact the energy demand profile of the structure which is crucial in devising an effective energy strategy. Therefore, it is necessary to develop future scenarios with regard to future function of the church and examine the effectiveness of the energy saving solutions in the light of future changes in the function of the church.

3.6 Sustainable initiatives in other Christian organisation

Over the past couple of decades, broader involvement of different major groups and organisations in implementation of principals of sustainable development has emerged as a necessity; as a result, churches around the globe have also become part of the dialogue on theory and practice of sustainable development (Votrin, 2005). However, the extent of involvement and the approach toward tackling the environmental issues is understandably different between various Christian organisations.

In the UK, the CoE launched an environmental campaign in 2006 to significantly reduce its carbon footprint. The final target was set at an 80% cut by 2050 in line with the UK government. The details of the StF campaign and its methodology have been discussed in the previous sections. This section reviews similar actions taken by Christian organisations to be more environmentally friendly.

3.6.1 Catholic Church

The Catholic Church claims that its involvement with the environment goes back many years prior to the current discussions of environmental justice; the church uses two commandments of Jesus as the base of their approach toward environment: Love God above all and love your neighbours and yourself (Jacobs, 2011). The attitude of the church regarding the environment is stewardship of the environment which has been trusted upon humans by God and they should manage the environment carefully and responsibly. Consequently, a number of Popes have made statements concerning the environment and the necessity of care for God's creation in an attempt to develop a theological basis for environmental justice in accordance with biblical scriptures.

Historically, however, the Catholic Church has tended to keep its distance rather than getting seriously involved (Deane-Drummond, 2007):

- In the aftermath of Vatican 2, environmental issues were on the margin of the church's concerns and the natural world was viewed as a tool for the exclusive use of human beings.
- In the 1965 council document (The Church in the Modern World) everything is considered to be related to humans as their centre.
- In the 1967 document (The Development of People) there is no mention of the destructive impact of industrialism on the environment
- In the 1988 document (Social Concerns), there is finally a mention of some environmental questions but many churches and politicians had raised their concern prior to 1988 to the Catholic Church

Since then however, and especially during the reign of the current Pope and his predecessor, more official statements have been made by the Vatican on the subject of environment and the involvement of the Catholic Church has become more apparent (Deane-Drummond, 2007). The Catholic Church is the largest religious organisation in the world and the latest statistics estimate the members to be in excess of 1.1 billion worldwide (Glatz, 2009). The size, diversity and spread of churches around the globe may be a reason why the Catholic Church does not have a specific environmental campaign to cover all its properties. However, independent actions have been carried out by Catholic Churches the best example of which is the ASSISI sustainability initiative in Australia.

3.6.2 ASSISI Sustainability Initiative

ASSISI (A Strategic, System-based, Integrated, Sustainability Initiative) constitutes the sustainability initiative of Australia's Catholic Bishops; Catholic Earthcare Australia (CEA) and Global Carbon Systems (GCS) have formed a partnership to provide Catholic organisations with the necessary means to report their environmental performance (CEA, 2011). Endorsed and supported by Al Gore, the former United States Vice President and

Nobel Peace Prize winner, the church is carrying out a carbon audit of thousands of churches and parish buildings as well as 300 hospitals and 1500 schools; the project is considered to be enormously complex and probably the largest voluntary environmental campaign in Australia (GCS, 2009).

The aim of ASSISI is to develop a pathway to best practice in achieving ecological sustainability in Catholic churches, schools, hospitals and religious congregations in Australia through (CEA, 2011)

- Enabling catholic organisations to measure their ecological footprint
- Reduce their footprint using the intelligence gained from the audit tool

The Audit tool used for the project is ESP (Enterprise Sustainability Platform) which uses a single platform to provide

- Consumption and emission reports
- Data activity tracking reports
- Energy reports

Currently, it is estimated that the church is responsible for the emission of up to 1.5 million tonnes of greenhouse gases which is close to the emission level of the entire Federal Government, except the Defence Forces (GCS, 2009). ESP is being offered to all catholic organisations including churches, hospitals, schools, agencies, universities and religious congregations and CEA (2011) is optimistic that over time, using the results of all the participating entities, it will be possible to accurately report on the carbon footprint of Australia's Catholic Church. The pilot programme was carried out in selected Catholic schools, parishes and a hospital in both Australia and New Zealand and the plan is to reach the entire church during 5 years; using the audit data from across the country, the ASSISI will be then capable of reporting each organisation's ecological footprint beginning with water, energy and carbon (McAloon, 2009).

ASSISI is perhaps the most comprehensive environmental project undertaken by a Catholic Church to measure, monitor and benchmark the ecological footprint of its various properties; in that regard, it shares certain similarities with the StF campaign. Both campaigns understand the significance of a comprehensive energy audit of their properties and call upon churches, schools and other entities to measure and record their footprint.

On the other hand, the StF campaign has defined a clear goal that is achieving an 80% reduction in carbon footprint in the CoE properties by 2050; ASSISI, however, is initially focusing on a country-wide audit of the Catholic Church properties which is estimated to take about 5 years. Using the data collected from the audits, ASSISI then aims at reducing the current footprint of the church but no clear instructions or guidelines have been prepared yet to address this challenge. According to the ASSISI (2009) briefing document, the campaign uses a 'learning communities' approach which will not be based on compliance with external models or frameworks and will provide educational support, material and services to Catholic churches, schools and parishes and enable collaboration between organisations and the state where the communities can make the decisions appropriate to their own context. In order to achieve that ASSISI is supposed to develop a set of common principles, a unique framework and an implementation plan, materials, workshops and a set of indicators to be adapted in all Catholic Church properties in Australia (ASSISI, 2009). The vision for 'learning communities' is illustrated in Figure 3.8.

Figure 3.8: ASSISI Learning Communities

Source: CEA, 2011

The ASSISI sustainable initiative is arguably a few steps behind the StF environmental campaign although the adapted methodologies of the two projects are different in certain areas. The main objectives of the ASSISI have been summarised as a comprehensive audit of the Catholic Church properties and reducing their ecological footprint none of which have been fully achieved yet. On the other hand, the CoE has already

- Undertaken a national energy audit gathering information on the energy consumed by the churches across the country.
- Completed church and cathedral surveys in collaboration with expert organisations such as the Carbon Trust.
- Published a set of guidelines for all major types of CoE properties to outline the measures which could be used to reduce their carbon footprint.

It is predictable that the ASSISI initiative will move in a similar direction after the completion of their nation-wide audit. It is likely that the data collected through the audits will be used to identify the key sources of energy consumption which will in turn be used to devise more specific strategies to reduce the footprint of the church in Australia. It is not clear yet if they will set specific targets similar to the StF since the ASSISI refuses to follow any external model (ASSISI, 2009) and prefers to focus on educating the Catholic members of the church and especially the children in order to achieve long-term ecological sustainability. However, examining the effectiveness of this approach will not be possible in the immediate future since the ASSISI is a fairly new project. What's clear, however, is that they have a long road ahead of them to develop a unique framework and an implementation plan to advocate sustainability in all Catholic owned properties in Australia.

3.6.3Sustainable Churches Project

'Sustainable Churches' was a project developed to introduce the Eco Management and Audit Scheme (EMAS) in churches; the pilot programme was initiated in Germany with the hope of expanding the practice to the rest of the European countries. According to the Institute of Environmental Management and Assets (IEMA, 2011), EMAS is a voluntary initiative designed to help different organisations improve their environmental performance. The first version of the scheme was introduced by Regulation EEC 1836/1993 and was launched in

1995; it was then reviewed in 2001 to include ISO 14001 as its environmental component and expanded its scope from industrialised facilities to all organisations which were interested in improving their environmental performance (Abeliotis, 2005). The latest revision of the scheme called EMAS III was published as Regulation N 1221 by the European Commission in 2009; by June 2010, 7709 sites and 4507 organisations have adapted the scheme, the majority of which are registered in Germany (1408) followed by Spain (1227) and Italy (1035) (Petrosillo, 2011).

The main objectives of the 'Sustainable Churches' initiative were as follows (European Commission, 2011):

- An integrated and Audit Scheme/Corporate Social Responsibility (EMAS/CSR) model to be introduced, established and audited in 13 church organisations
- Achieving 10% reduction in overall consumption (energy, water etc)
- Achieving 10% increase in social and environmentally friendly procurements
- Promotion of the model in churches throughout the Europe
- Creation of a European network to promote the model within churches beyond the time-scale of the project

EMASplus, a sustainability management system, was developed and successfully piloted in fifteen church-base and social enterprises in Germany, France, Austria and Spain; the key elements of the adapted methodology are illustrated in Figure 3.7.

Figure 3.9: EMASplus Sustainability Management

Source: KATE (2011)

Based on this methodology, the first requirement is a corporate vision geared toward sustainability. The next step is carrying out regular audits and development of an improvement programme based on that data. In this regard, it is very similar to both the StF and ASSISI campaigns. After that, there is a need for development of an integrated management system which embeds the sustainability measures into different aspects such as processes, structure, training and communication. Finally, regular sustainability reports are to be published followed by regular controlling through internal and external audits (KATE, 2011).

Energy savings of up to 10% were achieved without any significant investment and CO_2 emissions were cut by about 19t CO_2 per pilot project per year (European Commission, 2011). In addition, the project is believed to have had a positive impact with respect to staff motivation and awareness, efficiency and better economic outcomes for the institutions; checklists, a guidance document and a management handbook have also been prepared and available on the internet and open source software was developed to facilitate the establishment of sustainable management systems. EMASplus, like EMAS, is a voluntary system which requires the following minimum requirements: (KATE, 2011)

- Compliance with the legal standards in force
- Continuous improvement on the key environmental indicators
- Transparency and openness through publishing regular sustainability reports

'Sustainable Churches' is not technically in the same category as the StF or ASSISI environmental initiative as it is not limited to specific religious organisations and welcomes all churches to be involved with the project to enhance their environmental performance.

However, EMAS generally awards a certification which requires the participating organisation to identify and quantify the environmental impact related to their activities, products and services (Petrosillo, 2011). The list of the specific environmental aspects which should be considered is provided by EMAS some of which include (European Commission, 2009):

- Emission to air
- Water production and management
- Release to water
- Use of natural resources
- Energy and raw materials
- Local issues (noise, vibration etc)
- Impact on bio diversity
- Transport issues (employees as well as goods and services)

The above aspects should be described by specific indicators and for each significant aspect the organisation must define objectives for improvement and develop a programme outlining the responsibilities, means and deadlines; the progress should then be monitored and recorded on a regular basis and be properly documented (Petrosillo, 2011).

The set targets with regard to decreasing energy consumption (10%) are much lower than the StF final target (80%) but the European Commission (2011) is hopeful that following the successful pilot programme, further savings are possible in the long-term. However, the recent implementation of the project along with different participating organisations from different countries makes quantification quite difficult. Analysis of approximately 120 church-based organisations which have adapted the management system shows thermal energy savings in range of 3-30%, electricity by 10% and water by 5-25%; in addition, a ten year forecast assuming the recruitments of 200 new organisations estimates CO_2 savings of up to 38,000t to be perfectly achievable (KATE, 2011).

3.7 Summary

StF, ASSISI and Sustainable Churches are examples of systematic approaches toward reducing the carbon footprint of religious structures. However, there is a variety of less comprehensive good practices carried out by religious organisations which shows that an increasing number of religious institutions are taking a more pro-active approach towards the challenges of climate change. The World Council of Churches with its 349 members and over 560 million followers in over 110 countries has been actively involved with environmental matters and has emphasised the direct link between ecology and justice in their various environmentally related publications. They have also launched "Faithful Christians Cooling the Climate" campaign which provided guidance for individuals, churches, youth and congregations on how they can improve their environmental performance (Slaby, 2009).
Overall, the Christian religious institutions have recognised the serious consequences of climate change and been involved in various environmentally-friendly projects to offset their ecological footprint. Actions have been taken both on national levels (StF, ASSISI), independent or smaller scope levels and a European initiative (Sustainable Churches). A brief overview of such environmental actions was provided in this chapter.

StF remains the most systematic environmental campaign and considerably ahead of similar projects launched by its fellow Christian organisations. The StF campaign has already completed a nation-wide survey of its properties which is usually the first and one the most significant elements of such initiatives. In addition, it has set specific carbon targets of a 42% reduction by 2020 and an 80% reduction by 2050 (Church of England, 2008). The majority of other religious-based environmental campaigns have not set detailed targets which make it difficult to quantitatively measure their progress. StF is also the only campaign which has published a detailed guidance document for reducing energy consumption in churches, cathedrals, schools and clergy homes. However, as discussed in this chapter, the CoE faces unique challenges such as the decline of church attendance and financial difficulties. These challenges will impact the CoE's ability to provide the necessary support needed to carry out its ambitious environmental campaign. In addition, the current data including the independent survey carried out for Lichfield Cathedral shows that implementation of all the suggested StF guidelines will not result in an 80% reduction of carbon emissions and other measures should be taken into consideration to improve the energy efficiency of historic buildings.

Chapter 4: Heating Solutions and Building Fabric Improvements

4.1 Background

Achieving energy efficiency, as a key element of sustainability, in historic buildings could be a complex process due to inherent differences of such structures with modern buildings and the limitations of working in historic environments. The basis of the current conservation engineering practice in the UK was developed in the late 20th century from several landmark projects including St Paul's Cathedral, Ely Cathedral and more recently Windsor Castle. Forsyth (2008) argues that the critical assessment of these projects and monitoring their performance over a number of decades have led to.

- Recognition of the necessity of developing analytical and assessment models which acknowledge the considerable differences in behaviour between traditionally used materials (masonry and timber) as opposed to current ones (reinforced concrete and steel)
- Increased awareness of the vulnerability of historic structures to natural hazards and the need for damage mitigation strategies that will ensure the conservation of the original building fabric

Historic structures in the UK which are considered to be of historic or architectural value may become listed which may considerably limit the scope of renovation for such structures. In addition, listed churches are exempt from strictly following the Part L of Building Regulations which covers energy efficiency and carbon management. However, there is a range of viable sustainable measures which could be applied to historic structures in order to enhance their energy and environmental performance whilst preserving the fabric of the structure. Implementing such measures is recognised in planning policy where it is explained that "*listing should not prevent sympathetic adaptation and innovative solutions may be appropriate providing the special interest of the building is protected*" (Planning and the Historic Environment, 2008). Forsyth (2008) proposes that all structural interventions for historic buildings should be governed by four maxims of conservation which were first introduced by The Society for the Protection of Ancient Buildings (SPAB) and consist of:

- Conserve as found
- Minimum intervention
- Like for like repairs
- Reversibility of interventions

These are also in line with the current position of English Heritage on conservation of historic buildings and embedded at the core of British Standards 7913: 1998 A Guide to the Principles of Conservation of Historic Buildings. In addition to the SPAB's four maxims, special attention should be given to localised repair of historic structures from both a physical and aesthetic point of view and similar principles form the basis of most historic building legislations in Western Europe (Forsyth, 2008). Enhancing energy efficiency in historic buildings could be achieved through a range of sustainable options such as technological solutions, building fabric improvements (glazing, insulation), application of low carbon and renewable technologies and behavioural changes through education and awareness.

4.2 Heating Solutions

Heating is the main source of energy consumption and consequently CO_2 emission in churches and cathedrals; 79% of energy consumption in rural churches and 53% in urban/suburban churches are due to space heating (Church of England, 2008). Consequently, heating is responsible for 62% of CO_2 emissions for rural churches, 35% for urban/suburban churches and 36% for cathedrals. Therefore, devising an efficient heating strategy for churches/cathedrals will have a significant impact on the CoE's ability to reach its 80% carbon reduction target by 2050.

4.2.1 Background

According to Samek et al. (2007), there was no heating in historic churches originally and some monumental churches are still unheated; for centuries, the indoor climate condition of historic churches were mainly dependant on the outside temperature. There is no record of using heating systems in churches across the UK and Northern Europe prior to the 19th century although a small number of churches have been identified that used small fireplaces (Saunders, 2005). According to Bruegmann (1978), the main methods of heating buildings including hot air, steam and hot water were developed in the late 18th and early 19th century mainly in the UK. The first heating systems usually consisted of an oil or coal burning boiler and the heat was transferred through pipes beneath the pews; higher thermal comfort demands following the enhancement of living standards after the second World War resulted in replacement of these systems with new central heating systems which could warm up the entire church volume to about 12° C (Limpens-Neilen, 2006). With widespread use of domestic central heating and enhanced thermal comfort in modern buildings the demand for better heating in churches by local communities increased significantly (Kozlowski, 2004).

Consequently, most churches installed different types of heating systems to provide a better level of thermal comfort for their congregations during the cold seasons (Samek et al, 2007). Remarkably, religion and the habits of congregations were key factors in the level of thermal comfort provided; for instance, Roman Catholic churches were usually heated up to about 15° C whilst many Dutch Reformed churches were heated up to 20° C since people preferred taking their coats off during services (Limpens-Neilen, 2006). However, the negative impact of improper heating regimes on the fabric of historic churches was not recognised until recently. Economy and occupant comfort have traditionally been the main force behind installation of heating systems in churches and conservation concerns have been rarely considered (Camuffo & Valle, 2007). Rapid degradation of valuable artwork and the historic fabric of the building following the installation of different heating systems has been recently studied and documented in various countries. In addition, the environmental impact of church heating, which is the single largest source of energy consumption in churches, and the CO_2 emission rates associated with a particular heating regime have become of major significance with regard to climate change concerns. In order to have a better understanding on the subject, the performance of the most popular heating systems with regard to energy requirement, efficiency, thermal comfort, preservation and aesthetics are discussed.

4.2.2 Heating Systems

Overview

Bordass (1996) argues that churches are living entities and therefore, heating depends not only on the structure and the people's comfort expectation but on the function, usage and finance of the church. Today, there exists a variety of heating systems which could be installed in churches or cathedrals. The classification of such systems is carried out differently by different authors and experts on heating. In Germany, Pfeil (1975) classified the heating systems for large historic churches as follows: local heating surfaces, hot air and floor and pew heating systems. Other research distinguished the following systems for historic buildings: pew heating, floor heating and air heating (Arendt, 1993). On the other hand, Bordass (1983, 1996) used a different approach with regard to heating systems in Great Britain; he classified the systems based on heat emitters and distribution systems. In terms of heating methodology, the systems could generally be divided in two categories; central heating systems aiming at warming up the entire room and local heating systems which transmit the heat directly to the people through a local heating source (Camuffo & Valle, 2007). Each system has its own advantages and disadvantages with regard to factors such as energy consumption, CO_2 emission or conservation.

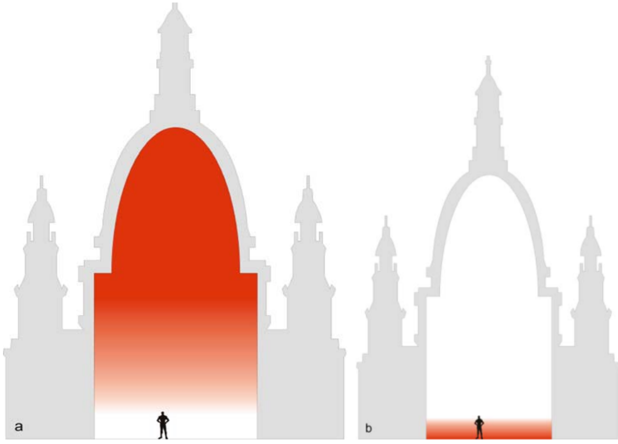


Figure 4.1: Central heating (a) versus Local heating (b)

Source: Camuffo and Valle, 2007

However, the simple illustration of differences between central and local heating systems with regard to heating methodology (Figure 4.1) is not representative of all central heating systems; in fact, under-floor heating systems avoid heating the entire volume of the room and directly heats the occupants.

Central heating

Historically, the first practical example of a central heating system is the Hypocaust developed by the Romans more than 2000 years ago (Figures 4.2&4.3); the system consisted of a furnace in the basement of the building and a series of channels which transferred the hot gas and smoke to the stonework of the floor warming one or more rooms (Mitchell, 2008). The system was widely used by the Romans to heat different spaces and especially the Roman Baths. The development of modern central heating system goes back to the late 18th and early 19th century (Bruegmann, 1978). Since then, a variety of central heating systems have been introduced to the market ranging from warm air heating to under-floor heating systems.

Figure 4.2: Example of Roman Hypocaust

Source: Drexel University (2011)

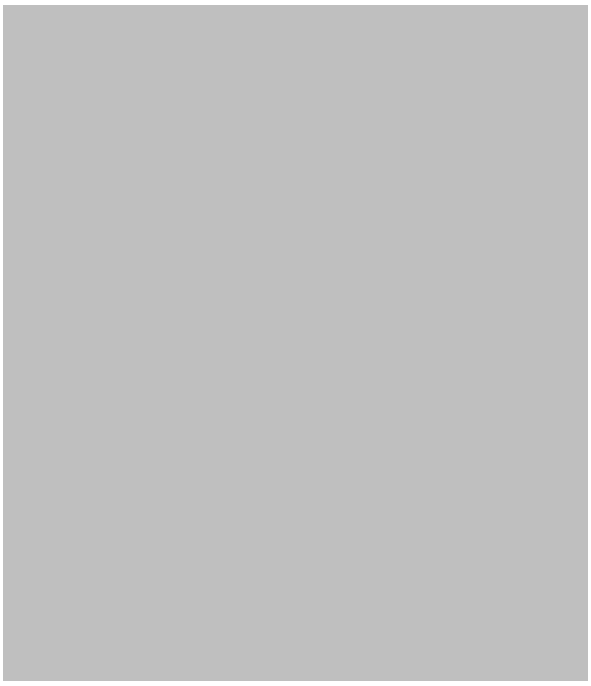


Figure 4.3: Plan of a Roman Hypocaust System

Source: Drexel University (2011)

The main advantage of central heating systems is implementing well-known techniques to warm the entire room; some of the most common systems that have been used in churches include central heating with radiator, warm-air heating and under-floor heating. Generally, central heating systems utilize fossil fuels for heat generation in a central location; the heat is then transferred, depending on the system, commonly by either water through pipes or forced-air through duct work. Natural gas and oil have been the main fossil fuels used in central heating systems; the UK market has been traditionally dominated by natural gas whilst oil has been the prime fuel choice in North America (Mitchell, 2008).

Under-floor heating

Under-floor heating systems generally combine radiant and convective heat on an approximately 1:1 ratio and the balance creates a suitable indoor environment (Douglas, 1999). The system provides a uniform radiant heat to warm the space; therefore, the energy loss is usually lower compared to other types of central heating systems. Depending on the system, either hot water tubes or electric cables are embedded in the concrete floor, attached to the underside of the subfloor or under a tiled floor (Sattari & Farhanieh, 2005).

Figure 4.4: Simple Under-floor system breakdown

Source: Heating central (2011)

Baldin et al. (2010) state that under-floor radiant heating is becoming more popular in residential, commercial and industrial buildings due to the distinctive advantages the system offers with regard to energy conservation and occupant comfort. The radiant nature of the system allows the heat to be directly transferred from the emitter to the receiver without heating the air in between and providing a uniform heat distribution in the place. The system allows employing low temperature water as well as offering flexibility in modifying the internal partitions of the space and is capable of providing good thermal comfort conditions especially in high structures such as churches (Fontana, 2010). Typically, the water is heated to 35° C-50° C in under-floor systems in comparison with radiator systems which heat the water to about 70°C-80°C; hence less energy is consumed for water heating. The low surface temperature also adds a safety element to the system and minimises the risk of burning for young children or older people. In addition, the unobtrusive nature of the system that is installed beneath the floor offers advantages with regards to space efficiency and aesthetics; the system allows the user to maximize the use of space without worrying about radiators or pipework and dust streaking on walls is minimised due to low air movement (Douglas, 1999). The impact of design parameters such as the type, number and thickness of the pipes on the overall performance of under-floor systems was studied by Sattari and Farhanieh (2005) and they concluded that

- The thickness and type of cover are the most important elements
- Pipe type, diameter and the number of pipes do not have a considerable impact on the system performance

In addition to these design parameters, Olesen (2002) suggests that pipe distance and water flow rate are the main design parameters and in order to reach the maximum heating capacity using floor covering with high thermal resistance materials should be avoided as they increase the required water temperature and reduce the efficiency of heat generators (Olesen, 2002). Under-floor systems are traditionally not amongst the most popular heating systems in the UK although the their market share is increasing; from the mid-1960s until the 1980s installation of under-floor heating systems in the UK declined and in 1997 only 2 percent of installations were of this type (Douglas, 1999). On the other hand, 30-50% of new residential buildings in Germany and Denmark use under-floor heating and in South Korea 90% of all residential buildings have under-floor heating (Olesen, 2002). Based on the surveyors, about 20% of the new buildings in the UK are estimated to install under-floor heating systems (Independent, 2005). The comparatively lower popularity of the system in the UK may be related to the system's drawbacks in terms of control systems, installation and capital cost. Ideally the floor temperature generated by the system must vary between 21° C - 29° C as recommended by international ISO standards (Olesen, 2002). However, due to poor control and lack of thermostats and sensors, some earlier versions of the system generated higher temperatures resulting in "hot foot syndrome" (Lafferty, 1997). In addition, the installation requires total altering of the floor to place the system's components; therefore, the system is quite intrusive and the capital cost of installation is generally higher than conventional radiator systems. Also, Access to the system to conduct any alteration requires major disruption to the floor since both the flooring and the screed/slab have to be lifted to gain access to the pipes or cables (Douglas, 1999). The installation cost of the system varies depending on factors such as the manufacturer, the heated space and the floor specification; Lafferty (1997) estimated 10-20% increase in cost in comparison to the radiator systems. However, Olesen (2002) believes the published information on cost comparison is not adequate and the prices will likely vary based on the experience and familiarity of the builders with the system. He adds that a study in Germany estimated about 10% difference between under-floor and radiator system installation but a higher overhead was charged by installers for under-floor systems as they believed the efficiency of the system makes it easier to sell. Today, following technological advancements, some manufacturers claim the cost of installing under-floor systems, especially for new buildings, could be in the same range as conventional radiator systems. According to Building Services and Environmental Engineer (BSEE, 2011) the final cost of an under-floor system over a 30 year period is estimated to be about £3.92 m^2 / year whilst the conventional radiator system will cost £4.81 m^2/ year over the same life time. Considering the long-term advantages of the system with regard to energy savings and thermal comfort, its popularity is increasing; as a result, cost reduction could be expected due to more familiarity of builders with the system and new technological advancements in the field. Examples of churches in the UK that have installed under-floor heating systems include St Mary's church in Banbury (Figure 4.5), St Brandon's church in Durham (Figure 4.6) and the Liverpool Roman Catholic church.

Figure 4.5: Under-floor heating system installed in stage area of St Mary's church

Source: Even heat (2011)

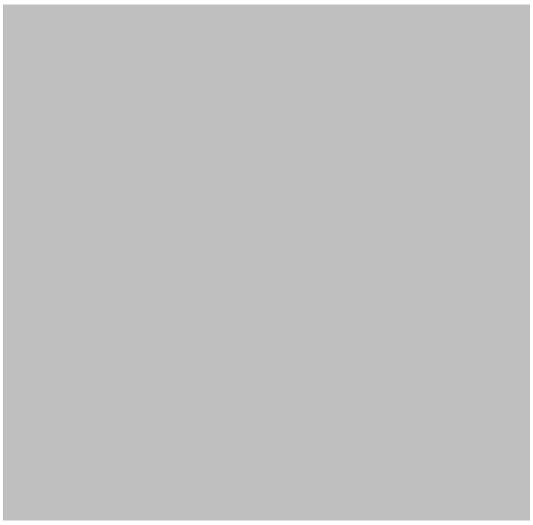


Figure 4.6: Under-floor installation St Brandon's Church

Source: Heat even (2011)

Based on the literature review on advantages and drawbacks of under-floor heating systems, the installation of the system could help the church reduce its carbon footprint and help reach the CoE achieve its environmental campaign's carbon target. However, when it comes to installation of under-floor heating in churches, due to the intrusive nature of the installation process, caution must be exercised to ensure the floor of historic churches will not be harmed.

Conventional Radiator System

Most churches in the UK use a conventional central heating system with radiators to warm the interior air and the occupants. Generally, the heat is generated by one or more boilers using fossil fuels; the heat is then transferred by water to radiators through a series of pipes. Technically, radiators are misnamed as most of their heat output is by natural convection; the radiator is hotter than the surrounding air so the heat is transferred to the air (Arslanturk & Ozguc, 2006). The major methods of heating buildings including hot water and steam were all developed in the late 18^{th} and early 19^{th} century, mainly in Great Britain (Bruegmann, 1978). Over the past century, the efficiency and convenience of the system along with the regulations applied to the field have significantly evolved. Mitchell (2008) states that following the signing of the Kyoto Protocol in 1997 new regulations were introduced to reduce the amount of fuels necessary to heat the building and consequently minimize CO_2 emission levels; consequently, boiler performance had to be improved, systems had to be fully pumped and the insulation of hot water cylinders' had to improve. As a result of these measures, central heating systems became more efficient and the thermal comfort levels generally increased.

Boilers probably are the key element and the performance of the system and the associated energy and carbon figures are directly related to their efficiency. According to the Energy Saving Trust (2011), boilers are responsible for around 60% of the carbon emissions of gas heated homes and their average life expectancy is about 12 years. The average boiler efficiency with regard to their age is as follows (DEFRA, 2006)

- Pre 1979 (50%)
- 1979-1997 (58.5%)
- 1997-2006 (63%)
- 2006 onward (81%)

As of April 2005, boilers must achieve an A or B SEDBUK rating which means they have to be condensing boilers (Mitchell, 2008) and as of October 2010, all installed boilers must be A grade or 88% efficient (Energy Saving Trust, 2011). SEDBUK stands for seasonal efficiency of domestic boilers and it grades the boilers as illustrated in Figure 4.7.

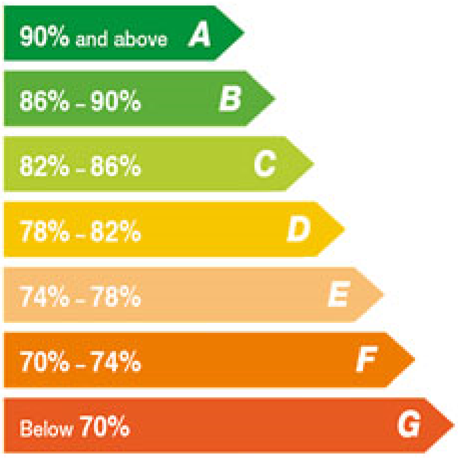


Figure 4.7: SEDBUK rating system

Source: SEDBUK (2011)

Condensing boilers simply capture the energy released by condensing the vapour and extracting this latent heat achieves higher boiler efficiency; the water vapour generated by burning of the fuel is condensed to liquid water by the boiler recovering its latent heat (Chen et al, 2010). The potential savings after the replacement of old boilers with grade-A condensing boilers are illustrated in Table 1 (Energy Saving Trust, 2011).

Table 4.1: Potential Savings with an A Grade Condensing Boilers

Old Boiler Rating	Annual Saving (£/yr)	Annual Saving (kgCO2/yr)
G (< 70%)	£225	1,100
F (70% - 74%)	£145	700
E (74% - 78%)	£105	500
D (78% - 82%)	£65	300

Source: Energy Saving Trust (2011)

Since many church buildings use central heating systems with radiators, replacing their old boilers with more efficient condensing boilers could help considerably reduce their CO_2 emissions. The CoE considers a traditional wet system with radiators and pipe work using a modern gas boiler and controlled by efficient thermostatic/humidstatic equipment to be the best form of heating a church (Church of England, 2010). However, the claim is not fully supported by the evidence and the CoE does not provide a detailed discussion or research results to back their claim. In fact, due to the nature of such heating systems the amount of energy that is spent to warm high volume monumental churches is quite large as the system should heat up the entire church volume. In addition, the system is not space efficient because the larger the church the more radiators are required to be installed to ensure proper heating and this may, in some cases, negatively impacts the visual aesthetic of the church indoor environment. On the other hand, the water is heated to a minimum of 70°C which could cause safety concerns and burning injuries.

Local Heating Systems

The local heating was mainly developed to reduce the operating cost; the most common types of local heating are IR heating consisting of high-temperature heat emitters to directly warm the people and pew heating where a mild heat is generated in the pew area to warm the feet of the church goers. The heat emitters are generally placed on the wall or hung from the ceiling and the generated heat warms the upper parts of the occupants. Quartz tube heaters and quartz halogen radiant heaters are two examples of local heat emitters. The main advantage of using local heating is energy conservation since the heat is directly transferred to the occupants. Limpens-Neilen et al. (2005) point out that by using local radiant heaters, heating the entire church volume is no longer necessary and combined with much shorter pre-heating periods required by local systems compared to central heating systems, the energy consumption of the structure is lowered. However, achieving suitable thermal comfort for the congregation is not easy; the IR heaters usually warm the upper parts of the body and leave the rest cold while pew heating does the opposite (Camuffo et al, 2005). This may be one reason why the CoE is not generally a big advocate of radiant heating for churches. The Diocesan Advisory Committee (DAC), in the short review of church heating systems, has warned the parishes about the advertisement of local heating systems as cheap to install and economic to run; according to the DAC (2010), the use of electric heaters should be limited to small churches with infrequent services and is not recommended for large churches or the ones with frequent events. In addition, the use of overhead radiant heaters is recommended only as a last resort due to unsatisfactory thermal comfort levels and aesthetical reasons (Church of England, 2010). However, the stand of CoE for pew heating is rather different; the advancements made in pew heating technology is recognised by the church and several parishes have installed the system. Nevertheless, pew heating's largest limitation is the fact that it could be only utilized in churches with pews instead of chairs.

A European project (Friendly Heating) was launched in March 2002 to investigate the possibility of a local system which meets the criteria for both thermal comfort and conservation (Limpens-Neilen, 2006). The project focused on providing localised heating through multiple heat emitters in the pew area (Fig 4.8).

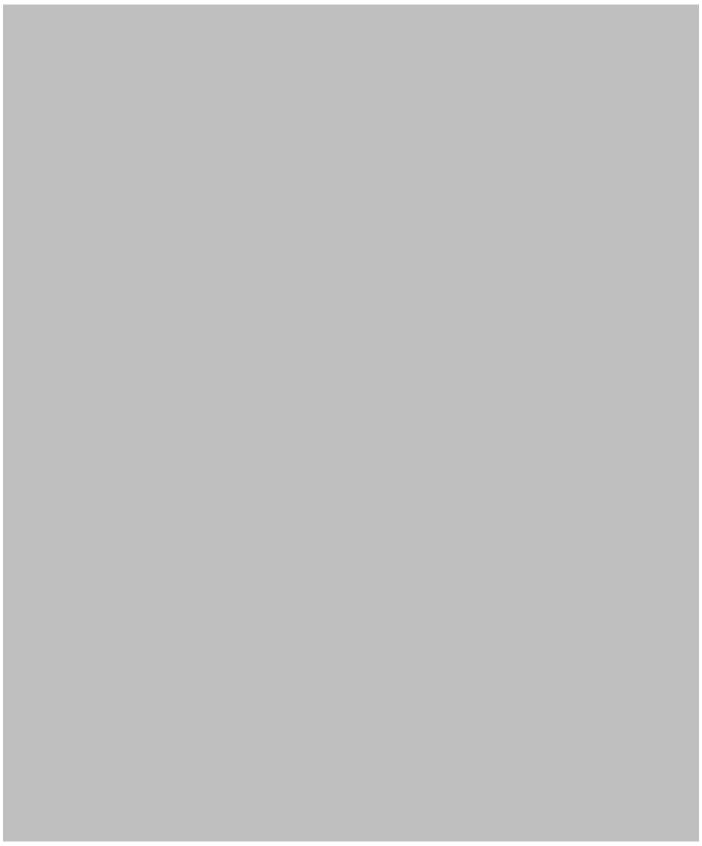


Figure 4.8: Friendly heating project: heat emitters located in A (under a kneeler), B (under a seat) and C (in the back to warm the hands

Source: Camuffo et al (2010)

The system has been successfully tested and proven to provide thermal comfort whilst minimising temperature and RH fluctuations to guard the fabric of the church. The system, however, has certain limitations; it is mainly suited for small churches with fixed pews where the heating regime is intermittent (Camuffo & Valle, 2007).

4.3 Conservation related issues

The aim of the CoE's environmental campaign is to reduce the carbon footprint of its properties by 80% by 2050. However, any strategy to reach that aim should ensure the long-term sustainability of the CoE assets. Historic churches are a significant part of the nation's cultural heritage and often contain invaluable artworks, priceless paintings and important decorative objects each of them with a specific vulnerability. Detailed knowledge of the historic climate, which is simply the original indoor climatic conditions to which the structure and the artefacts have acclimatized over centuries, is essential (Bratasz & Kozlowski, 2007). From a conservation point of view, it is extremely important to avoid extreme departures from the temperature and RH values of historic climate; high RH fluctuations cause major strain-stress cycles to vulnerable materials and damage the artworks (Camuffo et al, 2005). An ‘extreme departure’ from the historic climate is defined as “*a departure that exceeds by one standard deviation the most frequent values*” and for a symmetrical distribution this limit “*coincides with the 84th percentile of the observed values*” (Camuffo & Valle, 2007). Monumental churches are often large buildings with massive walls and insufficient insulation and an inappropriate heating strategy could cause certain conservation problems (Limpens-Neilen, 2006). Kerschner (1992) points out that often the ideal environmental conditions necessary for preserving the artefacts inside a church differ from the ideal conditions necessary to conserve the structure itself; therefore, the specific temperature and humidity standards should be designed to protect both the building and its assets.

Each valuable artwork inside a historic church has its own vulnerabilities. The common church assets and their associated weaknesses are listed in Table 4.2.

Table 4.2: Vulnerabilities of common church artefacts

Artefact	Vulnerability
Paintings on canvas and wooden panels	Cracking, swelling, blistering and soiling
Frescos	Efflorescence and blackening
Wooden artefacts	Cracking
Metal	Corrosion
Textile	Fading and soiling

Source: Camuffo & Valle, 2007

Schellen et al. (2003) believe that organs are the most vulnerable item since along with aesthetic preservation, they should maintain their functionality as well; pipe corrosion and deformation or cracks in the wooden parts could severely affect the characteristic voice of the organ. In addition, the placement of the organ in the upper parts of the church adds to the problem especially in case of central heating systems where the temperature in the upper parts of the church far exceeds the natural climate the organ is used to. The heat generated by warm-air heating or convective heating tends to rise to the upper parts of the structure where it is not needed; if the church is heated intermittently, this could affect the masonry work by dissolution-recrystallization cycles of soluble salts (Camuffo & Valle, 2007). From a conservation point of view, RH is the most important parameter; intermittent heating causes periodic fluctuations of RH as it drops to low levels when the heating system is operational and returns to high levels after turning of the system (Bratasz & Kozlowski, 2007). Therefore, it is necessary to define temperature and RH boundaries in the control system to avoid any severe RH fluctuations. Temperature settings are carried out based on the building characteristic and the collection inside; the low temperature is determined based on the sensitivity of the collection and the function of the building. In the Dutch climate, for instance, the low temperature should be set about 4° C to maintain a 45% RH (Schellen, 2007). With regard to heating methodology, under-floor heating systems that distribute the heat radiantly and uniformly are less likely to cause severe temperature fluctuations. The main problem with installation of under-floor systems for historic or listed churches is the intrusive nature of installation; either the floor must be taken up or a new level must be created above it. According to English Heritage (2003), both these options could be problematic as the first approach may damage the archaeological remains and the second one may have an impact on appearance of the interior. However, if the floor of the church has been lost or to be replaced, under-floor systems are a suitable option for historic buildings because they make good use of the large space and the radiant heat is gentle to the historic fabric (English Heritage, 2010). In central heating, the operation methodology is a key factor; continuous heating is recommended as it minimises the temperature and RH fluctuations but in cold climates even modest heating may lead to severe drops in the RH levels due to the limited quantity of water vapour in the air (Camuffo et al, 2009). However, continuous heating for large monumental churches requires a great amount of energy which besides being a financial burden will produce a great deal of CO_2 emissions. This illustrates the difficulties of devising sustainable heating strategies for historic churches due to the conflict between important parameters such as occupant comfort, energy and carbon and the conservation needs of the structure.

With regard to local heating systems, the placement of the heat emitter is important and care should be taken to ensure that Infrared Radiation (IR) will not reach the artwork (Fig 7). In addition, some local heaters such as quartz halogens exceed the glare threshold and emit ultra violet radiation which harms both the people and the artworks (Camuffo & Valle, 2007).

Figure 4.9: Improper displacement of local heaters

Source: Camuffo & Valle, 2007

The other important parameter with regard to conservation of artwork in historic buildings is the air pollution deposition. Spolnik et al. (2006) investigated the generation and transport of air pollutants for three different heating systems (central warm-air systems, electric pew heating and electrical IR heaters) inside two churches in Netherlands and Italy. Their investigation showed that warm-air systems have the most negative impact in resuspension and the intensity of air pollutants and the IR heaters proved to be the least harmful. In addition, it was shown that only warm-air systems produce pure organic particles which can cause soiling or blackening the artefacts in the sample churches.

Based on the literature review, local heating systems are very popular among conservation experts because different studies have shown that local heating presents the least damage to the historic fabric of the place. As a result, other important parameters such as CO_2 emission levels or thermal comfort have been considered as lesser priorities. On the other hand, the main priority of the CoE's environmental campaign is a significant reduction in the CO_2 emission of the church properties which seems to have been neglected or given less priority. Local heat emitters usually utilize electricity as the main fuel which could be problematic if the system is operational for long periods due to the high carbon factor of electricity. Therefore, a balanced approach toward heating strategy is required which not only helps the CoE reach its carbon objective but safeguards the historic fabric of its assets and provides suitable degree of occupant comfort.

4.4 Building fabric improvements

4.4.1 Thermal Insulation

The thermal efficiency of a material or building component is defined by its U value (transmittance value) which quantifies the rate of heat loss through that material; the lower the U value, the greater the thermal efficiency (Carbon Trust, 2011). Thermal insulation plays a key role in improving the overall energy efficiency of the building and a range of insulation materials and solutions with low thermal conductivity values have been developed to achieve the highest thermal insulation resistance (Jelle, 2011). Insulation could be applied to a range of building components including the wall, roof or the floor in order to minimise the heat loss of the building and reduce the energy consumption. However, Grobler and Masoso (2008) conducted research which established that adding wall insulation in certain cases could result in increased annual energy consumption of a building.

Part L1A of the Building Regulations which came into force in October 2010 has listed the limiting U values for different building components and Table 4.3 illustrates the new acceptable values in comparison with the 2006 version of the Building Regulations.

Table 4.3 Acceptable U Values for Different Building Components

Element	2006	2010
Roof	0.25	0.20
External Wall	0.35	0.30
Party Wall	N/A	0.20
Floor	0.25	0.25
Windows	2.20	2.00
Air Permeability	10	10

Source: Part L1A of Building Regulations (2006 & 2010)

However, due to traditional construction, the thermal characteristics of historic buildings are generally poorer than their modern counterparts (Carbon Trust, 2011). The typical U values for historic buildings are presented in Table 4.4.

Table 4.4 Typical U Values for Historic Buildings

Building element		U value W/m^2K
600mm solid brick wall with limestone facing		1.00
600mm solid brick wall		0.86
900mm limestone wall with lime plaster		1.22 – 1.88
Uninsulated pitched roof with slates		2.6
Stone floor	Uninsulated 30m x10m	0.45
	Uninsulated 60m x 20m	0.25

Source: Carbon Trust (2011)

Obviously, the U values linked to the historic components are much higher than the acceptable levels according to the latest standards. However, the areas where insulation could be applied to historic structures are limited to avoid change in the historic character and fabric of the church. In addition, the choice of insulation material is of great significance for historic buildings. According to English Heritage (2010), traditional buildings are characterised by the widespread use of 'breathable' moisture permeable materials which allow moisture within the structure's fabric. As a result, use of insulation materials based on natural fibres such as wool, hemp and flax is much more effective than the synthetic insulation materials because they allow moisture vapour to balance itself across the insulation layer and evaporate any condensation.

According to the Carbon Trust (2011), the roof is the most practical area to improve the insulation standard of a historic church depending upon the roof construction and the level of access. Generally it is possible to achieve a high level of insulation which is not harmful to the fabric of historic buildings; however, achieving a U value of 20 W/m^2K (Part L1A Building Regulations, 2010) for the roof of historic buildings could be challenging especially if there are constraints regarding the thickness of the insulation that can be provided above the rafters. A comprehensive checklist for insulating the roof of historic buildings is provided by English Heritage (2010b) which could be used as a useful reference on the subject.

4.4.2 *Improvements to Windows*

Windows make a major contribution to the character of historic buildings and can illustrate the history of the structure, craft skills, building economics and changing architectural taste; therefore, the first priority is retaining the original windows. On the other hand, older windows could be draughty and excessive air leakage through windows wastes heat and may be uncomfortable for the occupants (English Heritage, 2010). There are a number of non-intrusive solutions which could enhance the thermal performance of windows.

Secondary glazing where a fully independent window is installed outside of existing windows without altering their original form is considered to be an efficient solution; recent research shows that the heat loss through conduction and radiation could be reduced by over 60% using secondary glazing with a low emissivity hard coating facing outside (English Heritage, 2010). Replacing the existing windows with double glazing windows is not recommended as it significantly changes the appearance of the historic structure and usually requires specific permission for listed buildings. In addition, Wasielewski (2004) examined the cost analysis of replacing old windows with new one compared to repair and renovation of existing buildings; her research showed that not only is retaining original windows more economically feasible but a properly repaired rehabilitated and maintained window could last another fifty to one hundred years. Many historic churches have external wire grilles fitted to their windows to avoid vandalism. One solution to achieve better thermal simulation could be the replacement of these grilles (at the end of their service lives) with a layer of high performance acrylic (Carbon Trust, 2011). This solution could enhance the thermal performance and the air tightness of the windows whilst retaining protection to the original windows.

Chapter 5: Case Study; Lichfield Cathedral

5.1 Introduction

This chapter examines the effectiveness of various energy reduction strategies using Lichfield Cathedral as a case study. First, a background on the cathedral and its current levels of energy use are introduced followed by an introduction on Integrated Environmental Solutions (IES) simulation device which has been used as the simulation programme for this research. After that, a hierarchy of energy saving options is presented and the implication of each solution is discussed with respect to the case study and similar cases.

5.2 Background

In order to investigate how different sources of CO_2 emission for the Church of England (CoE) properties can be managed to help meet the emissions target (80% reduction in emissions by 2050), individual dioceses have been undertaking their own analysis. For example, more detailed survey work was undertaken in Lichfield Cathedral Close (LCC), part of the Lichfield Diocese. The Diocese of Lichfield is located in the northern region of the West Midlands covering an area of 1,700 square miles and serves nearly two million people; it consists of 290 benefices, 427 parishes and 583 churches (Diocese of Lichfield, 2011). The heart of the diocese is the Lichfield cathedral (Figure 5.1) located in Lichfield city and dating back to 1195 (Lichfield Cathedral, 2011).

Figure 5.1: Lichfield Cathedral

Source: Lichfield heritage, 2011

LCC comprises Lichfield cathedral as well as a number of other historic buildings such as the school (formerly the Bishop's Palace which dates back to 1687) and the Deanery which was built in the 18th Century; it also contains a visitors' centre, clergy homes and a number of private residences (Lichfield Cathedral, 2011). Lichfield cathedral has a unique architecture and is the only medieval cathedral in the UK with three spires. The cathedral has been through a series of changes during its rich history; it suffered irreparable damage and destruction during the English Civil War and the majority of its artwork and treasures were destroyed (Lichfield Cathedral, 2011). Since then, it has been through a number of restoration projects and the last major renovation was led by Sir Gilbert Scott during the mid-19th century (Lichfield Cathedral, 2011).

The historic nature of the cathedral and the existence of a number of listed buildings turn the LCC into a potentially difficult site for the CoE with regards to reaching an 80% reduction of its carbon footprint. The main reason behind this is the limited scope of work and the necessity of gaining proper permissions before undertaking any major refurbishment works in listed buildings such as Lichfield Cathedral. As a result, it could be argued that if Lichfield Cathedral is on target to achieve the CoE's CO_2 reductions, the majority of other dioceses are likely to be capable of achieving similar results.

5.3 Current Levels of Energy Use and CO_2 Emission

Based on the CoE's audit and the surveys conducted to identify the main sources of CO_2 emissions, 75% of the emissions are due to heating and lighting of which 45% are due to space and water heating (Church of England, 2008). However, more specific data is available for Lichfield Cathedral based on more detailed survey work and specific recommendations for the building have been made through two separate energy audits (Hodgson and Bassett, 2006; Marches Energy Agency (MEA), 2006). The overall CO_2 emissions, cost and energy figures for Lichfield Cathedral are presented in Table 5.1.

Table 5.1: Overall energy consumption, cost and associated CO_2 emissions

	Energy (kWh)	Energy / m2	Cost (£/year)	CO_2 (tonnes/year)
Gas	880,219	785.91	18,369	167.2
Electricity	158,887	141.86	14,281	68.3
Total	1,039,106	927.77	32,650	235.5

Source: MEA (2006)

The cathedral's energy consumption is about 1,039,000 kWh per year which is 4.4% higher than a typical CoE cathedral that consumes an average of 995,000 kWh per year.

5.4 IES Simulation Tool

5.4.1 Background

The growing complexity of buildings in design and operation has made building energy performance simulation an essential part of the planning process (Jentsch, 2008). However, the use of computer simulations is not limited solely to the design stage of a project. In fact, the commissioning and operational stages of the project are where the building simulation programs are expected to contribute the most as there exists fewer uncertainties; therefore, the deployment of building simulation needs to be managed and enforced across design, engineering and maintenance stages of the project (Augenbroe, 2004). The concept of building simulation first emerged in the 1960's where research initially focused on the study of fundamental theory for building simulation; in the 1970's and driven by the energy crisis of that period, the research expanded to develop algorithms for heating and cooling loads and energy transfer simulation (de Wilde and Augenbroe, 2009). Whilst the early groundwork was mainly focused on the energy performance field, it expanded to other fields including heating, lighting and ventilation (Augenbroe, 2004). During the 1980's, new advancements in the field of personal computers made building performance simulation more accessible and the efforts focused on programming and testing computational tools. In the same period, natural selection set in and only the tools which provided upgrading, maintenance and adding new desired features were able to survive (de Wilde and Augenbroe, 2009). During the 1990's, the design and development of new simulation programs capable of dealing with lighting, acoustics and air flow problems further broadened the computer simulation field.

Although most of the fundamental work was carried out more than two decades ago, building simulation is continuing to evolve and mature; major improvements have been achieved in model robustness and fidelity and the quality of user interfaces has increased significantly (Augenbroe and Malkawi, 2004). Today, building performance simulation packages are widely used in the industry during various stages of the project to provide accurate estimations of the key building performance indicators. Computer simulations are known to increase the speed of the design process, enhance the efficiency and provide a better understanding of the potential impact of design decisions (Augenbroe, 2004). Moreover, such programs facilitate the assessment of the response of the building or its components to specific external conditions using a computer model and help answer 'what if' type questions with respect to the performance of the building in various scenarios (de Wit, 2004). As a result, using building simulation programs could significantly help designers to assess the efficiency and effectiveness of various alternatives in order to select the most suitable option.

Over the past 50 years, a variety of building performance simulation programs have been developed and upgraded, and are in use in the building energy community (Crawley et al, 2005). The most commonly used simulation programs by engineers and consultants in the UK are Design Builder, Hevacomp, Tas Building Designer and Integrated Environmental Solutions (IES) Virtual Environment. Two of these programs (Design Builder and Hevacomp) use the simulation engine EnergyPlus (published by the U.S Department of Energy) without an extensive graphical interface whilst the other two (IES and Tas) use individual calculation cores consisting of underlying software products (Jentsch, 2008). All four programs are approved for use in compliance with Part L2 of the Building Regulations (2006) for England and Wales. IES, Tas and Hevacomp also include approved dynamic modelling routines (Jentsch, 2008). In addition to these four, there is a range of simulation programs and the directory of US Department of Energy (2011) lists 395 available programs used for evaluating energy efficiency, sustainability and renewable energy in buildings. Many of these programs have created a community that continually develop new components or models which can be added to a growing library; the average user usually requires some training and basic understanding of the underlying physical laws to use such programs and there is general consensus that the current generation of such programs is mature, robust and accurate enough for most applications (de Wilde and Augenbroe, 2009).

5.4.2 IES Software

The software selected for this research is the IES Virtual Environment. IES is an integrated suit of applications linked by a common user interface and a single integrated data model (Crawley et al, 2008). This allows the data input for one application to be used by the others and enables the user to run simulations for different aspects of the structure such as thermal or lighting simulation (Muhaisen and Gadi, 2006).

IES has been selected as the preferred building performance simulation program due to a variety of reasons. First, the program has been approved for use in compliance with the Part L of the Building Regulations (2010) which is concerned with energy use and carbon emission of buildings. In addition, IES has been assessed according to International Validation Test (ASHRAE Standard 140) and proved to meet or exceed all requirements of this test; in addition, it meets all the requirements of the ASHRAE Standard 90.1 (IES, 2011b). IES is used by many of the world's leading building and consultancy firms with expertise in green buildings; users of the software include each of the top 10 UK engineers, each of the top 10 UK consultants and five out of the top 10 architects according to Building Magazine's annual review of 2007 (IES, 2011). IES has a large and growing user base in North America, Europe, Asia and Australia and is available in both SI and IP units (Crawley et al, 2005). This proves that not only the software is in compliance with the relevant UK regulations but it is also trusted to provide accurate building simulations by the majority of the top engineering firms in the UK. Beside the credibility of the software, the key reason to select the IES was its capabilities to provide all the relevant information which it may be required to calculate during different stages of the research. The program provides a tool for detailed evaluation of building and system design and allows the optimisation with respect to comfort criteria and energy consumption through various modules including (Crawley et al, 2008 & IES, 2011):

- ModelIT—2-D and 3-D geometry creation and editing
- ApacheCalc—loads analysis
- ApacheSim—thermal simulation analysis
- MacroFlo—natural ventilation
- Apache HVAC—component-based HVAC
- SunCast—shading visualisation and analysis
- MicroFlo—3D computational fluid dynamics
- FlucsPro/Radiance—lighting design
- DEFT—model optimisation
- LifeCycle—life-cycle energy and cost analysis
- Simulex—building evacuation

Based on the scope of the research, the modules which have been used for this research are ModelIT and ApacheSim. These modules will allow simulation of the relevant issues to the research and can assist in drawing accurate conclusions with respect to energy use, CO_2 emission and occupant comfort. ApacheSim (the thermal simulation module) can address various issues including but not limited to building orientation and configuration, thermal insulation, glazing, shading, building dynamics, mixed mode and HVAC systems. In addition, the simulation is driven by real weather data covering any period from a day to a year and thermal conditions can be traced at intervals as small as one minute (Crawley et al, 2005).

The results of the simulation are shown in Vista which is the graphic tool of the software for data presentation and analysis. Vista provides an environment for interrogating the results in detail and includes function for statistical analysis of simulation results including (Crawley et al, 2005):

- Over 40 measures of room performance including air and radiant temperature, CO_2 and humidity
- Comfort statistics
- Loads and energy consumption
- CO_2 emission

5.5 Methodology

The aim of this chapter is to examine the potential impact of various energy reduction solutions on historic churches and cathedrals. The effectiveness of such measures depends on a variety of factors including the specific design and operation of a particular church. The Carbon Trust (2011) recommends following an energy reduction hierarchy to impact

- Behavourial changes
- Technological solutions
- Low carbon technologies

Therefore, the following energy reduction hierarchy is proposed:

User Accountability

Feedback on the level of energy consumption to change behaviour of those who use and run the church. Providing regular energy management and awareness training by energy experts for the staff in charge of running and maintaining the church

↓

Energy Management

Better management of heating times. Using smart meters. Monitoring the system to make necessary adjustments.

↓

Technological Solutions

Investigating the impact of using various heating solutions on energy consumption and carbon emissions of the building.

↓

Fabric Improvements

The impact of enhancing the building fabric on energy and carbon reduction

↓

Low and Zero Carbon Technologies

Application of higher investment options for heat and power generation

In order to examine the effectiveness of each option, three main sources have been used;

- Computer simulation of Lichfield Cathedral
- The audit of the cathedral carried out by MEA (2006)
- The audit of 20 churches in London by the Carbon Trust (2011)

5.6 User Accountability and Energy Management

The path toward comprehensive energy reduction begins with those in charge of running and maintaining the day-to-day operation of a church. It is important that they are aware of the energy use of the building in comparison with the benchmarks for that church. According to the Carbon Trust (2011), a smart metering and monitoring system is necessary to provide accurate information on how well a building is running against specific targets or benchmarks. Such systems will ensure the energy saving efforts are acknowledged which in turn increases awareness and motivates the users to make changes in their daily schedule to be more energy efficient. In addition, regular monthly reports can assist the managers to identify and deal with any slippage against set targets.

In addition to the staff, it would be beneficial to educate the congregation through awareness campaigns. According to de Dear (1998), an alternative to traditional comfort theory – termed the "adaptive model" of comfort- focuses on people's instrumental role in creating their own thermal preference. This is achieved through interaction with environment or modifying their own behaviour or because contextual factors change their expectations and thermal preference. Examples of actions which people might take to make themselves comfortable in a given environment are the addition of removal of clothing, adjustments of posture or changes of activity. As Camuffo & Valle (2007) noticed whatever the heating system, reaching thermal comfort in mild climates is easy. However, in cold climates thermal comfort and conservation involve conflicting needs and in service of sustainability, church goers may be required to take certain actions such as bearing with a low-temperature environment or wearing heavy clothing. The staff and the church occupants, therefore, need to cooperate in identifying and taking advantage of the adaptive opportunities applicable to their specific church.

In Lichfield Cathedral, the responsibility for energy management and usage rests almost entirely with the Administrator who is responsible for all cathedral facilities. MEA (2006) recommended a programme of education and awareness training should be initiated to encourage participation from all members of staff and it should specifically focus on use of heating, lighting, office equipment and the opening of windows. However, the report (MEA, 2006) warned that unless properly planned and delivered, any investment in a staff awareness programme may fail to yield the required results. The estimated cost and savings of energy management and awareness training for the Lichfield Cathedral Close is as follows

Table 5.2: Energy Management and Awareness Training

Action	CO2 Savings	Energy Savings	Cost	Payback
Energy management and training	11.9 Tonnes /year	51,2 kWh/year	3000	1.5 years
Better management of heating times	2.7 Tonnes/year	13.9 kWh	0	0
Total	14.6 Tonnes/ Year	65.2 Kwh	3000	

Source: MEA, 2006

The potential reduction in energy consumption of a building due to user accountability and energy management may vary from building to building. Previous studies have shown such measures have the potential to reduce the overall energy consumption between 3 to 15% (MEA, 2006 & Carbon Trust, 2011).

Therefore, an awareness training programme along with a robust monitoring system for Lichfield Cathedral could result in significant energy and carbon savings. Table 5.3 details the effect on Lichfield Cathedral (6.5% reduction)

Table 5.3: Impact of User Accountability and Energy Management

Source	Gas (kWh)	Electricity (kWh)	Comment
Lichfield Cathedral	880,219	158,877	Actual
	823,004	148,549	6.5% reduction
Energy saving	57,215	10,328	Gas: 3p/kWh
Energy cost saving	£1,716	£1,136	Electricty: 11p/kWh
CO2 emission saving	14.6 tonnes		

5.7 IES Model of Lichfield Cathedral

5.7.1 The 3-D Model

A dynamic model of the Lichfield Cathedral was developed using the IES software in order to examine the possible energy savings through implementation of various solutions. In order to gain specific information on the cathedral, several visits were made to the site during the course of the project; in addition, Archdeacon Chris Liley, who is the Administrator of the cathedral agreed to be interviewed on two occasions where he provided the necessary information for the model including:

- Material used in the main structure
- The specific height and length of the Cathedral
- The specific hours of worship and the number of attendees
- General information on the current heating system

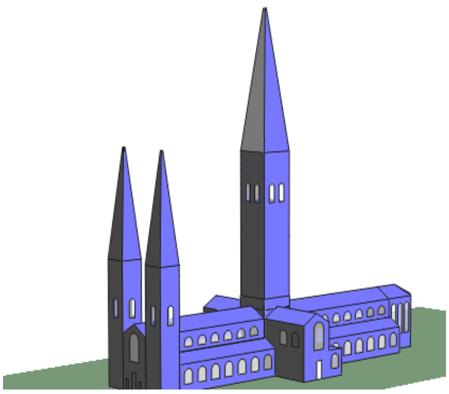


Figure 5.2: 3-D Model of Lichfield Cathedral

5.7.2 Material

The historic construction of a church will usually mean that the thermal characteristics are poorer than modern buildings. A survey of 20 historic churches carried out by the Carbon Trust (2011) showed historic churches have a high demand for heat, being thermally ‘heavy’ with a slow response that often requires pre-heating for several hours to reach the set point temperature. Also, the churches were generally leaky with air paths through stained glass grouting, lead work and poorly fitting doors. U values are one measure of the thermal performance of fabrics and relate to the insulating properties of the material.

Based on the materials used in Lichfield Cathedral and the information obtained through the Archdeacon, the assumed thermal characteristics for the cathedral model are summarised in Table 5.4.

Table 5.4: Assumed Thermal Characteristics for the Model

Element	Construction (main)	U Value (W/ m^2k)
External Walls	Sandstone	2.25
Windows	Single glazed panes in metal frames	4.65
Exposed Floors	Stone, uninsulated	0.45
Roof	Slate, uninsulated	2.60

5.7.3 Weather File

The weather file used for the model was the Birmingham Test Reference Year (TRY) weather file produced by CIBSE. The current CIBSE TRY file is derived from measured UK Meteorological (Met) Office site data from 1983 to 2004. TRY is considered as a 'typical year' for calculation of average annual energy consumption by simulation under typical weather conditions. As there was no TRY weather file for Lichfield City the Birmingham file was selected and used for the simulation purposes.

5.7.4 Profile Database and Thermal Templates

The heating systems for the building were entered into the model. The main heating in Lichfield Cathedral is provided by natural gas fired boilers, supplying hot water to radiators. For the purposes of the Base Model, a system seasonal efficiency of 81% was assumed for the Low Temperature Hot Water (LTHW) system (this being the default value). Lighting throughout the cathedral is a mix of lighting; T5 and T8 fluorescent switch start and high frequency lamps and tungsten filament bulbs and halogen spots (MEA, 2006) and was incorporated into the model accordingly.

Thermal templates were set up to replicate the way in which the church is occupied and used in reality. Heating templates mirrored the control strategy at Lichfield Cathedral, with heating periods between 06:00 to 18:30 Monday-Sunday. The cathedral is a naturally ventilated building and the dominant factor on the heat load of the model is the infiltration rate into the large volume of the main body of the church. This air change rate was set at 0.9 air changes an hour (ach) in order to reconcile energy consumption in the model with metered data from the cathedral actual data. The Air Change Rate (ACH) is defined as: $ACH(1/h) = q_v/V$

Where:

q_v = air flow rate through a space $[m^3/h]$

V= The volume of the space $[m^3]$

Basically, it measures how quickly the indoor air is replaced by air coming from outside the structure and describes the tightness of the building. Therefore, the leakier the building is, the larger is the infiltration rate and the ACH. In order to determine the air leakage in buildings, different methods are used including tracer gas measurement or pressurization testing.

For the scope of this research, it was not possible to independently determine the exact ACH for Lichfield Cathedral. It was recommended by supervisors that similar credible research should be reviewed to study alternative solutions. The best example was the research done by Carbon Trust (2011) on Notting Hill Church in London where:

- The modeling was carried out for a historical church.
- The simulation tool used was IES.
- The ACH was not independently calculated

Similarly, following the completion of the church model and incorporating the relevant data and assumptions, the infiltration rate was determined after a series of iteration. For Notting Hill, an infiltration rate of 0.95ach achieved reconciliation with actual data and following the same methodology, a rate of 0.9ach resulted in the same reconciliation for Lichfield Cathedral.

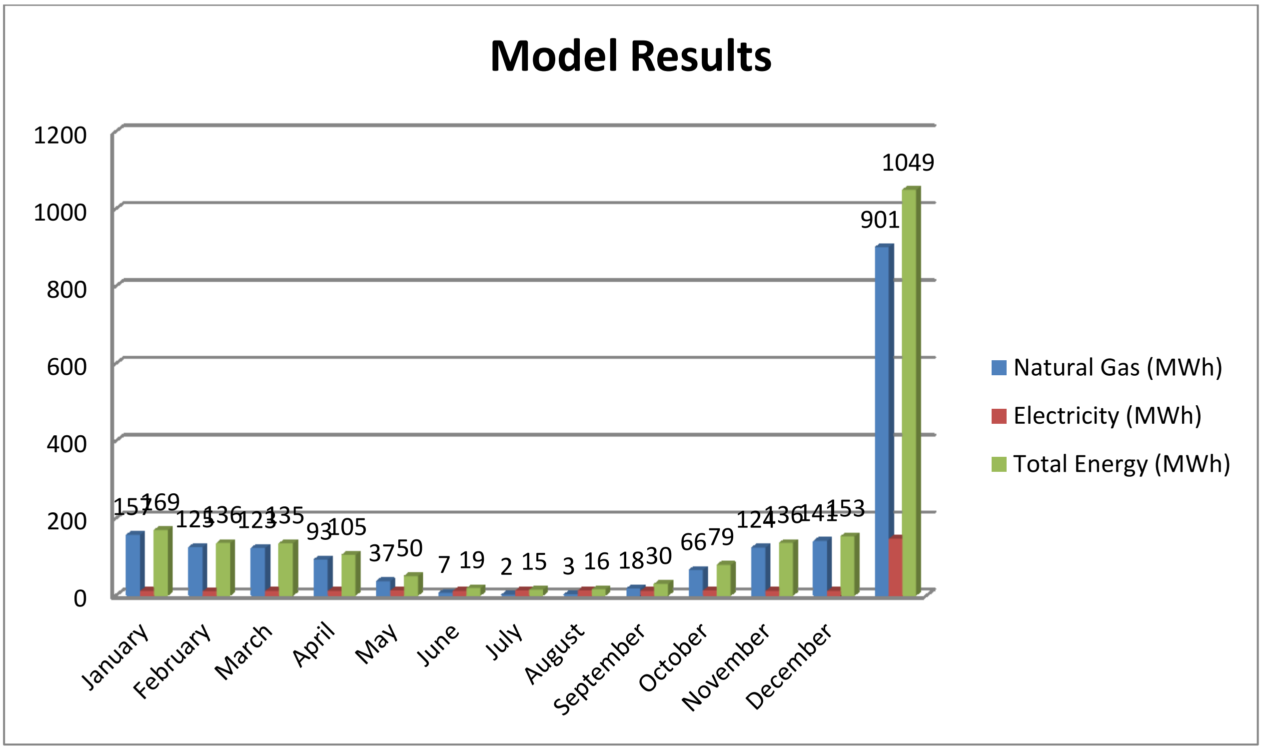
Table 5.5: Parameters and assumptions for the IES model

List of the Parameters and Assumptions Used for the IES Model			
Construction	**Length**	113m	
	Height	Central Spire: 77m	Western Spires: 58m
	Width	Across: 50m	Nave: 21m
	Heated Volume	Approximately 19,600 m^3	
Material	**External Wall**	Sandstone Width: 1-3m	U Value: 2.25W/m2k
	Windows	4mm Single Glazed	U Value: 4.65W/m2k
	Floors	Uninsulated Stone	U Value: 0.45W/m2k
	Roof	Uninsulated Slate	U Value: 2.60W/m2k
	Door	Wooden door	
Weather File	CIBSE TRY File for Birmingham City		
Heating Profile	Defined as Lichfield: Operational from 06:00 to 18:30 Daily		
Thermal Conditions	**Heating Profile**	Lichfield Profile	
	Simulation Set Temperature	20°C	
	DHW Consumption Pattern	Linked to Occupancy Profile	
	Cooling Profile	Off Continuously	
System	**Type**	Central Heating with Radiators	
	Seasonal Efficiency	81%	
	Fuel Type	Natural Gas	
Internal Gains	**People**	Occupancy	90
	Fluorescent Lighitng	Fuel	Electricity
		Illuminance: 150 lux	
Ventilation	Natural Ventilation		
Air Exchanges	Infiltration : 0.9 ach		

5.7.5 Model Results

The main model result for energy consumption based on the natural gas and electricity are provided as follows.

Figure 5.3: Energy Output from the IES Model



The Carbon Trust Agency and Marches Energy Agency (MEA) conducted an audit of the church to study the potential energy saving measures. The energy consumption of the cathedral and the associated carbon emissions were provided in the report and have been used as a reference for this study. The cathedral was contacted to ask about more recent energy consumption data but the MEA/Carbon Trust (2006) report remains the most detailed information available and no major changes has been carried out in either the cathedral's energy practices or function.

Table 5.6 provides a comparison of the actual energy consumption levels in the Lichfield Cathedral against the results of the IES model simulation showing a 1% difference in total energy consumption. Therefore, it is argued that the model provides an accurate representation of the cathedral.

Table 5.6: Actual versus Simulated Energy Consumption Levels

Source	Gas Consumption (kWh)	Electricity Consumption (kWh)	Total Energy (kWh)	Difference in total energy use (%)
Lichfield Cathedral	880,219	158,887	1,039,106	0.98
IES Model	901,317	148,120	1,049,438	

5.8 Technological Solutions

Chapter 4 provided a detailed account of the technological solutions which may be applied in historic churches to reduce the energy consumption and carbon emission levels. Since heating is the main source of energy use in churches (Church of England, 2008) selection of the proper heating system is essential. However, the key factor on the energy used for heating depends on the pattern of operation of a church and no single solution can be recommended for all churches and cathedrals. Most churches in the UK, including Lichfield Cathedral, use central heating with radiators (convective heating) to heat the space (Church of England, 2008). The main problem with this method of heating is the buoyancy effects of warm air leads to stratification of warm air at high level, and a deficiency at low level which particularly marked on preheating of a cool structure (Carbon Trust, 2011). For massive structures with high ceilings (like many historic churches) this method of heating requires a great deal of energy consumption especially if the church is in intermittent use. Therefore, the use of a low level radiant source is more efficient in heating a high lofted space by creating a micro environment in the occupied area and avoiding heating the full volume of the church (Carbon Trust, 2011). The available radiant heating regimes for churches include under-floor heating, radiant heating and pew heating. The implementation of each system in a church will depend on different factors including size, pattern of use and possibility of making renovations.

- ***Under-floor Heating***

  The mechanics of under-floor heating were described in Chapter 4 of this project. Of all terminal heating units, under-floor heating comes closest to meeting the optimum comfort profile - that is to have a relatively higher temperature at the floor zone than the ceiling zone (warm feet - cool head). It is hidden from view and has a long life but has a slow response to control (Carbon Trust, 2011). However, the installation of under-floor systems is expensive as the entire floor must be taken up to install the system so it is recommended to be used when the floor is to be replaced anyway (Carbon Trust, 2011).

Due to the historic nature of Lichfield Cathedral and being listed as a Grade I structure, it may not be possible to implement under-floor heating for Lichfield Cathedral. However, in order to understand the potential impact of this solution, a computer simulation was run in the IES software using the current profile of the cathedral but replaced the main heating system to be under-floor heating installed in the nave area of the cathedral.

Table 5.7: Under-floor Heating Energy Consumption

Date	Total Natural Gas (MWh)	Total Electricity (MWh)	Total Energy (MWh)
Jan01-31	83.50	12.28	95.78
Feb01-28	65.81	11.09	76.91
Mar01-31	64.90	12.28	77.18
Apr01-31	48.88	11.88	60.76
May01-31	19.36	12.28	31.64
Jun01-30	3.79	11.88	15.68
Jul01-31	1.29	12.28	13.57
Aug01-31	1.41	12.28	13.69
Sep01-30	9.49	11.88	21.38
Oct01-31	34.19	12.28	46.47
Nov01-30	65.61	11.88	77.50
Dec01-30	74.66	11.88	86.55
Total/Actual	472.95/880.22	144.22/158.89	617.17/1039.11

The results show a significant decline in energy consumption of the model from about 880,219kWh to 472,000 kWh. This significant decline can be attributed to the size of the cathedral which has a heated a volume of 19,600 m^3 (MEA, 2006). Therefore, smaller churches may not have this level of reduction but the nature of radiant heating systems which aim at directly warming people rather than the entire building result in lower energy consumption and consequently carbon emission levels.

- Radiant Heaters

In addition to under-floor heating which is a central heating system, it is possible to use local heating systems for smaller churches to provide radiant heating for the church goers. As discussed in Chapter 4, radiant heaters are another energy efficient option that can warm the people directly and can be used in churches with small size and intermittent use. However, for a cathedral the size of Lichfield, they are not suitable due to the huge volume of the church and the pattern of use.

- Pew Heating

Pew heating is another radiant heating method which was briefly discussed in chapter 4. The pew heating can be provided by a below seat water coil that is controlled to a low surface temperature of 43°C, to prevent burns to the occupants especially older people and young children; This temperature would be compatible with the low grade heat obtainable from condenser boiler systems or ground source heat pumps and the system could be zoned to suit the patterns of use within the church, and thermostatically controlled for comfort conditions. This system would be of greatest benefit in spaces that are used on an intermittent basis and have already installed pews (Carbon Trust, 2011).

The impact of installing such pew heating measures was examined in St John's Church in Notting Hill, London which follows a similar daily pattern to Lichfield Cathedral, and resulted in (simulated) 17% reduction in gas consumption and 3% increase in electricity use (Carbon Trust, 2011). Assuming similar reduction rates, the result for the Lichfield Cathedral would be as follows:

Table 5.8: Pew Heating Energy Consumption

Source	Gas (kWh)	Electricity (kWh)	Comment
Base Model	880,219	158,877	Actual
Pew Heating	730,582	163,643	Using Pews
Energy saving	149,637	-4,766	Gas: 3p/kWh
Energy cost saving	£4,489	-£524	Electricity: 11p/kWh
Net Cost Savings	£3,965		

5.9 Building Fabric Improvements

Thermal characteristics of the building fabric are crucial in the energy consumption of a structure. Whilst improvements to building fabric are robust and long term, the effects of such measures should be fully examined before implementation in historic buildings; the measures applied must be considerate of the historic character and aesthetic appearance of the church; therefore, areas where insulation can be added are limited (Carbon Trust, 2011).

- **Roof Insulation**

  Insulating the roof can provide significant savings in energy use especially for vast church roofs through which up to one third of the building's heat could be lost. However for historic churches, necessary care should be applied to avoid damaging the historic fabric of the church (Church of England, 2007). The level of insulation also depends on the roof construction and the level of access.

  The roof construction in the IES model of the Lichfield Cathedral was uninsulated slate that gives a U value of approximately 2.60 W/m^{2}k (Table 5.6). In order to examine the impact of roof insulation a 200mm layer of mineral fibre was added to the design construction (in the IES model) resulting in reducing the U value to 0.16 W/m^{2}k. Table 5.9 shows the energy use in Lichfield cathedral with the new roof.

Figure 5.4: Energy Use for Improved Roof

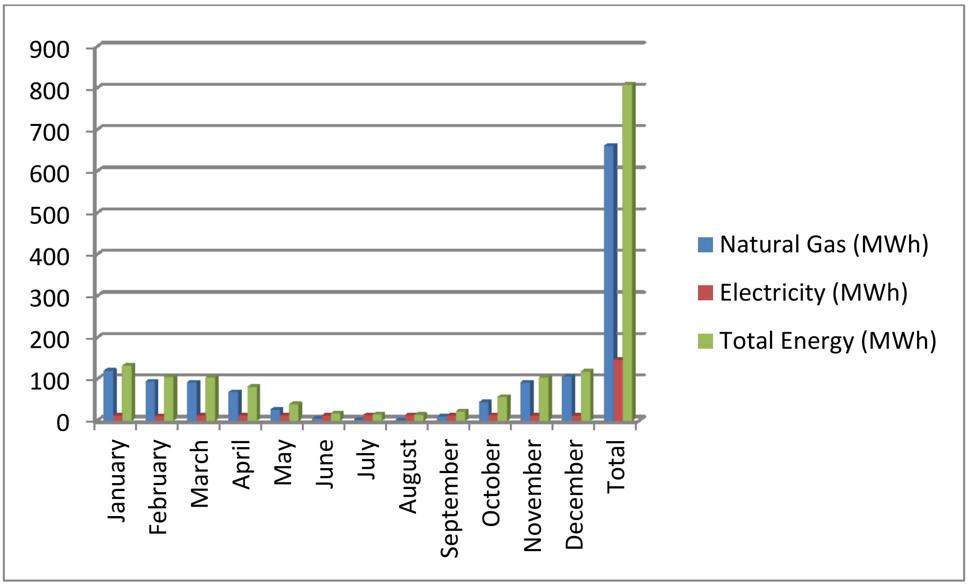


Table 5.9: Improved Roof

Source	Gas (kWh)	Electricity (kWh)	Comment
Base Model	880,219	158,877	Actual
Improved Roof	662,924	148,120	Insulated Roof
Energy saving	217,295	10,757	Gas: 3p/kWh
Energy cost saving	£6,519	£1,183	Electricity: 11p/kWh
Net Cost Savings	£7,702		

- **Improvement to Windows**

  The windows for the IES model were single glazed windows in a heavy frame giving a U value of 4.65 W/m^{2}k. Replacing windows with double-glazed windows seems to be the most practical approach. However, for most historic churches the replacement of original windows is not permitted. An alternative approach recommended by the Carbon Trust (2011) is to add a vacuum glass (6mm thickness) as an internal secondary glazing element. This will reduce the U value for Lichfield Cathedral windows to 2.79 W/m2k.

Table 5.10: Energy Use for Improved Windows

Date	Total Natural Gas (MWh)	Total Electricity (MWh)	Total Energy (MWh)
Jan01-31	150.59	12.61	163.21
Feb01-28	118.69	11.39	130.09
Mar01-31	117.07	12.61	129.68
Apr01-31	88.00	12.21	100.21
May01-31	34.36	12.61	46.97
Jun01-30	6.17	12.21	18.38
Jul01-31	2.01	12.61	14.63
Aug01-31	2.24	12.61	14.86
Sep01-30	16.48	12.21	28.69
Oct01-31	61.88	12.21	74.49
Nov01-30	118.48	12.21	130.69
Dec01-30	134.97	12.21	147.17
Total/Actual	850.99/880.22	148.12/158.89	999.11/1039.11

Table 5.11 Improved Windows

Source	Gas (kWh)	Electricity (kWh)	Comment
Base Model	880,219	158,877	Actual
Improved Windows	850,991	148,120	Improved Windows
Energy saving	29,228	10,757	Gas: 3p/kWh
Energy cost saving	£877	£1,183	Electricty: 11p/kWh
Net Cost Savings	£2,060		

- **Air Tightness**

In the IES model of the cathedral the air change rate was set at 0.9ach in order to reconcile the energy consumption of the computer model with the actual energy use in the cathedral. Improving the air tightness of the windows (discussed above) along with taking measures such as draught stripping doors and adding draught lobbies to church entrances could enhance the air tightness of the building further (Carbon Trust, 2011). The impact of such enhancement then could be quantified using the IES model. For instance if the measures discussed result in reducing the air change rate from the current 0.9 ach to 0.6 ach, the impact will be as follows:

Table 5.12: Energy Use for Improved Air Tightness

	Total nat. gas (MWh)	Total electricity (MWh)	Total energy (MWh)
	air tightnessl.aps	air tightnessl.aps	air tightnessl.aps
Date			
Jan 01-31	137.6203	12.6147	150.2350
Feb 01-28	107.4709	11.3939	118.8648
Mar 01-31	105.4786	12.6147	118.0933
Apr 01-30	77.7492	12.2077	89.9569
May 01-31	28.6912	12.6147	41.3060
Jun 01-30	4.1085	12.2077	16.3162
Jul 01-31	1.2430	12.6147	13.8576
Aug 01-31	1.4576	12.6147	14.0723
Sep 01-30	12.9523	12.2077	25.1600
Oct 01-31	54.1773	12.6147	66.7920
Nov 01-30	107.6195	12.2077	119.8273
Dec 01-30	122.8054	12.2077	135.0132
Summed total	761.3737	148.1206	909.4948

Table 5.13: Improved Air Tightness

Source	Gas (kWh)	Electricity (kWh)	Comment
Base Model	880,219	158,877	Actual
Improved Air Tightness	767,373	148,120	Improved Air Tightness
Energy saving	112,846	10,757	Gas: 3p/kWh
Energy cost saving	£3,385	£1,183	Electricty: 11p/kWh
Net Cost Savings	£4,569		

5.10 Low and Zero Carbon Energy Supply Technologies

The Church of England (2008) recognizes the use of a number of low and zero carbon technologies; however the guidelines recommend that low carbon measures should only be applied after other energy efficiency measures have been implemented. According to Church of England (2008), the renewable energy sources are sun, wind, well managed forests (i.e. wood) and intrinsic heat from the earth. Consequently, the following technologies could be used to harness the energy of the above mentioned sources:

- Solar photovoltaic panels for electricity and solar flat plate panels or evacuated tubes for heat collection
- Wind turbines at range of scales
- Burning wood in boilers for heat (i.e. biomass heat)
- Ground source heat pumps for heating and cooling generation.

According to Church of England (2008b), the two main Planning Policy Guidance documents that apply to alterations in church buildings are PPG15 on *Planning and the historic environment* and PPG16 on *Archaeology and Planning*. Depending on the selected technology, there may be significant alterations required, therefore making these planning documents applicable. In addition, if the building is Grade 1 or 2* like Lichfield Cathedral (or any listed church in London), English Heritage will also have to be consulted.

PV Panels

Photo-voltaic (PV) panels, comprising an array of cells mounted on a glass substrate, generate electricity from light. There are different types of PV cells but the most common ones are made of silicon (Church of England, 2008b).

Figure 5.5 : PV panels on St James church

Source: Carbon Trust (2011)

According to Carbon Trust (2008), PV systems come in three types:

- Mono-crystalline which is the most efficient and most expensive type and is made from slices cut from a single silicon crystal, grown under extreme clean conditions.
- Polycrystalline, made from many crystals fused together under heat;
- Amorphous thin film, which is the least efficient type and is made of very small crystals and powder of silicon, fixed to a plastic substrate.

It is estimated that PV systems should be able to operate for up to 25-30 years and the payback period is affected by the price at which energy is sold but very few installations have been carried out without assistance of government grants which is not sustainable in the long term unless the efficiency of the systems are highly improved in the future (Carbon Trust, 2008).

Assuming electricity price of 10p/kWh, Table 5.14 provides indicative PV output and cost for two different types of PV panels.

Table 5.14: Indicative PV output and costs

Examples of photovoltaic panel type	Area required per kW installed m^2/kWp	Energy output per kW installed kWh/yr/kWp	CO_2 saving $kgCO_2$ /kWp/yr	Capital cost per kWp £/kW**	Running cost saving £/kWp/yr*
Amorphous silicon modules	15	800	344	£5,300	£80
Poly-crystalline modules	8	810	348	£5,600	£81

Source: Church of England (2008b)

Wind Turbines

Wind turbines harness the wind energy and turn it into electricity and they are available in various sizes. However, the debate on the realistic output of wind turbines and their safety implications for buildings is ongoing. According to Church of England (2008b) the following considerations should be taken into account before installing wind turbines:

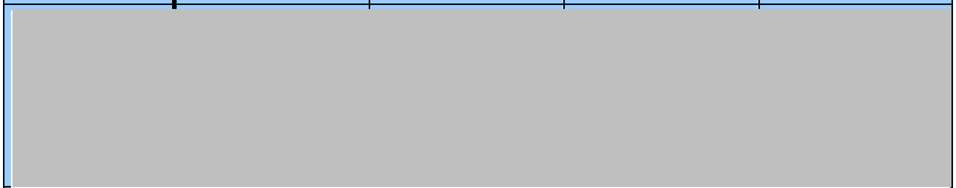
- The turbines require wind speed levels exceeding 5-6 meters per second in order to operate; therefore, the technology should be used where there is sufficient wind such as rural areas with few buildings and natural obstacles.
- They need to be located where they are as exposed as possible to the wind and away from buildings.
- As with PV, wind turbines will require the space to locate the inverter and connection to the building's electrical circuit.
- Necessary permissions should be obtained and the consent of neighbours should be acquired.

Figure 5.6: Wind Turbines

Source: Church of England (2008b)

Assuming electricity price of 10p/kWh, Table 5.15 provides indicative specifications and cost of different wind turbines:

Table 5.15: Indicative specifications and cost for wind turbines

	Swift	Qr5	Proven	Proven
				
Type	Building mounted	Building or ground mounted	Building or ground mounted	Ground mounted
Output/ kW	1.5	6	2.5	15
Turbine diameter/ m	2.1	3.1 (5m height)	3.5	9
Turbine height/ m	Min 50cm clearance above roof	Min 3m clearance from roof. 9m mast if ground mounted	7 or 11 if ground mounted	19.5
Installed capital cost/ £	£5,000-8,000	£33,000	£11,000	£40,000
Annual Electricity generated/ kWh	1,000-2,000	10,000 at 5.8m/s av wind speed	2,500-5,000 at 5m/s av wind speed	15,000-30,000 at 5m/s av wind speed
Annual CO_2 saving/ $kgCO_2$	430-860	4,300	1,075-2,150	6,450-12,900
Running cost savings/ £/yr*	£100-200	£1,000	£250-500	£1,500-3,000

Source: Church of England (2008b)

Biomass Technology

This technology uses wood in the form of logs, chips or pellets as fuel to produce space and water heating. Depending on the size of the installation, it is possible to use high efficiency stoves or boilers, which are very similar to fossil fuel boilers (Church of England, 2008b). The argument for carbon reduction with bio-mass technology is that the carbon released in burning of the fuel is almost the same as the carbon absorbed by the growth of the timber resulting in an almost neutral impact on carbon emissions (Carbon Trust, 2011).

Biomass is widely used in many European and North American countries but the UK market is not yet very well developed which affects the cost of using this technology (Carbon Trust, 2011). According to DEFRA (2006), the capital cost of automated biomass heating systems is significantly greater than that of conventional systems due to more complicated feeding mechanism and the small market of biomass appliances in the UK.

Some of the main considerations for installing biomass boilers are as follow:

- It is unlikely to be financially viable as an add-on system and is best used when the current boilers are to be replaced
- The technology has considerable space limitations as the boiler is larger and it requires additional space for fuel feeding system as well as storage for the wood pellets.
- It is important to find a local fuel supplier and maintain a secure fuel supply.
- Planning permission may be required before installation.
- Biomass boilers will need yearly maintenance checks and cleaning. Stoves will need manual loading and cleaning.

According to Church of England (2008b), the cost savings depend on the price of wood fuel which in turn depends on the type of the fuel and where it is coming from. Assuming electricity price of 10p/kWh, gas price of 3p/kWh, wood chip price 2p/kWh and wood pellet price 3p/kWh, Table 5.16 provides indicative costs and savings for biomass systems.

Table 5.16: Indicative costs and savings for biomass systems

Type of system	Average capital cost per kW	CO_2 savings per 1,000kWh heat generated/ kgCO_2/1,000kWh	Running cost savings per 1,000kWh heat generated/* £/1,000kWh
Biomass boilers	£400-350 (for 50-100kW systems; bigger boilers are more cost effective)	160	£10
CO_2 savings and costs are calculated assuming that a gas heating system is replaced by a wood chip boiler			
Biomass stoves	£500	405	£70
CO_2 savings and costs are calculated assuming that individual electric heaters are replaced by pellet stoves			

Source: Church of England (2008b)

Grants and Tax Incentives

One of the main factors for applying low carbon energy supply technologies in a cost effective manner are the government incentives and other grants which aim to promote the uptake of these technologies. In fact, without such simulants, the use of such technologies cannot be justified financially in most cases.

- Feed-in Tariffs (FiT): FiT is a government scheme introduced in 2010 to incentivize the small scale generation of low carbon electricity based on which a FiT will be paid for the electricity generated by renewable technologies. Table 5.17 shows Tariffs for various technologies

Table 5.17: Feed-in Tariffs

Technology	Scale	Tariff level in period (p/kWh)			Tariff lifetime (years)
		Year 1: 01/04/10-31/03/11	Year 2: 01/04/11-31/03/12	Year 3: 01/04/12-31/03/13	
PV	<4kW New build	36.1	36.1	33	25
PV	<4kW Retrofit	41.3	41.3	37.8	25
PV	>4-10kW	36.1	36.1	33	25
PV	>10kW-100Kw	31.4	31.4	28.7	25

Source: Carbon Trust, 2011

The Tariff is made regardless of whether the electricity is used on site or exported back to the national grid. The scheme is to be reviewed every five years and may change for future entrants.

- EDF's Green Energy Fund: Customers on EDF's Green Tariff pay a premium that is matched by EDF; this money is then re-distributed through the Green Energy Fund as grants to community and not for profit organisations for renewable energy projects (Carbon Trust, 2011)
- The Energy Saving Trust: The trust offers grant from their sustainable development fund and provided a grant for installation of PV panels on St James church as shown in figure. These grants are available for all energy efficiency measures, insulation and heating systems and controls. In addition, they are available to parish councils amongst many other organisations and intended for projects that explore models for best practice for sustainable living through innovative ideas and that support, or involve local communities (Carbon Trust, 2011)
- Renewable Heat Incentive (RHI): This is another government scheme to incentivize a range of renewable heat generating technologies where a payment will be made for heat generated by eligible technologies.

Table 5.18: Renewable Heat Incentives

Technology	Scale	Tariff level (p/kWh)	Tariff lifetime (years)
Small Scale			
Solid bio-mass	Up to 45 kW	9	15
Biodiesel	Up to 45 kW	6.5	15
Ground source heat pump	Up to 45 kW	7	23
Air source heat pump	Up to 45 kW	7.5	18
Solar thermal	Up to 20 kW	18	20
Medium Scale			
Solid bio-mass	45-500 kW	6.5	15
Ground source heat pump	45-350 kW	5.5	20
Air source heat pump	45-350 kW	2	20
Solar thermal	20-100 kW	17	20
Large Scale			
Solid bio-mass	500 kW+	1.6-2.5	15
Ground source heat pump	350 kW+	1.5	20

Source: Carbon Trust, 2011

Application for Lichfield Cathedral

The application of zero carbon energy supply technologies were discussed in an interview with Archdeacon Lily of Lichfield Cathedral. According to Liley (2010), the CoE recommends energy efficiency as a priority and zero carbon technologies are only considered after the other measures have been implemented. Due to the location of Lichfield cathedral, the renewable technologies applicable to the cathedral are quite limited although their potential use has been discussed.

Wind turbines were ruled out mainly due to the urban location of the cathedral which presented challenges with regards to turbulence from surrounding buildings, the associated noise pollution and their aesthetic appearance. In addition, initial study was carried out for potential use of ground heat pumps but it was deemed unfeasible due to high installation cost and inconclusive results on its potential advantages for the cathedral (Liley, 2010). Solar panels were also ruled out because it would be impossible to get the necessary permission for their installation.

Bio-mass boilers could be considered for future use in Lichfield cathedral. The boilers for the cathedral were replaced recently so it could only be an option when they need to be replaced. However, as discussed with the archdeacon, installing bio-mass boilers has its own challenges for Lichfield Cathedral. First of all, a local supplier must be available; otherwise, the carbon footprint of transporting the fuel may outweigh the potential savings. Moreover, delivery may be problematic due to limited space for vehicles to manoeuvre. Finally, the system requires regular maintenance and cleaning which may result in additional cost to the cathedral. In summary, similar to most other historic churches and cathedrals, the use of low and zero carbon technologies is not considered to be the most feasible option at this time. However, as the government provides more incentives and the market for these technologies expand, more of such technologies will be gradually introduced into the CoE buildings.

5.11 Discussion

5.11.1 Overview

Historic churches and cathedrals are an invaluable part of the UK's cultural heritage and must be preserved for the future generations. As discussed in chapter 3, the CoE launched an environmental campaign, called Shrinking the Footprint (StF), in 2006 to reduce the carbon footprint of its properties. Whilst the original target was achieving a 40% reduction by 2050, the target was modified to 80% reduction of CoE's carbon footprint by 2050 in order to be in line with the UK government targets. However, successful accomplishment of the set targets depends on a variety of factors and future social, environmental and financial uncertainties some of which are unique to the CoE.

5.11.2 Analysis of the StF Guidelines

Since the majority of historic churches and cathedrals in the UK belong to the CoE, the first step toward a sustainable energy strategy should be examining the feasibility and effectiveness of the proposed StF guidelines in achieving 80% reduction in the carbon footprint of the CoE's properties. The specific data regarding the StF environmental campaign and the specific recommendations of its guideline document were provided in chapter 3. In general, the guidelines are designed to encourage the process of employing more energy efficient strategies; however, the progress made in each diocese with respect to reduction of energy consumption and carbon footprint varies depending on the actions undertaken in that area. In addition to the StF guidelines, some dioceses have conducted individual surveys to identify the best energy saving opportunities. For example, the diocese of Lichfield hired Marches Energy Agency (MEA) to carry out a survey of Lichfield Cathedral Close (LCC) and provide an assessment of energy saving opportunities for the LCC. It was estimated that if all the energy saving solutions outlined in the StF guidelines and additional measures proposed by independent parties (Carbon Trust and MEA) were implemented, savings of up to 17% in carbon emission could be achieved for the Lichfield Cathedral. The following observations are made with respect to shortcomings of the StF campaign in achieving an 80% carbon reduction:

Financial Issues: financial limitations appear to be one of the main obstacles in implementing the energy saving measures and there was a discussion on this subject in Chapter 4. As many churches and cathedrals are faced with financial problems to handle their daily activities, implementing energy efficient measures such as new boilers, changes in heating regime or major insulation work could be costly and each diocese has to provide a balance between the usual church expenses and contribution to the StF campaign.

Archdeacon Liley who serves as the Administrator for Lichfield Cathedral provided more specific details regarding the financial difficulties of the Lichfield diocese. According to Liley (2010), the annual cost of maintaining the diocese is about £16 million of which £1.2 million is spent solely on running the cathedral. Whilst the diocese encourages its parishioners to donate 5% of their annual income to the diocese, the current donation levels remain to be about 3%. As a result of financial difficulties, the budget for many programs has been significantly reduced; for instance, the music budget is currently £60,000 but it used to be about £300,000. In addition, the cathedral is going through certain restoration work which is estimated to cost £8 million. Although the majority of the renovation cost (£6.8 million) is supposed to be covered by funding from organisations such as Heritage Lottery, the diocese has to raise about £1.2 million through corporate or individual sponsors which is not an easy task. According to Liley (2010), the annual budget is only enough to cover the maintenance costs of the buildings and leaves no room for major improvements. Therefore, unless the CoE can find a way to relieve the financial pressures, the progress made towards achieving its carbon reduction targets will be limited. The CoE therefore needs to increase its income in order to help support the changes it is demanding from its dioceses and parishes. This could be achieved through either encouraging more people to go to church or more charitable contributions from its current congregations. Other options include increasing rental rates on its properties and raising the charges for services such as weddings and funerals. In any case, a thorough assessment of the CoE's funds should be carried out in order to establish the best way to improve its financial situation. Investigation into any possible grants, from either the government or organisations such as the Carbon Trust, should also be assessed to see if financial assistance can be obtained from other sources.

Conservation Related Issues: The second major obstacle for the CoE in achieving its carbon reduction target is the limited scope of work which can be undertaken on historic buildings. As explained in Chapter 2, historic structures in the UK which are considered to be of historic or architectural value become listed which considerably limits the scope of renovation for such structures. In addition, listed churches are exempt from strictly following the Part L of Building Regulations which covers the energy efficiency and carbon management. However, implementing energy saving measures is recognised in the in planning policy where it is explained that "*listing should not prevent sympathetic adaptation and innovative solutions* *may be appropriate providing the special interest of the building is protected*" (Planning and the Historic Environment, 2008). A detailed account of the difficulties which may arise due to conservation issues were provided in section 4.3. Moreover, the problems which may arise due to conservation issues for Lichfield Cathedral were discussed with the Cathedral Administrator and the main issues included:

- The conservationists object to replacement of the original single glazed windows with more thermally efficient double-glazed windows because it requires removing the original frames which is considered damaging to the historic nature of the building.
- Installing an under-floor heating system which is more energy efficient due to its radiant nature is opposed as it requires digging up the entire floor of the cathedral
- Application of renewable technologies such as *Photovoltaic (*PV) panels is contested as they have to be installed on the exterior of the building which affects the aesthetics of the cathedral

The difficulties arising from conservation issues severely impact the scope of work which can be done on historic churches and cathedrals; consequently, the ability of individual historic churches to achieve 80% reduction in carbon emissions is further limited by such constraints.

Scope and Application of the StF Guidelines: As indicated in Chapter 2, the final target of the StF campaign was raised from the original 40% carbon emissions reduction to 80% reduction by 2050. Despite this significant increase in the final target, the StF guidelines have not been updated to recognise this change or clarify how the CoE intends to reach this target. In addition, the sole responsibility of devising an energy plan is set on the shoulders of the clergymen who are in charge of running and maintaining the church. Therefore, necessary measures should be undertaken to assist the clergymen who are in charge of developing carbon reduction schemes for a particular church as they may not necessarily have the expertise to handle this complex task especially within historic churches where knowledge of the limitations and constraints of working in historic built environment is crucial in devising an effective strategy. Finally, although the CoE encourages all its parishes to actively participate in the StF campaign, no penalties are considered if the energy and carbon target are not met. Due to the financial difficulties that many parishes experience and lack of additional funding from the CoE, the environmental issues will arguably not be the main priority and this may further undermine the ability of the CoE to reach 80% carbon reduction by 2050.

5.11.3 Analysis of the Energy Reduction Hierarchy

Establishing a sustainable energy strategy for historic churches and cathedrals is a difficult process which is further complicated by the limited scope of refurbishment work and the financial difficulties of individual parishes to invest in energy saving measures. However, different churches should employ various energy reduction measures that suit the specific characteristic of that building. The documents and guidelines provided by the StF campaign provide a good starting point to initiate energy saving measures; however, as discussed in the previous section even if all such measures are successfully implemented, the potential savings are not sufficient to help the CoE reach its carbon target by 2050. For instance, the MEA (2006) estimated that if all the StF guidelines are implemented in Lichfield Cathedral, the maximum possible savings in carbon reduction would be about 17%.

Achieving 80% reduction in carbon emissions by 2050 is unlikely for historic churches and cathedrals due to limited scope of work and the financial difficulties which were discussed in this research. However, it is possible to make significant reductions in energy consumption and carbon emissions through a variety of energy saving measures. The energy reducing hierarchy proposed by the Carbon Trust (2011) appears to be the most effective approach in development of a road map for individual churches to follow and it consists of behavioural changes followed by technological solutions and low carbon technologies.

5.11.4 Behavioural Changes and Better Energy Management

The first stage of the energy reduction hierarchy is concerned with the behaviour of the people in charge of a building's daily activities and how to implement low cost measures to enhance energy management. As indicated in section 5.6, these low cost measures have the potential to reduce the overall energy consumption between 3 to 15% (MEA, 2006 & Carbon Trust, 2011).

5.11.5 Technological Solutions and Building Fabric Improvements

A great emphasis must be placed on the selection of the appropriate technological solutions and especially the heating regimes in any energy reduction plan. The potential energy and carbon savings of various heating methods were discussed in chapter 4. However, the most important factor in selection of a heating regime must be the current and future specific function of the church. The provided services, the opening hours and the number of church attendees have a significant impact on the overall energy use of the building but the StF guidelines fail to address this matter adequately.

The majority of the CoE churches, including Lichfield Cathedral, use convective heating systems such as central heating with radiators. As discussed in chapter 4, convective heating systems operate by heating the entire church which is very energy consuming especially for large churches and cathedrals with high ceilings and poor insulation. Therefore the use of radiant heating systems which tend to directly warm the people instead of the entire building could result in considerable energy savings. Under-floor heating and pew heating were discussed as two alternative radiant heating systems which have been successfully employed in various churches in the UK. However, the installation of under-floor heating systems is intrusive and requires major ground work which limits its application to the structures where conservation concerns do not pose a problem. Moreover, building fabric improvements such as roof insulation and improvement to windows can reduce the overall energy consumption of the building. In general, Space heating performs two important functions in church buildings:

- Thermal comfort for those who use the church for worship and community activities
- Preservation of the heritage fabric and its contents for future generations.

On the other hand, enhancing the building fabric could also improve the energy efficiency of the building although the scope of work for historic churches is limited and any refurbishment work should get the necessary permissions to ensure the historic fabric of the building is not damaged.

Recommendations for Technological Solutions and Fabric Improvements

In order to achieve higher energy reduction levels, switching to radiant heating methods is strongly recommended; under-floor heating has proved to be very effective in reducing the energy consumption and pew heating is the ideal option for smaller churches with intermittent services. However, the function of the church is the key element in determining the most suitable approach. For churches and cathedrals which are in regular use and attract daily visitors (such as Lichfield Cathedral), a central heating method is preferred to ensure the thermal comfort of the congregation and the visitors. If there are no conservation obstacles, the installation of an under-floor heating system can ensure the thermal comfort of the church goers whilst reducing the overall energy consumption although a cost-benefit analysis is required to ensure the long-term viability of this option for a specific church. However, if the floor cannot be altered, the efficiency of the available system should be enhanced by

- Servicing the boilers and checking the combustion efficiency
- Ensuring cleanness of flue-ways
- Upgrading boilers to condensing boilers

On the other hand, the churches that are used on an intermittent basis should switch to local heating methods to reduce their energy consumption. If the church has already installed pews, the pew heating system is an ideal energy efficient system; otherwise, local radiant heaters could be used to provide thermal comfort during the church services.

Moreover, the following recommendations are made for building fabric improvements:

- Check the roofs for condition and completeness of insulation
- Consider improving roof insulation during major repairs if the roof construction allows and there are no conservation concerns
- Check the current condition of windows, seals and closing mechanisms to minimize air leakage paths
- Consider high performance glazing for replacement
- Check seals around doors and replace or repair if necessary

5.11.6 *Cumulative effects of the all the modelled energy saving measures at Litchfield*

The following table has been prepared to demonstrate the potential consumption reductions of the discussed solutions for Lichfield Cathedral.

Table 5.19: Accumulative reduction levels

Accumulative Consumption Reduction Levels					
No	**Energy Solution**	**Description**	**Energy and Emission**		**Reduction**
0	**Base**	Actual Levels	Gas (kWh)	880,219	
			Electricity (kWh)	158,877	
1	**Energy Management**	Better energy management and awareness training	Gas (kWh)	823.004	6.5%
			Electricity (kWh)	148,549	6.5%
2	**Underfloor heating**	Installation of Under-floor heating system	Gas (kWh)	472,951	46.1%
			Electricity (kWh)	144,221	8.0%
3	**Improved Roof**	Providing roof insulation to improve the U-value	Gas (kWh)	662,924	24.7%
			Electricity (kWh)	148,120	6.3%
4	**Improved Windows**	Addition of internal secondary glazing	Gas (kWh)	850,991	3.2%
			Electricity (kWh)	148,120	6.3%
5	**Improved Air Tightness**	Improvements in overall air tightness of the building	Gas (kWh)	767,373	12.8%
			Electricity (kWh)	148,120	6.3%

As repeatedly explained in the thesis, the potential for making improvements varies according to a building's specific character. This is especially significant with respect to technological solutions and making changes in the heating system of a church. In case of Lichfield cathedral, the current heating system (central heating with radiators) remains the most suitable option although a simulation for under-floor heating was carried out to investigate the potential impact of the system. However, based on the simulations, significant savings are possible through better energy management and improvements to building's fabric. Based on the results demonstrated in the above table the following accumulative savings are possible:

Gas consumption = 47% reduction resulting in overall consumption of 466,516/880,219 kWh

Electricity = 12.8% reduction resulting in overall consumption of 138,540/158,877 kWh

Total energy consumption, therefore is 605,056 kWh compared to the actual 1,039,096 kWh which shows a 41.77% overall reduction in energy consumption.

This is still short of an 80% reduction desired by the CoE. However, more significant changes are possible for churches with fewer restrictions for improvements. In addition, in cases where application of low carbon energy supply technologies is welcomed and possible; the potential savings will be even higher. For instance, the IES model used in the Carbon Trust (2011) study on Notting Hill's church in London used a combination of energy management solutions, fabric improvements, pew heating installation and solar panels that resulted in overall energy savings of 91% for the model.

Chapter 6: Conclusion

The feasibility of various energy saving measures were examined using Lichfield Cathedral as a case study. The cathedral is a Grade I historic building which severely limits the scope of refurbishment work on the structure.

The energy saving measures were placed on a hierarchy which consisted of behavioural changes of both the staff and the occupants. This was followed by technological solutions and low carbon technologies.

The first set of energy reduction measures deals with low cost methods to increase the awareness and motivation of the staff and occupants. This includes employing smart metering and monitoring systems in order to enhance the energy efficiency. Moreover, awareness campaigns to educate the congregation on taking advantage of adaptive opportunities. Such low cost measures could be applied to almost all historic churches and help reducing the overall energy consumption between 3-15% depending on the church and the measures employed. In Lichfield cathedral it resulted in 6.5% reduction.

The second level of the hierarchy deals with technological solutions and building fabric improvements. An emphasis was placed on the various available heating regimes and their associated advantages and disadvantages with respect to energy use and carbon emissions. It was argued that radiant heating systems (under-floor, radiant heaters and pew heating) are more energy efficient since they warm the people directly in comparison to convective heating systems (central heating with radiators and warm air systems). Moreover, the selection of the heating regime was linked to the specific function of the church and it was recommended that small churches in intermittent use will benefit by using local radiant heating methods while the larger churches with regular use could benefit from under-floor heating as an alternative to convective heating methods. However, it was discussed that due to the historic nature of the cathedral; installing under-floor systems may not be permitted which is the case for many other historic churches or cathedrals.

Building fabric improvements such as insulating the roof or use of double-glazed windows reduced the associated U value of such elements and results in lower energy consumption. However, the limitations of work in historic environment apply and necessary permission shall be obtained before any changes are made to the fabric of the building.

Low carbon technologies shall be considered after the first two set of measures (behavioural and technological) have been exhausted due to the high level of investment required. Finally, an analysis of the StF guidelines and the energy saving hierarchy and their feasibility in the historic environment were discussed in this chapter. It was concluded that although reaching 80% carbon reduction may not be realistic for historic churches and cathedrals, significant savings are possible for individual churches through implementing a combination of energy saving measures suitable for that particular church.

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