Low carbon heritage buildings

A user guide

Foreword

Yorkshire has a multitude of great heritage assets. We must find a way to conserve and renovate them in a low carbon manner, whilst still retaining their important heritage significance.

Traditionally constructed heritage buildings are often considered to be either too technically difficult to improve or too valuable to alter.

This guide, together with the companion case studies, aims to show that this isn't necessarily the case. It presents a process that can be used when balancing carbon reduction and heritage significance. I think it's a very important publication.

Cllr Arthur Barker

Councillor Arthur Barker

Low carbon heritage buildings

A user guide

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Introduction

Although nearly three years have passed since the Climate Change Act 2008 was enacted, very little comprehensive refurbishment work has been undertaken to enable the UK's existing buildings to contribute to carbon reduction. It has been estimated that around 80% (UK-GBC, 2008) of existing buildings will still be in use in 2050. This places an increased expectation on the carbon emissions performance of existing buildings.

Buildings broadly account for around 40% of all UK carbon emissions and so existing buildings must improve their performance to make their due contribution to these statutory carbon reduction targets. Heritage buildings also have a significant contribution to make to these emissions reductions. They are often poor performers in terms of energy and are possibly the group that has previously been given the least attention due to the difficult nature of achieving savings.

That heritage buildings are worthy of the effort needed to reduce their emissions is undeniable. The government believes "that the historic environment is an asset of enormous cultural, social, economic and environmental value. It makes a very real contribution to our quality of life and the quality of our places" (HM Government, 2010). They also represent a significant asset in terms of the energy and emissions embodied in their construction. In 2000 the manufacture and transport of building materials accounted for more than 10 per cent of UK carbon dioxide emissions (English Heritage, 2007) and the continued use of historic buildings can only help to reduce this.

This guide, funded by the Yorkshire and Humber Improvement and Efficiency Partnership, aims to show that, while every heritage asset presents a unique and occasionally difficult challenge, much can be achieved with a methodical, structured and thorough approach. By clarifying the steps involved in the process, it is hoped that owners and operators of heritage assets will see the issue of emissions reductions in their buildings, not as an insurmountable problem, but as a series of well understood processes that must be progressed.

This guide is designed to be used by all groups and individuals involved in the historic building environment. It is hoped the target audience of local authority professionals, architects, planners, home owners and developers will use the guide to bring their approach towards heritage and low carbon together. It can be read in conjunction with a sister document providing five case studies of buildings that have undergone the process outlined here. These case studies show the expected outputs from each stage and highlight the types of interventions that might be possible along with their approximate costs and carbon savings.

80%

of existing buildings will still be in use in 2050

40%

of all UK carbon emissions are from buildings

Manningham Mills, Bradford © Arup

Overview

It should be recognised from the outset that very few historic buildings will be able to achieve the thermal performance standards required of new buildings. Many may not be able to meet the 80% reduction target in the Climate Change Act (2008) but they can generally be made to perform much more effectively than they do now. Indeed, historic buildings have already been adapted in many different ways, decade by decade, since they were built. Their longevity is partly a testament to this.

Undeniably, the challenge can be difficult at times but this should not stop us from investigating the problem and taking advantage of potentially undiscovered simple solutions. Often the most difficult step is deciding to act in the first place.

The aim of this guidance is to take the reader through the process of understanding a heritage building and acting to reduce its emissions. This guide is split into two sections, as shown below. Each of the chapters within the two sections provides detail on a specific aspect, but it is important to understand the overall process.

It is critical to the success of any energy reduction program to first understand the building. This step is often overlooked or not carried out in sufficient depth. Time and effort spent here will be rewarded by more carefully targeted interventions that maximise the opportunities for carbon reduction whilst minimising the impact on the heritage significance and complementing the building's construction and condition.

Many buildings may not be able to meet the 80% reduction target in the Climate Change Act (2008), but they can generally be made to perform much more effectively than they do now.

Review

- What are the significant features?
- What is the condition of the building?
- How is the building being used?
- How is the building constructed?

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- Bill analysis and benchmarking
- Temporary sub-metering
- Permanent sub-metering
- Supplementary techniques

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Choosing your interventions

- Behaviour change
- Building fabric improvements
- Building services upgrades
- Low and zero carbon technologies

Review the building

The first step in any investigation is to assemble a team of people who can contribute to the various technical aspects of the work, starting with reviewing the significance, condition, use and construction of the building. These processes are not covered in detail in this guidance as they are relatively well defined elsewhere.

There are a number of general and specialist survey books (e.g. Oxley, 2003) available on the RICS website (www.rics.org). The Chartered Institute of Building Services Engineers also provides useful guidance (CIBSE, 2002 and CIBSE, 2008a). With regard to Heritage Statements, publications such as 'PPS5 Practice Guide (CLG, 2010 & English Heritage, 2010), 'Conservation Principles' and 'Understanding Historic Buildings' (both English Heritage 2008) provide an overview of the approach required. It is also worth consulting the Institute of Historic Building Conservation whose HESPR database contains details of Historic Environment Service Providers.

Examples of these early steps can be seen in the case study document accompanying this guidance where condition surveys and heritage assessments have been carried out on five buildings.

The aspect of this stage that is less well defined is understanding how the building is used. By recording usage patterns, occupancy and common practices relating to energy consumption, an insight can be gained into where changes to the operation of the building and the behaviour of the occupants might yield savings.

Significant carbon savings can be realised simply by changing the way the building is operated.

Investigate the building

Once the building has been reviewed and the starting point determined, more in-depth investigations can be carried out. This is the focus of the first section of this guidance.

Analysing the energy bills, particularly over an extended period of time, will provide a high level understanding of the source of the building's emissions and how the building performs against comparable ones of the same type leading to more carefully targeted and ultimately successful interventions.

Further depth of understanding can be gained from sub-metering, either permanently or temporarily, and there are various miscellaneous techniques that can give further insight into consumption patterns.

The amount of investigation that is carried out will depend on the scale of the building, but once this work has been carried out the building owner will understand how energy is being used and where it is being wasted. This knowledge will allow interventions to be targeted to where they will have the greatest effect.

Choosing your interventions

The second section of this guidance concentrates on how best to reduce the emissions of a building. The results of the early investigations may point towards a particular area of the building that would benefit from attention but it is important to not forget the basics.

Significant carbon savings can be realised simply by changing the way the building is used. A person can very easily change their behaviour in the short term. To make that new behaviour into an unconscious consideration of energy in everything they do is much harder. However, the benefits are worth it and are more important in heritage buildings due to their inherently more inefficient fabric and systems and the fact that changing behaviour also has zero impact on heritage significance.

Only then should attention be turned to the actual building, with interventions based around the fabric, systems and energy supply.

Planning context

Planning Policy Statement 5 (Planning for the Historic Environment) was released in March 2010. It sets out the national government's planning policy on the historic environment. The general content of this policy is likely to be transferred into the National Planning Policy Framework and was included in the draft which is out for consultation in 2011.

The Planning Policy Statement (PPS) is relevant to all 'heritage assets'. The definition of a heritage asset is:

'a building, monument, site, place, area or landscape positively identified as having a degree of significance meriting consideration in planning decisions. Heritage assets (as defined in this PPS) and assets identified by the local planning authority during the process of decision-making or through the plan-making process (including local listing).'

The term is therefore all-encompassing, covering both designated assets, such as listed buildings and conservation areas, and non-designated assets, such as those on a local list of heritage buildings.

Policy HE1 (Heritage Assets and Climate Change) in PPS5 highlights that:

'Local planning authorities should identify opportunities to mitigate, and adapt to, the effects of climate change when devising policies and making decisions relating to heritage assets by seeking the reuse and, where appropriate, the modification of heritage assets so as to reduce carbon emissions and secure sustainable development.'

However, whilst the PPS recognises that improving sustainability is important, this needs to be balanced against the need to conserve the significance of the heritage assets and their settings. It states:

'the public benefit of mitigating the effects of climate change should be weighed against any harm to the significance of the asset'.

This requires Local Planning Authorities to work with developers to:

'identify feasible solutions that deliver similar climate change mitigation, but with less or no harm to the significance of the heritage asset and its setting'.

PPS5 defines significance as "the value of a heritage asset to this and future generations because of its heritage interest. That interest may be archaeological, architectural, artistic or historic."

Therefore the type of works proposed to improve the energy efficiency of a heritage asset should both conserve its significance and be effective in carbon mitigation terms.

Early engagement with the Local Planning Authority will be critical to explain the rationale for the proposed works.

A planning application is likely to be required for alterations to the external appearance of heritage assets. Tighter restrictions apply to buildings within conservation areas, including the need for Conservation Area Consent for certain types of demolition. Listed Building Consent will be required for any internal or external alterations to listed buildings.

When submitting a planning application that affects a heritage asset (including its setting) a Heritage Statement must be produced, as set out in Policy HE6 of the PPS. The Heritage Statement should be made up of three parts:

- Assessment of significance
  - Description of significance of heritage asset
  - Contribution of setting to that significance
  - List of sources/expertise consulted
- Assessment of impact on significance
  - Heritage Impact Assessment
- Justification for works
  - Why are the works necessary to support continued use of asset?
  - What will be the benefits in climate change mitigation terms?
  - What other options have been considered and why have they been discounted?

Early engagement with the Local Planning Authority will be critical to explain the rationale for the works, to consider possible alternative solutions and to understand the level of information required for the application. Any decisions will need to be informed by the Local Planning Authority and the local heritage specialists

It is important that the extent of the carbon emissions reductions required from the entirety of the nation's building stock is appreciated and emphasised when interventions are being considered. It is vital that existing heritage assets are retained and remain viable for continued use. This means that interventions to produce carbon reductions must, in some circumstances, be allowed. Cost-benefit analyses and heritage impact assessments are the key tools that must be used to determine the suitability of interventions.

Section 1

Investigate the building

Approach

Bill analysis and benchmarking

Temporary sub-metering

Permanent sub-metering

Supplementary techniques

Approach

The energy performance of historic buildings is generally poor compared to modern buildings. The energy costs are consequently higher and these are expected to continue rising. On the one hand, historic buildings have many attractive features making building users more tolerant to some of their shortcomings. On the other, they are less attractive to organisations aiming to satisfy their Corporate Social Responsibility (CSR) and Carbon Reduction Commitment (CRC) targets through the use of energy efficient buildings.

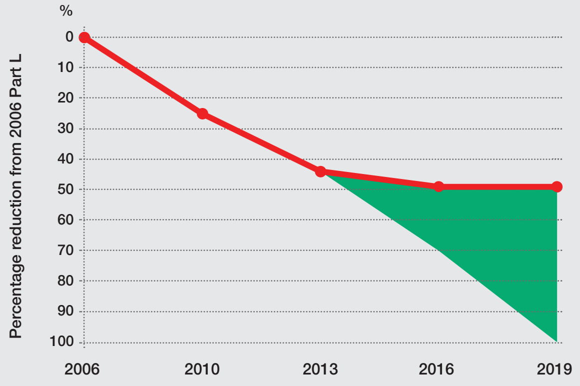
The current drive to energy efficiency in new buildings will lead to new buildings approaching zero carbon for regulated energy from 2019 onwards. The graph shows one proposed trajectory (CLG 2009) towards 2019. The line shows the expected reduction under current definitions, with the green wedge showing the additional contribution proposed to be required from off-site 'allowable solutions'.

However, new buildings constitute a small proportion of the existing building stock. It is estimated that approximately 80% of the building stock in 2050 has already been built. The existing buildings will need to perform efficiently and improvements made in their energy performance if they are to continue to be retained and used. This imbalance can be addressed through a programme of retrofitting historic buildings to become more energy efficient.

In assessing proposals to refurbish a heritage asset, designated or undesignated, the local authority should take into account the desirability of sustaining and enhancing the significance of heritage assets and their settings.

The current drive to energy efficiency in new buildings will lead to new buildings approaching zero carbon for regulated energy from 2019 onwards.

ONE PROPOSED ROUTE TO ZERO CARBON NON-DOMESTIC BUILDINGS



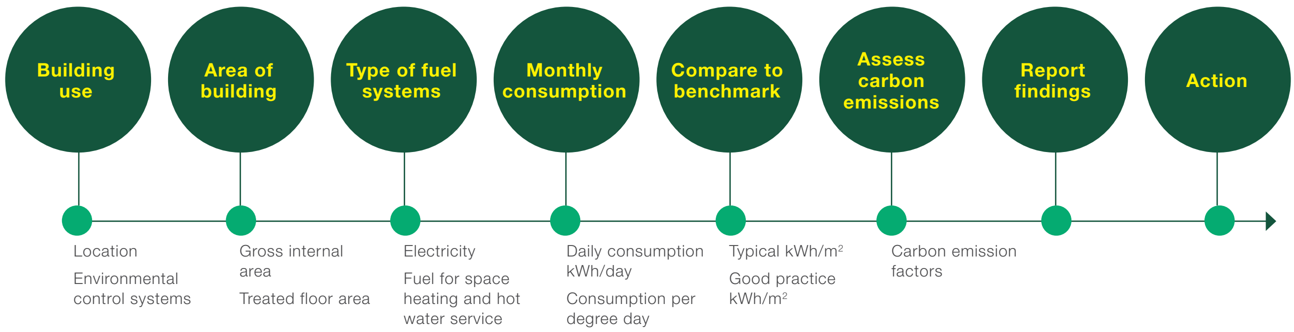
Renovating historic buildings therefore requires a different approach to modern buildings. A low carbon retrofit of a listed building where both the internal and external elements are protected presents further challenges. The key to a successful low carbon retrofit is to obtain a good understanding of the building characteristics before starting any refurbishment. Historic buildings are constructed to be breathable with high levels of ventilation due to the original coal heating systems with their requirement for high ventilation rates. However, conversely, modern buildings served by central heating systems and built with cavity walls, often work more efficiently when they operate as sealed buildings.

This guidance provides generic advice on low carbon interventions to heritage assets. The guidance can be applied to historic buildings and should be read in conjunction with that from other bodies such as English Heritage (English Heritage, 2010).

Process overview

Energy consumption patterns vary in all buildings. Energy consumption depends on various factors including how the occupants use and operate the building, its location, the type of construction, the systems within the building and their operation. The work needed can vary depending on the level of information available and the depth of study required. An important step within the overall process of reducing the emissions of a heritage asset is the understanding of energy consumption and one route to this understanding is shown below.

The route to understanding your building's emissions



The starting point for reviewing consumption is to be aware of the energy that the building is using and how this compares to benchmarks for similar buildings, reflecting its age, thermal characteristics and patterns of use. Benchmarks for comparison should be appropriate and tailored to the specific factors affecting the building and its use. It is in this that difficulties can lie.

Often benchmarks are not ideal, being for buildings of different ages, occupancy patterns, locations etc. It is here where a more in-depth understanding of the potential effects of these differences can lead to a better comparison with the (potentially adjusted) benchmark figures.

Energy consumption is reviewed on a per area basis. This allows comparison between different buildings of various sizes. The area used needs to be measured accurately and consistently, preferably from scale drawings. A common feature of historic buildings is the absence of accurate drawing records. In this case, it is advisable to procure a dimensional survey of the building from a survey company. The Royal Institute of Chartered Surveyors (RICS) publishes guidance on measuring floor areas in buildings (RICS, 2007). The Gross Internal Area (GIA) and Treated Floor Area (TFA) are commonly used to assess energy consumption.

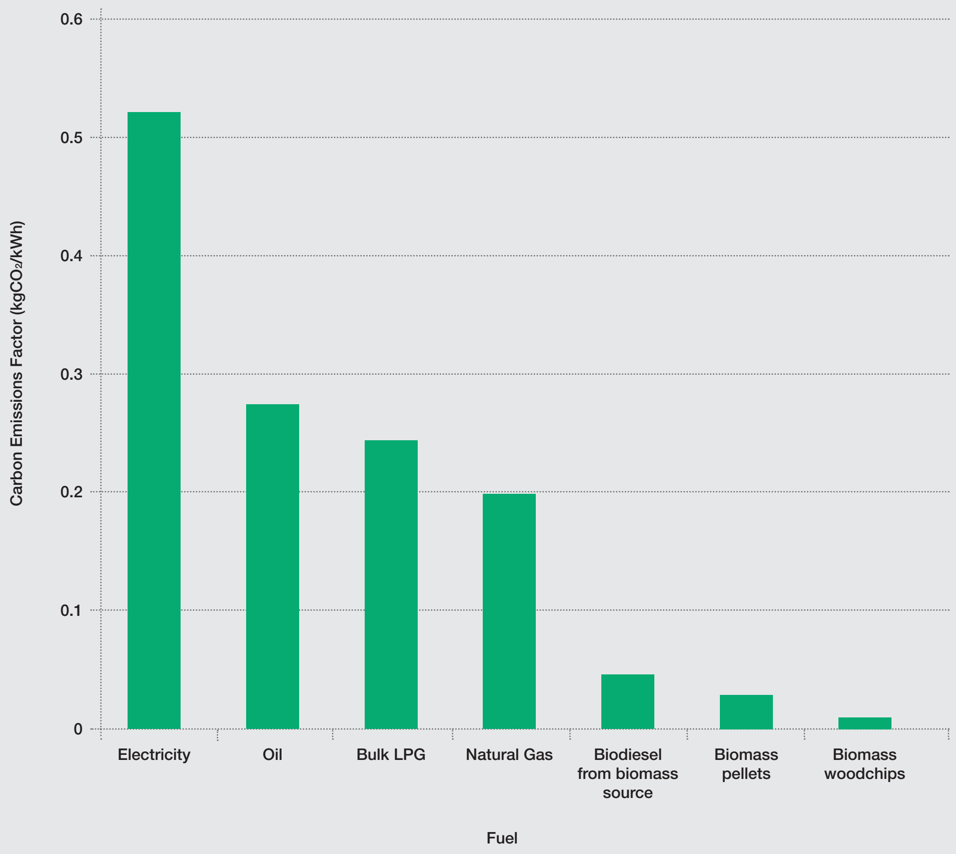
The next step is to identify the energy use in the building, typically subdivided as electricity for power and lighting and fuel for heating and domestic hot water. Monthly, quarterly or annual consumption figures can then be compared to benchmarks.

An alternative to examining the energy consumption of the building is to convert the energy figures into a measure of the carbon emissions of the building.

The energy is supplied in the form of a fuel which has a carbon emission factor attributed to it. This carbon factor specifies the amount of carbon dioxide that is released into the atmosphere when that particular fuel delivers 1kWh of energy ($kgCO_2/kWh$). The current Government standard figures for carbon emissions factors are listed in SAP2009 (DECC, 2010), a selection of which are shown in the graph below.

Alternatively, the Carbon Trust has a Carbon Footprint Calculator on its website that can be used as an alternative route to calculating the emissions from a building or organisation.

CARBON EMISSION FACTORS



Bill analysis and benchmarking

Benchmarking is used to assess whether energy consumption is better or worse than typical buildings of similar use. The Chartered Institute of Building Services Engineers (CIBSE) publishes energy consumption benchmarks for different buildings (CIBSE, 2004 and CIBSE 2008b). Typical and Good Practice targets are provided but there are no specific benchmarks for heritage buildings. Newly built buildings are expected to perform better than good practice benchmarks, while all buildings should perform better than typical benchmarks. Buildings that currently perform worse than typical benchmarks have a significant potential for energy reduction.

Buildings that currently perform worse than typical benchmarks have a high opportunity for energy reduction.

Bill analysis is a systematic method of reviewing energy use and comparing energy consumption with benchmarks. The process includes the following steps:

- Collect monthly energy data from utility bills or manual meter readings covering at least a year and establish an average daily consumption for each fuel system.
- Plot graphs of average monthly consumption for each fuel. Errors or significant changes in energy consumption will be evident from the graph. The graph shows periods of low and high consumption. The gas profile, in buildings with gas fired heating systems, shows a wider variation compared to electricity.
- Review annual consumption data with other years to identity whether the building is being operated more efficiently or otherwise.
- Divide the energy consumption figures by the floor area to allow comparison with benchmarks without the building size distorting the results.
- Convert fuel consumption in kWh/m^2 to carbon dioxide emissions ($kgCO_2/m^2$) using carbon emission factors.
- Compare the building with energy consumption and emissions benchmarks. Buildings exceeding typical benchmarks show the greatest opportunity for energy savings.

Specialist packages are available to make energy analysis easier and more repeatable, an example of which is the CIBSE TM22 (CIBSE, 2006) methodology.

When comparing the building to benchmarks, it is important to consider whether the system is providing an acceptably comfortable environment. For example, if the heating system is not operational, or failing to achieve the desired comfort levels, bill analysis could erroneously indicate the building as operating very efficiently leading to the cause of poor performance not being addressed.

The usage of the building needs identifying so that its energy consumption is compared to the relevant class of buildings. Assessing the building use might also include establishing the proportion of building using different temperature control systems e.g. air conditioning, comfort cooling or natural ventilation. The building use and environmental systems are used to develop a benchmark for comparing energy consumption.

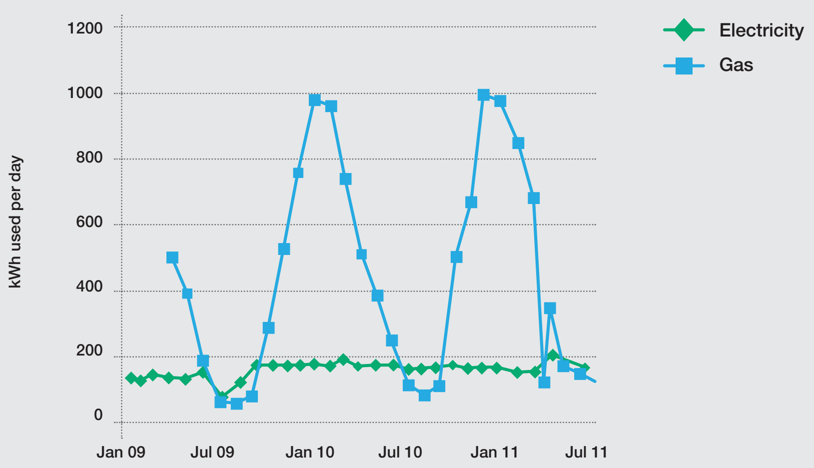
Changes to the building operation should be noted as they affect energy usage. For example, it is expected that the electricity consumption will decrease while heating may increase following installation of energy efficient computer equipment or lighting systems. Changes to the environmental systems, e.g. changing from an electric heating systems to gas fired heating systems, should also be identified.

Plotting graphs of consumption such as that shown here allows a review of the seasonal variations of heating fuel consumption to be carried out. In addition, Heating Degree Days could be used to assess the seasonal variation in energy consumption. Both approaches give an indication of heating performance and are used to identify the heating base load for a building. Heating Degree Days are a measure of the severity and duration of cold weather. (Carbon Trust, 2010)

A high heating base load could indicate all-year heating for close control systems or high domestic hot water demand. Conversely a low base load indicates the heating system is only operational in winter.

Changes to building use or systems should be kept in mind when analysing data over a number of years.

HISTORIC ENERGY USE OF MERCER GALLERY, HARROGATE



Temporary sub-metering

Sub-meters allow a more detailed assessment of energy end use.

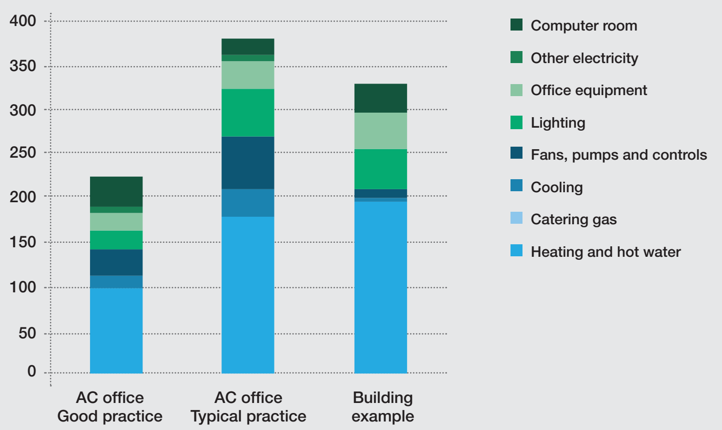
Analysing energy bills will only allow an understanding of how the building is performing as a whole. In all but the smallest buildings, this may not provide enough detail to identify where or when more energy is being used than necessary. This should be identified prior to undertaking refurbishment to reduce energy consumption to allow more targeted interventions. Sub-meters allow this more detailed assessment of energy end use.

Permanent sub-meters are generally not installed in historic buildings, as these have only recently become more widely used. It will therefore be necessary to install temporary sub-meters to measure energy consumption and possibly data loggers to measure the resultant environmental conditions. Clip-on or ultrasonic type sub-meters are available to avoid disruptions to the existing heating installations. For electrical services clip-on transducers or flexible transformers can be used to measure energy use.

Measuring energy consumption and, in the case of heating systems, the external conditions and the resulting internal temperature and relative humidity (where appropriate) allows the building energy consumption to be compared more accurately with benchmarks. However, it must be said that benchmarks split by energy use only exist for some more common building types.

The performance of the environmental plant (e.g. heating or cooling plant) should be investigated as part of assessing energy performance. For example, if room temperatures regularly exceed the target room temperature in winter then reducing the target room temperature will decrease heating energy consumption. Following a period of monitoring the room temperature, analysing the resulting energy consumption will give a true indication of actual energy consumption for the building.

BUILDING END USE CONSUMPTION COMPARED WITH BENCHMARKS



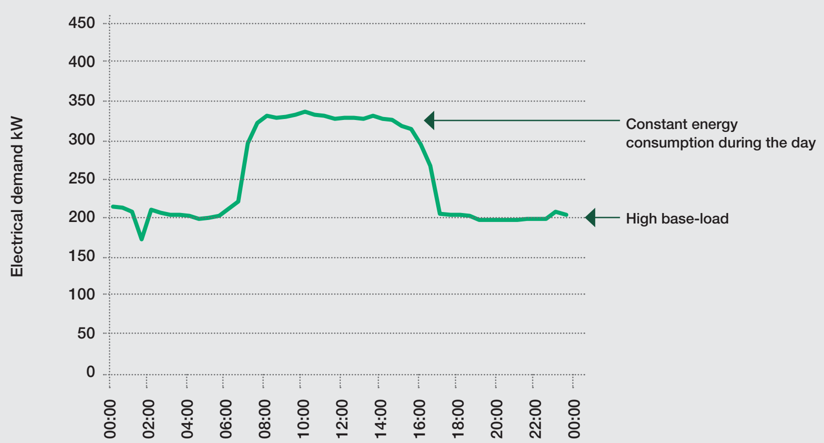
With regard to electricity, a TM22 analysis should be used to analyse the collated data to establish the end uses. A breakdown of the energy end use of the building can then be compared with good practice and typical energy consumption benchmarks. Energy saving can be readily achieved by ensuring individual end usage is less than good practice. Services that currently exceed typical practice should be targeted first.

In addition to temporary sub-meters providing more information on where energy is being used, it can also help with understanding when it is being used. This is often termed 'real-time monitoring'. The frequency of the data points can be set to give the most appropriate balance of resolution and the size of output files.

The daily profile of energy can provide insight into potential savings. Perhaps the heating system is activating too early in the morning, staying on later at night or coming on at the weekend. Once the issue has been identified, it is a simple and cheap process to alter the control settings to avoid wastage.

One of the most important parameters to interrogate with real-time monitoring is the base-load. This is the amount of energy being used when the building is not occupied. Many buildings have systems that need to run constantly, from security lighting to computer server rooms and the fabric of many historic buildings might benefit from constant low-level heat as opposed to frequent large temperature variations. Many are completely necessary but could form a focus for energy saving initiatives as their constant operation means savings will be maximised. There are often addition items that are running constantly that have gone unnoticed, from ventilation fans and display lighting to tea urns. Once again, it is usually a simple intervention to avoid this wastage.

GRAPH SHOWING REAL TIME ENERGY MONITORING FIGURES



Permanent sub-metering

As discussed in the previous section, the sub metering of energy use is important to establishing how much energy is used by the various systems serving different parts of the buildings, and to influence changes to user behaviour that will result in a measurable reduction in energy use. In smaller or domestic buildings, the long-term use of the techniques discussed as 'temporary' sub-metering may well provide a convenient way to understand long term energy use trends. However, in larger buildings or organisations, the installation of permanent sub-meters may be appropriate.

The reduction in energy consumption will be achieved through publicly displaying information, empowering individuals to change behaviour.

A reduction in energy consumption can be achieved through publicly displaying information to empower individuals to change behaviour and reduce local energy consumption. Installing sub-meters should be undertaken as part of all future low carbon refurbishment works.

Energy consumption should be automatically collected and displayed in real-time, allowing trend and benchmarking analysis to be undertaken with the overall aim of encouraging behaviour change. An example of such an approach is an energy dashboard.

It is recommended a dashboard type display is available via the internet or publicly displayed in a prominent position for all users to see the overall results of behaviour change. Energy reduction competitions could ensure wider staff involvement and acceptance the changes need for a reduction in energy use.

Dashboard

Example of a live dashboard showing a building's energy consumption. © Lucid

Sub-metering should be installed to include:

- Sub meters on the heating system to accurately measure heating energy in individual tenant areas.

- Separate sub-meters for small power, lighting, IT and mechanical equipment circuits.

- Power supply to server rooms and cooling systems associated with server rooms to be sub metered separately from general office areas.

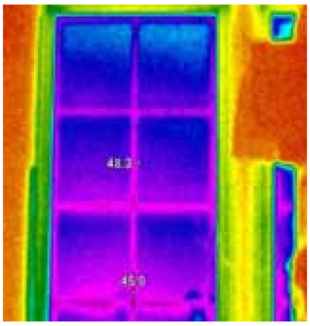
- The sub-metering of gas consumption to each gas boiler so actual consumption and heat generation can be correlated to monitor and maintain the boilers to ensure they are operating at peak operating conditions.

The installation of a dashboard has many advantages including:

- Benchmarking of energy consumption, identification of energy waste and as a basis for implementation of measures to reduce energy waste are the main benefits of installing sub meters and collating consumption data.
- Simple histograms of energy consumption on a daily or hourly basis allows trends, e.g. consumption, to be monitored against building occupancy.
- The information, particularly when display publicly, allows building users to review the impact of their actions on overall energy consumption. Comparing consumption in different buildings, and rewarding energy conscious consumption (e.g. by building wide competitions) will encourage energy reduction.
- Monitoring and target setting can be implemented to stimulate users into making improvements. The targets should be realistic and achievable. Continual monitoring will ensure savings achieved will be maintained.

Supplementary techniques

The following techniques are ways of looking into specific areas of energy loss or consumption. They are often chosen following the initial studies mentioned in the previous sections and vary in suitability depending on the scale or type of building. They are listed in an order they might be considered, from a quick low impact study to more intrusive or longer term investigations.



Heat loss

View from the inside, through this single glazing system the purple areas show the most heat loss through the metal frames.

Thermal imaging

Elements of the external envelope of the building such as roofs, walls, floors, windows, roof lights and doors tend to act as pathways or thermal bridges that allow the cold external environment to transfer to the interior of the building. This is particularly significant for buildings with solid walls such as most historic buildings. Simultaneously the warmer internal environment of building tends to transfer to the exterior. The combined effect is more rapid heat loss than in a well-insulated building with minimal cold bridging.

Thermal imaging using an infrared imaging camera enables visualisation of different surface temperatures which highlights the risk of thermal bridging. The images have different colours ranging from purple (coldest, maximum heat loss when view from inside) through blue, green and yellow to red (warmest, minimum heat loss) showing the range of thermal efficiency across the different elements of the building included in the photographs. This representation gives a strong impression of the weak points in the building fabric.

Thermal imaging identifies:

- Areas with poorly performing insulation particularly insulation that is not continuous.
- Zones suffering from high thermal bridging leading to uncontrolled heat loss and condensation. This is particular evident at wall/roof/floor junctions. This is avoided through careful detailing of the junctions to limit thermal bridging.
- Water ingress into the building fabric reducing its thermal resistance. Water ingress could be rain driven or rising damp. Damp brickwork provides a much more effective cold bridge than dry brickwork.
- Evidence of draughts through doors windows and doorways. The effectiveness of draught proofing measures can be assessed following the works using thermal imaging.

The image of the glazing systems above right highlight high heat loss through the single glazing system, the impact of highly conductive metal frames and the absence of the thermal breaks typical of most historic buildings before improvements to thermal performance of the windows.

Air pressurisation testing

A fan is temporarily set to measure how much air escapes from the building. The Air Tightness Testing and Measurement Association provides a method of air tightness testing. This gives an indication of air infiltration which is often the highest proportion of heat loss in historic buildings. It is also possible to use pressurisation in conjunction with smoke generation to give an indication of where the air leakage occurs.

Thermal modelling

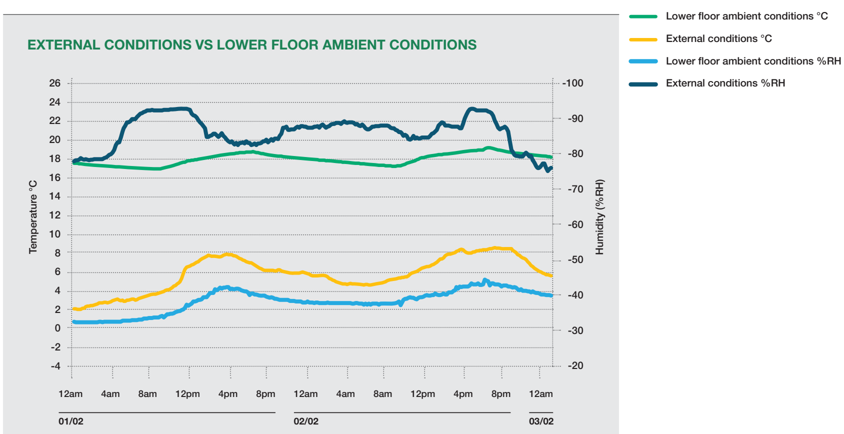
The current performance and the potential impact of interventions can be investigated using thermal models. A basic thermal model enables an initial estimate of energy losses through the various elements and routes. Indicative proportions of heat loss through the various elements can be established using basic thermal models providing a reasonable guide to the current, base performance of the building. Detailed thermal modelling using specialist software is used where greater accuracy is required. It should be noted that thermal modelling is a complex process which normally requires modelling specialists to model and interpret the results. As with any model, it tries to mimic the operation of the building. However, the calculations used can only be approximations of the real energy flow between different surfaces.

In situ U-value testing

This technique gives an accurate assessment of the thermal performance of the building structure e.g. walls. It should be carried out in winter and the equipment needs to be in place for a period of time. The measured U-values are not always comparable to calculated values, but in many cases they will be more accurate.

Environmental data logging

Monitoring the environmental performance is often undertaken in buildings housing valuable artefacts such as museums and art galleries. This involves monitoring and logging the temperature and relative humidity in interior spaces. This could include measurement of humidity within construction, surface temperatures etc. Data is recorded constantly and plotted against time to give a detailed profile of environmental conditions within the space and shows daily and seasonal fluctuations in detail.



Section 2

Choosing your interventions

Approach

Behaviour change

Fabric versus systems

Building fabric improvements

Building services upgrades

Low and zero carbon technologies

Approach

Building owners and their advisers should aim to understand the context, character and physical behaviour of historic buildings before trying to improve them to achieve a level of performance closer to modern standards. The internal conditions of historic buildings were originally determined by a number of factors including:

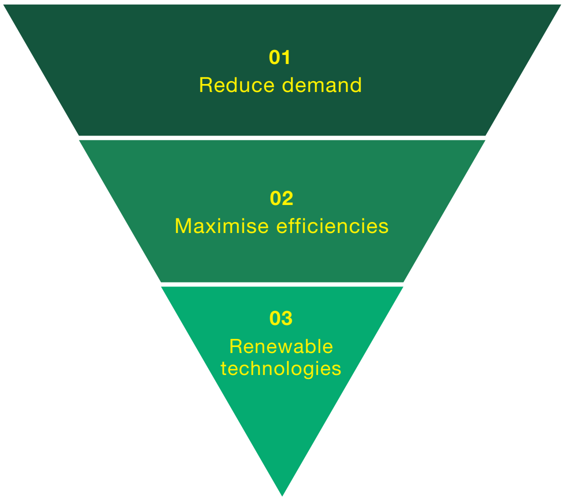
- Solid fuel was the primary heat source and required high levels of ventilation for effective operation. High construction tolerances and high infiltration rates were common.
- The construction allowed the building to breathe, ensuring that outward moisture transfer through the structure was balanced throughout the year with moisture ingress and evaporation.
- Many building users had more active lifestyles including manual labour and wore heavier clothing. Building occupants were more tolerant of poorer internal conditions as modern standards of comfort would have been considered a luxury enjoyed by a wealthy minority.
- Most remaining historic buildings are primarily of solid walled masonry construction including rubble-filled walls. Masonry provides good thermal mass and moderates the impact of external conditions.
- Many historic buildings have floor to ceiling heights of up to 4 metres allowing operation of the stack effect, a natural ventilation system by which warm, moist air rises and draws in fresh air.
- Internal heat gains were limited, mainly radiant energy from cooking stoves, fires and occupants. This is in contrast to the modern use of buildings which is characterised by high gains from various pieces of electrical equipment.

Masonry construction

Masonry provides good thermal mass and moderates the impact of external conditions.

There is a common misconception that a major part of reducing carbon emissions from buildings is through the generation of 'renewable' energy. In fact this should be the final stage of a best practice approach to refurbishment.

The key elements of the approach are show in the diagram in their order of importance working from the top downwards.



Buildings use energy at a rate dictated by how they are used. Reducing demand as a result of behaviour change can include organisational and process changes as well as individual efforts to reduce carbon emissions. Changing the behaviour of individuals and organisations can be difficult to achieve in the long run and the techniques needed can be unintuitive. However, the potential benefits for minimal financial investment and heritage impact make this step important.

Once demand has been minimised, the building fabric and systems should be improved to increase efficiency. However, the well-used adage of 'fabric first' needs to be applied with consideration to any architecturally significant features.

Following the increase in efficiencies, low carbon energy supplies can be introduced where practicable. Opportunities for sufficiently discreet measures may seem limited on listed buildings but the wide range of low carbon energy available means that there is often something suitable. It would be wasteful to use this 'renewable' energy without adopting the other measures as part of a holistic approach.

Reducing energy demand through behaviour change can involve organisational and process changes, as well as individual efforts to reduce carbon emissions.

The need to think of the whole building

Regardless of how much the emissions of a building are reduced, the building must continue to successfully perform as intended. A building's structure and fittings must perform many functions relating to providing a comfortable and healthy internal environment.

Elsewhere in this guide, the importance of approaching emissions and energy reduction as a complete process has been highlighted. It is also true that the building being addressed must be treated holistically, considering the fabric, services, usages and occupants as a complete system. In older buildings in particular, complex relationships often exist between these factors and it is important not to address one aspect without considering the impact on others.

One of the most complex interactions is around the need to consider the transfer of moisture and the provision of adequate ventilation following improvements to the fabric.

Historic buildings are generally draughty and leak air inwards and outwards through multiple routes from large chimney openings to fine cracks in plasterwork. In parallel, traditional construction allows solid walls to breathe by absorbing moisture from the air through traditional paints, plaster, brickwork, lime mortar and lime render. This moisture can, in some circumstances, pass through the wall to open air or can be reabsorbed internally when rooms are no longer occupied.

These 'natural' systems can easily be overturned as a result of initiatives to reduce energy consumption. Modern uses of buildings tend to generate more air-borne moisture. Insulating external walls and sealing air paths in historic buildings can prevent moisture from being dealt with effectively, perhaps resulting in condensation and mould growth although breathable materials such as lime mortars and plasters and natural insulation materials can be used. It is important to balance these changes reducing uncontrolled air leakage with a low-energy approach to providing adequate ventilation. For example, retain the ability to open some windows at least and use the requirement to ventilate chimney stacks as an opportunity to continue to make use of the building's traditional systems.

A holistic approach to building interventions is essential, with care being taken to examine the effects of changes on all building systems.

Heritage buildings are also often very thermally massive. This means that there is a lot of heavy material used in their construction which serves to dampen the effect of temperature changes. They are slow to heat up which can be an inconvenience in winter but can provide a cooler internal environment in summer.

The use of internal wall insulation can seem like the right solution for reducing heat loss but this insulating layer will reduce the effect of the thermal mass, meaning that the consequent effect on summertime temperatures should be considered, especially if restricted glazing areas lead to less-than-ideal ventilation levels. However, the ceilings, floors and internal walls may be providing a significant proportion of the thermal mass and will, of course, remain unaffected by treatments to the façade.

Differing usage patterns may also significantly affect the ideal mechanical systems. Buildings in intermittent usage such as churches and other community buildings will benefit from heating systems that are quick to respond, eliminating the need for long warm-up periods where the building is empty but energy is still being used. However, care should be taken to ensure that the rapid changes in temperature and humidity that this strategy will cause do not place the building fabric in danger of movement or moisture build up.

The heating system should also be considered when changes have been made to the building fabric. Is the system still appropriate and how will it cope with significantly lower loads? A mechanical system that is capable of providing more heat than is needed is not necessarily a problem, as long as it can be controlled. Increased controls on the heat supply or radiators may be needed to avoid overheating and excessive 'cycling' of internal temperatures.

Occupants will also need to learn to operate the building in a different way. If uncontrollable air leakage was previously unconsciously relied upon to provide sufficient fresh air, a building can quickly become stuffy and uncomfortable in winter if ventilation is not actively controlled.

Usage patterns

Buildings in intermittent use, such as churches and other community buildings, will benefit from heating systems that are quick to respond.


© Flickr

Behaviour change

Irrespective of the age or condition of a building, it is important to recognise that how buildings are managed and occupied greatly affects the amount of energy consumed. Opinions vary and there is limited data on this topic but for a building operated with an average approach to responsible energy use, it is not unreasonable to expect that beneficial behaviour can reduce energy consumption by up to 20%. These benefits could be even larger in heritage buildings.

Behaviour change can be effective at any scale, from an individual household to a large organisation. The exact approach varies depending on many factors, but the principles are consistent.

Here we have provided some key ideas to help you ensure building users behave in ways which maximise energy efficiency, sharing immediate steps (or 'Quick Wins'), as well as principles of a longer term change management approach that organisations should adopt to maximise user engagement and cooperation.

Positive occupant behaviour can reduce energy consumption by up to

20%

Quick wins

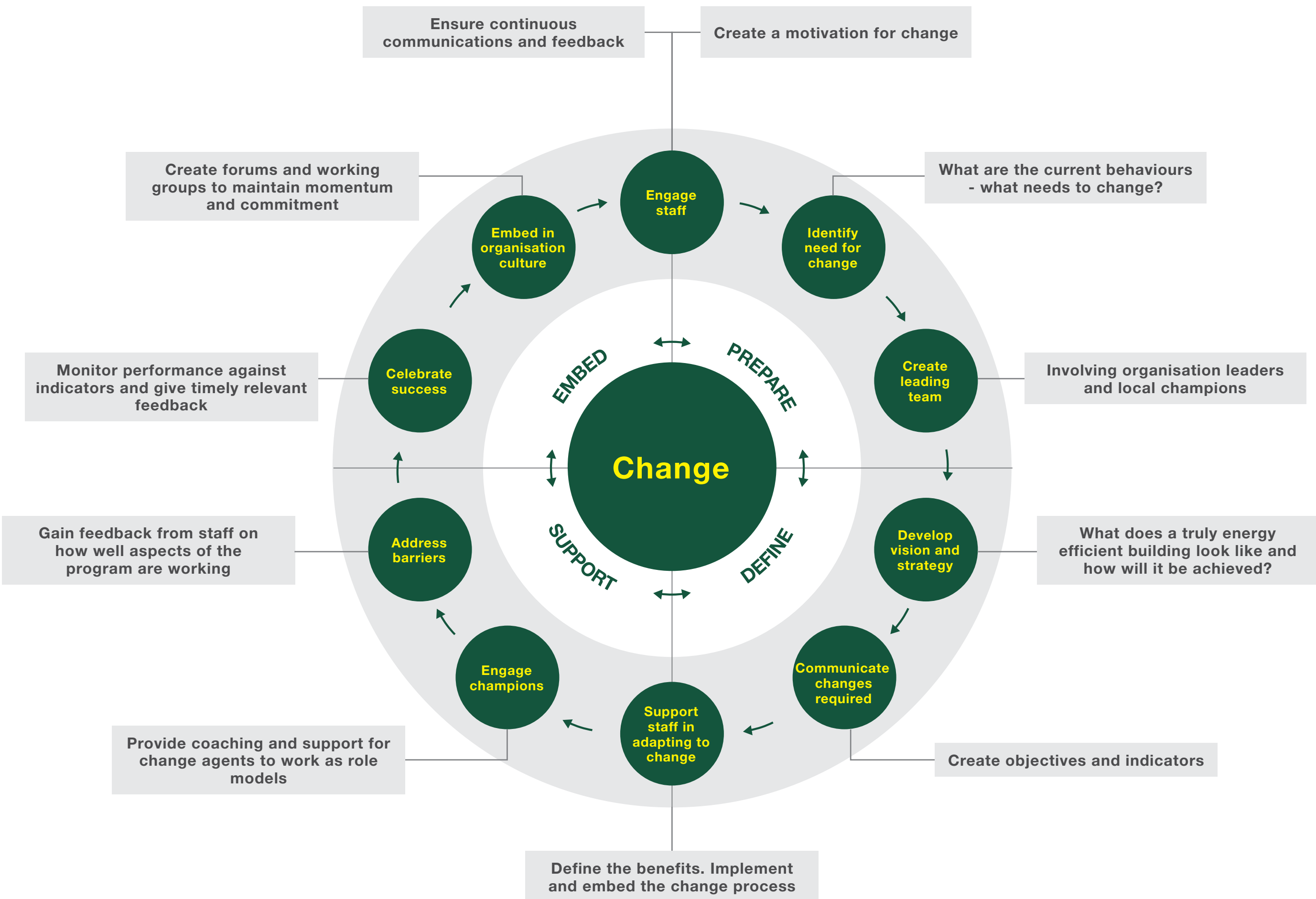
Individual domestic houses	Organisation
☑ Turn thermostat down by 1°C ☑ Reduce water cylinder temperature to 60°C ☑ Close curtains at dusk and check for draughts ☑ Turn off lights when leaving a room ☑ Don't leave appliances on standby ☑ Fill washing machine and dishwasher before using ☑ Only boil as much water as you need ☑ Fix leaking hot water taps ☑ Use energy saving light bulbs ☑ Do a home energy check	☑ Provide occupants with training on the most efficient way to operate the building ☑ Listen to why energy wasting behaviour exists; there will be a reason to overcome. ☑ Create a user guide to reinforce training ☑ Provide occupants with easy access to energy information ☑ Set everything to default to 'off' where possible ☑ Place information labels as a reminder ☑ Continually communicate the message of energy savings, highlighting the benefits ☑ Give timely, relevant and accurate feedback on energy saved ☑ Celebrate success and eliminate barriers

A change management process for energy efficiency behaviour

These actions are more appropriate for medium to large organisations. They have similar goals to the quick wins but are designed to affect change where energy use is more 'anonymous' and it is necessary to appeal to the collective group as well as individuals.

For domestic properties, extensive behaviour change should be driven by knowledge gathered from temporary sub-metering, using advice found on the Energy Saving Trust's website to reduce energy and emissions in the areas that are shown to be major contributors.

Taken individually, none of the steps below seem particularly important or revolutionary. It is when many of them are combined into an effective, sustained programme that real change can be made towards unconsciously energy efficient behaviour.



Fabric versus systems

We are used to investigating and implementing carbon reduction measures on relatively modern buildings. However, it is worth remembering that many heritage assets operate in a fundamentally different way and therefore need a different approach.

Many of the features and characteristics of historic buildings provided natural regulation of internal environmental conditions, balancing high thermal mass, lofty ceilings, low heat gains, moisture absorption, evaporation and ample natural ventilation. These characteristics can present challenges to successful retrofitting.

Measures that minimise the impact on significant historic building features are always preferable from a conservation perspective. Thoughtful design, coupled with an open-minded approach by all concerned, should enable the introduction of a range of measures that will significantly reduce carbon emissions.

The external façade establishes the building's character and major changes are unlikely to be acceptable. However, opportunities may exist in relation to secondary, rendered elevations. Internal insulation systems are likely to be more appropriate but require careful detailing and the application of appropriate materials. It is unlikely to be acceptable to replace historically or architecturally significant windows, but newer windows could be replaced in addition to other acceptable solutions to improve window performance. Draught proofing can make a major contribution to energy saving with minimal impact.

Improvements to airtightness and insulation measures that seal the building could very significantly reduce the ability to achieve natural ventilation. Measures to promote low energy ventilation and breathability should form part of the overall design strategy.

In buildings with sensitive historic interiors there may be a reluctance to consider certain fabric performance improvement measures. This could lead to a reliance on energy savings from upgrading building services plant to operate efficiently. This approach would reduce overall fuel consumption but it is a missed opportunity as the energy demand remains the same if the fabric performance is not upgraded. Extending this approach would lead to the implementation of low and zero carbon technologies without reducing energy demand. Whilst there are clearly greater limits on the scope for carbon emissions reductions in historic buildings, there are interventions that should make a significant difference and these are explored in more detail in the following sections of the guide. It is also important to bear in mind that continuing high energy bills could tend to make the building obsolete because of high operational costs compared with alternative buildings.

The nature of heritage buildings mean opportunities for fabric improvements are less, but it is still a vital step in carbon reduction that should not be overlooked.

Manningham Mills, Bradford © Arup

Building fabric improvements

Alterations to the building's fabric can often result in cheaper carbon savings than installing renewable energy.

The principal building elements should be graded of high, medium or low historical significance as part of a heritage assessment. This enables the development of appropriate refurbishment responses. Existing building elements of low significance are more likely to be able to be replaced with more efficient equivalents. More important historic elements can be approached with preservation in mind. Measures that are easily reversible are preferred, should relevant building technologies improve. Interventions that remove or lead to destruction of historic features are unlikely to be acceptable.

Successful low carbon retrofit requires the upgrade of both the building fabric and systems for control of the internal environment. Passive design should be used wherever possible. This aims to maintain occupants' comfort levels whilst minimising energy use by utilising free, natural sources of energy, such as the sun and wind, to provide heating, cooling, ventilation and lighting. Aspects of passive design can be classed as easy wins in reducing energy consumption to meet building regulations.

The following sections outline possible approaches to the improvement of building fabric, but the space available in this guide only permits some illustrative material. Building owners will need advice from a suitable range of experienced professionals in building heritage, architecture, engineering and surveying. For more detailed and comprehensive material the authors strongly recommend reference to the other publications referenced (such as English Heritage 2010, The Centre for Sustainable Energy and the Bath Preservation Trust 2011 and Carbon Trust 2007).

Air tightness

Historic buildings are leaky compared to modern designs resulting in a high infiltration rate. Infiltration is the uncontrolled ingress of external air into a conditioned (heated or cooled) space leading to an increased energy consumption being needed to maintain comfortable conditions. In most historic buildings infiltration provides the majority of external air for ventilation purposes. Similarly, conditioned air will escape from the building through the same pathways. The combined effect can account for up to 40% of heat loss from historic buildings. Improving air tightness is a particularly important carbon reduction measure but the following improvements require considerable care to achieve a successful result.

- Repairing windows and hardware so that they open and close properly
- Installing discreet draught strips to opening windows, doors and loft hatches
- Gap sealing around skirting boards, between floor boards, around windows, pipe entries, ducts and many other air routes
- Pointing, filling cracks in plaster and painting to seal the building envelope using appropriate materials
- Installing draught lobbies
- Replacing non-historically/architecturally significant windows and installing secondary glazing.

Whilst an improvement in air tightness will reduce energy consumption, it is imperative the consequences are addressed. A significance reduction in air tightness could potentially lead to an imbalance between moisture flow and evaporation from the building structure. In addition, the ventilation provision for cooking and supporting any boiler plant or localised direct-fired heaters should remain unchanged so that the safe operation of these systems is maintained.

Improving the airtightness of a building is often the cheapest way of reducing energy consumption.

Roof

The roofs of most historic buildings perform a key role in defining their character. Heat loss through roofs can be as much as 20% of the overall heat loss from unimproved buildings. Energy lost through the roof can be reduced by adding roof insulation and its application depends on the type of roof construction. Most historic buildings have pitched roofs and there is often scope for introducing insulation in the roof space. Roof leaks should be repaired and pipework in roof spaces should be overhauled in conjunction with any retrofit works.

The insulation can be installed above ceiling level in buildings with loft spaces. The insulation is applied between and over the roof joists in a cold roof. Most buildings should already have some loft insulation but it can be topped up. This is a cost effective solution with a choice of widely available installation materials.

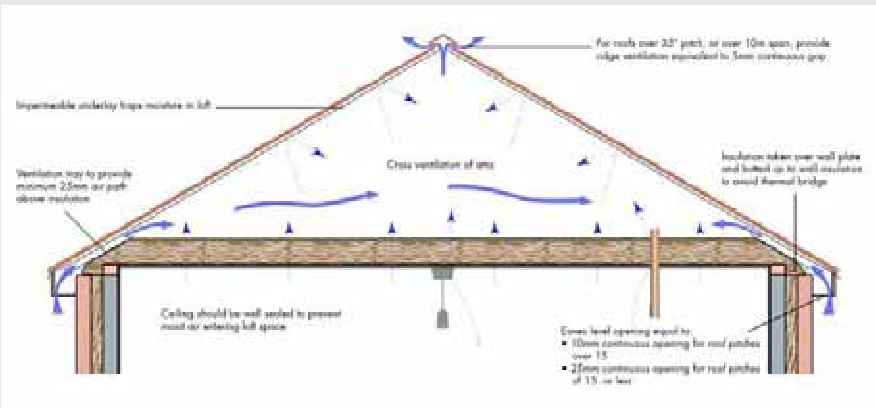
The recommended minimum depth of appropriate breathable materials such as mineral wool, glass wool or sheep's wool insulation is 270mm. Consideration should be given to exceed the minimum thickness, to give an element of future proofing. When installing insulation, there are a number of issues that must be taken into account.

Roof insulation

High levels of insulation can be applied to reduce heat loss.

VENTILATION

The roof void will be a cold space in winter and, if not well ventilated, moisture could lead to potentially serious problems of mould and rot.



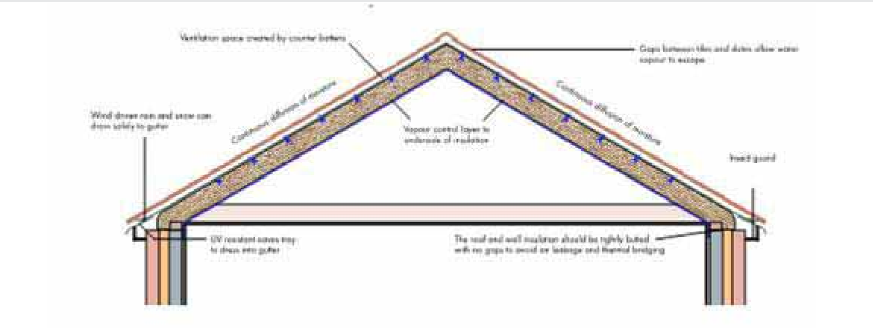
AVOIDING ASSOCIATED PROBLEMS

- Water tanks and pipework in the loft space must be insulated to avoid frost damage.
- The loft hatch must be insulated and provided with an effective draught-seal.
- Avoid penetrations through the ceiling. If these are unavoidable, carefully seal them.
- Thermal bridges can occur at gaps in the insulation and junctions with chimneys and external walls. Careful detailing is required to avoid condensation problems.

INSULATION PLACEMENT

Some historic buildings do not have a ceiling below roof level or the roof space forms attic rooms and it is appropriate to insulate at rafter rather than joist level. To insulate warm roofs of this type, semi-rigid insulation boards can be inserted between the rafters, ideally with a 50mm ventilation path between the roof finish and the new insulation but this can be difficult to achieve in older roof designs. To promote natural ventilation a breathable, natural material such as wood fibre or hemp batts is preferred.

Upgrading the thermal performance of flat roofs in historic buildings can be challenging as ceilings may be of significant importance, perhaps incorporating coffered plaster panels, ornate plaster mouldings and the use of traditional lath and plaster. In these circumstances insulating the roof when it is due to be re-covered is often likely to be the best approach with materials and detailing to suit the specific circumstances.



Walls

The majority of historic buildings, particularly in the North of England, have load bearing, solid masonry walls. These provide thermal stability and protection against external weather conditions but have poor thermal resistance and can be responsible for 30-40% of heat loss. Such walls can retain warmth in winter and delay the point at which rooms become overheated in summer. It is important to make use of the thermal mass of the building where possible to provide natural modulation of internal temperatures. However, if it is decided to insulate the interior face of external walls it should be remembered that the remaining exposed structural floors and masonry internal walls will still provide thermal mass.

Walls often make up the largest element of a building's fabric. Changes could be difficult, but may yield significant savings.

The walls also help to avoid the formation of condensation by absorbing and evaporating moisture, thereby balancing moisture transfer through the structure in a relatively complex process (English Heritage 2010).

Before considering altering the thermal properties of a building's walls, it is important to understand their construction method as seemingly similar walls can have significantly different build-ups that will affect how they will respond to treatment.

Approach to wall insulation

Externally applied insulation systems will generally be unacceptable because of the loss of historic features and the associated harm to the traditional character and appearance of a building. However, there may be scope to remove render from rear and secondary elevations and to replace it with an external wall insulation system. In such cases a breathable system such as wood fibre board or hemp finished with lime mortar and a porous paint should be utilised.

Internal insulation solutions need to be sensitive to the historic character of the internal spaces but can provide major improvements to thermal performance. Insulating the inner face of external walls raises some technical issues and challenges designers to produce an aesthetically satisfactory design solution in liaison with conservation advisers. Where there are few original features a greater depth of insulation might be applied which might achieve a standard close to current Building Regulations standards but it should be accepted that this will not always be possible. Decorative plasterwork to walls may rule out this solution but original decorative timber mouldings could be carefully removed and set aside for re-fixing once the insulation has been installed. .

Modern, impermeable insulation systems such as polyurethane foam have the advantage of high performance for minimal depth but are not appropriate for historic buildings because of the loss of breathability and the risk of consequential damage caused the build up of moisture in the structure There are new, high performance, very slender insulating materials such as Aerogel but it is very costly and is also impermeable. In these circumstances it is appropriate to consider the use of breathable, natural methods of insulation such as wood fibre board or hemp batts. Although the insulation is deeper in profile (perhaps 100mm to achieve a standard equivalent to polyurethane foam) some systems can be fixed directly to the wall surface and plastered, reducing overall depth.

VAPOUR BARRIERS AND THERMAL BRIDGING

Insulating the external walls can greatly improve thermal performance but walls are connected to other structural elements, particularly internal walls and brick or stone floors which will continue to act as a path or bridge for external colder temperature conditions. Where possible insulation systems should be returned along these elements to reduce the effects of the cold bridge created where they meet the exterior wall. Thermal bridging also occurs though window frames and this issue is discussed in the windows section of the guide.

It is important to consider the compatibility of the new materails with the old, particularly in relation to moisture transfer.

Floor insulation

The insulation strategy will depend on whether there is a basement or cellar and if it is to be cold or warm. The lowest heated floor should ideally be insulated. If this is a solid floor the treatment will depend on the material but it may not acceptable to take up historic floors. Should the replacement of a solid floor be feasible, the use of breathable materials such as limecrete should be considered. Careful and early advice and consultation is required. Suspended timber floors can be insulated between the joists but it is essential to maintain ventilation. (CSE/BPT 2011 and English Heritage 2010).

Windows

Single glazed windows are a prominent feature of historic buildings and are highly visible internally and externally. They are a sensitive conservation issue. From the introduction of technologically advanced sash windows onwards, buildings have tended to have more windows and larger areas of glazing. However, this approach relied heavily on low cost fuel as the windows caused major heat losses. Some of the issues include:

- Unless the building is very unusual, the largest proportion of the wall area is still masonry and apart from draught proofing, improving the thermal performance of windows will only have a restricted and subordinate impact on overall energy consumption.
- Historically or architecturally significant window frames and glazing such as leaded lights and crown glass will need to be preserved.
- Inappropriate modern windows should be replaced with carefully designed high performance replacements sympathetic to the building but this will be expensive.
- Slender glazing bars and frames in historic windows limit the potential replacement of later, modern panes with double glazed units.
- Window frames suffer from cold bridging and replacing the glazing will not solve this related heat loss and condensation problems.
- If retained, existing windows should be repaired, decorated and draught stripped to maximise the very great energy savings available from these measures. (English Heritage 2011).

Typical poorly maintained window frame to offices

Replacement glazing

The performance of existing single glazed windows can be improved by replacing the existing window panes with high performance double glazed units. The overall thickness of thermally efficient double glazing is typically 24mm. This would be unsuitable for most historic windows as there is insufficient depth to the glazing bars.

Double glazing with a krypton-filled cavity as low as 4mm is technically possible, but it is difficult to ensure that such units are sufficiently stable and gas tight to maintain their integrity and keep acceptable levels of thermal performance over the desired life of the glazing. Highly efficient vacuum glazing as slender as 6mm overall has been introduced but it is still extremely expensive.

In areas of lower significance, a balance may be achieved with slim-line units of 10-16mm providing a lower cost option to increasing thermal performance.

There are many options for improving the thermal performance of windows, depending on the nature and significance of existing installations.

Secondary glazing system

Secondary glazing has the advantage of being able to fill the entire window opening, with the potential to overcome the cold bridging issues particularly associated with steel window frames. It also provides draught proofing and can increase security.

Horizontal sliding secondary glazing systems are the most common type available on the market. The great majority of these are single glazed because of the weight of double glazed panels in relation to both installation and operation. Such windows are commonly provided in order to maintain the operation of existing opening lights and to reduce the visual impact of the secondary glazing installation. The mullions and transoms would be arranged to coincide with existing systems. Standards seem to be improving and the limited extra benefit from installing secondary double glazing may make this the most cost-effective solution. However, high performance secondary double glazing should be considered for historic buildings with unusually large areas of glazing.

The secondary double glazing system should permit access to open external windows when required for ventilation and maintenance although some windows not used for ventilation could have fixed, demountable panels to reduce costs. The heavy glazed panels may require opening lights to be mounted as a side-hung casement rather than sliding sash windows and this may restrict suitability for some buildings. Although the payback is relatively distant at current energy costs, these are expected to rise substantially and actual payback is likely to be considerably sooner.

In addition to these techniques, it should be remembered that the use of heavy curtains or well fitting shutters can approximately halve the heat loss through some types of windows (English Heritage, 2009)

Building services upgrades

Fabric upgrade is likely to involve a balance being struck between achieving the highest possible energy efficient retrofit and avoiding impact on the building's historic and architectural significance. Conversely building services systems suffer fewer constraints and can usually be upgraded to match solutions adopted for new buildings. However, it is challenging to install new services in historic buildings as they were not designed for the high level of servicing required in modern buildings. These constraints mean some systems and strategies cannot be employed. For example, a displacement ventilation system may be more efficient but there may not be enough space and it may be more appropriate to consider a less efficient system such as fan coil units that can be accommodated. This spatial restriction limits the efficiency of new systems that could be installed. Penetrations through the historic facade must be avoided wherever possible. Re-using existing penetrations is preferable. If new penetrations are unavoidable, they should be restricted to secondary facades.

Historic buildings often have outdated environmental control systems and more efficient modern systems are now available. The renovation of existing systems provides an opportunity to upgrade. For example, less efficient single pipe heating networks or inefficient lighting systems can be replaced by more effective two pipe systems and energy efficient lighting systems respectively.

The effectiveness of environmental control systems depends on how they are operated. A number of systems do not operate at their optimum efficiency and this can be addressed by undertaking routine maintenance of plant and educating building users to operate the systems more efficiently. If systems are working these steps should be undertaken before considering upgrading environmental control systems.

Updating or altering building services plant can potentially yield large carbon reductions with no heritage impact.

The following approach should be considered to upgrade the environmental control system. Less costly interventions normally undertaken within the existing budgets should be implemented immediately. The next level of interventions will be those that can be undertaken when an area of the building undergoes routine refurbishment. The last phase includes systems that affect the majority of the building and installation of these systems consequently needs to be carefully sequenced. All new plant should be selected from the current Energy Saving Trust list of energy efficient plant. The list of interventions is indicative only. There are many more possible measures that will emerge from more detailed investigations.

‘Easy Win’ interventions

Intervention	Cost	Carbon	Building owner/ occupier
Train building users or staff to operate the systems more efficiently according to their needs.	£	🌍🌍🌍	🏠🏠
Provide accurate instructions about how the systems are supposed to be operated by updating the Building User Guide and Operation and Maintenance Manuals.	£	🌍🌍🌍	🏠🏠
Test and re-commission mechanical and electrical systems.	££	🌍🌍🌍	🏠🏠🏠
Ensure the controls operate as required - optimised to reduce energy consumption.	£	🌍🌍🌍	🏠🏠
Install temporary sub metering to identify scope for energy reduction for the different systems.	£	🌍🌍🌍	🏠🏠
Install programmable time switches on equipment and plant.	££	🌍🌍🌍	🏠🏠🏠

Cyclical refurbishment

Intervention	Cost	Carbon	Building owner/ occupier
Upgrade controls routines with modern, more efficient methods/software.	££	🌍	🏠🏠
Replace single pipework heating systems with two pipework systems.	££	🌍🌍	🏠🏠
Install demand control systems so that the systems only run when essential (e.g. CO_2 sensors for ventilation control).	££	🌍🌍🌍	🏠🏠
Install daylight dimming and presence/ absence detection systems in small zones so that artificial lighting is only switched on when the space is occupied.	££	🌍🌍	🏠🏠
Install energy efficient lighting systems (e.g. LED, T5 fluorescent) where appropriate.	££	🌍🌍	🏠🏠
Replace all hot water storage with point of use systems as appropriate.	££	🌍🌍	🏠🏠

Major refurbishment

Intervention	Cost	Carbon	Building owner/ occupier
Replace central plant (e.g. boilers, chillers, air handling units, fans, pumps and control systems) with modern more efficient systems even if the existing plant is still within its operational life.	£££	🌍🌍🌍	🏠🏠🏠
Install energy efficient condensing boilers.	££	🌍🌍	🏠🏠
In replacing chiller plant consider free cooling operation or variable-speed centrifugal compression.	££	🌍🌍	🏠
Refrigerant based comfort cooling or heat pump systems be replaced with modern efficient systems, minimising distances between the indoor and outdoor plant.	£££	🌍🌍	🏠🏠
Upgrade ventilation with low velocity, pressure tested ductwork.	££	🌍🌍🌍	🏠🏠
Install sub-meters on heating, power and lighting systems to enable identification of opportunities for energy reduction.	£	🌍🌍🌍	🏠🏠🏠

If the energy reduction interventions are carried out as part of a refurbishment cycle, much of the cost can be discounted being necessary irrespective of energy saving efforts.

As the final stage of building adaptation it is appropriate to consider installing low and zero carbon energy technologies and these are considered in the following section.

Low and zero carbon technologies

Technical assessment to confirm the applicability of low and zero carbon technologies should follow the same principles for historic buildings as that applied to new buildings. Low and zero carbon (LZC) technologies must be technically suitable for the application and be sympathetic to the historic character of the building. The LZC technologies should only be installed after improving the fabric performance and ensuring any installed building services plant is running efficiently.

Feed in Tariff support is available for LZC technologies that generate electricity, e.g. photovoltaic systems.

LZC technologies that generate heat e.g. biomass boilers are supported by the Renewable Heat Initiative (RHI). RHI support was due to commence from 30th of September 2011, but the scheme is now expected to be operational by end of November 2011 when the support level is finalised.

For each of the technologies considered on the following pages, an indication of the relative capital expenditure required and carbon saving potential is given. These are approximate with the exact figures depending on many factors that are too in-depth to consider here. These metrics are considered for two building types:

A variety of grants that change frequently from various sources could contribute significantly to the expense of LZC systems.

Domestic or small commercial properties

Commercial properties or a medium or large scale

Biomass Boilers

Overview: Biomass boilers use wood, typically in chip or pellet form to generate heat. Biomass comes from short rotation crops such as poplar or willow. It can be burned directly or used to produce gas through anaerobic digestion or gasification.

Size: 5kW-10MW heat output.

Best suited to: Buildings with a constant heat load although thermal stores can be used. Buildings such as large homes, schools, offices and hospitals are suitable applications. These buildings should have accessible storage facilities and local fuel supplies. Appropriate for community heating schemes. Adverse effect on local air quality and often restricted in Local Air Quality management zone e.g. city centre locations.

Heritage specific issues: Tall boiler flues could affect the character of the buildings. An external boiler-house may minimise these impacts and siting the boiler-house so that only low buildings are within zone of influence for the flue would minimise the required flue height.

Advantages: They use fuel with a low carbon emission factor and can directly replace gas-fired boilers. It is a reliable, flexible and well tested technology.

The proposed Renewable Heat Incentives (RHI) will apply to these systems, significantly reducing the payback periods.

Disadvantages: Biomass has a lower energy density compared to fossil fuels. They require regular maintenance for cleaning. A relatively constant heat load is necessary for optimum operation. Large fuel stores with adequate access routes are required along with reliable fuel supplies. Require a relatively steady heat load as controllability can be limited.

Not suitable in local air quality management areas.

	Capital expenditure	Carbon saving potential
	££	
	££	

Solar Thermal

Overview: Solar thermal cells generate hot water from solar energy for use in heating and hot water. They are available in two forms, flat-plate (FP) and evacuated tube (ET) collectors. Flat plate collectors are less efficient than evacuated tube collectors but they are cheaper. This is a well tested, simple and robust technology.

Size: Flat Plate - 430 kWh/m² per year   Evacuated tube - 550kWh/m² per year

Best suited to: Buildings with a significant hot water demand (particularly during daylight hours) including houses, sports complexes, hotels and hospitals. They should have accessible south facing or flat roofs to maximise hot water output and allow for maintenance. Evacuated tube arrays can be fragile and vandalism prevention should be considered.

Heritage specific issues: Panels are mounted at roof level. Would require a roof that is not visible from any significant viewpoint – either a valley roof, a roof set behind a parapet or a flat roof on a taller building. Important to consider damage to historic roof structure and the increase in structural loading as well as visual impact.

Advantages: They use a renewable energy source. Well developed technology. Evacuated tube panels are more efficient and have a higher yield than flat plate collectors. They can be used for space heating due to higher water temperatures. Generate hot water with limited conventional fuel use.

The proposed Renewable Heat Incentives (RHI) will apply to these systems, significantly reducing the payback periods.

Disadvantages: Flat plate panels are less efficient than evacuated tube panels and as such require more roof space to generate the same about of heat.

Requires storage of domestic hot water. Storing hot water imposes water treatment regimes leading to energy consumption even when there is no hot water demand.

	Capital expenditure	Carbon saving potential
🏠	£	🌍
🏢	£	🌍

Photovoltaic Arrays

Overview: Photovoltaic cells (PV) convert solar energy into electrical energy. They are two main types; crystalline or thin film cells. Mono-crystalline are the best commercially available. Output from solar panels depends on tilt, orientation, shading, and efficiency of the PV cell. Careful design is required to optimise electrical output.

Size: Mono-crystalline - 105 kWh/m² per year   Thin film - 50 kWh/m² per year

Best suited to: Can be put on any type of building. PVs have been installed in the UK however large and therefore expensive arrays are required to generate significant output. Structurally sound roof tops that are accessible for maintenance are also required.

Heritage specific issues: Panels are mounted at roof level. Would require a roof that is not visible from any significant viewpoint – either a valley roof, a roof set behind a parapet or a flat roof on a taller building. Important to consider damage to historic roof structure and the increase in structural loading as well as visual impact. Installing free-standing panels within the grounds of the building or placing on ancillary structures may be more appropriate.

Advantages: Renewable method of generating electricity that can be exported to the grid. Can be incorporated in roofs or facades.

Benefit from FIT from government which reduces the payback. Installations less than 50kW experience higher levels of benefits.

Disadvantages: High capital cost. They require regular cleaning. Optimum positioning is required to maximise yield. Semi-transparent systems are more expensive and less efficient.

	Capital expenditure	Carbon saving potential
🏠	£££	🌍 🌍
🏢	£££	🌍 🌍

Small Wind

Overview: Small horizontal and vertical axis turbines are available. They can be connected to the electricity grid either directly or via a battery which stores electrical energy at times of no wind. They also require a minimum wind speed of 6m/s to operate and are heavily influenced by surrounding obstacles due to turbulence effects. They can be integrated into buildings however vibration and noise effects need to be considered.

Size: 2.5kWe - 50kWe building integrated or free standing.

Best suited to: Large homes and small offices. The turbine should be situated away from adjacent buildings and trees. If building integrated the turbine should be well isolated to prevent vibration effects. Noise and flicker effects need assessing before construction.

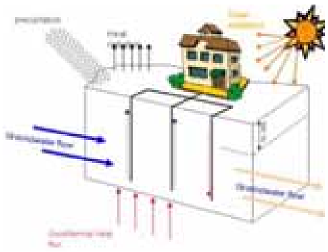
Heritage specific issues: The need to be located in free-flowing air means highly significant visual impact is almost guaranteed. Effect of vibrations through the structure would need to be carefully investigated along with the effects of installation and the additional weight.

Advantages: Renewable energy source. Can export electricity back to the grid. Benefit from FIT from government which reduces the payback

Disadvantages: Actual power output likely to be much lower than the rated output. Performance heavily affected by surrounding obstacles. Risk of noise, vibration and flicker issues.

	Capital expenditure	Carbon saving potential
(home)	££	(half leaf)
(building)	££	(half leaf)

Ground Source Heat Pumps



Overview: GSHP systems utilise the ground as a heat source or sink. Closed loop systems circulate water through either a vertical or horizontal pipework loop. Open loops systems use ground water as a cooling/heating medium. Both can use a heat pump (fridge technology) to upgrade heat from the ground to a higher, more useful temperature, or to provide cooling within the building by the rejection of heat into the ground.

Size: Varies with ground condition and type of GSHP however 1kW – 200kW.

Best suited to: Can be used for any type of buildings with an equal heating and cooling load over the year (prevents the ground from freezing or overheating) such as offices, large houses, or schools. Buildings are required to be above an underground water source for open loop, or to have a large open area for horizontal closed loop. Adequate ground conditions are required for all types including suitable thermal conductivity, specific heat capacity, soil composition and ground temperature. These ground and location conditions are more important than the type of building in terms of applicability.

Heritage specific issues: Assuming suitable external ground provision and conditions, this technology could have a low impact on heritage assets. However, consideration should be given to the potential for archaeological remains. It is more efficient with low temperature output and suited to systems such as underfloor heating systems. However, the system is only suitable if heat loss is significantly reduced after thermal improvements to the building fabric.

Advantages: Can provide both heating and cooling. Reliable, well tested technology with long service life. Installation of GSHP is concealed below ground, i.e. does not affect historic character.

The proposed Renewable Heat Incentives (RHI) will apply to these systems if they are used for heating only, significantly reducing the payback periods.

Disadvantages: Cost of civil work can be prohibitively expensive. It is not renewable and requires an electricity supply. Cost and disruption of installing under floor heating is considerable.

	Capital expenditure	Carbon saving potential
	£££	
	£££	

Air Source Heat Pumps (ASHP)

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Overview: ASHP's use the atmosphere as a means of rejecting and scavenging heat. They upgrade heat captured from the air to heat the building, and reject heat to cool the building. They are common within the UK and are similar to standard air conditioning units however they benefit from high efficiencies when operating in optimum conditions.

Size: Modular and so large outputs can be achieved.

Best suited to: All building types with sufficient external plant space. Buildings with a simultaneous heating and cooling loads can benefit from high efficiencies when using variable flow refrigerant systems. More efficient with low temperature output and suited to systems such as underfloor heating systems. The systems is only suitable if heat loss is significantly reduced after thermal improvements to the building fabric. Thermal performance after retrofit to be of similar standard to new buildings.

Heritage specific issues: This technology could be low impact on the heritage aspects, assuming there exists a suitable location for the plant. As with ground source it is more efficient with low temperature output and suited to systems such as underfloor heating systems. However, the system is only suitable if heat loss is significantly reduced after thermal improvements to the building fabric.

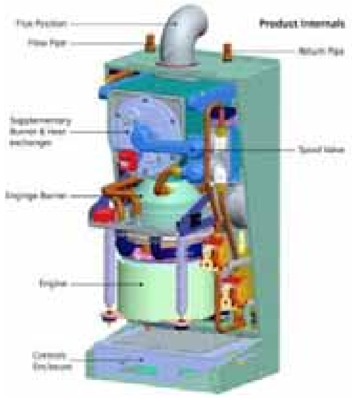
Advantages: High efficiencies can be achieved whilst in optimum conditions. Can provide both heating and cooling. Well developed and low cost technology.

Disadvantages: It is not renewable and requires an electricity supply. Efficiencies vary with external temperature (unlike GSHPs which have a reasonably constant efficiency). System performance needs to be optimized to ensure low output

Cost and disruption of installing under floor heating is considerable.

	Capital expenditure	Carbon saving potential
🏠	£	🌍
🏢	£	🌍

Gas Fired Combined Heat and Power (CHP)



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Overview: CHP generates electricity and heat simultaneously. Gas/steam turbines or reciprocating/Stirling engines can be used to power generators to produce electricity and heat. They are typically sized to provide the constant base heating load of a building. Conventional boilers provide supplementary heating.

Size: Varies from 5kWe domestic to 50MWe industrial applications

Best suited to: Buildings with a year-round demand for heating and electricity for example, swimming pools, leisure centres, hospitals, hotels, and university campuses. Excess electricity can be exported to the grid.

Heritage specific issues: The high heat load of heritage buildings may suit this technology which needs to be sized on heat demand. May be able to be installed with minimal heritage impact but will require a significantly larger plant room on non-domestic installations.

Advantages: Generates both heat and electricity. Relatively reliable, proven technology. High operating efficiencies if heat is fully utilised.

Disadvantages: Higher CO_2 emissions than biomass CHP. Requires regular maintenance and a constant, predictable thermal load.

There is a need for long operating hours to make the systems financially viable.

	Capital expenditure	Carbon saving potential
🏠	££	🌍
🏢	££	🌍🌍

Biomass Combined Heat and Power (CHP)

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Overview: Biomass CHP typically utilise wood chips or pellets to generate heat to produce steam to power a steam turbine. Gasification plant can also be used to produce gas from biomass. The gas is then used to power a turbine. They are suitable for large district energy schemes.

Size: Most suitable for very large scale (3MW+).

Best suited to: Buildings with a year-round demand for heating and electricity for example, swimming pools, leisure centres, hospitals, hotels, and university campuses. Appropriate for community energy schemes.

Heritage specific issues: It is unlikely that single heritage assets would be large enough to justify a system using this technology. Participating in an existing or new distributed energy scheme would probably have minimal heritage impact.

Advantages: Uses fuel with low carbon emission factor. Generates both heat and electricity.

Disadvantages: Requires predictable and constant thermal loads and large fuel storage areas with adequate vehicular access for deliveries. Plant requires regular maintenance and cleaning. Reliable fuel supplies are a necessity. It needs to be operated for 4000-5000hrs a year to be cost effective.

There will also be a considerable space requirement for the plant room and flues of a considerable height.

Emissions of oxides of nitrogen gas need to be considered in relation to local air quality issues.

	Capital expenditure	Carbon saving potential
	Not applicable	
	£££	

Summary

Depending on the motivation for energy reduction measures, there are a number of ways of determining the most effective technology for a given building. If carbon saving is paramount then calculating the carbon saved per pound invested might be appropriate. If cost saving is the real driver, then financial payback periods are more suitable.

Whichever metric is used, all costs and benefits should be taken into account, from increased maintenance costs to payments from schemes such as the Renewable Heat Incentive and Feed In Tariffs.

	Domestic		Non-domestic	
Technology	**Capital expenditure**	**CO_2 potential**	**Capital expenditure**	**CO_2 potential**
Biomass Boilers	£ £	🌍🌍	£ £	🌍🌍
Solar Thermal	£	🌍	£	🌍
Photovoltaic Array	£ £ £	🌍🌍	£ £ £	🌍🌍
Small Wind	£ £	◐	£ £	◐
Ground Source Heat Pumps	£ £ £	🌍🌍	£ £ £	🌍🌍
Air Source Heat Pumps	£	🌍	£	🌍
Gas fired CHP	£ £	🌍	£ £	🌍🌍
Biomass CHP	-	-	£ £ £	🌍🌍🌍

Achieving an 80% reduction in overall emissions by 2050 will require every sector to play their part. Changes in national policies, regulations and definitions will help to reduce the emissions of heritage buildings but they should not be relied upon.

A national move to a lower carbon electricity supply and the increased focus on distributed energy will help to lower the emissions of heritage buildings.

Projections by the Committee on Climate Change (Committee on Climate Change, 2008) indicate that an 85% reduction in emissions levels from the national grid is needed by 2030 to make the overall 80% reduction in the nation's emissions feasible. Such a change would drastically reduce the emissions of many heritage buildings but efficiencies should still be targeted and energy consumption reduced where possible, if not only because energy costs are expected to rise at rates significantly higher than general inflation. Energy price inflation greatly accelerates payback on investment in retrofitting measures.

The decarbonisation of the heating supply will necessarily be much more localised. It remains to be seen whether concerns over the long-term reliability of biomass cause restrictions in the use of this popular low carbon fuel. However, whatever the fuel, decentralised heating networks will undoubtedly play a central role in the delivery of low carbon heat.

The growth of these networks may be facilitated by the proposed incorporation of 'Allowable Solutions' into new building regulations from 2016. This framework will allow those constructing new buildings to 'claim' the carbon reductions from investments made in, amongst others, district heating schemes and retrofitting existing buildings.

85%

emissions reduction needed by 2030 in national grid supply.

Summary

Yorkshire has a multitude of heritage assets with varied constructions and styles that together help to make Yorkshire such a unique and wonderful place.

From the cloth industry of the West Riding and the steel industry of the South Yorkshire, to the open landscape of the Wolds and North Yorkshire Moors, our heritage buildings are part of the fabric of Yorkshire.

In order for these buildings to continue to endure and be valued for centuries to come, they must, where possible, contribute to the national targets to reduce carbon emissions.

It is the intention of this guide to provide clarity on the process that should be undertaken to reduce the carbon emissions of heritage assets. The importance of first understanding the building cannot be stressed enough. The heritage significance, condition, construction and use of the building are the foundations on which a carbon reduction program must be built.

The details of the steps used in the process will vary with different building types and sizes, but the principle of using gradually more investigative methods to identify sources of carbon emissions is universal.

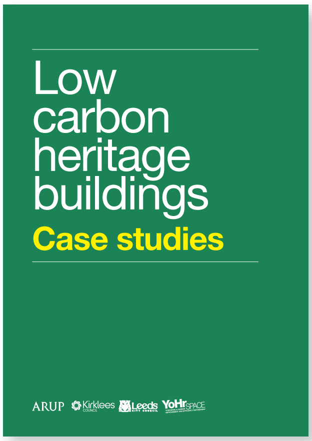
In addition, this guide provides insight into the applicability and suitability of possible interventions to heritage buildings. Whatever the building, there is always something that can be done to reduce emissions. Some interventions have no impact whatsoever on the heritage impact, such as behaviour change and changes to building systems.

Our heritge buildings must continue to endure and be valued for centuries to come.

This guidance document is supported by a collection of Case Studies.

Five buildings have undergone the process outlined here, including condition surveys, heritage statements and options appraisals. The results and the detailed cost benefit analyses provide further insight into the practical possibilities for heritage assets.

The case studies complement this guidance and together it is hoped they will encourage the owners of heritage assets to take action to allow their buildings to continue to play a vital part in our region's built environment.


Low carbon heritage buildings
Case studies
ARUP

References

Bath Preservation Trust and the Centre for Sustainable Energy, 2011, Warmer Bath - A guide to improving the energy efficiency of traditional homes in the city of Bath

BRE on behalf of DECC, 2010, The Government's Standard Assessment Procedure for Energy Rating of Dwellings (version 9.9)

Committee on Climate Change, 2008, Building a low-carbon economy – the UK's contribution to tackling climate change

Carbon Trust, 2007, CTV026 - Heritage and culture: Energy saving in historic sites and modern buildings

Carbon Trust, 2010, CTG004 – Degree Days for energy management

CIBSE, 2002, Guide to building services for historic buildings

CIBSE, 2004, Guide F: Energy efficiency in buildings

CIBSE, 2006, TM22 Energy assessment and reporting method

CIBSE, 2008a, Guide M: Maintenance Engineering and Management

CIBSE, 2008b, TM46 Energy Benchmarks

Communities & Local Government, 2009 Zero carbon for new non-domestic buildings: Consultation on policy options

Communities & Local Government & English Heritage, 2010, PPS5 Planning for the Historic Environment: Historic Environment Planning Practice Guide

Communities & Local Government, 2010, Planning Policy Statement 5: Planning for the Historic Environment

English Heritage, 2007, Understanding SAP Ratings for Historic and Traditional Homes: English Heritage Interim Guidance

English Heritage, 2008a, Conservation Principles: Policies And Guidance For The Sustainable Management Of The Historic Environment

English Heritage, 2008b, Understanding Historic Buildings: Guidance for Local Authorities

English Heritage, 2009, Research into the thermal performance of traditional windows: timber sash windows

English Heritage, 2010, Energy Efficiency And Historic Buildings -Application Of Part L Of The Building Regulations To Historic And Traditionally Constructed Buildings

HM Government, 2010, The Government's Statement on the Historic Environment for England 2010, Department for Culture, Media and Sport

Richard Oxley, 2003, the Survey and Repair of Traditional Buildings, Donhead Publishing

RICS, 2007, Code of Measuring Practice

UK-GBC, 2008, Low Carbon Existing Homes

Further interesting reading

It is not possible to go into detail on every subject around this issue. The following documents are useful sources of further information.

The Prince's Regeneration Trust, 2010, The Green Guide for Historic Buildings

The Energy Saving Trust, 2005, Energy Efficient Historic Homes - Case Studies (CE138)

This document has been funded by the Yorkshire and Humber Improvement and Efficiency Partnership and was produced by the following team under the guidance of Leeds City Council and Kirklees Council.

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