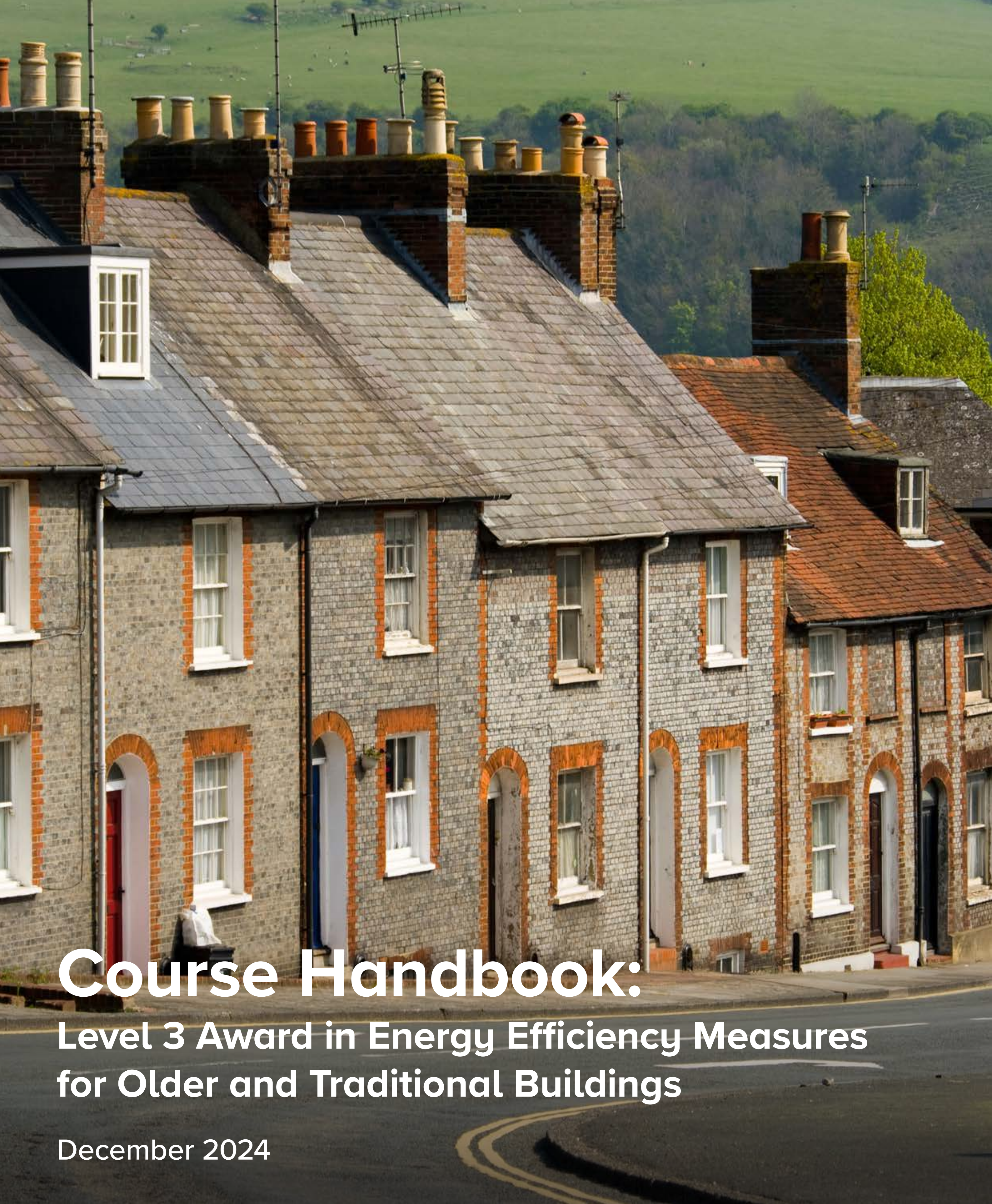

Course Handbook:

Level 3 Award in Energy Efficiency Measures for Older and Traditional Buildings

December 2024

Victorian iron roof truss.

Historic England

HISTORIC ENVIRONMENT SCOTLAND | ÀRAINNEACHD EACHDRAIDHEIL ALBA

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Cover: Terraced houses in Lewes, East Sussex.
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Introduction

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This handbook is for learners undertaking the Level 3 Award in Energy Efficiency Measures for Older and Traditional Buildings. It is designed to be used as an additional resource to support the guided learning hours delivered by a registered training provider. It will also be useful for learners to refer to upon completion of the qualification.

The Level 3 Award aims to give learners an understanding of how older and traditional buildings perform; the suitability of energy efficiency measures (EEMs) for their given construction type; the heritage considerations that may impact decisions with regards to the introduction of energy efficiency measures; and how to evaluate, justify and implement options to improve their energy efficiency.

In addition to being a requirement for certain retrofit roles and funding pathways, the qualification provides essential learning for anyone who is assessing, coordinating, designing or installing retrofit measures in traditionally constructed buildings.

The content of this handbook is based on the National Occupational Standards (NOS) that underpin the qualification:

- EEM01 — Assess the age, nature and characteristics of older and traditional buildings
- EEM02 — Evaluate the options for introducing energy efficiency measures to older and traditional buildings
- EEM03 — Advise on energy efficiency measures in older and traditional buildings.

The knowledge and understanding criteria from these NOS are noted throughout for easy reference.

Above: St Mary's Street, Lincoln.

Energy Efficiency Measures for older and traditional buildings

Historic buildings are an important part of our heritage. They help us to understand our history and enrich our sense of place. They help to create each UK nation's distinctive character and contribute to national identity. Historic buildings also enhance quality of life and wellbeing. Grouped together, they form the centrepiece of our historic villages, towns and cities.

Well-preserved older buildings may be protected through listing (national or local), and many more are valued as part of a local heritage that contributes to the identity and quality of a place. More recent buildings can also be listed, but the Level 3 qualification and this handbook deal only with buildings of traditional construction.

Traditionally constructed buildings were typically built before 1919 using different methods to modern buildings; they therefore need different treatment. This handbook and the award cover traditional construction types and their needs when introducing energy efficiency measures.

Climate change is increasing maximum summer temperatures, the volume and intensity of rain and storm events, the direction of prevailing weather and external humidity and sea levels. By transitioning to net zero, the UK is taking an important step in reducing carbon emissions and our impact on the planet.

There are approximately 6.5 million traditional pre-1919 buildings in England, Scotland and Wales, roughly 20–30% of all buildings in the UK. The most sustainable building is the one that already exists. It is therefore vital that these buildings are included in climate change mitigation strategies to help tackle the **causes** of climate change. These buildings are also at high risk of harm from the **impacts** of climate change, which will continue for decades even if current greenhouse gas reduction targets are met. Consequently, they will also need to be adapted to increase their resilience in a changing climate.

Relevant Standards

There are a range of industry standards that provide helpful guidance for introducing energy efficiency measures.

PAS retrofit standards

The Publicly Available Specifications (PAS) numbered 2030, 2035 and 2038 — referred to as PAS2030, PAS2035 and PAS2038 — are a set of overarching industry documents sponsored by the UK government and facilitated by the British Standards Institution. These standards underpin the principles laid out in this handbook and should be reviewed on an ongoing basis (see links in the resources section). The PAS outline a **whole building approach** — a holistic perspective that helps identify measures that are suitable, proportionate, effective and sustainable (see 4.1) — and aim to support the adaptation of UK building stock to meet UK climate change targets. Compliance with the PAS documents is not mandatory or legally binding (unless it is a requirement of funding streams), but it does set out good practice, and many publicly funded projects now require compliance as part of their own terms.

PAS2035 and **PAS2030** are designed to be used in conjunction with one another. They focus solely on the retrofitting process of existing dwellings.

- **PAS2035** is a strategy and planning document
- **PAS2030** sets out the installation standards and considerations for contractors and installers
- **PAS2038** is a strategy and planning document specifically relating to non-residential buildings.

Other standards

These are standards that lay down good practice and requirements for specific contexts. Whereas PAS are developed quickly to meet an immediate need, British (BS), European (BS EN) and International (ISO) standards are developed over a longer period with wider consultation.

- **BS 5250** — Management of moisture in buildings.
- **BS 8631** — Adaptation to climate change: using adaptation pathways for decision-making.
- **ISO 13788** — Hygrothermal performance of building components and building elements.
- **BS 7913** — Guide to the conservation of historic buildings.
- **BS EN 16883** — Conservation of cultural heritage: guidelines for improving the energy performance of historic buildings.

Referring to a specialist

Completing this award and reading this handbook alone are not going to give you the comprehensive expertise needed when dealing with traditional buildings. They will give you a better understanding of how these buildings are designed to perform, possible interventions, and points to consider when developing proposals. However, a key learning point of the NOS is understanding the limits of your professional competence and knowing how and when you need to seek specialist consultation and advice.

These are some of the specialists that may need to be consulted:

- a heritage consultant
- a local authority planning or built heritage conservation officer
- a building surveyor
- a structural engineer
- a building services consultant
- an independent damp and timber consultant
- a conservator
- an archaeologist
- an ecologist
- a fire consultant.

Anyone who lacks knowledge and experience with traditional buildings will be less able to identify building defects; to specify appropriate and cost-effective repairs; and to recommend, design or install suitable energy efficiency measures. It is therefore important to find contractors and advisers with verifiable experience and knowledge of traditional buildings. Many professional advisers use conservation accreditation schemes to demonstrate they have the relevant skills and expertise.

It is also important to refer to professionals, builders and contractors who have experience using the whole building approach.

The rest of this handbook leads readers through the steps of implementing energy efficiency measures in historic buildings; it covers everything from identifying heritage buildings to analysing buildings and generating reports for stakeholders. Resources sections provide further information and direct readers to relevant organisations, guidance and databases. These sections repeatedly refer readers to the three bodies responsible for overseeing the preservation of old and traditional buildings and historic environments in the devolved nations: Cadw, Historic Environment Scotland and Historic England.

Resources

For more information about conservation accreditation and finding specialists see:

- Historic England, *Conservation accreditation for professionals*
- Historic Environment Scotland, *Find skilled tradespeople and professionals*.

Above: Heritage specialists survey and record a listed building.

Chapter 1

Traditional Buildings and Heritage Matters

Overview

This chapter covers the following topics:

- Establishing the age of a building.
- Implications of building age for energy efficiency measures.
- Construction, performance and materials in older and traditional buildings.
- Identifying the heritage values and significance of a building.
- Applying conservation principles to older buildings.

1.1 Building age

National Occupational Standards:
EEM01: K1, K2

Key points

- Ways to establish the age of a building.
- The implications of building age for the introduction of energy efficiency measures.

Above: Terraced housing of traditional construction, with features that have been adapted over time to reflect different styles, revealing the history of each building and contributing to the distinctive character of the area.

Establishing the age of a building

Traditional buildings are generally defined as those constructed before 1919; they typically have external walls of solid stone, earth, or brick or timber frames with infill panels. Buildings are often their own best evidence for their age and history. The design and construction of buildings follow conventions that have changed over time and vary by region.

The first distinction to be made is between polite and vernacular architecture:

- **Polite architecture**
  Conforms to architectural styles that are national rather than local. They are built with a particular style in mind, for example, Georgian or neoclassical.
- **Vernacular architecture**
  Conforms to regional or local building traditions. They use the materials and resources available in the area where the building is located.

Most buildings will have been subject to some alteration over their lifetimes, as different generations have adapted them to changing needs and fashions. This means that a single building can include several different building styles, materials and construction details.

Buildings through the ages

Layout and plan are the basis of building design and provide evidence of a building's age and development. Regional conventions of domestic planning changed slowly over time.

Medieval — up to the later 16th century

It is generally only houses of relatively high status that have survived from this time, and those that have are much altered. Buildings were made of thick stone rubble or heavy timber frames with daub-and-wattle panels, stone and earth floors and thatch or stone-tiled roofs. Buildings were often vernacular in character, that is, constructed in a local style using locally available materials. Most houses had a simple rectangular plan. The hall or main living area was open to the roof, usually with further accommodation at either end.

Buildings surviving from this period are rare and, where known, will be listed.

Polite: Row of Edwardian houses built in the fashionable style of the time and seen in towns across the UK.

Vernacular: A terrace of early 19th century industrial cottages typical of South Wales and built with local stone and slate.

Pre-Georgian — from the late 16th century to the late 17th century

In this period, Britain became much more prosperous and a 'Great Rebuilding' took place. The houses of ordinary people became more substantial and survive in greater numbers than in the medieval period. Stone and timber frame were still the most common building materials, but there was some use of brickwork in areas with little good building stone. Thatch and stone tile were still common for roofs. Open halls were still in use in the beginning of the period, but by its end houses were built with full upper storeys and earlier open halls were often infilled with an intermediate floor to create additional rooms. The central open hearths began to be enclosed in 'smoke bays', or chimneys.

Few buildings from this period survive, and any that do are almost certain to be listed.

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Georgian — from the early 18th century to the early 19th century

Many more buildings from a greater range of social levels survive from this period. While rural typologies remained more consistent with earlier styles, industrialisation began to centralise the development of towns and cities, with the appearance of terraces to house migrant workers. Stonework, including high-quality ashlar, was prominent — or render where good stone was not available. Brick was also in widespread use. Lower pitched roofs and use of slate became increasingly common. In this period, windows were vertical rather than horizontal, usually sash.

Most buildings, except for the humblest, had two or more full storeys and were often taller than they were long. Classical influences in form and detail were prevalent, with a strong emphasis on symmetry. Elements such as classical columns and pediments were common in polite architecture and were sometimes used in simplified form in vernacular buildings, too. It was common for greater expense to be lavished on the main elevation, sometimes resulting in different materials and less fashionable detailing at the back.

Earlier buildings were also often refronted to conform to Georgian architectural fashions, leaving rear elevations unaltered and therefore providing important clues to help dating.

Buildings surviving from this period that retain sufficient original features are likely to be protected either by being listed or by being included in a conservation area.

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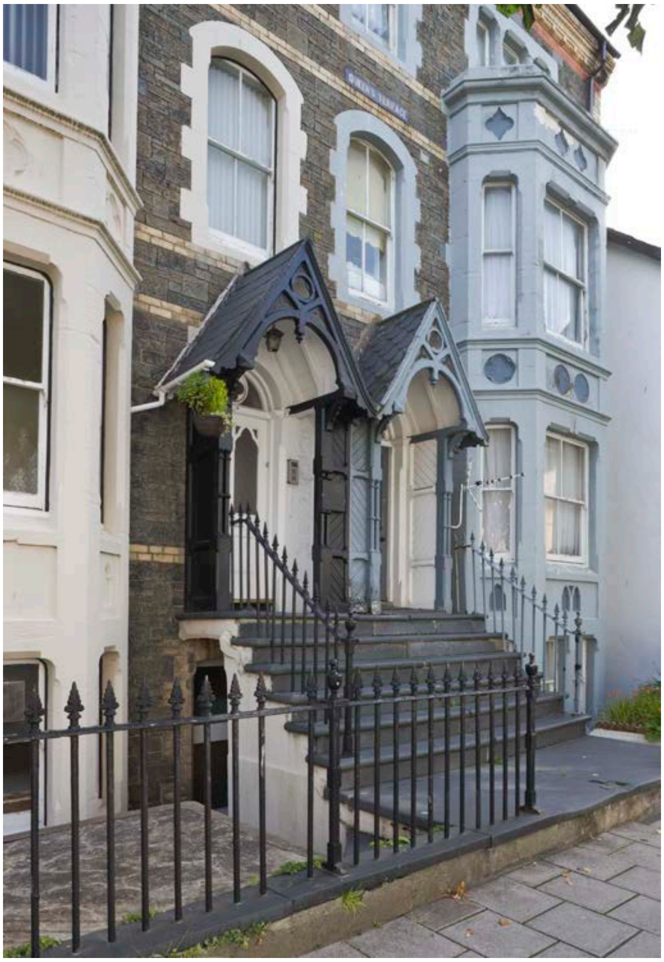
Victorian — after 1840

The introduction of the railway and greater industrialisation made the transportation of mass-produced building materials much easier. This led to the large-scale development of building stock to meet the needs of the industrial era and a growing population, and to the decline of regional building traditions.
Local stone was still dominant, but brick and terracotta were also in widespread use. Slates of uniform size were the most common roofing material. Sash windows were in general use. Technological advances saw the increasing use of innovative materials such as iron, larger panes of glass and, later, concrete. This period also saw the advent of early cavity walls.

Patterned, encaustic floor tiles or etched glass were often used for entrance halls. Fireplaces were of ornate marble, slate or cast-iron inset with patterned tiles. Gothic Revival was influential; buildings often had pointed arched door surrounds and windows, decorative use of contrasting materials, and irregular facades and plan forms.



Edwardian — from the late 19th century and into the 20th century

Various other revival styles became widespread, including the resurgence of traditional or vernacular forms and a new enthusiasm for 'mock' building styles, such as mock-Tudor or Gothic Revival.

Only a small proportion of buildings from the Victorian and Edwardian periods are protected by national or local listing, but many are located within conservation areas. They are often attractive, well-planned and soundly built houses that form high-quality built environments.

Implications of building age for energy efficiency measures

The older a building is, the more likely it is to be protected. Buildings with listed status are sensitive to change as it may harm historic fabric. Therefore, some energy efficiency measures may not be suitable for these buildings.

Building age can also be indicative of the type of construction. Traditional construction methods are less likely, though not unheard of, in more recent buildings. Energy efficiency measures need to work with the type of construction and with how it manages moisture and heat if they are to be effective.

Ways to research the history of a building

- Check historic environment records, including listed building records, for any previous investigation and interpretation.
- Check historic maps to establish whether or not a building was present by a certain date, allowing for the possibility of significant change or complete rebuilding since the maps were created. (This approach is best for houses built after the 19th century, due to the publication dates of available maps.)
- Contact building owners, particularly for recent changes. Owners may also have access to deeds or other documentary resources.
- Search public records and archives for information like the plans of landed estates, historic environment records, listed building records and conservation area appraisals. See the resources list below for further details.
- Study the building fabric, which often yields as much information as any number of documents.

Resources

England

- The National Heritage List for England (NHLE) is the only official up-to-date register of all nationally protected historic buildings and sites in England: www.historicengland.org.uk/listing/the-list
- Heritage Gateway, which offers local and national information relating to England's heritage, allows you to cross-search over 60 resources: www.heritagegateway.org.uk/gateway

Wales

- Archwilio provides online public access to the historic environment records for each local authority area in Wales. The database is maintained and enhanced with further information held by the Welsh archaeological trusts: www.archwilio.org.uk
- Cof Cymru is Cadw's online record of the national historic assets of Wales, which includes listed buildings, scheduled monuments, protected wrecks, World Heritage Sites and registered historic landscapes: www.cadw.gov.wales/advice-support/cof-cymru/search-cadw-records
- Coflein is the online catalogue for the National Monuments Record of Wales (NMRW), the national collection of information about the historic environment of Wales: www.coflein.gov.uk

Scotland

- The Heritage Portal allows you to search, browse and view decisions and designation records, download spatial datasets or use the map search: www.historicenvironment.scot/advice-and-support/listing-scheduling-and-designations/listed-buildings/search-for-a-listed-building/
- Canmore is the online catalogue of the National Record of the Historic Environment. It contains detailed information and archive images for more than 300,000 places in Scotland: www.canmore.org.uk
- Pastmap allows you to find out more about the heritage in your local area: www.pastmap.org.uk

General

- The Brooking National Collection of Architectural Detail charts the evolution of the constructional elements of Britain's buildings, such as windows and staircases, over the last 500 years: www.thebrooking.org.uk

1.2 Building construction, performance and materials

National Occupational Standards:
EEM01: K4, K13, K14, K15, K16, K17

Key points

- The construction of older and traditional buildings.
- Local and regional variations.
- Performance differences between traditional and modern constructions.
- Effects of geographical location, climate and exposure to the elements.
- Implications of the introduction of energy efficiency measures.

Construction, performance and materials in older and traditional buildings

The construction of older and traditional buildings

Walls

Timber, earth and stone were the dominant early building materials, but the use of timber as the main building material was becoming rare by the 18th century. Timbers were heavier in early buildings, becoming thinner as timber supplies were depleted. Timber was used as a framing material, either in square panels or — where timber was plentiful, and display was important — close-studded. But whether the timbers were close together or far apart, there was always an infill panel in which lime and mud-based daub was applied onto wattle — thin slats or woven sticks. Where it was available, brick was also sometimes used as an infill material, particularly in later timber-framed buildings.

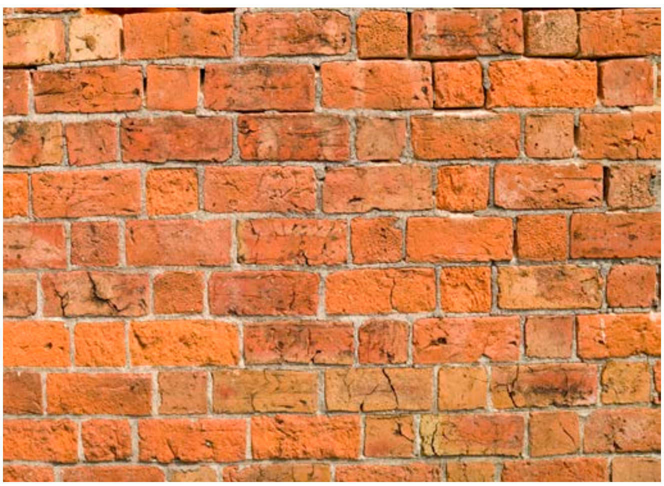
Mass masonry walls were built of stone that might be random rubble, which was roughly coursed or more finely laid, depending on the properties of the local stone and the level of investment in the building. Lime or earthen mortar was used for jointing, and it was common to cover walls with limewash or lime render until the fashion for exposed materials took hold in the mid-19th century.

Earthen buildings were commonplace in areas where sources of timber or building stone were not available. Known by different regional names, including mud, cob, witchert, pisé, clay lump and clom — their use was once widespread.

By the 18th century, brick was also available in many regions. Whilst the industrial revolution brought about the mass production of brick, it continued to be manufactured and used locally, resulting in many different colours, forms and textures which reflected local clay types. Regulations to control brick sizes were only introduced in the 18th and 19th centuries.

Cavity walls were first experimented with from the early Victorian period. These early cavity walls were constructed in various ways: with larger bricks tied across the cavity, with ceramic wall ties and with cast-iron wall ties (from the 1860s). A variety of brick bonds which used brick on edge — such as rat trap bond — were also used in the 19th century. There are also examples of cavity walls where the outer leaf is one or more bricks thick, giving the appearance of a solid masonry wall. The absence of headers can indicate that a wall has a cavity — but not always: some cavity walls use headers to tie across the cavity. Drilling through a mortar joint and using a borescope is sometimes the only way to correctly identify the presence of a cavity.

Right: Detail of cob wall.



Above top: A traditional rubble wall with lime mortar.

Above middle: Detail of historic brickwork.

Above bottom: The interior of a solid brick wall, showing how it is built up.

Above top: Timber frame with brick infill.

Above middle: Rendered timber framed cottages.

Above bottom: This former Methodist chapel has walls made of cob on a plinth of brick with some flint.

Roofs and chimneys

The design of roofs has developed from heavy oak to thinner softwood timbers as new sources of material became available and construction techniques evolved. By the Victorian period, iron trusses and steel had begun to be used in roof structures. Roof materials were often determined by local availability. Thatch was once widespread, but stone or clay tiles were common where suitable raw materials were available. Slate had a regional distribution until the early 19th century but was widely available in standardised sizes thereafter.

Chimneys can be constructed of many different types of materials and can vary from basic stone structures to very tall and ornate brick ones. They usually have projecting brick or stone courses at the top to help shed water and keep the stack dry. Chimney pots were particularly popular from the Victorian period onwards. They were made of clay and were mass produced using moulds to offer a wide variety of practical and decorative designs.

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Top left: Welsh slate roof.

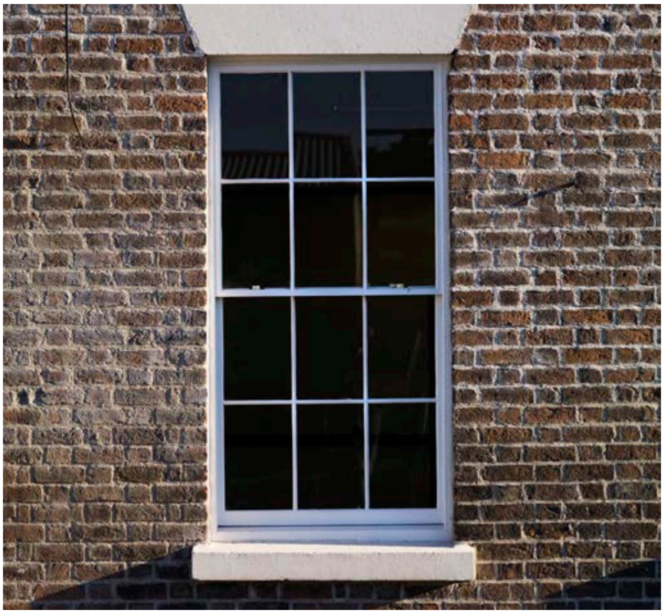
Bottom left: Victorian iron roof truss.

Top right: A traditional pantile roof.

Bottom right: Chimneys in a variety of materials and designs.

Doors and windows

Doors and windows are critical in maintaining the character of a building and can help identify the period in which it was built. Early in the medieval period windows often had no glass at all because of its rarity and cost; they simply had vertical plain or moulded timber bars (mullions), or possibly horizontal bars (transoms), in very tall windows. They were closed to the elements by shutters, sliding screens or hung materials. Windows were generally made of oak until the mid-18th century, after which painted softwood became popular. Casement windows were also made of cast or wrought iron, bronze or steel, sometimes with lead strips to hold the glass panes together. Small-paned timber box sash windows were popular from the Georgian period. The panes of glass increased in size during the Victorian period as new methods of glass manufacturing were developed.



Above right: Sash window.

Bottom: Transom and mullion window.

Floors

Solid floors were constructed from earth or concrete slab and were often finished with stone slabs or clay tiles. In areas where gypsum was in plentiful supply, plaster was also used. Suspended timber floors usually rest on brick or stone piers. Grilles in the exterior walls just below the level of a suspended floor provide ventilation and ensure that the floor remains dry and free of rot and insect attacks. Up until the Georgian period, floorboards were generally irregular hand-cut wide planks of oak or elm. They became narrower and more uniform in size as production was mechanised and softwood was introduced.

Until the middle of the 19th century, the local availability and affordability of building materials were key factors in what was used — only the wealthy could afford to import from beyond the local area. This changed in the 19th century with the industrialised production and distribution of materials, though some regional traditions survived.

The way in which building materials were handled also varied with place and time. For example, there were distinct stylistic developments in the method of timber framing and its infill panelling, in the coursing and dressing of stone, as well as in the bonding of brick and the laying of slate roofs.

Above: Floor joists; the floor rests on top with the space below separating the floor from the foundation.

Next page: Decorative medieval floor tiles with coat of arms detail.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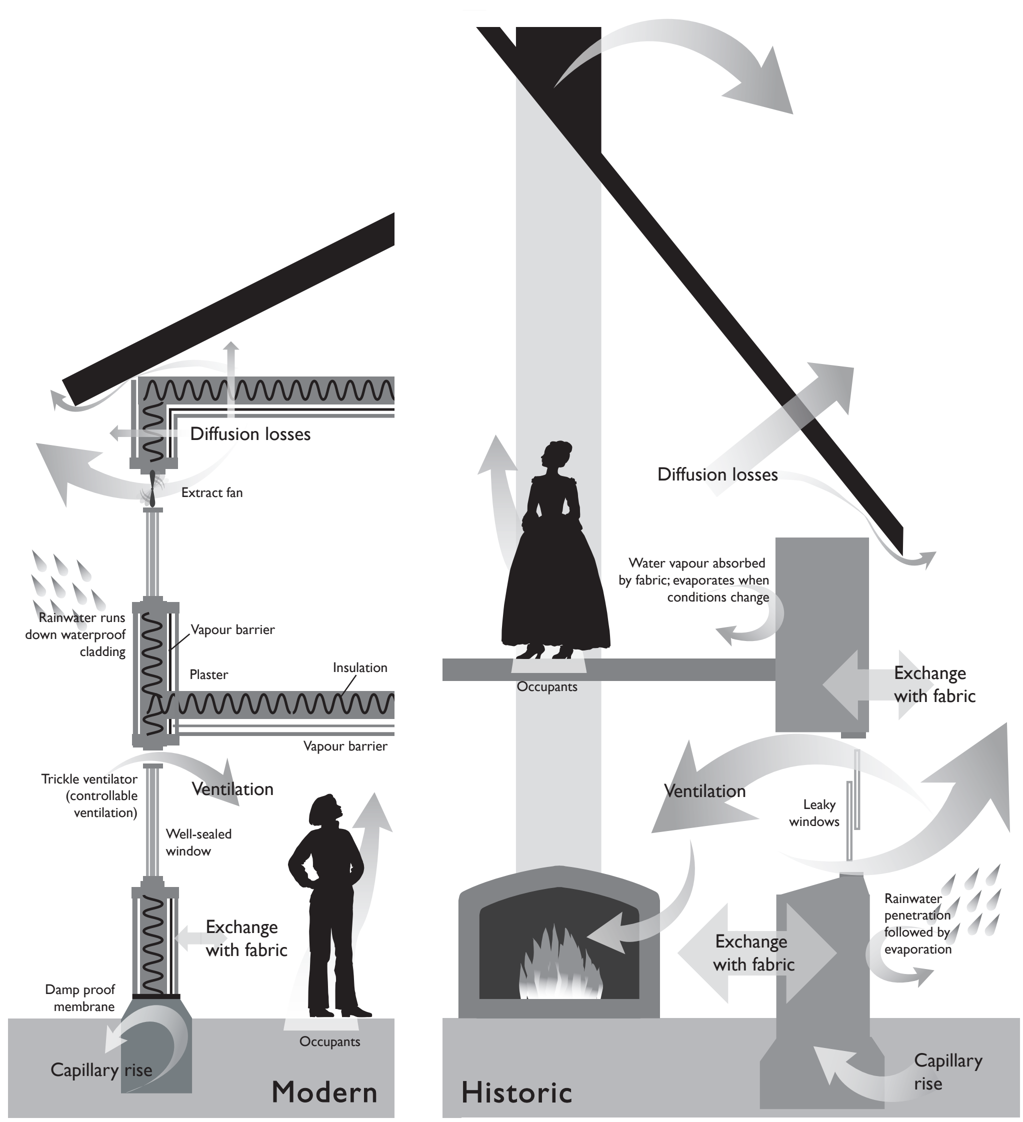
Performance differences between traditional and modern constructions

The key distinction between traditional and modern construction relates to how moisture and heat are managed.

Most modern buildings depend on impermeable barriers to control the movement of moisture through the building fabric. In contrast, most traditional building materials are both **moisture-permeable** and **hygroscopic**, taking in moisture from their surroundings and releasing it again according to environmental conditions.

Buildings of traditional construction also tend to have greater thermal mass and therefore greater thermal inertia than their modern counterparts; the material heats up and cools down more slowly and can help buffer the internal environment from external changes.

In a well-maintained traditional building where the behaviour of traditional materials has not been compromised by modern interventions, the ability to buffer moisture and heat helps to even out fluctuations in humidity and temperature. The daily and seasonal cycles of wetting and drying and heating and cooling balance out over time without causing fabric decay and maintain a healthy, comfortable indoor environment.



Above: Building performance: key differences between historic and modern construction.

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Top and bottom: Here, impermeable cement mortar has been applied to historic brick and rubble stone walls. The use of an inappropriate material has affected the performance of the traditional materials, leading to damage to the building fabric.

Movement of moisture

Permeable materials contain pores that are interconnected, creating pathways through which moisture can move in both liquid and vapour form. They can take up moisture from their surroundings (absorption) and release it (desorption) in response to changes in the humidity of those surroundings. Regulating their moisture content in this way enables a buffering effect between the internal and external environments.

Traditional construction assemblies are predominantly semi-permeable and allow moisture to move through their thickness. Even when some of the materials are non-permeable (such as lead) or have low permeability (such as granite), others (such as lime mortars, renders and plasters) will retain beneficial permeable properties that still contribute to the buffering potential of the building assembly.

Moisture in both liquid and vapour form moves through traditional materials in a number of different ways:

- Vapour can be transported through the pore structure of a permeable material by **diffusion**, driven by differences in vapour pressure. In the UK, moisture vapour normally travels from the inside (higher vapour pressure) to the outside (lower vapour pressure). However, when elevations are exposed to sunshine after being wetted by rain, moisture vapour can move towards the inside and condense in cooler parts of the building fabric (reverse condensation).
- Air containing water vapour will move through any unobstructed **air pathways**, such as cracks or gaps, due to differences in vapour pressure or temperatures on either side of the building component. This can result in concentrated locations where movement of moisture as water vapour occurs. Traditional buildings were not built to be draughty, but sometimes cracks or unintended air pathways appear.
- Liquid water is affected by **capillarity** or **gravity**. Most traditional permeable materials are capillary active. They can temporarily absorb liquid water in their near-surface pores and then dry out through evaporation. This process can happen both internally and externally. When building components are exposed to large volumes of water (due to broken or defective drainage, leaking pipes or flooding), liquid moisture will flow through permeable materials under the influence of gravity.

Condensation

Condensation takes two forms, surface or interstitial:

- Surface condensation occurs when warm moist air comes into contact with cold surfaces at or below their dew point. In a traditional building, surface condensation is most commonly seen on windows but can also form on surfaces where thermal bridging has occurred or inappropriate materials have been used.
- Interstitial condensation occurs between or within building fabric. This happens when warm moist air penetrates a building element and condenses when it reaches a colder surface at the interface between materials or when the dew point is reached within the thickness of building fabric. This occurs where the wall is warm on one side and colder and below the dew point on the other. In traditional buildings interstitial condensation can occur where internal wall insulation abuts a masonry wall or within the thickness of a mass masonry wall.

Absolute and relative humidity

- Absolute humidity is the measure of water vapour or moisture in the air, regardless of temperature. It is expressed as grams of moisture per cubic metre of air. Absolute humidity of air can vary depending on temperature and vapour pressure.
- Relative humidity is the measure of water vapour or moisture in the air in relation to the air temperature.

Air contains moisture, and the amount is expressed as the extent to which it is saturated. 100% relative humidity (100% RH) is the point at which the air cannot hold any more moisture without it condensing. The warmer the air, the more moisture that can be held — so a reduction of temperature means an increase in RH.

Having high humidity internally can create the perfect environment for pests and fungi to colonise. These can result in the degradation of timbers which also have a high moisture content and a poor internal environment for the development of fungi spores. It can also result in insulation being less effective where condensation forms on its cold side — most commonly seen on loft insulation where the air travelling from the warm room below has condensed on the insulation.

Heat transfer

Buildings transfer heat in three ways:

Conduction — The movement of heat through material due to a temperature difference across it, for example, when heat inside a building moves through a wall to the colder outside environment.

Convection — The movement of heat as an excited molecule of gas or liquid (e.g. air or water) from hot to cold — for example, when warm air rises naturally. Higher temperature gas or liquid molecules expand the space they occupy. The heated, less dense molecules rise to replace the denser, cooler ones, which then sink into the warmer areas.

Radiation — The movement of heat through light waves such as sunlight or infrared.

Depending on their inherent properties, building materials can absorb heat (by exposure to solar radiation or warm air), store it, and then release it when the surroundings are cooler. In certain buildings of traditional construction, mass solid walls and floors help regulate the internal temperature in relation to external fluctuations. This is called **buffering**.

Buffering is governed by the following properties of building materials and systems:

- Buildings with a high **thermal mass** can hold heat within their thickness.
- Buildings with a high **thermal inertia** heat up and cool down slowly.
- Buildings with low **thermal diffusivity** have a low rate of heat transfer through the material.

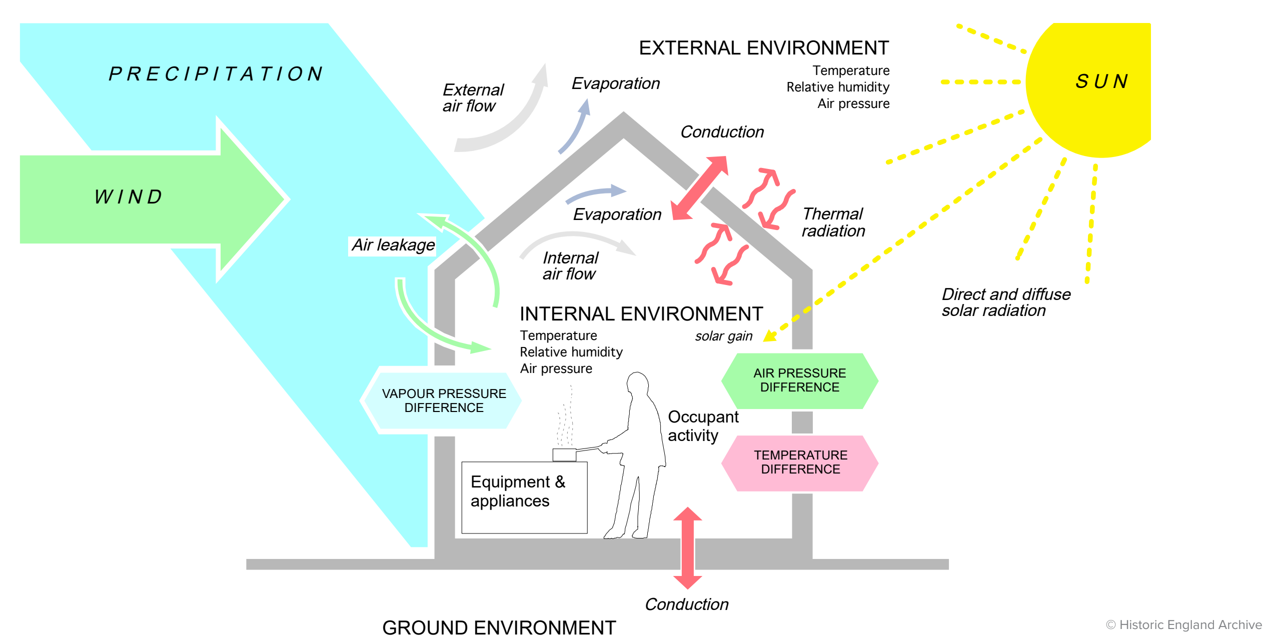
The **thermal resistance** (the ability of a material or system to resist the flow of heat by conduction) of traditional construction is often underestimated. Some traditional materials, such as cob (earth) and thatch, are naturally effective insulating materials. In situ testing has shown that the **thermal conductivity** (the ability of a material or system to conduct heat) of brick and stone is often lower than commonly thought. This means they can be more thermally efficient than assumed. In these cases, additional insulation would not provide the levels of benefit anticipated and would instead contribute to a performance gap.

The amount of moisture present within the pores of a permeable material influences its heat transfer properties. When the moisture content is too high and a material is wet, transfer of heat by conduction will occur more easily than if the moisture content were in equilibrium with its surrounding environment.

Effects of geographical location, climate and exposure to the elements

The performance of a building will be affected by regional variations in climate and by local exposure to wind, rain and sun. If a building is frequently subjected to driving rain, for example, the walls will remain wet for long periods. Conversely, high exposure to the sun can lead to summer overheating. Exposure will vary between elevations and will be affected by nearby features, such as trees or other buildings.

Interactions between building envelope and environment



Implications of the introduction of energy efficiency measures

Energy efficiency measures for traditional buildings need to be tailored to the circumstances of each case. This means understanding not only the way in which a building's materials perform in general but also the way in which the particular characteristics of the building and the interactions between elements may affect its performance, such as the way in which moisture and heat is managed.

The effects of climate change will impact the ability of traditionally constructed buildings to manage moisture content and transport. Securing and maximising the innate ability of traditional materials and constructions to buffer our internal environment against temperature and humidity fluctuations is becoming increasingly important.

The specifics of a building's design, size and the way it is divided internally, as well as its context and setting, may all affect its thermal performance. Changes to building fabric, heating and ventilation made in an attempt to improve energy efficiency may have unintended consequences, leading to problems of excess moisture, overheating or fabric damage, and may impact occupant health.

It is therefore essential when planning interventions to traditionally constructed buildings to understand the way a building is performing as an integrated system. It is essential that proposals are considered in a holistic manner, using a whole building approach, to ensure existing buildings are resilient, well adapted and continue to provide healthy environments in our changing climate.

Resources

The following resources provide more detailed information on the materials of old and traditional buildings and their performance.

Cadw, *Understanding Traditional (pre-1919) and Historic Buildings for Construction and Built Environment Courses*

Historic Environment Scotland, *Scotland's Traditional Building Materials*

The Engine Shed, *Building Materials*

Historic England, *Introductions to Heritage Assets*

Historic England, *Traditional Buildings and Energy Efficiency*

The Building Conservation Directory includes articles about a wide range of materials and features

1.3 Heritage values and conservation principles

National Occupational Standards:
EEM01: K5, K7, K8, K9, K10, K11, K12

Key points

- Heritage legislation.
- How to identify heritage values.
- How to identify the significance of a building.
- Principles of conservation and their application when introducing energy efficiency measures.
- The whole building approach.

Identifying the heritage values and significance of a building

Built heritage legislation and guidance

Some buildings have been identified as nationally important and are protected as buildings of special architectural or historic interest through the process of statutory listing. Changes to listed buildings are managed through applications for listed building consent, which is part of the planning system.

Listed buildings are not all traditionally constructed, however; a large number of the nation's historic building stock is designated. The older a building is and the fewer the surviving examples of its kind, the more likely it is to be listed.

National listing

Listing is the mechanism through which a building or structure of special architectural or historic interest is recognised by law. Listing brings the special interest of the building under the consideration of the planning system so that it can be protected for future generations. The protection also extends to boundary walls and other structures within the 'curtilage', or area surrounding the listed building.

Each of the home nations carries out listing under a different legislation and manages it through its relevant heritage body. All heritage bodies provide access to their lists as well as advice and guidance on the process, implications of listing for planning consents, and instruction about how to manage and maintain listed buildings.

Listed Building Consent is required to make any changes to a listed building's interior or exterior that would affect its character as a building of special architectural or historic interest. Listed Building Consent is administered by the local planning authority. This is covered in more detail in Chapter 5.

Listing is not intended to be an obstacle to change. Instead, it signals a special interest that should be considered in the planning process to ensure that any planned change does not cause harm to historic fabric or the building's significance.

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All images: Listed buildings are varied in type, period and construction, from stately houses and palaces to rural farmhouses and urban terraced homes.

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Scheduling

Scheduling is the selection of nationally important archaeological sites. It uses different legislation to listing. Whilst the majority of buildings and standing structures are protected by listing, they can also be scheduled if they meet relevant national criteria.

Works to a scheduled monument require Scheduled Monument Consent. The process for scheduling and administering consents varies in each devolved nation; further information and a list of scheduled monuments is available on the website of the relevant national heritage body.

Above: Norwich Castle, a scheduled motte and bailey castle now open to the public as a museum and gallery.

Right: Stirling Castle, a scheduled monument that is one of Scotland's most significant royal castles, is now open to the public as a visitor attraction and museum.

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Local listing

Some buildings and sites that are not nationally listed or scheduled are identified by local planning authorities as historic assets of special local interest and are designated on local lists.

Buildings and sites included on local lists are not automatically protected by additional planning controls. However, local policies for their conservation enable local planning authorities to take their special interest into account when changes that would require planning permission are proposed. Local planning authorities may also choose to remove certain permitted development rights through an Article 4 Direction, thereby bringing the relevant changes under the control of the planning system.

Conservation areas

Conservation areas exist to manage and protect the special architectural and historic interest of a place. Extra planning controls and considerations apply to conservation areas so that historic and architectural elements are protected. These generally affect proposals for exterior changes, both directly to buildings and to wider streetscapes (for example, the removal of trees). Before designing any proposals for changes to buildings in conservation areas, it is important to understand how the building contributes to the area as a whole.

Information on local listing and conservation areas is available on the websites of individual planning authorities.

Buildings can also be protected through other types of designation — for example, as part of a World Heritage Site or an Area of Outstanding National Beauty (AONBs). Visit the website of the relevant statutory heritage body for a comprehensive list of designation types.

Above: The Close, Llanfairfechan, is a conservation area in Conwy. Built by the Arts and Crafts architect Herbert Luck North between 1899 and 1945, the almost unaltered buildings and layout are a textbook example of high-quality Arts and Crafts domestic architecture, unique in Wales.

Listed buildings account for a tiny percentage of the total building stock; many unlisted buildings also contribute to a sense of place and history. All older and traditional buildings, whether or not they are listed, locally listed or in a conservation area, have their own distinctive characteristics, and understanding them is the key to caring for them appropriately.

Works that fall within the definition of development, including the alteration and extension of existing buildings, may need planning permission, while works of maintenance and repair generally do not. The local planning authority will be able to provide advice on what consents may be needed.

Heritage values and significance

People and communities value buildings for a variety of reasons. Four heritage values are used to capture what makes a building special:

1. **Evidential value:** This is the extent to which the physical fabric of a building reveals how and when it was made, how it was used and how it has changed over time. This aspect of significance relies primarily on a detailed understanding of fabric — the story of the building itself.

2. **Historical value:** A building may exemplify a particular past way of life or be associated with a specific person or event. Building fabric will be important in these cases to establish how it illustrates this past. But other sources of information — documents and personal accounts — will be helpful for discovering and verifying the associations between buildings and notable people or events.

3. **Aesthetic value:** A building may be visually satisfying because of its design, construction and craftsmanship and because of how it relates to its setting. Here, value is established by considering the building's design qualities, the character it has acquired through the passage of time and its relationship to its landscape or townscape setting.

4. **Communal value:** This is the significance of the building to people to whom it has been and remains important because, for example, of the part it has played in cultural or public life. For some buildings, like historic pubs or libraries, communal value may be readily apparent from its character and purpose. In other cases, the memories and stories that imbue a building with communal value may not be immediately obvious and may only be revealed through engagement with the communities to which it belongs.

These values help us to identify and describe what is **significant** about a heritage asset.

Significance is one of the guiding principles running through the historic environment sections of each devolved nation's planning policy. Slightly different terminology is used in each to define significance and the heritage values or interests from which it is derived, but they share the same guiding principles as those outlined above. The relevant planning policy for each nation is:

- **England** — National Planning Policy Framework (NPPF)
- **Wales** — Planning Policy Wales
- **Scotland** — National Planning Framework 4 (NP4)

Understanding significance is the first step when proposing changes to a protected building, including retrofit interventions.

Next page:

Top: The National Lido of Wales, Pontypridd is the only open-air swimming lido still operating in Wales. Its construction in the 1920s was funded by the Miner's Welfare Fund, which used tax on coal industry profits to improve educational and leisure facilities in mining communities. The lido has long played an important role in the life and civic pride of local residents, leading to its recent restoration following a period of disuse in the 1990s

Far bottom right: The Royal Arcade in Norwich exemplifies Art Nouveau design, with intricate ironwork, a glass roof and ornate decorative tiling. Opened in 1899, the arcade is still home to local businesses today but has retained its original decoration as designed by local architect George Skipper. This includes motifs emblematic of the Art Nouveau style, such as peacocks and flowers.

Middle left: These houses in Swindon were built in the 1840s to house the workforce for the new Great Western Railway works. The Swindon railway village, designed by Brunel, is one of Britain's best-preserved railway settlements and helps us to understand the living conditions of railway workers, including the development of public health and leisure facilities for residents.

Bottom left: Interior of the Spinning Mill, Shrewsbury Flaxmill Maltings. This is the world's first iron-framed building, paving the way for modern skyscrapers. It is one of the most important buildings of the industrial revolution, with its physical fabric key to its evidential value and significance.

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Conservation principles

Older and traditional buildings contribute value to the heritage of places, but their continued use also makes practical sense. Replacing them would require significant energy, carbon and cost. But keeping buildings in beneficial use will often mean that changes need to be made.

Conservation is the process of managing change so that the best interests of both the building and its occupants are ensured. Conservation principles provide a guiding framework for achieving this outcome.

They stipulate that:

- The special qualities of historic assets should be protected, enhanced, enjoyed and understood by everyone.
- Decisions about change should be based on a proper understanding of the building and what is significant about it.
- The historic environment is a shared resource that adds distinctiveness, meaning and quality to the places where we live; additionally, it is a social and economic asset.
- Caring for the historic environment depends on informed and active participation and draws on specialist knowledge and skills.

In line with these principles, any proposals for change should be based on clear objectives and should grow out of an understanding of the building's special characteristics — its heritage value and its character as an older or traditional building.

Right: Matching materials: patch repairs to a slate roof should use replacement slates of a similar colour, texture and thickness.

Next page:

Top left: Minimum change: in this stone repair project at Dunkeld Cathedral, many ashlar blocks with minimal signs of decay were retained.

Top right: Minimum change: a skilled joiner should be able to retain a maximum amount of original material in a traditional sash and case window by only replacing rotten timber.

Middle left: Reversibility: metal reinforcement plates can be removed at a later date.

Right: Reversibility: lime pointing can be removed easily if replacement is needed at a later date.

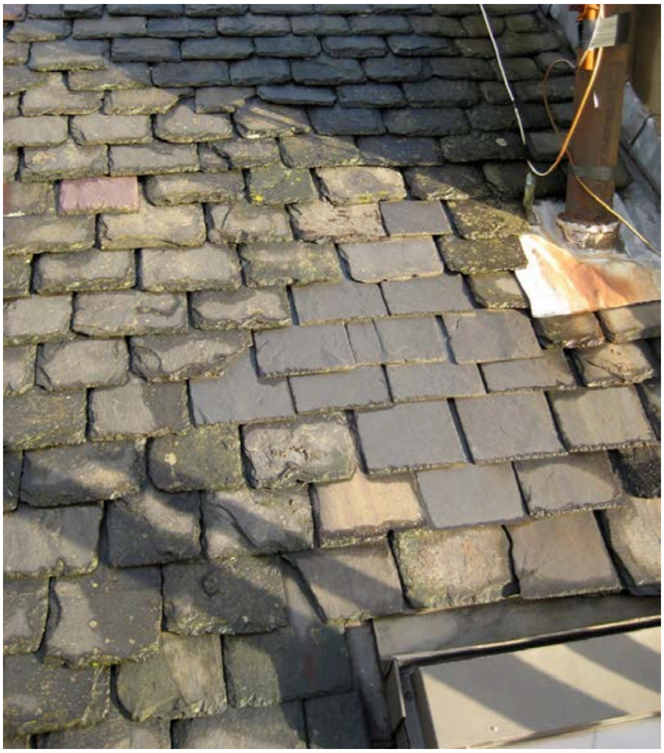
Bottom left: Matching materials: various types and combinations of sands are tested to produce different mortar samples. These are compared with the properties of the original lime mortar to ensure a like-for-like repair is carried out and the 'breathable' performance of the building maintained.

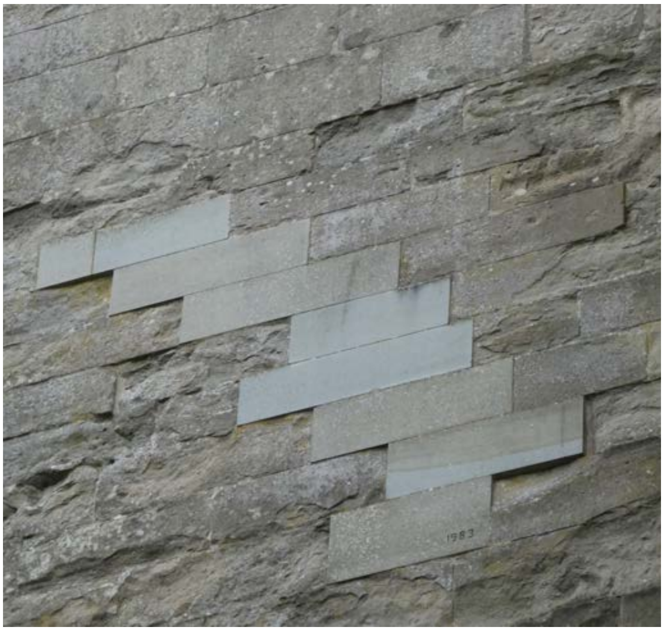
Applying appropriate conservation principles when introducing energy efficiency measures

The introduction of energy efficiency measures is most likely to impact the evidential and aesthetic value of both the interior and exterior of a building. It is the statutory duty of any person proposing changes to a listed building to robustly justify any impact on significance. See 5.3 for more information on assessing significance and justifying proposals.

There are some basic tenets that should guide the introduction of energy efficiency measures to older and traditional buildings. They include the following:

- Keeping a building well maintained and in a good state of repair not only protects the building but is an energy efficiency measure in its own right.
- Using original or matching materials is likely to work well with the characteristics of the building, both in terms of its heritage value and its performance.
- The most appropriate works are those that entail minimum change to materials and character.
- Only materials and techniques that do not produce permanent negative consequences that could restrict future works should be used.
- Changes should be reversible — that is, they should be able to be undone without significantly damaging or harming the original fabric.





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The whole building approach

The whole building approach uses an understanding of a building in its context to: find solutions that save energy; work with the character of the building; respect its heritage value; and maintain a comfortable, healthy indoor environment. The approach takes into account the way a building is used and the needs and behaviour of the people who occupy it, as well as the characteristics of the building itself. These characteristics include the construction and materials used in the original design, as well as alterations that may have affected the building's performance.

Above all, the whole building approach treats each building as a specific case rather than as an instance of a broader category. It recognises that no two buildings are exactly the same and that what works in one case might not work in another, even if the two cases seem similar. The approach is site specific and considers the interactions of the building's fabric with the people who manage and use it. This holistic perspective should help identify measures that are suitable, proportionate, effective and sustainable.

See 4.1 for further details about applying a whole building approach to the introduction of energy efficiency measures in older and traditional buildings.

Above: It is essential to consider the whole of a building when developing proposals for change, including its fabric, alterations over time, context, location, use and occupancy.

Resources

For more information on conservation principles, heritage values and significance, see:

Historic England, *Conservation Principles, Policies and Guidance*

Cadw, *Conservation Principles*

Historic England, *Assessing Significance*

Historic England, *Historic England Advice Note 12: Statements of Heritage Significance*

Cadw, Heritage Impact Assessment — this includes Cadw's guidance for assessing significance

The following links provide Historic England, Cadw and Historic Environment Scotland's descriptions of listing and other designations. Databases of listed houses and other protected buildings can also be found on these sites.

Historic England, *What is listing?*

Historic England, *Protecting heritage beyond the list* (local listing, conservation areas and natural designations)

Cadw, *Historic assets*

Historic Environment Scotland, *Listing, scheduling and designations*

Historic Environment Scotland, *Living in a conservation area*

Above: Brincliffe Edge Road, Sheffield.

Chapter 2

Understanding the Building

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Overview

This chapter covers the following topics:

- Identifying common building defects and their implications for energy efficiency measures.
- How repairs of common building defects affect the choice of energy efficiency measures.
- Types of heating and ventilation systems and their implications for energy efficiency measures.
- Occupant behaviour and its implications for energy efficiency measures.
- Types of further analysis and investigation available.

Above: Essential maintenance work to remove vegetation before further works are undertaken.

2.1 Building defects and condition

National Occupational Standards:

EEM01: K22, K23, K24, K25, K26, K27, K28, K29

EEM02: K6, K7, K30, 31

EEM03: K13

Key points

- How to identify common building defects and their implications for energy efficiency measures.
- How building materials deteriorate over time.
- How alterations affect the performance of a building.
- The importance of repair and maintenance.
- Repairs and their implications for energy efficiency measures.
- Adapting retrofit measures for existing building features.

Identifying common building defects and their implications for energy efficiency measures

A building's condition is a key factor that influences its energy use. Before planning a retrofit, assess the condition of the building. Note any defects and any need for remedial action. This may require the services of specialists.

Repair and maintenance are important energy efficiency measures in their own right (see 4.2). A good state of repair is also vital to the effectiveness of any planned retrofit interventions, especially when it comes to moisture ingress.

Identification of defects

Defects can be identified:

- visually
- through invasive or specialist investigation and assessment.

Example: Visual defect identification

Dampness is visible in the walls. This might take the form of tide marks, salt deposits, staining, mould or blistering paint. The cause of the dampness is unclear, as is the extent to which it has affected adjacent parts of the building fabric, such as the timber floor joists built into the masonry. It may be necessary to investigate by opening up small areas of the building fabric. Once the timber has been exposed, a moisture meter, correctly calibrated to measure moisture in timber, can be used to measure the moisture content. Note that, depending on the method and equipment used, the presence of salts can impact and invalidate moisture meter readings, so specialist interpretation is often required to establish the exact source and extent of dampness. Using a moisture meter would not be effective in measuring the moisture content of masonry.

Left: The visible damp on these interior walls indicates a moisture issue.

Example: Defect identification when visual identification is not possible

A defect in the installation of loft insulation is causing condensation on the roof timbers or on the cold side of insulation — for example, on the internal face of a masonry wall. The defect cannot be confirmed unless the building fabric is opened up and inspected. This is an invasive process that involves some damage to existing building fabric. Where this is not allowed or where permission is not clear, a specialist non-invasive investigation, such as thermography, may be required to find out whether existing energy efficiency measures are causing defects.

Further specialist analysis may be required to fully understand the building's condition prior to the introduction of energy efficiency measures. A range of specialists may need to be consulted, such as a heritage consultant, local authority planning or conservation officer, building surveyor or building services engineer (see page 6).

There will also be situations in which there is insufficient evidence readily available to make recommendations on repairs or the introduction of energy efficiency measures, and further specialist analysis or investigation is required. Necessary assessments and investigations might include:

- fire assessment
- significance and Heritage Impact Assessment
- building condition survey
- keyhole investigation
- opening up
- testing, monitoring, and remote sensing, including airtightness testing, infrared thermography and in-situ U-value monitoring
- moisture management evaluation
- moisture risk assessment
- building services assessment
- archaeological investigation
- ecological assessment
- overheating assessment.

Above left: A thermal image being taken on the roof of a building.

Above right: Microwave moisture meters being used.

Structural defects

Buildings can suffer due to maintenance issues, neglect or damage, which can lead to structural defects, such as cracking of masonry or deterioration of timber elements due to water ingress or defective drainage systems. Changes in ground conditions, seasonal effects or vegetation growth can lead to foundation or wall movement and subsequent cracking in masonry. If the cause of a defect is not addressed before the affected area is repaired, it will lead to further and potentially more significant damage to the structure. If structural movement has occurred, confirm whether the movement is ongoing or is historic and has ceased.

To determine the cause of potential structural issues and whether they are ongoing, it is recommended that you consult an expert. An appropriately qualified or experienced structural engineer should be appointed to assist with the diagnosis and treatment of problems and to determine whether repair or monitoring is required.

Top: Damage to thatched roof and chimney.

Bottom: Cracked masonry render.

Common building issues and defects, and their causes

The following table is a non-exhaustive list of the common sources of defects in buildings. In addition to outlining some of the implications for energy efficiency measures, it provides guidelines about what to look out for during a pre-retrofit assessment.

Table 1: Common building defects

Issue or defect	Cause(s)	Effects
Moisture ingress	Driving rain; rising and penetrating damp; internal moisture vapour; inadequate ventilation; inadequate or damaged drainage systems; elevated external ground levels; defects to exterior building fabric.	Decay of building fabric and structure; reduced thermal resistance of the building fabric, particularly external walls.
Inadequate or defective ventilation	Poor maintenance; blocking of vents; raised ground levels; sealed windows; lack of ventilation system in existing design.	Moisture accumulation and increased relative humidity leading to condensation and mould growth.
Structural defects and structural movement	Water ingress; changes in ground conditions; vegetation growth; lack of maintenance; insect attack; changes in structural loadings from new openings, extensions etc.	Loss of integrity of structural elements; structural movement (cracking).
Cavity wall issues	Blocked cavities; wall-tie failure.	Moisture accumulation leading to condensation and mould growth.
Presence of asbestos, radon and other harmful materials	High levels of radon present in geographic location; past material choices.	Harm to human health.

It is important to identify and remedy the **cause** of any issues, not just the symptom. If structural repairs are not carried out prior to introducing energy efficiency measures, any new work could exacerbate the issue, especially where additional weight is being added to the structure — for example in the case of new services, insulation or photovoltaic panels. This could lead to abortive work and wasted resources.

Defects can also be present in existing energy efficiency measures. This could be due to the use of inappropriate materials or poor-quality installation, which leave cold spots and thermal bridges.

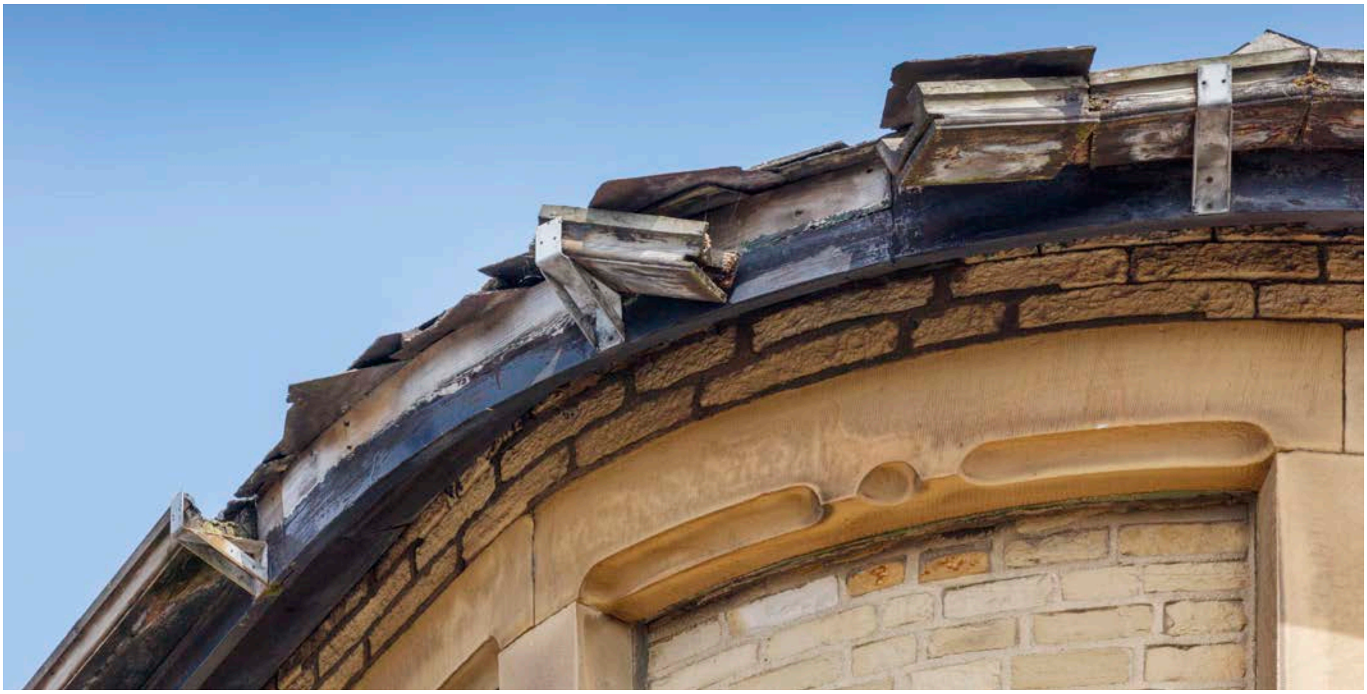
Some previous energy efficiency measures (such as loft insulation) may have slumped over time and may no longer be fulfilling their original purpose. Any defective energy efficiency measure should be removed prior to new retrofit work taking place.

Alterations to buildings can also affect their performance. Inappropriate repairs — for example, cement repointing — can have an adverse impact on performance. The presence of extensions to the building can also impact performance.

Above: Missing and slipped slates can cause water ingress.

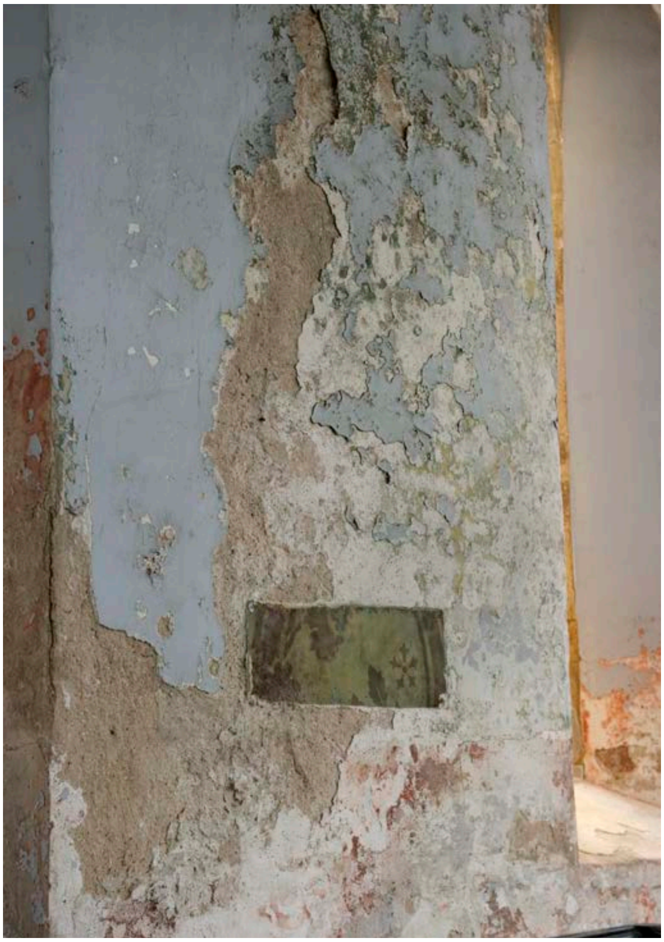
Above: Mould build-up at the top of a staircase, likely due to excess condensation.

When repairs have been completed prior to retrofit work taking place, it is important to ensure that the building fabric has dried out before further work takes place. This is the case with respect to all traditional building fabric types — including stone, brick, timber, plaster etc. This drying could take some time, but fabric must be allowed to dry properly before retrofit work is undertaken.



Top: Faulty rainwater goods can lead to moisture build up and water ingress.

Below: Vegetation growing out of building fabric can cause structural damage and moisture accumulation.



The decay of traditional building fabric

While traditional building materials are often long-lasting and durable, they will still degrade and deteriorate over time if they are not maintained correctly or if inappropriate interventions or materials are used.

Moisture can have a significant detrimental effect, triggering a variety of decay mechanisms. Keeping traditional building fabric free from excess moisture is of critical importance.

For example:

- Soft sandstone is vulnerable to decay caused by saturation of moisture and the action of salts.
- Cast iron will rust in the presence of excess moisture.
- Salt crystallisation can break apart the clay used to form fired clay bricks.
- Timber will suffer from fungal attacks; excess moisture can lead to both wet rot and dry rot. Insect infestation, such as furniture beetles, are also attracted to moisture.

Top left: A hard cement mortar has been used to fill the gap at the edge of a brick panel, trapping moisture against the timber frame.

Top right: Timber windowsill decaying as a result of moisture saturation.

Bottom left: Water ingress has caused the decay of internal finishes.

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Physical processes like weather and the distribution (or shifting) of weight over time can also lead to the decay and deterioration of traditional building fabric. Freeze and thaw cycles can cause traditional materials such as stone and brick, for example, to decay. If a building has been structurally overloaded, it can crack or deflect.

If **inappropriate materials** are used, retrofit can itself contribute to decay. Changes to building fabric, heating or ventilation to increase energy efficiency can affect the fabric's ability to manage moisture and heat.

For example, using materials that prevent building fabric from drying out or failing to ensure thermal continuity when installing insulation can cause some of the fabric to be relatively cooler and more likely to form areas of concentrated condensation and mould growth.

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Top: A patch of cement render has fallen off, likely due to moisture being trapped behind it.

Bottom: Bricks decaying as a result of freeze / thaw cycles.

Example: Repointing with lime mortar

The use of cement mortar and renders in traditionally constructed buildings can trap moisture within the fabric, leading the render to crack and the masonry to spall — which will cause damage to both the inside and outside of the building. Replacing cement mortar and render with more traditional lime-based equivalents will allow the external fabric to both absorb and release moisture, depending on the environmental conditions, reducing the risk of trapped moisture. The properties of lime mortars can vary depending on the mix (e.g. ratio of binder to aggregate). It is important that the lime mix used is appropriate to the building fabric, its condition and its level of exposure.

Above: Lime mortar is applied between stones.

Defects caused by previous alterations

Past alterations to the original construction of a building, including previously installed energy efficiency measures (such as insulation), can affect its performance. For example:

- **Loft insulation** is designed to retain heat in habitable spaces by preventing it from leaving the building. But this can also create a colder space above the insulation, which increases the risk of condensation on roof timbers if adequate increased ventilation to the loft space is not provided. Condensation on timber can lead to saturation and decay mechanisms taking hold. Previously installed loft insulation is also sometimes of insufficient depth and can slump over time.
- A **thermal bridge** is a relatively less insulated area of a building that therefore becomes more vulnerable to condensation and decay. Avoiding thermal bridges entirely is difficult, so using ventilation and permeable materials is important in traditional buildings to minimise risks.
- The **use of inappropriate materials** when making alterations to a traditional building can lead to defects and fabric decay. For example, the use of cement mortars and renders can affect the permeability of traditional building fabric and prevent walls from drying out, leading to damp. These issues will need remedying and inappropriate materials must be removed before introducing further energy efficiency measures. See 4.2 for detail on suitable materials when installing energy efficiency measures.

Above: Cement mortar applied to this stone wall has led to increased stone decay.

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- **Junctions and interfaces** between original structures and later extensions can present challenges when retrofitting as they are likely to perform differently in terms of heat transfer and moisture. Detailing these areas correctly is important for the overall success of retrofit work.

Inappropriately designed and installed alterations can impact a building's resilience to climate change impacts (see 4.1) and heritage significance (see 1.3 and 5.3). Now, for example, inappropriate energy efficiency modifications are increasingly leading to overheating.

Overheating occurs when a building does not allow heat to escape sufficiently, causing internal temperatures to increase to the point that occupants experience discomfort. This can happen if the building is over-insulated, if the beneficial thermal inertia of mass walling is undermined by the application of internal insulation, or if there is insufficient attention paid to issues like reducing solar gain. Thermal improvements should be balanced with ventilation and with a consideration of summer temperatures and of the risk of overheating.

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Top: A later brick addition to a timber framed building.

Right: This building has various later extensions at the rear of the original structure.

Impact of defects on thermal conductivity

The thermal conductivity of a material refers to the ability of that material to conduct heat. Materials with lower thermal conductivity transfer heat at a lower rate. The thermal conductivity of traditional building materials varies but is generally lower than modern materials, such as steel. The thermal conductivity of a material (expressed as W/mK) is not dependent on the thickness of the material in question. Instead, the U-value represents the thermal transmittance of a given thickness of material or assembly (expressed as W/m2K). U-values are explained further in 3.1.

Alterations to a building can change the thermal conductivity of that building's fabric. For example, where insulation is introduced, the insulation will usually have a lower thermal conductivity than the original construction, thus preventing heat transfer.

When the building fabric becomes wet, the material has a higher rate of thermal conductivity. This means that more heat is lost through wet building fabric than dry building fabric which, once again, emphasises the importance of good repair and maintenance prior to retrofit. If insulation gets wet, regardless of the type, it becomes less effective, as the increased thermal conductivity will allow for greater heat transfer.

Early cavity wall defects

Cavity walls have a longer history than many people assume, with early prototypes, known as early cavity walls, dating back to the 1820s (see 1.2).

These early cavities can cause problems when retrofitting a building. They can become blocked or bridged by falling debris or a raised ground level. Cavity wall ties can fail, giving rise to cracks within brickwork, and to the instability of the structure itself.

Where such early cavities are found, these should be thoroughly assessed for the presence of defects or bridging across the cavity to ensure that any retrofit measures are suitable for the structure. Cavity wall insulation defects are not the only risk to the performance of cavity walls. Other measures, including loft and floor insulation, can also impact on the cavity wall's ventilation and moisture performance.

It has become common to fill or partially fill the cavity with a variety of insulation materials. For most early cavity walls, cavity fill insulation will always be unsuitable; instead, the construction needs to be treated as a solid wall, insulated either internally or externally or not at all (see 4.2).

How required repairs affect the installation of energy efficiency measures

Evaluating measures following defects

It is essential to fully assess the implications of necessary repairs and existing building defects when evaluating the options for energy efficiency measures.

Top: Building fabric that is wet has a higher thermal conductivity than dry building fabric, making it both cold and wet.

Example: Defect — Blocked gutter and downpipe

A blocked gutter or downpipe is saturating the external face of a masonry wall. No external wall insulation should be installed until the gutter has been repaired and the building has been allowed to dry. The same blocked gutter and downpipe may appear to have few implications for underfloor or loft insulation. However, if a blocked gutter is saturating the masonry at wall head level, it could be that this is leading to saturation of joist ends in the roof. Likewise, floor joists could be saturated if sub-floor ventilation is blocked or if drainage is not functioning as it should. Further evaluation and resolution are needed before introducing the measures.

Above: Brick wall behind faulty downpipe is dark with damp and vegetation is growing from the pipe.

Left: Guttering below a stone roof is blocked with grass that is growing in the gutter.

Adapting for existing features

Energy efficiency measures may need to be adapted to accommodate existing building features that are often inherent to traditional buildings.

Example: Feature — Press cupboard

A press cupboard is built into the thickness of a mass masonry wall. The masonry on the back wall of the cupboard is thinner than the surrounding masonry and is therefore more vulnerable to condensation and related decay.

If internal wall insulation were to be installed, careful consideration of how to insulate behind this press cupboard would be required.

Example: Feature — Decorative cornice

If the cornice is part of the overall significance of the building, it would need to be preserved. Internal wall insulation would have to be adapted to take this feature into account.

Particular care is required to ensure that internal wall insulation and loft insulation are detailed correctly at the interface in order to ensure that no cold spot is left, as cold spots are vulnerable to condensation-related decay.

Asbestos and radon — impact on choice of measures

Asbestos is not a traditional building material itself, but it was used in many ways, for example, in light fittings, shelving units, lagging, ceiling and floor finishes, roof coverings and board linings to roofs. Asbestos is a serious health hazard for both building occupants and installers of measures. Any retrofit work should allow for an assessment of the presence of asbestos in a building. Where it is found, an assessment should then take into account all applicable Health and Safety Executive guidance around its removal and disposal. There is no safe limit for inhaling asbestos fibres, and with retrofit happening at scale, the risk of disturbing asbestos-containing materials is high.

Radon gas is a naturally occurring hazard that may impact the choice of retrofit measure. Radon is a colourless, odourless, radioactive gas found in some parts of the UK. It can pose a significant risk to health. A map of affected areas is provided by the UK government, along with guidance on how to approach an affected building. In terms of retrofit, the impact of radon is likely to be most significant when floors are being insulated. If radon might be present, additional protective measures will be necessary. Adequate ventilation will need to be considered to mitigate risks to health, as well as measures to reduce air infiltration and exfiltration.

Resources

Cadw, *Maintenance matters!*

Historic England, *Looking after historic buildings*

Historic Environment Scotland, *Maintenance of traditional buildings*

Above: In this case a thin insulation material was used on internal walls to retain decorative cornices.

2.2 Building services: types of heating and ventilation system

National Occupational Standards:
EEM01: K18, K19, K20, K21

Key points

- Types of heating in the building and their implications for the introduction of energy efficiency measures.
- Ventilation systems and their implications for the introduction of energy efficiency measures.
- Measurement of airtightness.

Types of heating and ventilation systems and their implications for energy efficiency measures

Building Services Engineering encompasses a wide variety of mechanical, electrical and passive systems that make a building functional, comfortable and safe. This section will introduce:

- heating systems
- ventilation systems
- infiltration
- airtightness.

As with building defects, it is important to conduct a thorough assessment of the existing building services prior to replacing them, installing new building services or introducing energy efficiency measures. This assessment should include a review of the size, capacity and present loadings of existing services, as well as their condition. Any defects should be identified and remedied before further works are planned.

Table 2: Heating

Heating system	Description	Fuel	How can they be identified?	Implications of building services energy efficiency measures
Gas and oil boilers, and central heating systems	Fossil-fuel-fired heating plant that produces heat for central heating systems including warm air heaters.	Natural gas	• Flue • Floor-/wall-/frame-mounted boiler • Internal gas pipework • Warm air systems will have ductwork and grilles • Gas meter box	Combination boilers (boilers that directly produce heating and hot water) can be weather compensated (reducing the flow temperature to suit the external temperature) in addition to the standard programmable timer and room thermostat(s) that should be installed. Boilers that heat the hot water indirectly (via a hot water cylinder) can still have weather compensation; however, the degree of compensation needs to be limited.
		LPG	• Flue • Internal and external LPG pipework • Floor-/wall-/frame-mounted boiler • External LPG store • Warm air systems will have ductwork and grilles	
		Oil	• Flue • Internal and external oil pipework • Floor-/wall-/frame-mounted boiler • External oil tank • Warm air systems will have ductwork and grilles	

Heating system	Description	Fuel	How can they be identified?	Implications of building services energy efficiency measures
Biomass	Fuel derived from plant material that produces heat for central heating systems.	Wood chip and wood pellet	• Flue • Floor-mounted boiler • Boiler-mounted fuel hopper on smaller boilers • Separate fuel store and feeder system for larger boilers • Thermal store may be installed	The thermal response (how long it takes for the heating plant to react to a change in heating demand) can be slow for this technology. This is why thermal stores are sometimes used with biomass boilers. The controls that are required for this technology vary in complexity according to the size of the heating plant. It can be possible to operate smaller biomass boilers connected to a typical heating system by using the integral user control interface which has a digital display on the boiler. Larger biomass boilers with automated fuel delivery systems can require more complex proprietary controls and Building Energy Management Systems (BEMS).
Open fires, gas fires and stoves	These can be fossil fuel fired or they can burn wood. They heat the room in which they are located with radiant heat; a proportion of heat is lost via the chimney/flue. The sale of house coal was banned in May 2023. Smokeless alternatives to house coal that are authorised for use in smoke control areas are available.	Natural gas	• Flue/chimney • Internal gas pipework • Gas meter box	This type of heating can only be controlled manually by adjusting either the output of the heater for gas and oil fires or amount of solid fuel that is combusted.
		LPG	• Flue/chimney • Internal and external LPG pipework • External LPG store	
		Oil	• Flue/chimney • Internal and external oil pipework • External oil tank	
		Coal (smokeless alternative)	• Flue/chimney • There may be a coal store and fireplace accessories	
		Wood	• Flue/chimney • There may be a wood store and fireplace accessories	
Flueless gas appliances	These can be wall-mounted fires where the flame is visible or floor standing space heaters. They heat the room in which they are located with radiant heat; because of requirements for open external ventilation grilles, there will be heat losses.	Natural gas	• Internal gas pipework • Wall-mounted fire • Gas meter box	This type of heater is unlikely to be suitable for historic buildings because the products of combustion (including water vapour) will be present in the space being heated. In addition, the space being heated will require permanently open fixed external ventilation grilles. When the weather is cold, the low-temperature external air will enter the room. This will have an adverse effect on energy consumption, thermal comfort and the ability to use heat recovery ventilation systems in the space. This type of heating can only be controlled manually by adjusting the output of the heater.
		LPG	• Internal and external LPG pipework • External LPG store • Wall-mounted fire	
		Butane	• Floor standing portable heater with self-contained butane cylinder	

Heating system	Description	Fuel	How can they be identified?	Implications of building services energy efficiency measures
Electric heating	These heaters come in a wide variety of forms including radiators, flat panels, fan convectors and underfloor heating.	Electricity	• Power supplies to mains plugs or fuse connection units	Controls are possible; however, this will require wiring to individual electric heaters or a group of heaters using the same power circuit. This type of heating can be expensive to operate, and controls are strongly recommended to allow room temperature adjustment and so that the heating is programmed to operate only when it is required.
Electric boiler and central heating system	Electrical heating plant that produces heat for central heating systems.	Electricity	• Floor-/wall-/frame-mounted boiler • (similar in appearance to a fossil-fuel-fired boiler without the flue and piped fuel supply)	Controls are essential because this type of heating can be expensive to operate. This will allow room temperature adjustment, and the heating can be programmed to operate only when it is required.
Air source heat pumps (ASHPs)	ASHPs use the heat available in the outside air to heat the building. ASHPs are a very efficient heating technology.	Electricity	• Outdoor unit • Buffer vessel or thermal store may be installed • Air-to-air systems will have indoor units which can be wall mounted, ceiling recessed or concealed within a purpose-made enclosure	This technology is a building services energy efficiency measure, and it can require the replacement of the existing heat emitters, pipework and pumps. It is essential to install and configure the controls to ensure that the heat pump operates effectively. In smaller buildings and most residential properties, the manufacturer's proprietary controls will usually be installed. BEMS are more likely to be installed in larger buildings with more complex building services installations. Smart time-of-use electricity tariffs can be used with smart meters and thermal storage to generate heat when the electricity cost is lowest.
Ground and water source heat pumps (GSHPs and WSHPs)	GSHPs and WSHPs use the heat available in the ground or water to heat the building. They are a very efficient heating technology. There are different types of external collectors for both GSHPs and WSHPs.	Electricity	• Internal heat pump • Buffer vessel or thermal store may be installed • Manhole covers may be installed externally to allow access to manifold chambers	This technology is a building services energy efficiency measure, and it can require the replacement of the existing heat emitters, pipework and pumps. It is essential to install and configure the controls to ensure that the heat pump operates effectively. In smaller buildings and most residential properties, the manufacturer's proprietary controls will usually be installed. BEMS are more likely to be installed in larger buildings with more complex building services installations. Smart time-of-use electricity tariffs can be used with smart meters and thermal storage to generate heat when the electricity cost is lowest.

Heating system	Description	Fuel	How can they be identified?	Implications of building services energy efficiency measures
Hybrid heat pumps	This technology combines an air source heat pump with a conventional boiler. The boiler will typically be used during the coldest weather with the heat pump providing the majority of the heating during the heating season.	Electricity and Natural gas/Oil/LPG	• Floor-/wall-/frame-mounted boiler • Flue • Outdoor unit • Internal and external fuel pipe • Oil and LPG will have external fuel storage	This technology is an improvement upon fossil fuel boilers; it does not, however, fully decarbonise the heating system, because fossil fuels are still being used. The maintenance cost is typically high because both the boiler and heat pump need to be maintained. It is essential to install and configure the controls to ensure that the heat pump operates effectively. In smaller buildings and most residential properties, the manufacturer's proprietary controls will usually be installed. BEMS are more likely to be installed in larger buildings with more complex building services installations.
District heating	These systems generate heat at one location and then typically use below-ground heating pipework to connect to individual buildings. The heat is transferred to each building using a heat exchanger; some heat energy is lost due to the system distribution pipework.	Varies	• Heat exchanger • Heat meters are common	District heating systems typically use fossil fuels although modern systems are starting to use heat pumps. When fossil fuels are used, there will not be any emissions at the heated building, but they will be generated at the location of the district heating plant. It is possible to insulate some heat exchangers which can reduce the amount of heat loss.
Combined heat and power (CHP)	Fossil fuels are typically used to generate electricity, and the heat can be used for space heating. This technology tends to suit larger buildings/sites or district heating systems where there is constant energy demand.	Varies	• Floor-mounted generator • Flue • Internal and external fuel pipe • Oil and LPG will have external fuel storage	CHP systems can be designed and controlled to be heat led or electrical-power led, depending on the application. It is essential to have a good understanding of the energy profile of the building to ensure that the CHP plant machine is correctly specified.
Heating, Ventilation and Air Conditioning (HVAC) systems	These systems use a variety of energy sources to control the temperature of the mechanically ventilated air. Air conditioning also controls the humidity of the air.	Varies	• Large air handling units (AHUs) or medium-sized ventilation units • Ductwork	AHUs can sometimes require BEMS depending on the complexity of the installation. Heat recovery is common in most HVAC systems to avoid the energy contained within conditioned air being exhausted externally.

Ventilation

The term **ventilation** generally refers to air movement and air exchange. **Air movement** is the movement of air around a space. This recirculation of air within a space can happen through air exchange or through the heating and cooling of air, which causes it to rise or fall respectively. **Air exchange** is air swapping between different spaces, either between rooms or between external and internal environments, e.g. through an open window or a loosely fitting door.

There is no such thing as good or bad ventilation. It is simply a question of what effect the ventilation is intended to achieve. Air exchange between external and internal environments is important to prevent the build-up of carbon dioxide, water vapour, and aerosols and particulates, all of which contribute to poor indoor air quality and can lead to ill health. Too much air exchange, however, especially when uncontrolled, can make the living environment cold and uncomfortable.

Ventilation in historic buildings

Ventilation is essential in historic and traditional buildings to manage the build-up of moisture. Traditional building fabric and construction material, such as timber, stone, earth and lime, which allow a degree of moisture movement, are generally permeable. The movement of air across building fabric aids with vapour dispersal, reducing condensation, mould and fungal growth, which would otherwise lead to the deterioration of the building fabric.

Ventilation can be **controlled** (e.g. opening a window) or **uncontrolled** (e.g. air infiltrating through gaps and cracks in the building fabric). A building that has lots of gaps in the fabric will have a higher infiltration rate, resulting in a greater heat loss/gain than a well-sealed, low-infiltration-rate building. Reducing infiltration can significantly improve energy efficiency. However, a balance must be found between improving the airtightness of a building and reducing airflow to the point that poor internal conditions result.

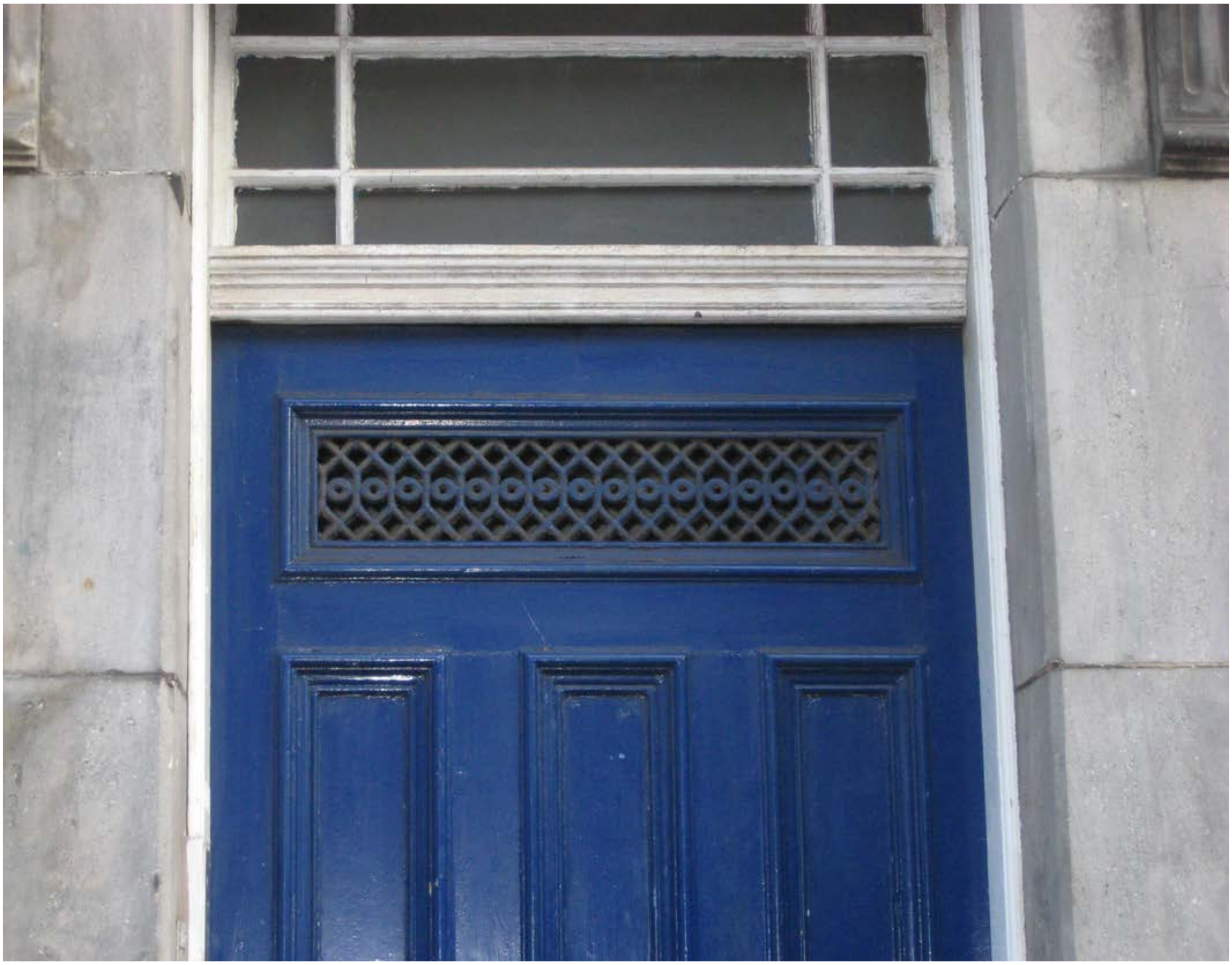
Above left: This ceiling vent has been overpainted and is therefore blocked and not functioning as designed.

Above right: Vents and other building service elements can be decorative and contribute to the heritage significance of a building, such as this ceiling vent.

Next page top: Ventilation grille in an external door.

Next page bottom left: External vent allowing ventilation into the subfloor.

Next page bottom right: A blocked fireplace has a vent to allow ventilation through the chimney flue.



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Air infiltration

Air infiltration is the uncontrolled movement of air through the building envelope where free-air paths exist. Gaps and cracks can rapidly transport both heat and moisture (as water vapour) between the inside and outside of a building, affecting heat-loss calculations, heating design and energy performance. The amount of infiltration depends on the airtightness of the building, the wind and the density of the air. The most common locations of infiltration are:

- the periphery of openings, including windows, doors and roof lights
- junctions between the main structural elements
- joints between walling components
- gaps in membranes, linings and finishes
- service penetrations, e.g. gas and electricity entry points and overflow pipes
- building defects.

Types of ventilation

Natural ventilation uses the outside air for ventilation purposes or cooling for thermal comfort.

Internal air quality depends on both the control of the natural ventilation and the quality of the external air. Building locations where the external air is polluted will have poor indoor air quality when natural ventilation is used.

The effectiveness of natural ventilation depends on wind and density differences between inside and outdoor air (warm air is less dense; it is therefore buoyant and rises). Closing any building openings will reduce the effectiveness of these strategies or may prevent them from working entirely.

Types and examples of natural ventilation

Cross-flow ventilation — this type of natural ventilation is normally wind driven and it occurs when there are ventilation openings on both sides of the space concerned. It is a more effective method of ventilation than single-sided ventilation (with openings on one façade of a space).

Stack ventilation — this type of natural ventilation is driven by differences in air density. Fresh cool air enters the building via ventilation openings at a lower level and the warmer air leaves the building via higher level openings. The difference in height between the openings is referred to as a column of air.

Natural ventilation is identified by the presence of openable windows, external grilles (which also work with mechanical ventilation system) or roof-mounted windcatchers.

The majority of natural ventilation is manually operated and therefore dependent on both user education and behaviour. Forms of natural ventilation that are automatically controlled include external louvres with motorised dampers and roof-mounted windcatchers. These can be controlled to maintain a comfortable internal environment and good indoor air quality.

Natural ventilation can be a lower energy and lower carbon option compared to mechanical ventilation, although naturally ventilated spaces ordinarily lose more heat energy to the external environment than mechanical solutions with heat recovery included. Where building occupants understand the natural ventilation strategy and are actively engaged and invested in its success, natural ventilation can be effective. In practice, this is not the case, and it is common for windows to remain closed when the weather is cold, meaning that the internal spaces are not ventilated.

Mechanical ventilation uses an electrical fan to ventilate the internal space by providing outside air. It cools, providing thermal comfort and mitigating against the overheating of equipment (this only works if the external air is cooler than the internal air), and removes moisture and odours.

There are various mechanical ventilation strategies:

- **Mechanical Extract Ventilation (MEV)** generally uses natural ventilation such as background ventilators for the air supply and mechanical extract fans to exhaust the air. These include localised extract fans, commonly found in bathrooms or kitchens (cooker hoods), which operate intermittently. Alternatively, there are also mechanical extract ventilation systems that operate continuously.
- **Positive Input Ventilation (PIV)** uses a mechanical supply fan to create a positive pressure that displaces the internal air and drives it externally via any gaps in the fabric. The supply fan is commonly installed in the loft and the supply air is filtered to improve the internal air quality.
- **Mechanical Ventilation with Heat Recovery (MVHR)** uses a heat exchanger and a supply and extract fan. This avoids the energy contained within heated or conditioned air being exhausted externally. MVHR is a building services energy efficiency measure.

- **Purge ventilation** refers to the manual operation of windows or mechanical ventilation to rapidly remove pollutants or water vapour from a space.
- **Mixed mode ventilation** uses a combination of mechanical and natural ventilation. It is common for the mechanical ventilation system to be automatically controlled to maintain indoor air quality when this cannot be achieved by natural ventilation alone.

Mechanical ventilation systems are often identifiable by the presence of external and internal grilles (which also work with natural ventilation systems), fans or air handling units, ductwork (unless small façade fans are installed) and system controls.

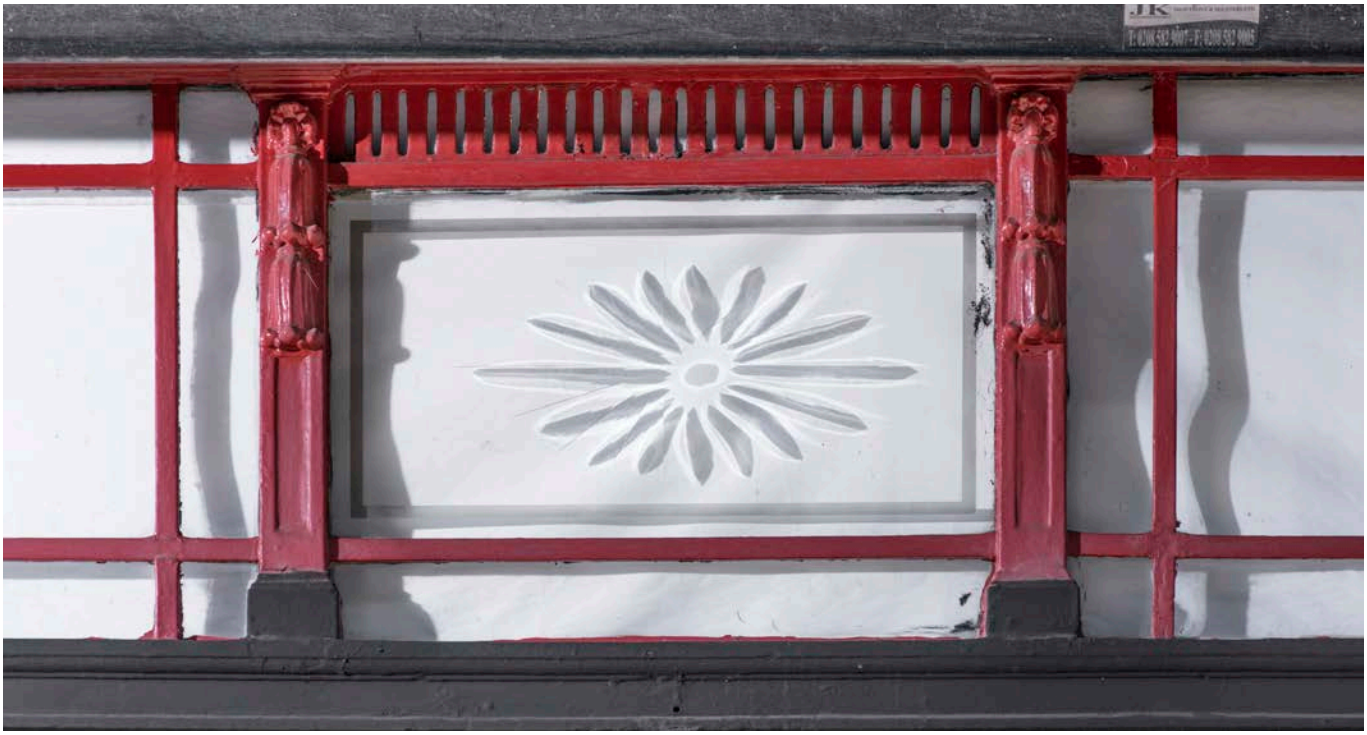
Mechanical ventilation systems can be controlled manually or automatically. The system can be activated automatically: by the operation of lighting; by the detection of presence; according to temperature or humidity levels; or according to time. All mechanical ventilation should be controlled so that it only operates when it is required.

Building regulations require a degree of mechanical ventilation to bathrooms and kitchens. In addition, some older buildings may not have sufficient cross-ventilation or internal volumes to allow the full dispersal of water vapour. In these instances, mechanical ventilation should be considered.

Permanently open ventilation provides ventilation for the building fabric or for the combustion process. This type of ventilation is generally identifiable by grilles or airbricks in the façade (external and internal). Low-level grilles are typically used to ventilate basements or to allow moisture to evaporate from sub-floors. They are usually fixed, permanent openings with no control. Adjustable internal grilles that close the opening are not permitted when their function is to provide outside air for combustion purposes (i.e. flueless fires, open fires and stoves).

Trickle ventilators, another example of permanently open ventilation, provide background level ventilation which is particularly useful in the colder winter months when windows are often closed. These can be identified by small openings internally and externally at the top of windows. Most have internal manual adjustments.

Care should be taken not to undermine the purpose of permanently open ventilation by covering it unless specialist advice has been sought and alternative ventilation provision has been accounted for.



Above: Ventilation grille in the transom light of a historic shopfront.

Airtightness

In older and traditional buildings, lack of airtightness can account for the largest proportion of total heat loss. For new buildings and large extensions, building regulations require a minimum standard of air permeability. A ventilation rate can be estimated through calculations using the building volume, areas of openings and average wind speed. This can be added to the rate of mechanical vents and extracts that are designed according to specific flow rates.

There are two test methods for determining the airtightness of a building. Testers need to have received appropriate training and be registered.

- **Fan pressurisation method**
  Also known as the 'blower door method', this is the most common procedure. A fan is temporarily mounted into an external door, and airtightness is measured at a relatively high pressure of 50Pa. This pressure can cause unnecessary stress on sensitive historic building fabric. Industry guidance requires that both a pressurisation and depressurisation test are performed to mitigate any problems caused by the pressurisation and this more accurately reflects the process of natural air leakage.

- **Pulse method**
  This method of testing uses a lower test pressure differential of 4Pa, which is more representative of the conditions that a building normally experiences. The pulse method works by releasing a pulse of air and measuring the decrease in building pressure. This test is much quicker than the fan pressurisation method.

In addition to the above testing methods, experienced professionals can use the following methods to identify areas where air permeability could be an issue:

- **Tracer gas tests**
  This type of testing uses a harmless, odourless gas. Specialist equipment can detect the gas concentration, which helps to identify areas of air leakage. Tracer gas testing is highly accurate and allows for precise identification of specific leak paths; it is usually only used in specialist applications such as pinpointing small or challenging leaks or in high-performance buildings.

Left: Fan pressurisation test or 'blower door method'.

- **Smoke tests**

  Smoke testing can give a visual indication of the air leakage paths through the building envelope. Whilst this does not give an empirical measurement of the airtightness, some testing companies use smoke tests to identify the location of air leakage.

  It is common for smoke tests to be used when a building does not achieve the design air permeability target. By understanding the location of air leakage, it is possible to plan and carry out targeted remedial work to improve the airtightness.

- **Infrared thermography**

  Infrared thermography can provide invaluable information on historic buildings, without requiring intrusive investigation. An infrared camera that records radiation is used to indicate surface temperature. This technology can be used for many purposes in older and traditional buildings, including identifying air leakage paths.

- **Ultrasound testing**

  This type of testing is particularly useful for identifying air leakage areas that are hidden within the fabric. It works by detecting the sound waves that are produced by air leakage.

Resources

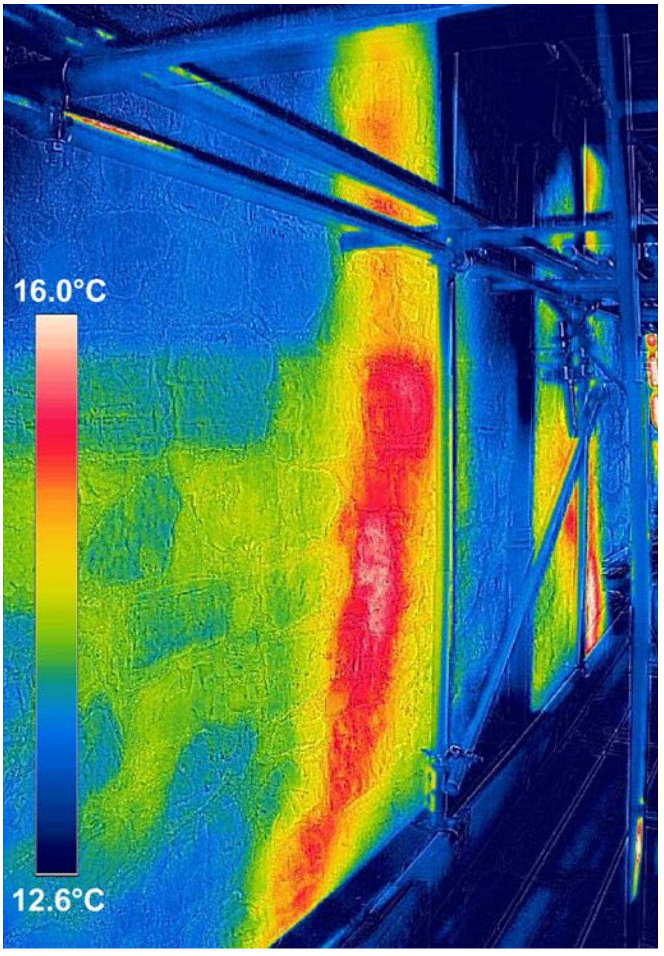
Historic England, *Building Services Engineering*

CIBSE, *Guide B2 ventilation and ductwork*

CIBSE, *TM23 Testing buildings for air leakage*

Build test solutions, *Pulse vs Blower Door*

Xiaofeng Zheng, Edward Cooper, Mark Gillot and Christopher Wood, A practical view of alternatives to the steady pressurisation method for determining airtightness, *Renewable and Sustainable Energy Reviews 132* (Oct. 2020)



Above: Smoke testing around a fireplace.

Bottom: Thermal imaging of a disused flue.

2.3 Energy usage and occupant behaviour

National Occupational Standards:
EEM02: K8, K9, K10, K11

Key points

- How occupant behaviour affects energy usage.
- How occupant behaviour impacts moisture and humidity level.
- How to measure and assess the implications of occupant behaviour on proposed energy efficiency measures.

Occupant behaviour and its implications for energy efficiency measures

Occupant engagement and energy use

How occupants engage with a building has an impact on building performance and energy efficiency. Changing occupant engagement can lead to a substantial reduction in energy usage and can influence the performance of energy efficiency measures. The table below lists some key factors that affect occupant behaviour in relation to energy use.

Table 3: Factors affecting energy use

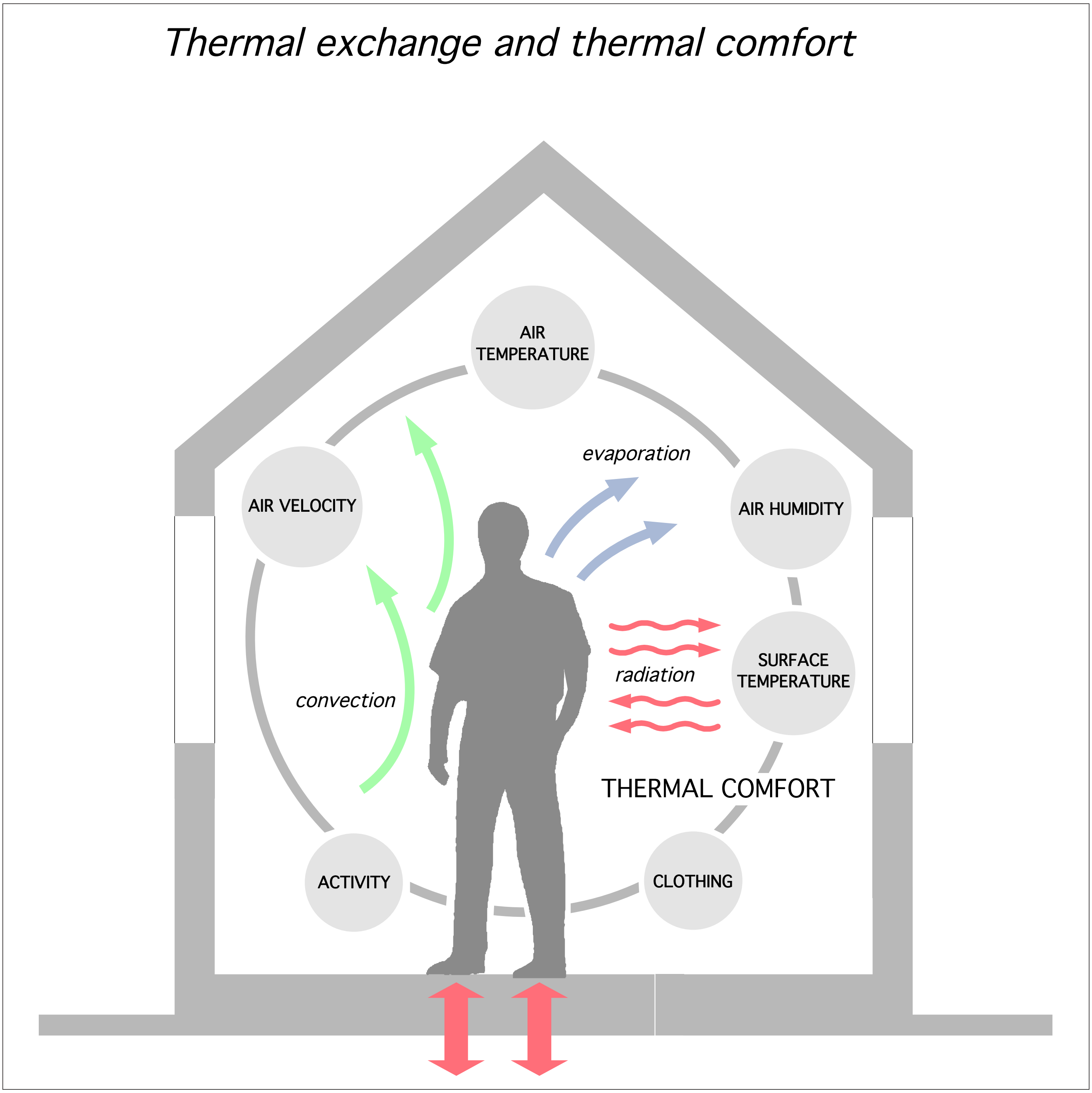
Factor(s)	Description and influence on energy use
Social	Social factors include occupant age, health and lifestyle. An elderly couple spending a lot of time at home, a family with children and a single person who is out at work all day will have very different energy needs.
Economic	Economic circumstance can affect energy usage and occupant comfort — for example, the types and age of electrical appliances in the home and the budget available to pay for heating. The availability of grants to improve the energy efficiency of a property usually depends on economic circumstance. Occupants in fuel poverty are most likely to experience poor thermal comfort, resulting in adverse health impacts.
Geographical	The geographical location of a building, including its exposure to the elements as well as regional weather patterns, affect building performance and the thermal comfort of the occupant, and their energy use as a result. For example, in humid locations, occupants may experience increased discomfort and want to use mechanical cooling.
Psychological	This includes perception of comfort and comfort-taking (enjoying a greater degree of thermal comfort) and how this impacts occupants' energy usage. Psychological impacts can also arise from other factors listed here. For example, an occupant may wish to reduce their energy usage due to their environmental values which result from their social circumstance.
Building type, use and occupancy	The building type and how it is used will affect energy use. The size of the building, conversions from, for example, industrial to domestic use and level of occupancy will all factor into energy use — as will whether occupants are out at work all day, or work from home, and so on.
Systems types and controls	How an occupant uses their building's heating, cooling and ventilation systems has a significant influence on a building's energy usage. Ventilation can be occupant controlled or not, and occupants can override programmed settings for immediate comfort.
Tenure types	Tenure types can have an impact on the maintenance of a building and its energy efficiency as well. For example, an owner-occupier is able to implement measures to increase their property's energy efficiency, whereas a tenant is unlikely to be able to do this. This affects occupant energy usage.
Environmental quality (internal and external)	The surrounding environment might affect the way occupants engage with systems. For example, occupants might not open windows if they live in an area of high pollution or noise, which will impact ventilation.

Influences on thermal comfort

Environmental **temperature** and **humidity** form the basis of our thermal comfort — our thermal satisfaction with our surrounding environment. A broadly acceptable range of conditions is:

- **17–24°C** (internal design criteria for dwellings, depending on the type of room)
- **40–60% humidity**.

However, our perception of the conditions within this range can vary greatly depending on other factors.



Above: Influences on thermal comfort.

Temperature

Humans produce heat through metabolism:

- **Basal metabolism** is the involuntary production of heat from organs, e.g. heart and lungs.

  People have different basal metabolisms and may therefore feel comfortable at higher or lower environmental temperatures. Our basal metabolism fluctuates and can be affected by age, health, sex, hormones, time of day and other factors.

- **Muscular metabolism** is the heat produced when muscles are moved voluntarily, e.g. while carrying out physical work or when shivering.

  People's muscular metabolism changes according to the level of activity at a given time. We may prefer a higher or lower temperature when sitting still than we do when moving around.

Thermal comfort is also relative to other conditions. For example, if we move from a very cold environment to a warmer one, we may initially feel too hot, before we begin to acclimatise. Once we are acclimatised, other factors can take effect; for example, if we become less active, we may begin to feel too cold.

The movement of air also affects our perception of comfort. Experiencing draughts can make us feel colder than the ambient temperature might otherwise make us feel. Moreover, some parts of the body, like ankles and the back of the neck, are more sensitive to draughts.

Effect of heat transfer on occupant comfort

The three heat transfer mechanisms outlined in section 1.2 — convection, conduction and radiation — impact occupant comfort.

Occupants can lose heat to building fabric and surfaces. Conductive heat losses can occur from building occupants to surfaces they are in contact with, such as a cold floor, therefore making the person feel less comfortable. Radiant heat losses and gains can also occur between occupants and surfaces; however, here they do not need to be in contact with the relatively cold or warm surface.

Convection influences the amount and speed of air movement within a space which will impact how comfortable a person feels.

Heat transfer also occurs from the occupant to the environment via **evaporation** and **respiration**.

Traditional buildings are constructed using a broad range of techniques and materials. Those of thinner construction — single-skin brick or timber frame — may lose more heat through the fabric (by conduction) than well-insulated modern counterparts. However, mass solid wall construction, thick stone or earth, have considerable thermal mass or thermal inertia. As discussed in Chapter 1, this means they heat up and cool down more slowly. This ability to 'buffer' heat and moisture helps to even out fluctuations in temperature and humidity and to maintain the thermal comfort of occupants in some conditions. This can be particularly useful in light of increasing summer temperatures.

Humidity

Humidity levels outside of the broadly acceptable range carry health risks. For example, overly dry conditions can cause respiratory problems and dryness of skin, and wet conditions encourage mould growth.

Occupants can influence humidity in several ways by creating additional moisture. Breathing releases water vapour into the air. Activities such as boiling water in a kettle, cooking food, bathing, showering and drying wet clothes also contribute water vapour.

Temperature affects humidity, as warm air can hold more moisture than cold air. Hot and humid conditions can feel oppressive. As moist air cools, it becomes saturated and condenses to liquid. This can lead to condensation forming on surfaces or in materials.

Thermal comfort is hard to achieve for all occupants. Research indicates that **thermal comfort** and **ventilation issues** are the primary concern of occupants. Views shift with seasonal change depending on the building type — for example, whether it is naturally or mechanically ventilated. It is common for users of naturally ventilated buildings to complain that they are too cold in winter and too hot in summer. Conversely, users of air-conditioned buildings complain that they are too cold in summer and too hot in winter.

Occupant behaviour to remedy discomfort

When occupants are not thermally comfortable, they will take action to remedy their discomfort. Turning up the heating or air conditioning is a primary way people control their environment. This can lead to increased energy usage — and to unnecessary usage when the building is not sufficiently energy efficient to prevent excess heat loss. Occupants may also choose to block ventilation routes in an attempt to reduce draughts, thereby reducing internal air quality and increasing the risk of damp conditions and mould growth.

In addition to the physical effects of the building environment on occupant comfort, psychological factors also have an impact. For instance, the perceived level of control over users' environment influences how comfortable they report feeling. People appreciate the ability to modify their environmental temperature, e.g. via a thermostat or opening windows, and they report higher dissatisfaction when this is not possible.

Studies show that identical buildings can vary in their energy use by a factor of three or more due to occupant behaviour. Additionally, as the efficiency of building fabric improves, e.g. through retrofitting, the proportional impact of occupant behaviour increases further.

Assessing energy use in buildings

There are various ways that we can measure and assess the energy use in buildings and understand how our behaviour impacts use:

- **Fuel bills**
  Typically, these are higher in the darker, colder months, as we use additional energy to light and heat our homes.
- **Meter data**
  We can analyse energy use by looking at meter data — for example, electricity use vs. gas use for heating and hot water. Sub-meter data can provide further information on different building areas or specific equipment.
- **Smart meter data**
  This can provide live energy use readings and time-specific data.

Above: Smart meters can keep track of the daily energy use.

Resources

For the studies showing the high impact of occupant behaviour, see:

Kirsten Gram-Hanssen, Standby consumption in households analyzed with a practice theory approach, *Journal of Industrial Ecology* (2010)

William O'Brien *et al.*, International review of occupant-related aspects of building energy codes and standards, *Building and Environment* 179 (July 2020)

Adrian Leaman and Bill Bordass, Are users more tolerant of 'green' buildings, *Building Research and Innovation* 35, 6 (2007)

Timber frame house in Kelvedon, Essex.

Chapter 3

Modelling Building Performance

Overview

This chapter covers the following topics:

- Energy Performance Certificates
- Energy modelling and methodologies
- The impact of using default U-values and alternative sources of U-values
- The range of thermal and moisture models.

Above: Infrared thermography testing.

3.1 Energy modelling and methodologies

National Occupational Standards:

EEM01: K3

EEM02: K21, K22, K23, K25

Key points

- Energy Performance Certificates.
- Standard Assessment Procedure (SAP) and Reduced Data Standard Assessment Procedure (RdSAP).
- The Simplified Building Energy Model.
- Calculating and obtaining U-Values.
- The limitations of energy modelling for older and traditional buildings.

Energy performance certificates

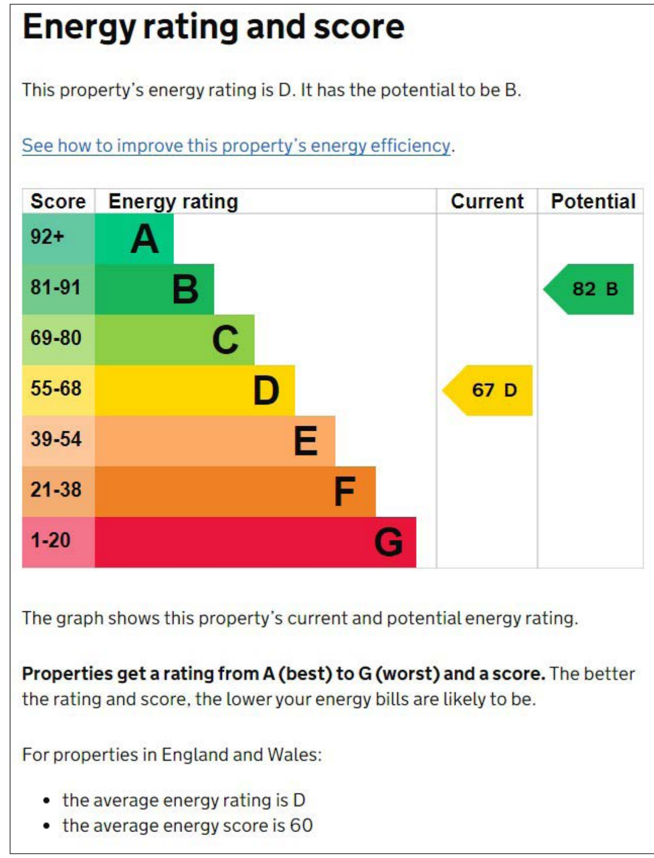
UK law requires an Energy Performance Certificate (EPC) when a building is constructed, sold or let. EPCs rate buildings from the most energy efficient (A) to the least energy efficient (G) and suggest possible energy improvements. Scores are based on an evaluation of the building's fabric and operation. EPCs must be carried out by qualified assessors and are valid for 10 years. They are listed on a searchable register of EPCs.

These assessments are UK-wide. New and refurbished buildings must demonstrate compliance with requirements set out by the various national building regulations:

- Part L of the Building Regulations in England and Wales
- Section 6 of Building Standards Scotland.

The ratings reflect buildings' energy performance but not actual energy consumption. The improvement recommendations are generic and standardised based on building type and rating, rather than specific to an individual building.

There are two models used to calculate EPCs: the Standard Assessment Procedure and the Reduced Data Standard Assessment Procedure.



Energy rating and score

This property's energy rating is D. It has the potential to be B.

See how to improve this property's energy efficiency.

Score	Energy rating	Current	Potential
92+	A		
81-91	B		82 B
69-80	C		
55-68	D	67 D	
39-54	E		
21-38	F		
1-20	G		

The graph shows this property's current and potential energy rating.

Properties get a rating from A (best) to G (worst) and a score. The better the rating and score, the lower your energy bills are likely to be.

For properties in England and Wales:

- the average energy rating is D
- the average energy score is 60

Minimum Energy Efficiency Standards (MEES)

In England and Wales, the Government's Minimum Energy Efficiency Standards (MEES) sets a minimum EPC rating that all properties on the private rental market must meet. There are exemptions.

Listed buildings, alongside places of worship and certain low-usage buildings, are not always required to meet these minimum ratings. These buildings should still be assessed and an EPC report produced, but where implementing recommendations to improve the rating would unacceptably alter the character or appearance of the building, it may be exempt from compliance. Any such exemption must be evidenced.

As with all measures to improve the energy efficiency of a traditionally constructed building or building of heritage significance, recommendations set out in an EPC should only be implemented as part of a staged approach that takes account of the whole building and risks to building fabric and performance.

For recommended upgrades and improvements to listed buildings, conservation-accredited architects or local authority conservation officers should be consulted.

EPCs and the modelling and methodologies they are based on are currently under review. Requirements to meet minimum EPC ratings vary across the UK nations and are also constantly evolving. Always check the latest standards for the relevant nation and give careful consideration to the measures recommended by an EPC assessment — see the end of this chapter for information on the limitations of EPCs and energy modelling for older and traditional buildings.

Above: Energy Performance Certificate.

Energy modelling methodologies

Standard Assessment Procedure (SAP) and Reduced Data Standard Assessment Procedure (RdSAP)

SAP and RdSAP are the UK government–approved methodologies to estimate the energy performance of domestic buildings (dwellings) and to generate Energy Performance Certificates.

- **SAP** is used for newly built dwellings and dwellings converted from commercial to domestic via Change of Use. Assessments must be undertaken by assessors who hold an On Construction Domestic Energy Assessor (OCDEA) qualification.
- **RdSAP** is used for existing dwellings only. Assessments are completed by a domestic energy assessor (DEA) who holds a Domestic Energy Assessment qualification. RdSAP software cannot be used for commercial buildings, public buildings, newly built dwellings or dwellings which have been converted from commercial to domestic.

SAP does not require visiting or surveying new buildings when assessing them; instead it uses the original building plans and a more comprehensive methodology. Input data for RdSAP, on the other hand, is gathered from site surveys alone. The process is streamlined to minimise the time required on site and to ensure consistency and comparability across all Domestic Energy Assessments (DEAs) and resulting Energy Performance Certificates (EPCs).

RdSAP relies on a set of standard assumptions about the building, irrespective of the occupants, including the standard occupancy and standard heating patterns. For any non-standard entries into the RdSAP calculation, a generic set of conventions including assumed U-values is used; all DEA schemes use the same conventions.

Due to the limitations of RdSAP when used for older and traditional buildings (see below), some recommendations may be inappropriate for the fabric performance, character and appearance of the building. Carrying out inappropriate work to meet a specific EPC rating can result in harm to the building fabric and to the health of the occupants.

Simplified Building Energy Model

The Simplified Building Energy Model (SBEM) is the UK government–approved energy assessment procedure for existing non-domestic buildings. The assessor must hold a Non-Domestic Energy Assessor (NDEA) qualification.

> The Minimum Energy Efficiency Standards and the models and methodologies on which the EPCs are based are under ongoing review by the UK government. In the meantime, careful consideration should be given to the measures recommended by an EPC assessment.

SAP, RdSAP and SBEM calculations

The calculations used in these models are based on energy balance — that is, the range of factors that contribute to energy efficiency, including:

- The thermal insulation of the building fabric.
- The air-leakage ventilation characteristics of the dwelling and of ventilation equipment.
- The efficiency and control of the heating system(s).
- Solar gains through dwelling openings.
- The fuel used to provide heating — both for water and for the space — ventilation and lighting.
- The energy for space cooling, if applicable.
- Renewable energy technologies.

These calculations use various data inputs to model the building in question, including a combination of building-specific information, for example:

- Building size and its component U-values.
- Assumptions about the building’s climate.
- Occupancy and use of the building.

These assessments are UK-wide. New and refurbished buildings must demonstrate compliance with requirements set out by the various national building regulations:

- Part L of the Building Regulations in England and Wales
- Section 6 of Building Standards Scotland.

U-values

How U-values are calculated

A **U-value** is a measure of the rate of transfer of heat through a structure — whether the structure is a single or a composite material — divided by the difference in temperature across that structure. It provides an overall coefficient figure of **thermal transmittance** for a given material or construction. It is calculated as the heat flow in watts through a measured area (m^2) of material, considering the difference between internal and external temperatures (K). It is expressed in W/m^2K, watts per metre square Kelvin.

The U-value tells us how well insulated a structure is. The lower the value, the better insulated the structure. High levels of thermal transmission are not only a matter of the materials used; insulation systems that have not been installed properly can have considerably higher thermal transmittance than anticipated. This is often as a result of **thermal bypass**.

Materials can be attributed an **R-value** — the measure of **thermal insulance**, a material's resistance to heat based on its density and thickness — expressed as m^2K/W. Thermal insulance is the opposite of thermal transmittance. Summing a series of R-values and dividing 1 by this number will produce an overall U-value for a construction assembly, such as a wall.

Manufacturers of material will typically quote U-values or R-values for use in calculations. 'Standard' U-values are regularly given in literature or software for common building elements, such as brick cavity walls or suspended timber floors. These are often generalised but are broadly considered to be within accepted conventions for new buildings; applied to traditional buildings they can sometimes be inaccurate.

Sources or processes to obtain U-values

There are various online tools available that can help calculate the U-value of the different combinations of materials that form a building element, e.g. masonry, insulation and internal linings forming a wall. Some tools include libraries listing materials or products and the U-value data and information. There are also software packages that contain in-built U-value calculators.

U-values can also be measured in situ by installing heat flux sensors and temperature monitors on the internal and external faces of a wall, floor, roof or other material. Assuming theses readings are obtained correctly according to conventional procedures, they can give more accurate values than those estimated using online tools or software.

Left: In-situ U-value testing.

When calculated U-values or in-situ U-values should be used

Research has shown that modelled U-values for solid walls have generally been poorer than in-situ measurements. In-situ measurements are often more accurate because they can capture the specificities of the physical construction such as pockets of air, the variation in the density of a given brick or group of bricks, or gaps in insulation. For example, historic masonry walls perform better — i.e. have lower U-values — than conventional calculations indicate. These differences can be sufficiently large that the amount of additional thermal insulation required to bring a wall's U-value up to regulations would need to be adjusted. Similar research has been conducted on floor constructions, roofs and windows, with a range of results.

Therefore, when possible, U-values should be measured in situ. If it is not possible to do so because of practical or financial reasons, calculating U-values based on more accurate survey information — i.e. attempting to identify the composition of the element and calculating U-values based on these layers — is preferable to using default values.

The limitations of models for older and traditional buildings

The use of SAP, RdSAP and EPCs to evaluate the energy efficiency of buildings has several limitations, particularly when it comes to older and traditional buildings. These methods rely on assumptions about energy consumption and building performance in a way that prejudices traditionally constructed buildings.

Assumptive data and calculations

As noted earlier, RdSAP calculations are based on data that is assumed — that is, generic and standardised — including the use of default constructions and U-values for building elements according to the age of the building. Building age is categorised into 'bands' that broadly correspond to the various updates to building regulations over the years.

Default U-values are assigned to the floors, walls, roofs, windows and doors. The assumptions behind these values might be broadly accurate for modern buildings, provided they were constructed according to the minimum standards of their contemporaneous regulations.

However, only one category — Band A — encompasses buildings constructed before 1900, greatly limiting the range of defaults applicable to older and traditionally constructed buildings. These defaults cannot possibly account for the huge variety in historic constructions, not to mention potential variations within the layers of a particular wall (i.e. its build-up). Assumptive U-value data for walls has improved in RdSAP with additional variables like construction material, thickness and presence of wall lining.

But still, U-values and airtightness are particular areas of weakness in SAP and RdSAP calculations, and RdSAP has been criticised for disproportionately overestimating energy demand for pre-1919 buildings.

Limited assessment

As EPC inspections are non-intrusive and relatively cursory, any constructions that are not easily identifiable will by default be attributed minimum standards. This could mean assuming that there is no loft insulation if the loft is not easily accessible or failing to account for retrofitted cavity insulation if there is no direct evidence of its installation.

The EPC methodology allows for extensions added to the main part of the dwelling and some elements of different construction to be calculated separately to account for resulting variation in construction age and type. However, these allowances are still limited by the age banding and U-value assumptions mentioned earlier and assessors may lack the capacity and knowledge to make these calculations, especially when traditionally constructed elements of the building are not easily identifiable.

SAP and RdSAP calculations are also independent of factors related to the individual characteristics of the occupancy of the building at the time when the rating is calculated. For example, they do not factor in the specific number of or details about the occupants, or the specific use or efficiency of particular electric appliances. Nor do they consider the particular heating patterns or temperature settings of the building. They also assume average UK climate conditions using data from Sheffield.

Inappropriate recommendations

EPC reports include a 'potential rating', indicating how the EPC rating may be improved through the implementation of recommended changes. However, this potential rating can only be achieved in full if the three recommendations are completed in order. This is because improvements and their resultant 'point' increases are cumulative within the SAP methodology.

This disadvantages older and traditionally constructed buildings since factors such as construction type, exposure or historically significant fabric can mean that some of the recommendations set out in the EPC report are technically unsuitable or would cause harm to heritage significance.

Appendix S of the SAP methodology allows a select few recommendations to be 'suppressed' if there is documentary evidence that they will cause harm:

- **Cavity wall insulation** — where there are access issues, because of narrow cavities or high exposure or where there is a recognised moisture risk and fabric or health impacts.
- **Loft insulation** — when excessive moisture found in the loft could create further issues if left untreated.

The EPC methodology therefore does not currently account for the risks to fabric, performance and significance of older and traditionally constructed buildings.

Inconsistent assessments

Research has also shown that EPCs are inconsistent. One in four EPCs record property size so inaccurately that it significantly affects the awarded rating; sometimes multiple EPC assessors produced significantly different results for the same properties, with pre-1919 buildings having the greatest range of discrepancies in their awarded ratings. This is partly due to the extent of unknowns — but also because the diversity in the historic fabric and techniques of construction are not adequately accounted for in the RdSAP methodology.

Resources

Further information on EPCs, U-values and modelling methodologies can be found here:

Historic England, *Energy efficiency and historic buildings: Energy Performance Certificates* (EPCs) case studies

NBS, What is a U-value? *Heat loss, thermal mass and online calculators explained*

Brian Anderson, *Conventions for U-value calculations* (BRE Scotland, 2006)

Department for Energy Security and Net Zero and Department for Business, Energy and Industrial Strategy, Standard Assessment Procedure: *Overview of how a home's energy performance is calculated using the Standard Assessment Procedure (SAP)*

BRE Group, *Standard Assessment Procedure*

For more on the weakness of U-values and air tightness in SAP and RdSAP, see Christopher Whitman and Oriel Prizeman, U-value monitoring of infill panels of a fifteenth-century dwelling in Herefordshire, UK, APT Bulletin XLVII, 4. (2016)

On EPC's inaccurate recording of property size, see Jenny Crawly et al. Quantifying the Measurement Error on England and Wales EPC Ratings, *Energies* 12, 8 (2019)

On different EPC estimates by different assessors, see David Jenkins, Sophie Simpson and Andrew Peacock, Investigating the consistency and quality of EPC ratings and assessments, *Energy* 138 (Nov. 2017)

On the inadequacies of RdSAP methods for older buildings, see Samantha Organ, Minimum energy efficiency — is the energy performance certificate a suitable foundation? *International Journal of Building Pathology and Adaptation* (Oct. 2020)

3.2 Thermal and moisture models

National Occupational Standards:
EEM02: K24, K27, K28, K29

Key points

- The range of available thermal and moisture models.
- Why and how hygrothermal modelling is used.

Model types

Broadly speaking, there are two kinds of energy models that can simulate building performance:

- **Dynamic models** are complex and sophisticated simulations; they rely on very high levels of data input that must be fully coordinated with the building geometry, requiring technical knowledge from across architectural and engineering disciplines to produce accurate hourly or half-hourly simulated energy use data. They are reliably predictive of real energy use when conducted in accordance with relevant protocols, but the process is extensive.

Example: Integrated Environmental Solution (IES)

IES is an example of dynamic modelling software that uses whole building energy simulation analysis to evaluate energy efficiency, comfort, ventilation, HVAC performance, energy consumption, CO_2 emissions, peak demands, energy cost and renewable energy production.

- **Simplified models** use sets of assumptions, calculations and algorithms to replicate the dynamic model process but with a reduced input data requirement and a simpler modelling process. While the simulated outputs are less granular, producing monthly or annual energy use calculations, they can be comparable to dynamic models in terms of reliability and accuracy under the right circumstances.

- **Steady state models** are a type of simplified model. Unlike dynamic models, steady state models do not account for the accumulation of mass and energy within the system and instead assume that variables are constant. Examples of steady state models include U-value calculations (see 3.1), basic heat loss calculations (see 3.2 and 2.2) and Glaser calculations (see 3.2).

Example: Passive House Planning Package (PHPP)

PHPP is an advanced steady state model that uses building physics to evaluate building performance, primarily energy consumption, peak demands and MVHR requirements. It is used to assess renewable energy production, and plug-ins such as PHRibbon can be used to calculate embodied carbon. It contains algorithms and calculations to approximate dynamic models.

Hygrothermal models

Hygrothermal modelling can simulate the movement of heat and moisture through building assemblies by calculating information on temperature, water content and humidity on the surfaces and within the layers of a construction. Simulating the performance of part of a building can evaluate the risks of problems associated with moisture and heat such as damp, condensation, mould growth, heat loss and thermal bridging.

Above: Continuous hygrothermal monitoring setup.

This type of simulation is only demonstrable for the particular build-up, orientation and exposure modelled. Where these parameters change for other parts of the building, the same level of risk cannot be inferred and specific simulations need to be undertaken. The material and climate data needed to accurately undertake this modelling is not available for many traditional building materials and locations and can be difficult to measure or obtain.

- **The Glaser method** is one method of testing for the risk of surface and interstitial condensation within a construction build-up. It is a relatively quick and simple method but is a steady-state calculation that relies on assumptions and has several limitations such as the exclusion of some forms of moisture movement mechanisms. It can be used to provide an overall estimation of risk.
- **WUFI** is a dynamic modelling software that can more accurately and realistically describe the behaviour of moisture in a build-up. It can model a fuller range of moisture movement mechanisms, e.g. capillary action, and account for heat and moisture storage within construction layers.
- **Therm** is a multidimensional thermal modelling software tool that can be used to assess the thermal performance of building components and connections between building components. Thermal bridges occur when heat bridges the cold exterior and warm interior. They can occur when one plane meets another, e.g. at the junction between ground floor and wall or wherever the building structure changes. Thermal bridges are either measured in W/mK to quantify the linear heat flow occurring at a given location and expressed as a Ψ (Psi) value, or measured in W/K to gauge a specific 3D point and expressed as a χ (Chi) value. Therm can evaluate the performance of a given junction or point and calculate the respective Ψ (Psi) or χ (Chi) value.

  Therm can also be used to analyse the risk of condensation or mould growth on an interior surface at a thermal bridge condition by calculating the 'surface temperature factor', or FRSI.

Reducing thermal bridging by prioritising thermal continuity when detailing insulation proposals results in consistently higher surface temperatures and corresponding lower condensation risk. Thermal bridges become increasingly critical as the U-value of a construction improves, since differences in surface temperatures can be more extreme when junctions are poorly detailed or implemented and concentrated spots of condensation and mould growth can occur.

Assessing heat loss

A considerable proportion of heat loss from buildings occurs due to a lack of airtightness and excess air infiltration. See section 2.2 for methods of assessing airtightness, air infiltration and systems for controlled ventilation.

In-situ Building Performance Evaluation (BPE) using these assessments can mitigate assumptions in and limitations of EPC methodologies.

Heat gains

Buildings are affected by heat gains as well as losses. Major factors and sources of heat gains include:

Solar Gains

These are affected by the geographical latitude, time of year, building orientation, local climate conditions, the number of windows and type of glass, and the presence of solar control measures, e.g. external shutters and overhangs, internal blinds and special glass coatings.

Internal Gains

These are generated by activities within the building that produce heat indirectly or not as their primary function, such as people, lighting, cooking, heating water, the operation of electrical appliances and the circulation of hot water through pipework.

The difference between heat gains and losses creates a heat balance calculation that needs to be compensated for in order to maintain thermal comfort in a building. Broadly speaking and depending on the building type and use, in the temperate UK climate, overall heat gains generally remain lower than the overall losses during the winter months, and this is made up for with heating. In some summer months — and with increasing frequency due to the warming climate — heat gains may outweigh losses and lead to overheating and subsequent danger to health.

Co-heating tests

A co-heating test is a way to measure the whole energy losses of a building. It involves heating an unoccupied building to a specified temperature, typically 25°C, and then maintaining that internal temperature for a period of days while energy and climatic data is collected, including the internal humidity and external climatic conditions. Monitoring the energy requirement of maintaining the internal temperature relative to the external conditions allows for the calculation of the heat loss coefficient.

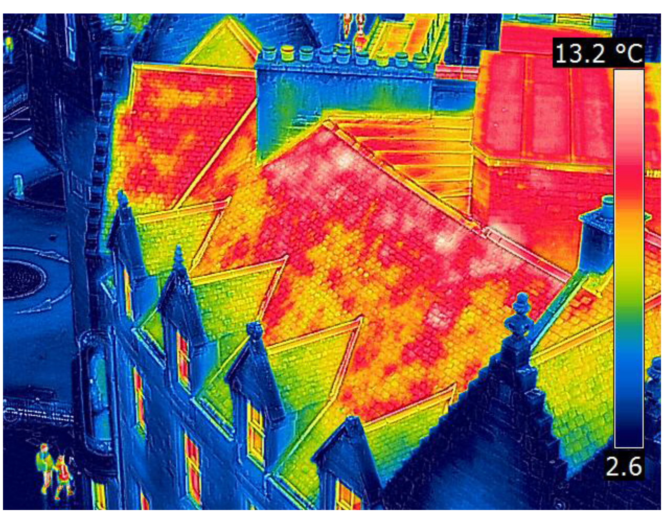
Airtightness test

As calculations typically rely on standardised and average data, testing for airtightness can be a more accurate method of assessing airtightness in older buildings, and is also a requirement for new buildings. See 2.2 for methods of assessment.

Infrared thermography

Infrared thermography can be used to evaluate several properties of a building. Thermal cameras can produce imagery indicating the temperature of building surfaces. This information can highlight areas of greater heat loss that, in the case of an image of an external wall, could indicate thermal bridging, the absence of insulation or the presence of hidden construction elements, such as timber framing.

Internally, this technique could be used to highlight areas at risk of mould growth, and it is a useful tool for detecting hidden defects and water ingress. Used in conjunction with other methods described here, it can be a useful tool for selecting and targeting areas for certain retrofit improvements.



Above: Infrared thermography testing.

For example, it could be used to highlight thermal bridges caused by poorly installed windows or badly designed structural details, or it could be used in conjunction with an airtightness test to identify sources of draughts.

Building sensors

Sensors can be used to monitor buildings and provide insight into their internal environmental conditions. As well as temperature and humidity, increasingly inexpensive tools that monitor air quality data — including VOCs, particulate matter and CO_2 levels — can be used to evaluate a building's risk to occupant health. Such equipment can be used to provide spot readings indicating potential requirement for further investigation or can be installed to provide longer term data to monitor the performance of a building more effectively.

Resources

[Cadw, *Investigation of moisture and its effects on traditional buildings*]

Above: Air quality sensor.

Chapter 4

Approaches, Options, Measures

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Overview

This chapter covers the following topics:

- Giving advice on introducing energy efficiency measures to older and traditional buildings.
- The range of energy efficiency measures relevant to older and traditional buildings.
- Assessing technical risks associated with energy efficiency measures and how to mitigate the risks.

4.1 Approaches to implementing energy efficiency measures

National Occupational Standards:

EEM01: K9, K10

EEM03: K1, K2, K3, K4, K12

Key points

- Reasons for improving energy efficiency.
- The whole building approach.
- The performance gap.
- Establishing intended outcomes.

Above: Llanthony Secunda Priory, Gloucester. The building is from various periods, including a Medieval range and Victorian farmhouse. A whole building approach is essential to ensuring the complexities of the building and its context are considered when investigating options to improve energy efficiency.

Reasons for improving the energy efficiency of older and traditional buildings

This is a non-exhaustive list of reasons for incorporating energy efficiency measures in older and traditional buildings. The reasons are often complementary and interconnected.

Carbon

Seeking to reduce carbon emissions relating to a property is imperative if we are to transition away from fossil fuels and reduce the impact of global warming. Reducing carbon emissions is intrinsically linked to reductions in energy use. One report estimates that fabric improvements to UK listed and unlisted historic dwellings in conservation areas could amount to operational carbon savings of between 4.6 and 7.7 $MTCO_2$ per year. In addition, the reuse and retrofit of existing buildings is widely acknowledged to be a more sustainable solution than the demolition and construction of new buildings. In part, this is because embodied carbon is saved when existing structures and materials are reused.

Energy savings and cost

Energy efficiency measures should reduce energy consumption and therefore energy costs. Whilst occupant behaviour will still have a considerable impact on energy usage, the higher the energy performance of a building, the lower the energy demand, providing more resilience against fuel poverty and fluctuating energy prices, which are often driven by external factors outside the occupier's control. The extent of energy efficiency measures will, among other things, depend on the available budget. If funds are limited, then the focus should be on the key works that generate the greatest reduction in energy for the money spent. Payback times, material or technology lifespan, and associated maintenance costs are important to consider.

Health and comfort

Implementing energy efficiency measures can create healthier, more comfortable spaces. Better health and greater comfort have knock-on effects like improved productivity and wellbeing, which reduces pressures on local health services and reduces the number of sick days taken by employees. The health and comfort of the building occupants should be a priority in any project. This requires understanding what makes building users comfortable and providing them with the ability to control their immediate environment.

Right top and bottom: Climate change impacts, including increased extreme weather events, are putting the historic built environment at risk.

Regulations, ratings and funding requirements

Energy efficiency measures may need to be introduced in order to comply with building regulations and to meet minimum EPC requirements or grant funding criteria. It is important to understand what specific outcomes are required to meet each of these, how these outcomes work as part of a whole building approach, and if they can tie in with other planned repair, renovation or extension proposals for the building, while sustaining heritage significance.

Resilience against climate change impacts

In our changing climate, our historic built environment is at increasing risk of adverse impacts. Our precise understanding of these impacts is still emerging, but it is largely understood that the UK will see an increase in precipitation and extreme weather events, with milder but wetter winters and hotter summers. A whole building approach to retrofit should therefore consider climate resilience and include effective adaptation interventions. This means addressing risks arising from the potential impacts of climate change, including the increased wetting of the building fabric, overheating and flooding resulting from rising temperatures, intensified storm events, and increased rainfall.

Climate resilience — Flooding

Flooding is the UK's number one climate change risk. The selection of interventions and energy efficiency measures in flood zones requires specific consideration. If flood risk is not taken into account, it is possible that inappropriate installations may be made which then would have to be removed and replaced after a flood. This is not simply a question of selecting waterproof insulation materials, as these can trap moisture within the building fabric. See the resources listed at the end of this section for more information.

Above top: Flooding in York city centre in 2012.

Above bottom: The River Severn overflowing its banks at Worcester in 2007.

Futureproofing our built heritage

A whole building approach to retrofit will put the building into a good state of repair, eliminating any defects that already exist. It can also protect and enhance the heritage value and significance of the building by, for example, reinstating lost architectural details. Carrying out energy efficiency measures on our older and traditional buildings can improve resale value and help safeguard the building's long-term use and user enjoyment. When weighing up reasons to improve energy efficiency in historic and traditional buildings, doing nothing can often be considered a risk.

Reduced carbon emissions, energy savings and costs, occupant and building health, energy performance ratings and climate resilience all have the potential to be enhanced by choices made to improve energy efficiency. However, it is important to remember that they can also be undermined by inappropriate, ill-considered or incorrectly implemented choices.

Top: An empty historic building in Appleby. Improving energy efficiency as part of broader works to bring the building into good repair and new use can help to safeguard its future.

Bottom: Former military barracks in a conservation area in Bicester have been repurposed to provide housing.

Whole building approach

With historic and traditional buildings, there is rarely a one-size-fits-all solution to energy efficiency measures. Opportunities and constraints can vary widely depending on context, and the optimum solution in one case might be quite different in another, even if buildings appear similar. Therefore, a site-specific approach is needed.

A **whole building approach** is a systematic process for devising and implementing suitable, coordinated and well-integrated solutions. It uses an understanding of a building in its context to find balanced solutions that save energy, sustain heritage significance and maintain a comfortable and healthy indoor environment. A whole building approach encourages us to start from a position of knowledge by considering wider environmental, cultural, community and economic issues. It views the building as a system of interconnected materials, functions, users and services and provides interventions that work together to deliver the maximum benefits as effectively as possible.

A conventional approach to refurbishment changes elements individually. But treating the building in a piecemeal way can result in negligible energy and carbon savings and can damage the building fabric and lead to abortive work.

A whole building approach does not require that all refurbishments be undertaken at once. Work can be carried out in phases; but each phase should contribute to the wider objectives and plan for the building, and each measure should be considered for potential risks. One measure should not adversely affect the outcomes and performance of another.

Example

Upgrading windows and insulating walls improves airtightness. But these improvements will also reduce air movement, causing a build-up of moisture. A whole building ventilation strategy must be in place in order for airtightness to be beneficial.

Left: An exposed rural cottage. Its location will affect the choice of energy efficiency measures.

Right: A whole building approach considers the building's context. Here, in response to predicted increased rainfall and exposure of this building, the crow steps have been protected by lead.

To developing a whole building approach, the following are key:

- an informed understanding
- a logical and systematic process which questions what is required and why
- an iterative design process.

The approach requires engagement with building users, owners and managers throughout the whole process, including handover. Outcomes should be reviewed to inform future processes.

How to establish intended outcomes

- Establish what the priorities and drivers are for the short, medium and long term.
- Set out how these are interrelated and how they fit within the broader plan for the building.
- Consider other planned improvement works, expansions and anticipated changes to use and occupation, and how heritage values and building fabric can be maintained.
- Establish a baseline from which improvements can be measured, including for energy use, carbon emissions, comfort concerns and thermal performance of fabric.
- Engage with everyone who has a role in maintaining, operating and using the building to inform the brief.
- Try to set both quantitative targets, relating to carbon and energy reductions, and qualitative targets, relating to occupant comfort and usability.
- Document decisions and set up a framework for measuring and reporting progress as the work develops in order to facilitate a continuous feedback loop to inform decision-making.

Understanding the user's expectations of energy efficiency measures is important when planning a retrofit project. If a user reports certain discomforts in a building, those are areas that need to be addressed as part of the project.

The ease of use of new systems and the ease of maintenance will have a long-term impact on the performance of the building. A building whose systems and new fabric are hard to maintain are at risk of poor maintenance, which over time diminishes the performance of the energy efficiency measures.

Minimising the performance gap

The performance gap is the difference between the predicted or calculated building performance at the design stages of a project and the actual measured performance once the building is occupied. The predicted performance is based on modelling, while the actual performance is based on meter readings.

With retrofit projects, the difference can be significant, meaning that reductions in energy use, fuel cost and CO_2 emissions are often not as initially predicted.

When older and traditional buildings have undergone energy efficiency measures, a performance gap may arise due to several factors, including:

- Incorrect baseline assumptions regarding fabric performance.
- 'Prebound effect', when less energy is used than had been calculated. Average energy consumption for heating older homes is consistently lower than the calculated energy ratings which is why energy savings from thermal upgrades are often lower than anticipated.
- Natural variations in thermal performance of structural and fabric elements that cannot be fully determined in the design stages.
- Inaccuracies in the data and models used to predict energy performance.
- The difference between in-situ performance and laboratory test results.
- Unrealistic design expectations.
- Inadequate design and specification of improvements.
- Ill-considered detailing of critical junctions.
- Poor construction and installation quality.
- 'Rebound effect', when occupants increase energy consumption following energy efficiency improvements or use the money they have saved on energy bills for other energy-intensive activities.
- Unexpected operating conditions or changes in building occupancy or patterns of use following installation of measures.
- Ineffective handover and training of building users to ensure effective operation of new products and systems.
- Poor maintenance of building and building services.

The following are essential steps in the whole building approach and can help minimise the performance gap:

- Develop an engagement plan agreeing on clear outcomes and expectations with building owners, occupiers and caretakers.
- Thoroughly assess existing building conditions, including:
  - Building context, form and situation (including site constraints, future climatic context, identification of planned improvement, maintenance and upgrade work).
  - Significance and building history (as discussed in Chapter 1).
  - Building use and patterns of occupation (including appraisal of existing occupancy levels, types of occupants and their requirements).
  - Existing building construction and condition (including defects, thermal and moisture properties and any previous retrofit measures carried out).
  - Existing services and energy use (including appraisal of efficiency, capacity and life expectancy of ventilation, cooling, heating, hot water, lighting systems and power supply and consideration of options for lower carbon energy supply).
- Dedicate sufficient time, resources and expertise to developing an appropriate design and specification for the works.
- Specify simple and appropriate control systems.
- Appoint suitably competent specialists, contractors and suppliers.
- Effectively commission and hand over the building, providing adequate training to building users.

Resources

For more on climate change impacts and adaptation in a heritage context, see:

Historic Environment Scotland, *A guide to climate change impacts*

Historic Environment Scotland, *Short guide: Climate change adaptation for traditional buildings*

Historic England, *Improving climate resilience through adaptation*

Historic England, *Flooding and historic buildings*

Cadw, *Flooding and historic buildings in Wales*

For more information and reports on the benefits of the whole building approach, see:

Historic England, *Whole building approach for historic buildings*

Department for Energy Security and Net Zero and Department for Business, Energy and Industrial Strategy, *Demonstration of energy efficiency potential* (DEEP)

IEA, *Multiple benefits of energy efficiency* (2019)

On the estimated carbon saving of fabric improvements, see:

Matthew O'Connell, Grosvenor (written in collaboration with The Crown Estate, Historic England, National Trust and Peabody), *Heritage and carbon: Addressing the skills gap*

4.2 Range of energy efficiency measures

National Occupational Standards:
EEM02: K1, K2, K3, K4, K5

Key points

- Energy efficiency measures for building fabric.
- Energy efficiency measures for building services.
- Materials and construction techniques.
- Interactions and effects of combinations of energy efficiency measures.

The range of energy efficiency measures relevant to older and traditional buildings

The following tables outline some of the key energy efficiency measures relevant to older and traditional buildings. For clarity, they are listed by **building component**. However, it is important to consider the interconnectedness of each measure. Possible interactions with other measures are listed in the table, alongside specific risks and their relative likely impact level.

The lists are not exhaustive. An indication of relative cost has been provided as a guide only, based on the potential economic impact when compared to other interventions of the same category. Accurate costs should be provided by contractors or a cost consultant familiar with retrofit interventions as part of the planning stage of a project.

Level of intervention and technical risk

Alongside relative benefits and costs, measures have been rated by level of intervention and technical risk to help give an indication of the level of likely disruption and potential for harm to historic fabric and to occupant and building health. There are three levels of intervention:

- **Low**
  These interventions will require minimal disruption to the building fabric. They can be implemented quickly with little to no specialist input, often with a quick pay-back. They pose minimal risk of maladaptation or negative impact on occupant or building health and are likely to be reversible or to be part of the standard maintenance regime of a property. Statutory consent, such as LBC, is unlikely to be required.

- **Medium**
  The intervention will require some consideration as it might impact the building fabric and therefore comes with greater risk of maladaptation or negative impact on occupant or building health. However, it is typically reversible and has a minimal visual impact. In some circumstances, specialist advice may be required. Statutory consent, such as LBC, will usually be required in listed properties.

- **High**
  The intervention will cause irreversible change to the existing building's appearance, significance or built fabric. It poses high risk of maladaptation or negative impact on occupant or building health from factors such as moisture accumulation, reduced indoor air quality (IAQ), overheating or accelerated decay. The intervention requires specialist input for installation and is likely to be highly disruptive to install. It might cost more than it saves, in terms of capital and carbon cost, resources and environmental impact. Statutory consent, such as LBC, is highly likely to be needed in listed properties.

Consents such as Listed Building Consent (LBC) and planning permission may be required for many of these measures, particularly if the building is listed or scheduled, or in a conservation area, National Park, Area of Outstanding Natural Beauty or World Heritage Site. Check requirements at an early stage with the local planning authority (see 5.3 for legal and regulatory requirements).

Table 4: Key EEMs for older and traditional buildings — Whole Building

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Reduce energy demand Reduce energy consumption within the existing arrangements. This includes actions such as optimising use of natural daylight, reducing the number of energy-using appliances and reviewing occupant behaviour.	Low	£££	Reducing the consumption of energy (what is often called sufficiency) is the first of the three pillars of the energy transition (see 5.2). It should be the first step when developing proposals. Assess natural daylighting and whether it can be optimised in a space by redirecting mirrors or rearranging furnishings. Where lighting is required, consider zoning to light only spaces in use. Consider electrical equipment and whether it is really needed. Where necessary, assess if its operating times can be reduced. Occupant behaviour — including putting on warmer clothing, closing curtains before turning up the heating and taking shorter showers — can reduce energy demand.	Reduce energy demand within the existing building arrangements as far as possible before carrying out any other EEM.
Planned and proactive maintenance Maintenance is both a prerequisite to undertaking energy efficiency improvements and an energy efficiency measure in and of itself.	Low	£££	While this may not seem like an EEM at first glance, a large amount of energy, comfort and material loss is experienced through poor maintenance. Ensuring a state of good repair of building fabric and services will reduce energy demand and help to achieve sufficiency. It should therefore always come before any further interventions are considered: this is the most sustainable thing you can do with your building. Maintenance activities are wide-ranging, from clearing and repairing rainwater goods and drainage systems to reaffixing or replacing damaged roof slates/tiles and removing vegetation. There is extensive guidance available (see resource list at the end of the chapter).	Ensure building is in good condition before carrying out any other EEM.
Address notable defects Addressing moisture and the source(s) of damp issues, cracks and gaps can improve thermal efficiency of building fabric and reduce unwanted heat loss.	Low to Medium (dependent on extent of defect)	£££ / £££	Failure to address repairs to vital elements of the building envelope will result in significant decay. Unresolved defects exacerbate heat loss from a property, increase energy consumption and impact the health and wellbeing of occupiers. Wet building fabric has higher thermal conductivity than dry fabric. Vegetation or algal growth could be a sign of excess moisture in walls and should be investigated.	Ensure notable defects, including sources of moisture/ damp issues, are resolved before carrying out any other EEM in that area.

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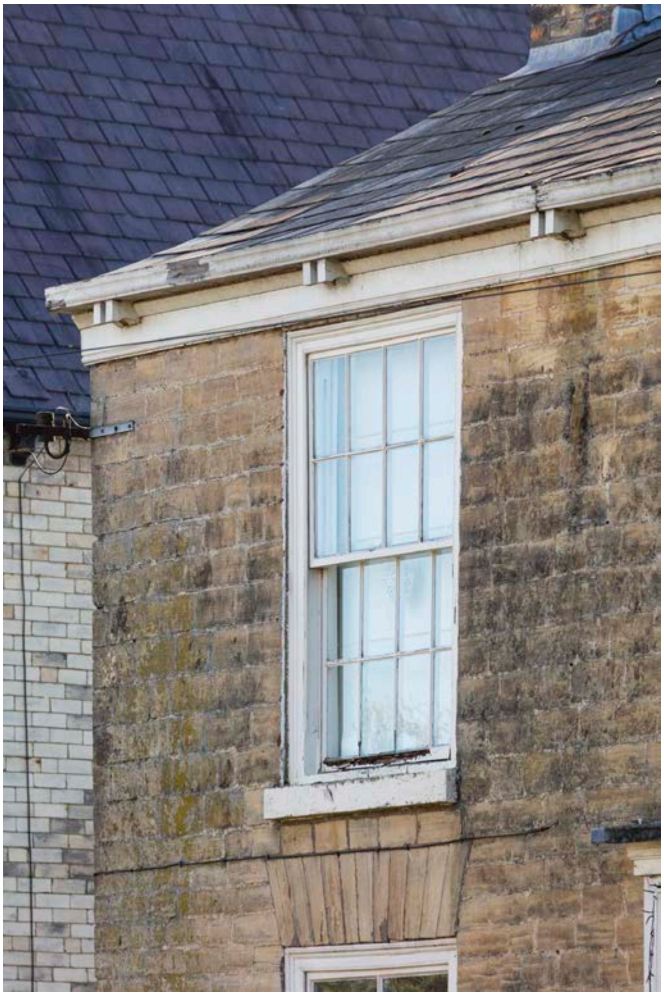

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Above top: Repairs to timber sash window.

Above bottom: Blocked guttering and vegetation growth.

Above top: Timber sash window in need of repair.

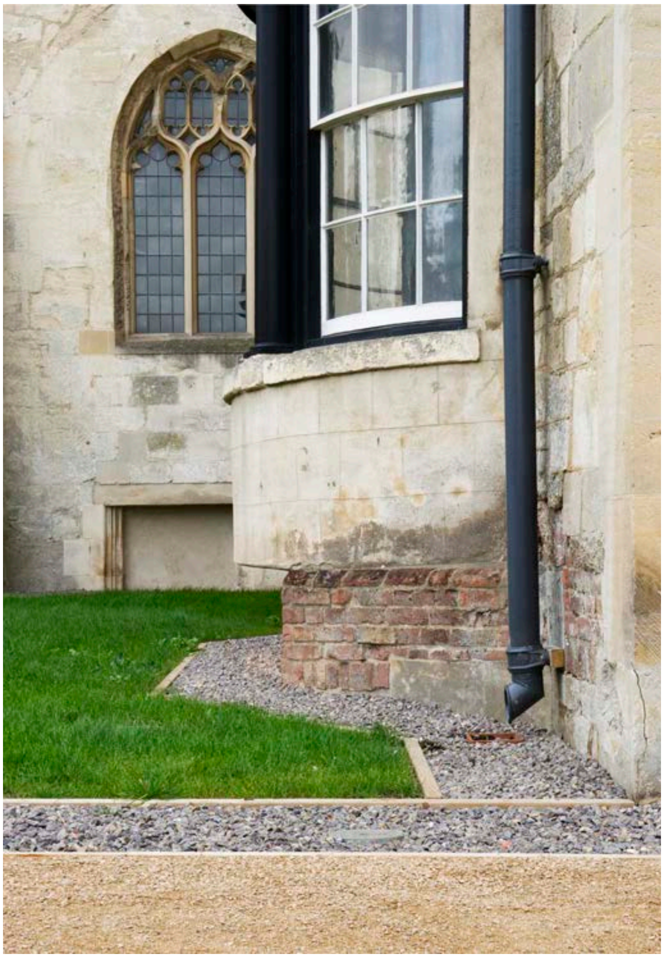
Above bottom: Slipped slate tile.

Table 5: Key EEMs for older and traditional buildings — Roofs and Chimneys

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Update rainwater goods Ensuring rainwater goods and drains are well designed, adequately sized and well maintained can help eliminate water penetration and damp, leading to improved thermal efficiency of building fabric.	Low	£££ / £££	Consider increased rainfall as a result of climate change and whether capacity needs to increasing accordingly. Where alterations have already been made to the building, consider whether rainwater goods have been updated to accommodate any additional run-off.	Planned and proactive maintenance. Insulation of roof and walls.
Chimneys: draughtproofing, blocking or reducing airflow Reducing the airflow through chimneys results in reduced heat loss through a reduction in the rate of air change in a property, improving occupant comfort during heating season. In summer, chimneys can provide passive stack ventilation.	Low	£££	Chimneys are a substantial source of ventilation in traditional buildings and can also be a common source of water ingress if not properly maintained. Heat loss can be reduced through the use of permanent or temporary measures, such as installing a register plate with fixed ventilation, fitting an enclosed stove, fitting a damper plate or using a chimney balloon to allow residual airflow. Consider how controlled ventilation can be maintained throughout the building if fully blocking a chimney, and ensure flues remain ventilated to the outside to prevent moisture build up and condensation.	Insulation of roof and walls. Service upgrades.
Insulate a pitched roof at ceiling level (loft insulation) Adding layers of insulation to a roof above the ceiling to reduce heat loss through the ceiling.	Low	£££	Loft hatch should be draughtproofed and insulated. Batt type (blanket) insulation should be laid in two layers, one at 90 degrees to the other.	Wall insulation. Services upgrades.
Insulate a flat roof Adding layers of insulation to an existing flat roof to reduce heat loss through the roof.	Medium-High	£££	A cold roof can be installed from the inside by removing the ceiling, whereas a warm roof needs a full roof recovering, and may impact the roofline. Both require correct installation of a vapour control layer, with all joints taped or sealed. Sufficient ventilation must be installed to avoid condensation damage, particularly if the area below is used for high-humidity activities, as are bathrooms and kitchens. In a warm roof scenario, it may be possible to apply insulation directly over the waterproofing layer and then apply a protective ballast layer (inverted flat roof). This is an economic solution for small flat roofs that cannot be insulated elsewhere and can be designed to be sympathetic to the existing structure. Prior to installation, the existing waterproofing layer must be tested for condition and resilience to moisture. Roof height will be affected, which may have an impact on any surrounding built fabric. Warm roofs may require specialist drainage arrangements and, therefore, specialist design input.	Rainwater goods. Wall insulation. Solar panels.

Cold roof / warm roof

Broadly, there are two approaches to roof insulation. The term ‘cold roof space’ or ‘cold roof’ is used to describe a roof with insulation at the level of the horizontal ceiling of the uppermost floor, leaving an unheated roof space (attic or loft) above the insulation. In contrast a ‘warm roof space’ or ‘warm roof’ has insulation between or just under or over the rafters, so that the whole of the volume under the roof can be heated and used. Some buildings have combinations of these two arrangements.



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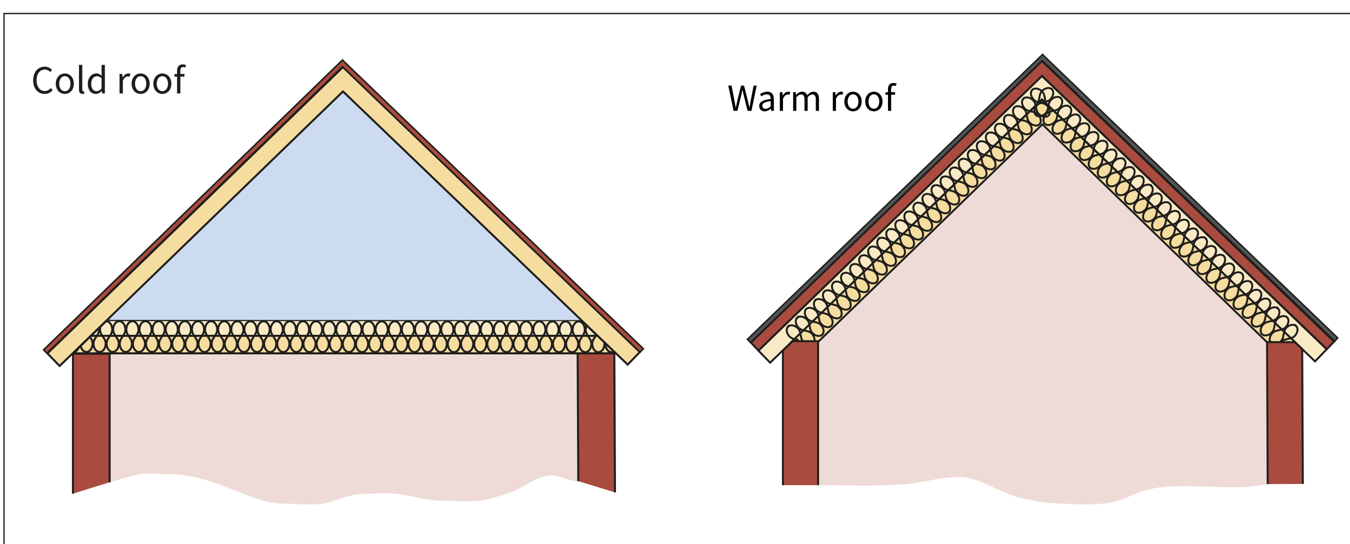

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Above left: New downpipes and landscaping for drainage at the medieval Blackfriars Priory, Gloucester.

Above bottom: Image of Cold and Warm roof.

Above right: Sheep's wool between joists.

Above middle: Flat roofs are most commonly insulated between rafters.

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Insulate a pitched roof between rafters (warm pitched roof) Adding layers of insulation to a pitched roof on the rafter (sloping) plane between the rafters. This has less impact on the useable area of internal spaces and the roof height than below or above rafter insulation, respectively.	Medium	£££	Thickness of insulation must be considered in the context of the building but is likely to be restricted to the depth of the rafters. Typically, a 50mm ventilation gap is needed between the insulation and the underside of the sarking board or felt (where present). Rafters remain a cold bridge. Minimise gaps between the insulation and rafters to maximise insulation efficacy and minimise risk of thermal bypass and infiltration, which allow moist air and lead to condensation issues. This intervention can be combined with additional insulation beneath the rafters to reduce cold bridging and subsequent surface condensation risks, but care needs to be taken not to concurrently increase interstitial condensation risk to roof structure.	Wall insulation. Services upgrades.
Insulate a pitched roof over rafters (warm pitched roof) Adding layers of insulation to a pitched roof on top of the rafters.	High	£££	This intervention is most viable where the roof covering is to be replaced or repaired as part of the project. Otherwise, it can be prohibitively invasive and expensive. It is likely to require LBC on protected buildings. Careful installation and detailing with other measures such as wall insulation maximises thermal continuity which minimises risk of cold bridges and condensation.	Rainwater goods. Wall insulation. Services upgrades. Solar panels.
Insulate a pitched roof beneath rafters (warm pitched roof) Adding layers of insulation to a pitched roof underneath the rafters. This intervention may not require any alteration to the roof covering or change the outward appearance of the building.	High	£££	Thickness must be considered to minimise risk of interstitial condensation. The position below the rafters allows for maximum ventilation beneath the roof covering to reduce interstitial condensation build-up; however, the intervention can reduce ceiling heights and room area in occupied spaces. Risk of condensation forming on a cold structure can be high if insulation depth and ventilation provision are not adequately considered.	Wall insulation. Services upgrades.
Room-in-Roof (RiR)/Hybrid pitched roof insulation Where there is a habitable space within the roof, it is often necessary to implement a combination of roof insulation types; partly on a horizontal ceiling and partly at the rafter line.	High	£££	Each area of roof insulation type retains its considerations as listed above. Ensuring thermal continuity in consistency of coverage and thermal performance and rigorous detailing of junctions is essential to minimise the risks of thermal bridges and condensation.	Rainwater goods. Wall insulation. Services upgrades. Solar panels.

Table 6: Key EEMs for older and traditional buildings — Walls

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Permeable render Permeable renders can reduce the amount of penetrating moisture from rain, accelerate drying and provide greater airtightness.	Medium	£££	Whether replacing an existing render system or installing a new one, permeable render systems, such as lime, require a good level of skill, which can mean that this is a more costly option. There are additives that can improve thermal performance, such as hemp, but their full impact on moisture performance of the renders is not yet fully understood. It is important that the wall substrate be in a good state of repair and free of moisture issues prior to application, otherwise the render may fail. Consider moisture behaviour in a wall prior to selecting render for a project, particularly for buildings that are not currently rendered. When applied to a previously unrendered wall, consent may be required if the building is listed or scheduled or in a conservation area or other heritage designation.	External wall insulation. Window and door upgrades.
Permeable plaster Internal wall plastering can help improve thermal efficiency and airtightness within a room.	Medium	£££	A high level of specialised skill is required for this intervention, which can make it more costly than modern plaster solutions. As with permeable render, there are additives that can improve thermal performances but their full impact on the moisture performance of the renders is not yet fully understood. It is important that the wall substrate be in a good state of repair and free from moisture issues prior to application, otherwise the plaster may fail. Consider moisture behaviour in a wall prior to choosing to plaster internal walls on a project. The presence of significant decorations, such as wall paintings, may mean plaster is not an option.	Internal wall insulation. Ceilings upgrades. Window and door upgrades. Floor insulation.

Insulating walls

Options for wall insulation are outlined below. When insulating walls, take account of and document sources of moisture.

Depending on the substrate, insulation type and location, wall insulation can increase moisture risk and that of condensation, mould growth and fabric decay. It may also undermine the thermal inertia and buffering potential of mass solid walls, heightening risks of summertime overheating and humidity.

On light-weight structures, wall insulation can reduce solar gains to the internal environment and reduce overheating in summer if either external wall insulation or an internal wall insulation material with a high decrement delay factor (time it takes for heat to pass through) is used. Such materials tend to be natural-fibre and permeable products that also mitigate moisture risk.

Left: Insulated lime plaster applied directly to a masonry wall.

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
External wall insulation (EWI) The application of an insulation material and a weather-protective finish to the outside of the wall can reduce heat loss and improve comfort, while reducing the amount of penetrating moisture from rain and providing greater airtightness.	High	£££	Where thermal continuity is ensured through robust detailing, EWI minimises risk of thermal bridges compared to internal wall insulation (IWI), especially around wall-floor junctions. However, EWI significantly impacts the exterior appearance of a building, and relevant approvals may be required. Consideration needs to be given to the detailing of junctions and openings, for example around windows, along ground level and at eaves, to ensure consistent coverage and avoid thermal bridges and water penetration. Roof lines may also need to be extended to provide adequate protection to the top of the insulation. Careful detailing will also be needed at the base of walls to ensure continuity of insulation and the maintenance of ventilation pathways. Use vapour-permeable systems on traditional construction and ensure all vapour-impermeable finishes are removed prior to installation. Defects and damp within existing walls must be addressed before application. All wall-mounted services and fittings (like rainwater goods, canopies, lighting) must be removed prior to installation and reinstalled with appropriate fixings. Various additions to a building can present difficult detailing challenges, including boundary walls and fences, meter boxes, flues and downpipes. Due consideration should be given to material compatibility, exposure, moisture risk and impact on occupant comfort and climate resilience.	Roof insulation. Rainwater goods. Window and door upgrades. Floor insulation.

Left: Contrast between part of a building with external wall insulation and part that has none. The visual impact is considerable.

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Internal wall insulation (IWI) Applying insulating materials to the inside surface of external walls can reduce heat loss and improve thermal comfort in winter months. Great caution must be taken not to create moisture paths to the interior, cause interstitial condensation or overly cool the exterior fabric, which increases moisture content and initiates decay mechanisms.	High	£££	This varies in complexity and risk level depending on the building fabric type, the building's exposure to weather, the depth of insulation, internal fixtures, fittings, services and decoration to the exterior walls, and will have an impact on the internal floor area of a room. Kitchen and bathroom units, skirting, tiling, wood panelling, shutters etc. must all be removed prior to installation. The use of permeable systems is critical for traditional construction. This requires impermeable finishes (like gypsum plaster) to be removed prior to installation. Coverage is vital and should include junctions and reveals to minimise thermal bridges. Party walls also need to be considered; insulation should extend 1m along internal walls from the external wall. Installing IWI always poses moisture risk, with risk increasing more rapidly below a U-value of 0.8 W/m2K. Installation of IWI can undermine the thermal inertia and buffering potential of mass solid walls, which can heighten overheating and moisture risk, and the risk of frost damage to external wall surfaces. Due consideration should be given to material compatibility, exposure, moisture risk and impact on occupant comfort and climate resilience.	Ceilings upgrades. Window and door upgrades. Floor insulation. Permeable plaster. Roof insulation.
Cavity wall insulation (CWI) Inserting a blown or injected insulation material into the cavity of a wall. Great caution must be taken not to create moisture paths to the interior.	High	££	Relatively quick to install in modern construction types. However, not all cavities will be suitable — for example, if they are too narrow or the building exposure to weather is too high. For the most part, CWI will always be unsuitable for traditionally constructed 'early cavity walls'. Cavity walls might be insulated externally or internally, with due consideration of material compatibility, exposure, moisture risk and impact on occupant comfort and climate resilience.	Window and door upgrades. Floor insulation. Roof insulation.
Insulate timber frame The addition of frame infill insulation material or replacement of existing frame infill material with a better performing insulation material.	High	£££	This approach has less visual impact than EWI and less impact on the useable area of internal spaces than IWI. However, if the existing frame infill is historic fabric, its removal is unlikely to be acceptable due to the impact on the significance of the building. Thickness and extent of coverage is likely to be restricted to the depth of the frame members. Great care must be taken to minimise gaps between the insulation and timber frame to minimise cold bridges and risk of timber decay. Where possible, adding a thin layer of IWI in combination with this measure will reduce thermal bridging and associated surface condensation risks, however this may impact the internal aesthetic and increase interstitial condensation risk. Appropriate materials are essential to mitigate the risk of interstitial condensation. Due consideration should be given to material compatibility, exposure, moisture risk and impact on occupant comfort and climate resilience — as with all proposals for the addition of insulation.	Window and door upgrades. Floor insulation. Roof insulation. Permeable plaster/ render.

Table 7: Key EEMs for older and traditional buildings — Windows and Doors

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Draughtproofing and repair Repairing existing windows to make them operational and tight-fitting, as well as fitting draughtproofing strips around all windows and doors.	Low	£££	Minimally intrusive, economic and quick to install, this intervention is simple but highly effective. Historic Environment Scotland guidance suggests that if done effectively, it can reduce unwanted air infiltration by up to 80%. Draughtproofing doors can be done from the outside or inside depending on the product type. Ensure chosen specification is suitable for the door or window type.	Wall insulation. Window upgrades. Renders and plaster. Services (reduces heat demand). Secondary glazing.
Insulated blinds and curtains Reduces heat loss through contact with the glass and frames.	Low	£££	Insulated blinds and curtains are minimally intrusive, economic and quick to install. Appropriately thermally insulated curtains can have both warming and cooling benefits in winter and summer. They can be designed to occupants' tastes and enhance the interior visual comfort. Installation can be easily reversed at a later date for updates or improvements.	Draughtproofing and repair. Wall insulation. Window upgrades. Renders and plaster. Services (reduces heat demand).
Awnings/brise-soleil The installation of external shading devices.	Medium	£££	Awnings and canopies have played an important role in British architecture for centuries. They reduce solar gains and provide weather protection, such as allowing windows to remain open when it is raining to aid ventilation. Awnings impact the appearance of a building, posing challenges for installation on protected buildings, unless a precedent can be established. Multiple design options allow for choosing a sympathetic design to the building. The choice, scale and scope of the awning installation affect the price, with fabric awnings costing significantly less to install than timber.	EWI. Window upgrades. Services (reduces cooling demand).
Shutters Installing or bringing back into use shutters internally or externally. Many traditional UK buildings had shutters, as they offer a range of benefits. External shutters provide shade in the summer and reduce solar gains leading to overheating, and they reduce heat loss in the winter. They provide additional security and weather protection.	Medium	£££	External shutter installation will have a notable impact on a building's external visual appearance. They are expensive, with a continued maintenance commitment. Internal shutters are often cheaper and can have less impact on a building's visual aesthetics, particularly when the interiors are less significant. They have many of the same benefits as external shutters but are less effective against solar gains and weather protection.	Draughtproofing and repair. EWI and IWI. Window upgrades. Awnings. Services (reduces heating/cooling demand).
Insulated panels to doors Insulation added to the rebates in a door to improve thermal performance.	Medium	£££	Coupled with other draughtproofing and repair measures to external doors, this can reduce heat loss and improve thermal comfort. It may lead to an unacceptable change in the appearance of the door (both to the interior and exterior). Available space is minimal, so high efficiency insulation products are required. Insulation should be fixed in a way that minimises thermal bridging while avoiding damage to historic fabric.	Draughtproofing and repair. IWI. Permeable plaster. Insulated blinds/ curtains.

Top left: Draught stripping on a window.

Bottom: Insulation was added to this door behind a layer of plywood.

Top right: Brush pile seals added to a sash window.

Middle: Original internal shutters.

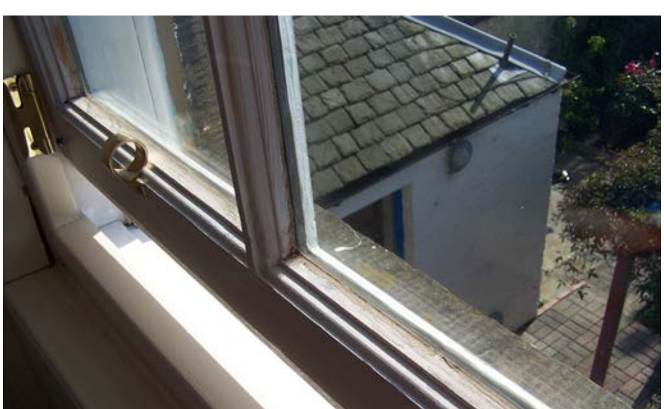
Bottom right: External awnings installed on windows where historic fixings for external blinds were identified in the window reveals.

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Secondary glazing Addition of a second glazing panel (single, double or triple glazed) to the inside face of an existing window. This can be as effective at reducing heat loss as replacing an existing window, and more so than just replacing glazing alone, with the advantage that the original window and glass is retained. Where secondary glazing is properly designed and installed in its own frame, reductions in heat loss, infiltration and acoustics can be maximised.	Medium	£££	In properties with historically significant windows, it may not be appropriate to remove the original window glass or frames. Secondary glazing may therefore be an option to improve airtightness, thermal efficiency and noise. Various designs can be chosen to be sympathetic to the existing building: sliding, hinged or fixed. Frames are available in metal or timber, although metal frames can lead to a cold bridge more readily than timber. The cost of this intervention is affected by the material choice, size and number of units. Ventilation is a key consideration to avoid condensation and overheating. If secondary glazing is to be installed, existing windows should not be draughtproofed to avoid risk of condensation in the interspace. It is imperative that both glazing systems remain operable, particularly in vertical sliding sash windows. This will aid provision of adequate ventilation, allow summertime purge ventilation and reduce overheating risk, as well as maintain occupant agency in regard to thermal comfort. Care is needed with the design and installation to avoid any damage to shutter boxes and architraves.	Draughtproofing and repair. IWI. Permeable plaster. Shutters. Insulated blinds/ curtains. Services (reduces heat and/or cooling demand; increases cooling demand if poorly designed).

Above: Secondary glazing installed on a sash window.

Above and next page: Internal and external views of secondary glazing installation — the exterior appearance has not been affected by the introduction of this measure.

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Complete replacement of windows/doors Replacement of existing windows and doors with more energy-efficient units.	High	£££	Whilst complete replacement of a window or door can significantly reduce heat loss through fenestration, studies have shown that replacing historic doors only leads to small improvements on whole house heat loss, and the replacement of historic window and door frames can lead to substantial damage to building fabric. Well-designed and properly detailed secondary glazing can lead to results that are just as good and that avoid the harm to historic fabric. Frame choice should be informed by the architectural and historical context of the existing building. Timber and metal are both traditional forms of window frame. Avoid UPVC windows when not original due to their unsympathetic aesthetic and considerable embodied carbon. When modern, unsympathetic replacement windows have come to the end of their life, there is an opportunity to improve thermal performance and enhance the appearance of the building. With improved airtightness, ensure there is still sufficient controlled ventilation.	Draughtproofing and repair. IWI/EWI. Permeable plaster. Shutters. Insulated blinds/ curtains.
Upgrade glazing in windows Replacing existing single-glazed panels with thin-profile double-glazed units in existing frames can improve thermal performance of windows and improve occupant comfort.	High	£££	The thermal performance of a window can be improved by replacing the glazing. Options include higher-performing single glazing, vacuum glazing and slim-fit glazing. These can work well when existing window frames are in good condition and are able to withstand the additional weight of the glass and when the glazing bars and frames are of sufficient size to accommodate the additional depth of glass and hide the seals without requiring adjustment. Upgrading the glazing in existing window frames is unlikely to achieve the same thermal performance as installing secondary glazing or a new window but will still reduce heat loss and improve thermal performance. Window frames will remain a cold bridge.	Draughtproofing and repair. IWI. Breathable plaster. Shutters. Insulated blinds/ curtains.
Introduce a draught lobby Adding a secondary door to create a draught lobby between habitable rooms and the outside.	High	£££	Requires sufficient space and consideration of impact to the heritage significance of a room. This is particularly effective where external doors are in frequent use and an insulated curtain would prohibit easy access. Consider space required for access by a range of users including those with disabilities. Be aware that door swings will impinge on a space, and new partitions could interrupt existing heritage features and wall linings.	IWI. Floor insulation. Breathable plaster.



Left: The original timber window frame can accommodate new double-glazing, making the change visually discreet.

Next page: Double glazed units in sash windows.

Table 8: Key EEMs for older and traditional buildings — Floors

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Increase floor airtightness Sealing gaps under skirting boards, around pipe work and in between floorboards.	Low	£££	Minimally intrusive, economic and quick to install, this intervention is simple but highly effective. Increasing floor airtightness might increase overheating risk, particularly in urban areas, when the possibility for beneficial summertime ventilation is lost.	Floor coverings.
Floor coverings Use of carpets, tiles, rugs and other floor coverings.	Low	£££	Depending on the extent and scope of the intervention, these are minimally invasive and economic to install. Floor coverings can be aesthetically sympathetic to the significance of a building and the occupants. Introducing rugs and carpets to a space will enhance the thermal performance by reducing radiant heat loss. A fitted carpet on a suspended timber floor will improve airtightness, reducing the loss of heat through the floorboards. Tiled floors and removable rugs will help keep spaces cooler in summer, which may be beneficial for spaces prone to overheating.	Increase floor airtightness. Insulating floors.
Insulation between/ under floor joists Adding insulation between and/or under the floor joints of a suspended (timber) ground floor. Suspended timber floors can be insulated from above and below depending on access. If fitted from above, semi-rigid insulation is suspended between joists on netting or boards supported on timber batons.	Medium	£££	Before work commences, assess floor for historical significance and plan for careful recording, removal and storage of floorboards during work. Ensure any damp or defects are addressed prior to installation. Retain (and/or improve) existing ventilation paths below the floor. Ensure existing and new services are considered with appropriate access and lagging to pipework located on the cold side. This intervention might increase overheating risk in urban areas, when the possibility for beneficial summertime ventilation is lost.	Increased floor airtightness. Floor coverings. IWI/EWI. Services upgrades.

Left: Plugging gaps between floorboards.

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Insulation on top of existing floor finish Adding rigid insulation and new floor finish on top of an existing ground floor (e.g. suspended timber floor or concrete slab).	High	£££	Complex and time-consuming, this can reduce thermal bridges and improve thermal performance. Choice of materials requires careful consideration. Depth issues can reduce ceiling height and create knock-on works, including stair, door and skirting adjustments. The use of thinner materials can negate these effects and reduce the need for additional work, but specification should depend on sub-base. The existing floor covering and the construction make-up of the ground floor slab will have a notable impact on the cost. It is essential that the existing floor slab be in good condition before an insulation product is applied. Any moisture left in the slab will cause deterioration and cracks and may indicate movement that will damage the new intervention. This increases moisture risk and decay potential for structure and finish of suspended timber floors. This might increase overheating risk in urban areas, when the possibility for beneficial summertime ventilation through suspended timber floor or thermal inertia of solid floors is lost. Done sympathetically, it has minimal aesthetic impact on the building. Historically significant flooring would need careful removal and reinstatement; this requires considerably more skilled work and time than a modern carpet, presents risk of harm, and is not recommended. This measure is likely to require LBC on protected buildings, as it introduces new materials into the existing structure and may change the position of internal finishes.	Increased floor airtightness. Floor coverings. IWI. Services upgrades.
Replacement of solid ground floor Existing floor (timber or uninsulated concrete slab) is replaced with new insulated concrete floor.	High	£££	Highly invasive. This EEM is most appropriate in cases where the existing floor is non-historic (likely concrete). The installation of vapour-permeable materials will minimise the risk of water concentration at wall bases. The use of vapour-permeable limecrete will reduce the risk of moisture being pushed to wall footings, which causes rising damp. If floor is being replaced, consider the installation of underfloor heating in conjunction. Where considerable digging out is required, ensure building footings are not undermined. Carry out investigations to establish the water table to help inform strategy and detailing. Note any depth of thermal insulation material that will be saturated, will not maintain thermal properties, and cannot be accounted for in U-values calculations. In buildings in a radon-affected area, additional measures will be required to mitigate the risk.	Floor coverings. IWI. Services upgrades.

Table 9: Key EEMs for older and traditional buildings — Surroundings

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Planting Vegetation and foliage that surrounds a property can have a significant impact on the thermal performance, maintenance requirements and flood risk of the structure.	Low	£££	Trees can offer solar shading and cooling to a structure as well as reduce flood risk and increase biodiversity and access to nature. This cooling effect has been proven to be particularly beneficial in combatting overheating due to heat island effect in urban areas. Conversely, trees can also restrict light, affect ground conditions and increase the maintenance of rainwater goods due to leaf litter or roots breaking through underground drainage. Some vegetation growth can cause damp, and vegetation with invasive root systems can lead to structural issues. However, trees have also been found to stabilise temperatures inside buildings. It is important to provide a balanced approach in which the impact on the fabric, internal and external environments and the wider ecosystem are considered. Changes to planting, such as the removal of trees, may require permission in protected environments. Before carrying out any work on significant trees, check that they do not have Tree Protection Orders (TPOs) in place and are not located within a conservation area or registered park or garden. Removal of trees can also result in ground movement since the root structure is no longer present, and in dampness since moisture is no longer being taken up by the tree.	Rainwater goods. Below ground drainage. EWI. Photovoltaics.
Hard and soft landscape Landscaping directly around a building, both hard and soft, impacts the energy efficiency of a building both positively and negatively.	Medium	£££	Hard landscaping will increase surface water run-off, which puts a strain on drains and risks flooding, but it also offers opportunities for rainwater harvesting. Soft landscaping can facilitate more infiltration and reduce surface water runoff, which can aid groundwater and aquifer against water scarcity. However, be mindful of areas with low infiltration rates, such as clay soils, which may restrict the rate of natural drainage. It is important to consider climate change when selecting planting schemes and look for drought-resilient species in areas at risk of intensive dry spells. LBC is likely to be needed. Some buildings in conservation areas are covered by Article 4 Directions which restricts demolishing or building boundary walls or fences or laying hardstanding in front gardens.	Rainwater goods. Planting. Below ground drainage.
Below ground drainage improvements Improvement to below-ground services can improve water discharge away from the building, leading to less damp, and lower risk of flooding.	Medium	£££	Below-ground drainage that is poorly maintained or undersized can lead to issues with capillary action up walls under extreme pressure (rising damp), flooding, subsidence and heave, causing structural damage. Ensure that below-ground drainage and rainwater goods are well maintained and sufficient for the property. Consider increased rainfall as a result of climate change and whether capacity will need to be increased as a result. Consider whether the rainwater goods and drains have been updated to accommodate any additional run-off caused by additional or larger pipes. Ensure regular inspections and maintenance are carried out. Whilst unusual, it is not impossible for a house to be on a scheduled monument, in which case consent will be required for below-ground works.	Rainwater goods. Planting. EWI.

Table 10: Key EEMs for older and traditional buildings — Building Services

Energy Efficiency Measure (EEM)	Level of intervention	Indicative cost	Key considerations and technical risks	Interactions with other measures
Service Controls Installation of controls for building services, including programmable timers for heating and hot water systems, ventilation systems and lighting controls. Building Energy Management Systems (BEMS) are required for more complex building services systems to provide a high level of automatic control, functionality and fault indication.	Low to Medium	£££-£££	Lighting controls can be used to operate lighting when people are present and to work in conjunction with natural daylight. Individual rooms can be temperature controlled by radiator valves (where applicable), heater controls or room thermostats. The energy efficiency of a heating plant can be improved by optimal start and weather compensation in many systems. In larger buildings, the heating system will need to be zoned to ensure that energy is not wasted. Ventilation system controls can vary depending on the size and complexity of the system, from manual or automatic control to programmable timers for heat recovery systems. Large ventilation systems using Air Handling Units (AHUs) often need a BEMS. BEMS will include a control panel that contains indicator lights and a variety of manual and automatic controls switches. These panels will often contain a user interface. Larger BEMS systems will have outstations that allow the control of building services near that location. Installation of control panels and large plants needs careful consideration and may require additional consents.	Hot water, lighting and central ventilation plant.
LED lighting The majority of luminaires with replaceable lamps can be fitted with low energy LED lamps.	Low	£££	They are available in a variety of light outputs, forms and colour temperatures. Decorative and feature LED luminaires will be more expensive than replacement lamps.	n/a
Insulation A variety of mechanical services can be thermally insulated to conserve energy. These include pipework, hot water cylinders, valves, ductwork and heat exchangers.	Low	£££	Insulating pipework and other services can be a low-cost way of saving energy but needs to be carefully designed and installed to avoid associated risks.	n/a
Heat recovery Heat recovery ventilation uses a form of heat exchange to recover the heat energy from mechanically ventilated exhaust air to add this heat energy to the fresh air intake.	Low to Medium	Varies	The form of heat recovery can be small, self-contained domestic units, medium-sized domestic/commercial ducted units and large air handling units (AHUs). There are various heat exchangers that have different efficiencies. The most common one is a plate heat exchanger that recovers heat without allowing the air streams to mix in.	n/a

Low- and zero-carbon heating systems

Heat pumps

Heat pumps are a very efficient heating technology that use existing heat in the environment to heat a building. They achieve this using an electrically powered heat pump. There are several types:

- **Air source heat pumps** (ASHPs), which use the heat available in the ambient outside air.
- **Ground source heat pumps** (GSHPs), which use the low-grade heat available from the ground as a result of solar radiation. This heat is taken from the ground using a closed-loop ground collector, which can take the form of vertical boreholes or shallow trenches.
- **Water source heat pumps** (WSHPs), which extract low-grade heat from a body of water, such as a river, sea, pond or lake. This technology is only viable where there is a body of water on site.

Net-zero carbon can be achieved using green electricity.

Top: An air source heat pump next to a traditional building.

Above: Barn conversion with Ground Source Heat Pump plant in outhouse.

Heat pump technology provides heat at operating temperatures that are ideal for use with underfloor heating systems. It is also possible for heat pumps to be used with warm air systems and larger radiators, though, on average, radiators for heat pump systems need to be bigger than those used with conventional heating systems.

- **Installation and impact to historic fabric and character** — installation of heat pump technology can require the replacement of existing heat emitters, pipework, pumps and electricity supply. It is important that care is taken when creating new pipe runs to avoid cutting through historic timbers and damaging other building fabric. Both GSHPs and WSHPs will require an internal location for the heat pump, buffer vessel and associated controls.
- **Energy demand of older buildings** — older buildings tend to have a continuous demand for heat during the heating season. This non-stop operation can cause ASHPs to activate their defrost cycle when ice builds up on the external heat exchanger. During the defrost cycle, the ASHP does not provide heat to the heating system. A suitably sized buffer vessel can provide a sufficient thermal store to overcome this issue. Alternatively, the defrost cycle can be accommodated by having some of the heat emitters on permanently with no heating control. However, this can cause discomfort and waste energy.
- **Groundworks** — installation of GSHPs requires a suitable external area for boreholes or shallow trenches, and WSHPs require groundworks from the body of water to the pump. When the works fall within the curtilage of historic buildings or within protected landscapes and areas, a full archaeological assessment may be required. WSHPs may also require ecological and environmental assessments as installation works need to consider the impact on protected species.
- **Noise emission of ASHPs** — all ASHPs have an outdoor unit. The acoustics of the outdoor unit need to be considered before installation. It is possible to attenuate the external noise using acoustic housings or acoustic screens — these, however, incur additional costs. GSHPs and WSHPs do not produce any external noise as the heat pumps are located in an internal plant room.

In some cases, an ASHP may need to operate at higher than the optimum flow temperature, but with careful design and fabric improvements this need not be the case.

There are hybrid ASHPs available that work with boilers. The boiler typically operates when the ambient external temperature falls below 10°C. Hybrid ASHPs would improve the heating system's environmental performance and would reduce the overall CO_2 emissions, but it is not possible to achieve net-zero carbon with this heating technology alone.

Photovoltaics

Photovoltaics (PV) convert the sun's energy into electricity. Surplus generated electricity can be exported back to the grid.

The most common form of this technology is PV panels, which are most efficient when installed facing south at an inclination of 30° from horizontal. Consequently, the viability of this technology depends on the geographic location and the orientation of the proposal. PV panels are often roof mounted, but they can also be installed at ground level.

The electricity generated by PV panels will not meet the full demand for electrical heating. It will, however, contribute towards the electrical demand. Space for battery storage is required because, as generated electricity is seasonal and weather dependent, peak periods for electricity generation may occur when there is no heat demand. Installation of PV panels also requires an internal location for some inverter types and battery (if applicable). Maintenance access is required if roof mounted.

Above: Solar panels on the roof of Gloucester Cathedral.

Consent will be required for installing any type of PV installation on a listed building or scheduled monument. Aesthetic impact needs to be assessed within the setting of heritage assets. Planning permission may be required for a building in a conservation area or for installations that affect designated wildlife sites. With roof-mounted installations, check that the roof can support the additional wind, snow and static load imposed by the PV panels and that it complies with building regulations.

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Hydroelectric power

Hydroelectric power uses the kinetic energy from flowing water to generate electricity. Surplus generated electricity can be exported back to the grid.

This technology is only viable where there is a natural water source on site with a sufficient head and flow rate. A good understanding of the water source is required as hydro turbines for a site are selected based on the hydraulic head and flow available. It is also important to assess climate risks; flooding or drought will mean that the turbine cannot operate. Generated electricity is seasonal and weather dependent.

Hydroelectric generation can be well suited to sites with historic watermills or existing infrastructure (for example, an original wheel pit), provided that direct and indirect impact significance of assets, including historic machinery, is considered. Environmental and ecological impacts need to be assessed and ecological impacts on fish migration mitigated by including fish ladders or eel passes.

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Above: Holding pond and sill of the micro-hydroelectric plant at Blair Castle.

Top: Solar panels in grounds of historic estate.

Wind turbines

Wind turbines use the kinetic energy from the wind to generate electricity. Surplus generated electricity can be exported back to the grid.

The viability of this technology depends on the geographic location and the site terrain. Generated electricity is weather dependent.

Obtaining planning approval for installations that would affect the significance of historic assets can be difficult. Even a small wind turbine with the capacity to power two typical heat emitters can be up to 15m in height. Installation also requires an internal location for the inverter and battery (if applicable). Planning permission will evaluate bird migratory routes and further ecological and environmental assessment may be required to consider bats and other protected species. Acoustics also need to be fully assessed.

BioLPG

BioLPG is a low-carbon fuel made from a diverse mix of biological feedstocks and processes. It is chemically identical to LPG and as such works with existing LPG plants. BioLPG is an emerging fuel in the UK, and the carbon emission savings occur at industry level. As such, they vary depending on the generation source. BioLPG can be purchased from suppliers, who offset the carbon dioxide savings using a certification scheme.

BioLPG requires a fuel storage location above or below ground. Above ground tanks can have a visual impact. BioLPG also requires site access for fuel delivery. Carbon emission savings need to be confirmed with the supplier as they will vary according to the fuel source.

Consent will be required for a fuel container within the curtilage of a listed building. There are some restrictions on unlisted buildings so planning permission may be needed, particularly in National Parks, Areas of Outstanding Natural Beauty (AONB) or World Heritage Sites.

Biomass

Biomass boilers produce heat by burning wood chip or wood pellets. Combustion produces carbon dioxide emissions and particulates. Biomass technology is considered carbon neutral insofar as the carbon produced during combustion is offset by the carbon absorbed during tree growth. However, there are still some carbon dioxide emissions associated with transporting the fuel. Regulations for biomass boilers are evolving in the devolved nations, so it is important to check local regulations.

Biomass boilers will work with existing heat emitters. They require considerable space to support their infrastructure: an internal location for the boiler, buffer vessel and associated controls and a fuel storage location adjacent to the boiler room. The size of these spaces can be challenging to accommodate, and the impact of a new structure, where required, would increase the risk to heritage.

A flue is required to discharge the products of combustion. Planning permission may consider the local air quality; the carbon dioxide emissions and production of particulates can make it difficult to obtain planning consent for this technology in urban areas. It also requires site access for fuel delivery and regular cleaning to remove the ash.

Electric boilers

Electric boilers produce heat using electrical elements. Hydraulically, they connect to heating systems in the same way as conventional fossil fuel–fired boilers.

Strictly speaking, they are not an alternative energy source or renewable technology. However, if the electricity is provided by a green electricity supplier, then these boilers can operate with zero carbon dioxide emissions.

They are less common than conventional boilers due to fuel prices, which, historically, have been high compared with natural gas, LPG and oil. Electricity supplies will usually need to be upgraded due to the high power requirements.

There are other measures that have not been evaluated in this section, including: hydraulic balancing valves, fan selection, natural ventilation, condensing boilers, pump selection, power factor correction, night cooling, metering strategies, district heating and cooling, Variable Air Volume (VAV) ventilation, displacement ventilation, Combined Heat and Power (CHP), mixed mode ventilation, rainwater harvesting, Variable Refrigerant Flow (VRF) refrigeration systems and waste water heat recovery. For more information refer to the resources section below.

Above: A biomass boiler next to a traditional building.

Materials and construction techniques

Traditional materials

Most traditional materials, including lime plaster and harling, are to a greater or lesser extent **permeable** and **hygroscopic**.

- **Permeable** traditional materials permit water transport in both vapour and liquid form due to their porosity and capillarity.
- **Hygroscopic** properties of traditional materials help maintain a healthy indoor environment by buffering relative humidity levels, minimising the risk of surface and interstitial condensation and diminishing the risks of mould growth and fabric decay.

Methods and materials that work to preserve these properties should be favoured over those that restrict it — for example, choose lime over cement mortars, renders and finishes. Should a scheme require the use of impermeable products, it should be very carefully considered and ideally the materials only used as a last resort; be sure to address any moisture issues first. However, simply swapping out non-permeable materials for those with permeable properties is not going to remove all risks. Material choice needs to be complemented by the appropriate choice of intervention, consideration of interaction with other measures and accurate detailing. Permeable materials are not a substitute for good ventilation.

Above: Wood fibre board-based insulation.

Top right: Aerogel board used for solid floor insulation.

Bottom right: Hemp-lime being installed as an infill panel.

Embodied carbon

As well as ensuring that materials are suitable for use with traditional building fabric, it is also important to consider their **embodied carbon**. Embodied carbon is the carbon produced by the manufacture of materials and construction processes and depends on factors such as the kinds of materials, where they come from and how long they last.

The embodied carbon of energy efficiency measures can be reduced through the careful selection of materials, the use of the local supply chain and the application of a circular economy model. A circular economy is one in which materials are reused or repurposed so that nothing is wasted, thus allowing us to preserve finite resources. This approach can be applied to the refurbishment of buildings, as well as to individual building elements.

Insulation materials

Choices of insulation material and airtightness requirements impact the risk of poor internal air quality (IAQ). Non-permeable and petrochemical-based products can pose a higher risk of hazardous gases, volatile organic compounds (VOCs) and the concentration of particulates. Where airtightness is increased, inadequate ventilation provision will also reduce IAQ and heighten risks to occupants.

Options for insulating suspended timber floors include wood fibre insulation, which is vapour permeable.

The use of vapour barriers can also trap moisture in building fabric. The installation of air and vapour control layers should be considered carefully and only if needed to increase airtightness as part of a well-thought-out approach to fabric improvements that includes ventilation.

Importance of detailing

Careful detailing, especially around junctions and openings, is vital to prevent the risk of thermal bridges and other unintended consequences when introducing energy efficiency measures.

The technical guidance of the national heritage bodies includes advice and detail on specific materials and their use in improving the energy efficiency of traditional buildings. You should also check details and specifications with the manufacturer and make sure they comply with building regulations.

Resources

For more information on the range of energy efficiency measures suitable for older and traditional buildings, see:

Cadw, How to improve energy efficiency in historic buildings in Wales

Cadw, Renewable energy and your historic building — installing microgeneration systems

Historic Environment Scotland, *Guide to energy retrofit of traditional buildings*

Historic England, *Maintenance and repair for energy efficiency*

Historic England, *Resilient rainwater systems*

Historic England, *Modifying windows and doors in historic buildings*

Historic England, *Upgrading thermal elements: installing insulation*

Historic England, *Building Services Engineering, including installation of heat pumps, solar panels and other systems*

Historic England, *Low and zero carbon technologies*

The Sustainable Traditional Buildings Alliance (STBA) Guidance Wheel is a practical tool for exploring the interactions between energy efficiency measures: www.stbauk.org/guidance-wheel/

4.3 Assessing and mitigating risks

National Occupational Standards:
EEM02: K18, K19, K20

Key points

- Assessing technical risks
- Mitigating the risks

Assessing and mitigating technical risks associated with energy efficiency measures

Some energy efficiency measures can risk the maladaptation of our historic and traditional buildings. Insertion of fabric efficiency measures and renewable energy sources can have unintended consequences if they are not considered and planned properly. In addition, our changing climate is bringing about more severe weather events and new hazards that pose serious risk to our existing built environment.

Adopting a risk-based approach (see 5.2) to both carbon reduction and climate resilience will facilitate proper planning and mitigation. This approach ensures that our historic and traditional buildings are prepared for the known hazards and impacts likely to be experienced in our changing climate, while avoiding the unintended consequences of ill-considered energy efficiency measures.

Below are the most common risks associated with energy efficiency measures in historic and traditional buildings and suggestions for how to mitigate them.

Climate change impacts

Our changing climate is increasing the frequency and severity of many physical climate hazards that impact our built and natural heritage, including extreme flood and storm events, increased rainfall, warmer temperatures and severe drought. It is also introducing new hazards that could affect our built heritage, like the spread of new and invasive pest species, and is reducing some of the existing hazards in the UK, such as the risk of freeze-thaw events.

As our climate continues to change, interventions to improve energy efficiency that are designed now might not be as effective later. Climate change adaptation and mitigation need to be considered together from the outset.

Mitigation: Regardless of complexity, any works proposed for a building should consider the potential impact of hazards created by climate change. It is important to understand the hazards likely to occur, the effect they might have on the existing fabric and on any proposed changes, and any other direct impacts associated with the hazard, such as increased salination impact due to coastal storms. Adaptation measures should then be integrated into the whole building retrofit plan. Carry out a Climate Hazard Impact Assessment and agree to appropriate mitigation strategies to reduce the risks posed.

Insufficient ventilation

Adequate ventilation is needed for the occupants of a building and for the protection of the building fabric in all circumstances. Some energy efficiency measures can reduce the existing air permeability and air change rate in a property. If ventilation is reduced too much, there may be an increase in condensation, mould and fungal growth and overheating and a reduction in the removal of indoor pollutants. This can lead to the deterioration of the building fabric and negatively impact the health of occupants.

Mitigation: Assess and monitor existing room and fabric moisture conditions pre-refurbishment. Consider commissioning an airtightness test to assess infiltration levels. Differentiate between controlled (i.e. deliberate) and uncontrolled (i.e. infiltrating) ventilation. Assess existing ventilation provision and ensure the ventilation strategy addresses increased airtightness. Take into consideration occupancy pattern and capacity. Consider risks associated with reliance on occupant intervention (i.e. opening windows and trickle vents in windows where present) and usability and maintenance needs of automated systems. An automated system may be best when there is higher risk of insufficient ventilation.

Top left: Lack of ventilation and movement of moisture can lead to mould growth.

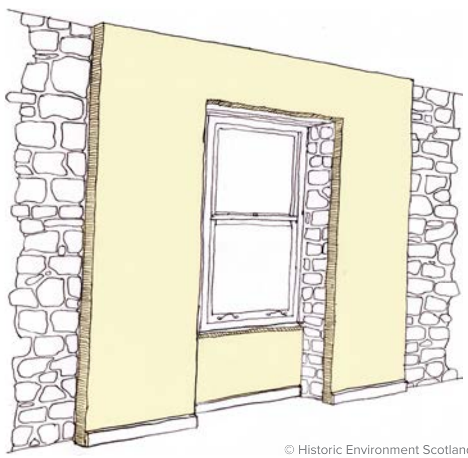
Bottom left and right: Ventilation slates in a roof to allow airflow into the roof space.

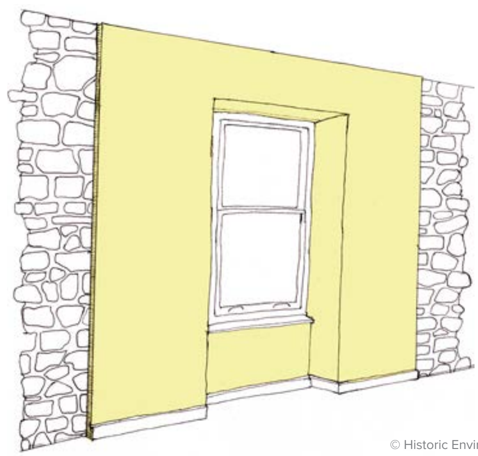
Top right: Ventilation and moisture exchange between the fabric is vital.

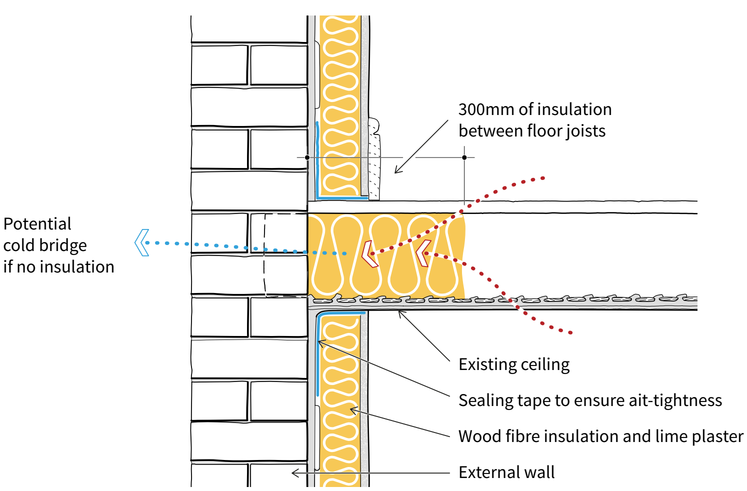
Thermal bridges

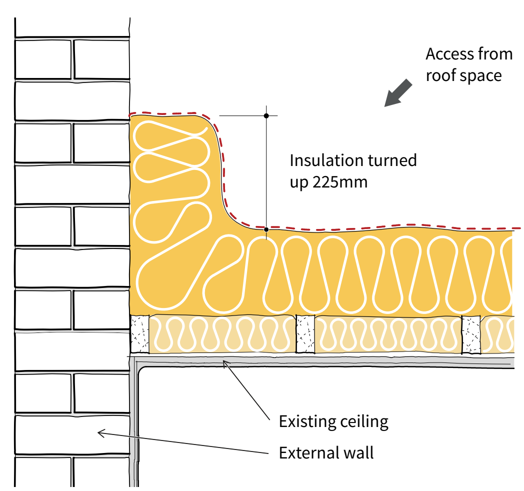
Thermal bridges occur when an area is less insulated than its surroundings. There are two types of thermal bridge: repeating (occurs at regular intervals, e.g. timber joists between ceiling insulation) and non-repeating (occurs at a junction between building elements, e.g. wall-floor junctions). The higher thermal conductivity of the bridging element leads to increased heat loss and lower internal surface temperatures on the bridging area, which can result in surface condensation or mould growth. Thermal bridging is almost unavoidable in retrofit projects, especially in historic and traditional buildings.

Mitigation: Thermal continuity, detailing and skill are key to reducing the risks associated with thermal bridges. Specify and clearly communicate details for key thermal bridges (e.g. windows, the wall to floor junction, the wall to roof junction) that minimise heat transfer at bridge position. Use appropriately experienced workforce and implement thorough process of checks throughout construction, with occasional visual inspection post-refurbishment.









Top left: Internal wall insulation is installed but not on the window reveals as it is too thick.

Top right: Thinner internal wall insulation is installed on the walls and window reveals – the use of a slightly thinner material has allowed full coverage and will reduce the risk of thermal bridging if detailed correctly.

Bottom left: To avoid a thermal break at a floor junction insulation should be added within the perimeter of the floor zone. It is also important to seal insulation at junctions with the ceiling to maintain air-tightness.

Bottom right: Where ceiling level cold roof insulation meets an external wall then the insulation should be turned up for at least 225mm to prevent cold bridging.

Thermal bypass

Heat loss that bypasses the thermal insulation layer between two areas of the construction. This is caused by a combination of conductive and radiative heat loss mechanisms, and results in uncontrolled air movement.

Mitigation: Detailing and skill are key to reducing the risks associated with thermal bypass. Ensure junctions and joints between insulation and air barriers are free from gaps (e.g. by ensuring a tight fit between insulation boards and taping joints with an appropriate material).

Trapped moisture

Moisture, both as a liquid and vapour, becoming trapped and possibly accumulating within building fabric as a result of changing either fabric or ventilation conditions. For example, where there is rising damp in a wall, or high levels of moisture within a solid floor, the application of vapour-closed materials or reduced whole-house ventilation could result in moisture-related problems (e.g. timber decay, mould growth).

Mitigation: Prior to refurbishment, establish moisture content of the structure and building fabric, and the cause of any existing problems. Check the fabric for any water leaks. Ensure any sources of existing water ingress are resolved before proceeding with the installation of measures.

Condensation (surface or interstitial)

Condensation occurs when water vapour comes into contact with a cold surface and turns to a liquid. Interstitial condensation is when this happens within the building fabric or at the junction of fabric with differing vapour resistivity. Water vapour passes through the surface and cools down within the structure, leading to the presence of liquid water within a building element. This can lead to fabric decay or mould growth that is hidden from view. It can occur in walls, roofs or floors as a result of incorrect specification and installation of insulation systems, air leakage, thermal bridging and reduced ventilation.

Mitigation: Carry out thorough assessment of context, moisture loads, fabric types and the condition of the building. Understand the restrictions imposed by the exposure of the different orientations of the building. Consider monitoring fabric elements (e.g. walls) prior to refurbishment to establish interstitial hygrothermal (heat and moisture) behaviour, including monitoring conditions within voids. Carry out condensation risk calculations informed by in-situ interstitial hygrothermal monitoring to the maximum extent possible within the project budget. Ensure that the technical properties of proposed new materials are clearly understood, particularly their behaviour in relation to the existing fabric and in relation to moisture (vapour permeability, hygroscopicity and capillarity). Avoid non-permeable and highly vapour-resistant insulation materials and barriers. Monitor the fabric at regular intervals post-refurbishment, particularly in high-risk areas.

Above: Visible condensation forming on glazing, leading to black mould growth on the frame.

Liquid moisture penetration

Excess liquid moisture in fabric caused by rain and poor fabric condition (e.g. poor pointing or cracks), defective rainwater goods, high ground levels, high water table, poor detailing (e.g. around windows), the addition of inappropriate materials or incorrect thickness or detailing. This reduces the ability of the fabric element to dry out and increases heat loss through damp fabric.

Mitigation: Careful surveying to understand the condition of the fabric. Where needed, repair any features that may reduce effectiveness of measures before refurbishment. Ensure all interventions are appropriate to material type, thickness, detailing and application/installation.

Overheating

High temperatures in buildings can cause discomfort, ill health and loss of life. Climate change is increasing the frequency of extreme heat events. Negative health due to extreme heat is becoming increasingly more common than that associated with extreme cold. Fabric energy efficiency measures can either improve or exacerbate problems (e.g. by insulating against high external temperatures, undermining thermal inertia, failing to maximise decrement delay opportunities and reducing the ability of a building to buffer fluctuations in heat).

Mitigation: Consider a strategy for the building to deal with higher temperatures (e.g. shading, thermal inertia, decrement delay, purge night ventilation, planting). Undertake overheating risk assessment to the maximum extent that the project budget will allow. Ensure effective ventilation is possible (i.e. cross and stack ventilation), and check that existing window openings and shading opportunities are not compromised by additional measures. Monitor and report experiences post-refurbishment.

Structural loading changes

Installation of new materials or services causing changes to the structural load. For example, solar panels or insulation installed on a roof.

Mitigation: Where structural loads will change as a result of the EEM, commission a structural survey of the area in question and get expert advice on whether the existing structure can take the new load. In some instances, strengthening may be required. This should be carried out in a sensitive way, avoiding the removal of or damage to existing fabric.

Hidden services

Pipes or electrical services may become hidden by insulation. Surface condensation on pipes may occur. Insulation around electrical wires may increase fire risk.

Mitigation: Carry out a thorough survey of services prior to the design and installation of energy efficiency measures, including a review of any existing plans and drawings. Any services at the end of their life should be upgraded prior to installation of insulation to avoid subsequent need to remove and replace. Review the risk of burying electrical cables beneath insulation resulting in the overheating of cables and potential fire hazard. Review the risk of condensation forming on buried water pipes, resulting in the excessive wetting of nearby material. Remove redundant pipework and insulate any pipes that are on the cold side of the insulation. Electrical circuits should be tested and cabling upgraded or repositioned above the insulation to prevent overheating prior to the application of any insulation.

Loss of internal space

Some energy efficiency measures will impact upon usable internal space, for example, internal wall insulation reduces the internal floor space of the room and will require the removal of fixtures and fittings to ensure thermal continuity.

Mitigation: Ensure that measured surveys are undertaken prior to any design work. Commission scaled drawings of the proposed interventions, with a thorough analysis of the implications on space and usability.

Loss of character/significance

If a building is listed, scheduled, in a conservation area or other heritage designation, materials and features are considered significant to the character of the heritage asset. The benefits of a particular intervention may not outweigh changes to or loss of the character of original features, such as windows, cornicing and fireplaces, and listed building approval or planning consent is unlikely to be granted. Buildings that are not afforded any heritage protections can still hold significance and contribute to our rich historic environment; this should also be considered.

Mitigation: Carry out an appraisal of the building's significance and commission a heritage impact assessment (see 5.2). If replacement of built fabric is justified, the use of sympathetic materials and construction techniques should be prioritised. The introduction of energy efficiency measures also presents the opportunity to potentially enhance the significance of the asset through careful design considerations and specification, for example, reversing previous inappropriate alterations.

Above: The character of the floorboards, including their surface finish or patina, their deflection and undulation all contribute to the historic interest of a building.

Performance gap

As seen in 4.1, the performance gap describes the difference between predicted (or calculated) building performance at the design stages of a project and the actual measured performance based on meter readings, which leads to higher running costs than anticipated, higher carbon emissions, longer pay back periods and client dissatisfaction.

Mitigation: Establish a clear engagement plan with building owners, occupiers and caretakers from the outset. Carry out a thorough assessment of the existing building condition, performance and use. Allow sufficient time, resources and expertise to properly develop the design and specification. Appoint suitably competent specialists and implement quality control systems during delivery. Plan for an effective commission and handover process with adequate training of building users. Carry out post-occupancy evaluation.

Personal capacity/opportunity/business case

People need the right opportunity to make significant changes to their property, with many factors contributing to decision-making, including costs, available resources, health and wellbeing and level of disruption. Timing is an important consideration, both in terms of when the level of disruption required can be accommodated and when finances are available to pay for work.

Mitigation: Engage users and understand the particular circumstances of their projects. Discuss fully with users the impact that undertaking the changes will have on their building (what areas need access, level of disruption etc.). Keep users informed throughout the process and review and obtain feedback following completion of the work.

Poor quality work/inappropriate material use

Using inappropriate materials, tools and techniques. For instance, the use of cement-based mortars in repointing and repairs can cause moisture accumulation and undermine permeability or hygrothermal performance of building fabric and accelerate deterioration and decay.

Mitigation: Allow sufficient time, resources and expertise to properly develop the design and specification. Have an experienced contractor, who uses appropriate materials, tools and techniques, repair and treat the existing fabric.

Resources

UK Government guidance, *Climate change: risk assessment and adaptation planning in your management system*

Historic England, *Mapping climate hazards to historic sites*

Welsh Government report, *Resilience of buildings to challenges associated with climate change*

Chapter 5

Review, Evaluate and Justify Proposals

Overview

This chapter covers the following topics:

- Reviewing information sources to refine proposed energy efficiency measures.
- Evaluating options for introduction of energy efficiency measures.
- Assessing implications of legal and regulatory requirements.
- Justifying recommended energy efficiency measures.

Above: 15 The Strait, Lincoln.

Next page: Terraced townhouses in York.

5.1 Sources of information and assessing risk

National Occupational Standards:
EEM03: K5, K6, K7, K9

Key points

- Identifying available information.
- Recommendations from a range of sources.
- Using information sources to undertake risk assessment for proposed energy efficiency measures.
- Undertaking an assessment of significance for traditional and protected buildings.
- Further information sources, testing and investigations.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Reviewing information sources to refine proposed energy efficiency measures

Identifying available information

There are many sources of information relating to a building's energy performance that can be used to evaluate and refine proposals for the introduction of energy efficiency measures. These sources of information may be readily available or may require assessments to be undertaken to produce accurate and up-to-date data. Some may be conducted as desk-based assessments whilst others will require site-based assessment.

Many of these have been covered in earlier sections, for example, assessments to identify common defects in buildings or to understand the building in its existing arrangement were discussed in section 2.1. Information arising from these assessments, as well as from new sources of information include but are not limited to:

- **Energy performance certificates** (EPCs) provide a cursory assessment and point of comparison between buildings via an A–G rating. See 3.1 for more detail on EPCs for traditional buildings.
- **Condition surveys** are architectural or structural evaluations that report on the condition of the building and usually include a full photographic record. Evaluations might identify weaknesses or failings within the building fabric. See 2.1 for more detail on assessing condition and building defects.
- **Heat loss surveys** (e.g. thermography) give insight into thermal inefficiencies like cold bridging, draughts and lack of insulation.
- **Building services surveys** establish the size, capacity and loadings of existing utility services, as well as type, age and condition of existing heating, cooling, hot water, ventilation, air handling, lighting or power distribution systems, electrical panels and switchgear and other equipment to inform design requirements. See 2.2 for more information on building services.
- **Measured surveys** provide two-dimensional information to form the basis of drawings or models. Increasingly, they also provide three-dimensional data, e.g. point-cloud or 3D LiDAR scanning.
- **Building Performance Evaluation** (BPE) uses in-situ measurements rather than assumed inputs to develop an understanding of a particular building. It will combine a range of assessments (including those listed here) and be used to make comparisons between actual building performance and design targets.
- **Site visits** to the building allow for full comprehension of the site and its surrounding context.
- **Communications with the owner or occupants** who are intimately familiar with the building can provide detailed knowledge, often revealing surprising and idiosyncratic information.
- **Heritage assessments** report on the historic significance and heritage value of a building, identifying listing status, conservation area considerations or important aesthetic features.
- **Environmental surveys** assess the impact of proposals on the environment. These include assessments such as Environmental Impact Assessment and protected species and ecology surveys.

Recommendations from a range of sources

Reviewing more than one source allows for a more developed understanding of the issues. Sources can sometimes also be contradictory. The generality of one source may not incorporate the nuance of another.

Example: Limitations of EPCs as a single source

EPCs often generally recommend the installation of additional insulation to improve the U-value of a wall. However, insulation may not be appropriate in the context of the location, because of exposure levels or incompatibility with traditional building fabric. The building might be in a conservation area, which may restrict the options for external wall insulation, or its listing may prohibit the installation of internal wall insulation due to significant heritage mouldings and details.

A simple visual survey or EPC assessment may fail to understand the full material build-up of a wall, and the installation of new insulation may worsen existing damp problems if the source of moisture is not effectively repaired or resolved prior to installation. It can also create new damp issues if the performance of traditional fabric and its ability to manage moisture is undermined. The effectiveness of some proposals might be undermined by the presence, or omission, of other factors. For example, insulating a mass solid wall could reduce the effect of its thermal mass.

Improving the airtightness of a building generally has a positive impact, but the inherent draughtiness of a historic building might be key to its effective ventilation and prevention of mould growth. Without also addressing ventilation, one may inadvertently create problems.

These considerations are particularly important in traditional and historic buildings, as the range of construction techniques, the materials used, and the peculiarities, idiosyncrasies and significance of the historic fabric is not often suitable for generic recommendations.

The fabric of buildings of traditional construction behaves differently from modern buildings with respect to heat and moisture transfer and buffering ability of the fabric which are required to maintain a healthy internal environment. Upgrade and retrofit measures should be designed sympathetically both to the physical performance of the existing fabric and to the special significance of the building.

See 3.1 for more detail on EPCs and their limitations.

Using information sources to undertake risk assessment

The information sources listed above can be used to inform risk assessments for proposed energy efficiency measures. Technical risks are explored in more detail in section 4. Examples of specific risk assessment types include:

- **Moisture risk analysis**

  Uses hygrothermal simulation to evaluate the way heat and moisture move through a construction to assess the risk of interstitial condensation, mould growth, frost risk and corrosion. See 3.2 for different assessment types.

- **Overheating risk assessment**

  Uses modelling, data about the building fabric, services and performance, and weather data to predict the internal temperatures for comparison against a standard.

- **Climate hazard and impact risk assessment**

  This is approached in various ways, but a typical assessment will quantify the risk as the result of the interaction between hazard, vulnerability and exposure.

- **Flood risk assessment**

  Takes into account the local topography and history of flooding in the area, using a range of sources, such as the Environment Agency, Natural Resources Wales or Scottish Environment Protection Agency flood maps. See 4.1.

- **Fire safety, health and safety**

  All health and safety, as well as fire risk assessments, should be carried out. Some will be specific to particular products or measures.

Further information sources, testing and investigations

Due to the limitations of some modelling methods, further investigations and testing are often very useful, and sometimes necessary, in order to fully understand all the factors at play or to explain discrepancies and inconsistencies in information

Example: Investigating existing systems

It might be the case that expectations and assumptions about insulation levels in a wall are undermined by thermography indicating cold patches. Opening-up work could be carried out to confirm the presence or absence of insulation. Before any additional measures are introduced, it is always prudent to carry out investigations of existing systems. Problems with excessive humidity levels might be caused by ineffective or defective ventilation systems, perhaps because of incorrect commissioning or poor maintenance.

Example: Energy assessment provided by an RdSAP model

The energy assessment provided by an RdSAP model might be contradicted by or differ greatly from the in-use data gathered from a utility meter. In this case, the model could be expanded upon by using full SAP/PHPP/IES modelling.

Resources

For a review of approaches to assessing climate change risk in the historic environment see Clare Vokes, Jennifer Brennan, Ben Kehoe, James Legard and Ellie Moore, Approaches to Heritage Climate Change Risk Assessment: An integrative literature review, *Historic England* (2023)

5.2 Evaluating options

National Occupational Standards:

EEM02: K26, K32

EEM03: K6,K10

Key points

- Risk-based approach.
- Fabric first approach and the potential risks for traditional buildings.
- Unsuitable interventions and inappropriate energy performance measures.
- When energy efficiency measures are not recommended.

Evaluating options for introduction of energy efficiency measures

The first step in choosing options is to decide on an approach to the renovations. The following two approaches are recommended.

Risk-based approach

A carefully considered strategy for introducing energy efficiency measures to an existing building, particularly a traditionally constructed one, is essential for managing and mitigating risks. A lack of planning and consideration can lead to the following issues on a project:

- **Abortive works**
  Poor sequencing can mean that an intervention needs to be removed or replaced to accommodate other interventions. This can cost a project unnecessary money and time.
- **Restricted options**
  The installation of an intervention too soon may eliminate or reduce the capacity to accommodate more appropriate interventions later on.
- **Inappropriate choice of interventions**
  Failing to consider all interdependent aspects of a retrofit for a building or failing to mitigate other areas of energy loss could result in a poor choice of interventions for a building. This may result in a poorer performance than intended (a performance gap) post-occupation, as well as unnecessary time and cost on a project.

A poor choice of interventions can therefore lead to the degradation of building fabric and health risks to occupants. For example, if the hygrothermal properties of the building are not considered when designing interventions for energy efficiency, there is a risk of interstitial condensation within the existing building fabric. This could lead to degradation of the building fabric and an increase in relative humidity, giving rise to poor thermal comfort for the occupant and potentially to health issues.

For all retrofits, a risk-based approach, which considers the whole building and takes into account the multiple interactions between elements and interconnected relationships that exist within a building, is encouraged. Potential risks can be identified and mitigated using various types of risk assessment (see 5.1).

Fabric first approach

A fabric first approach prioritises improvements to the existing fabric (both at a small and large scale) to reduce energy consumption before considering low- and zero-carbon technology integration. The approach is intended to be scalable and is based on the principle that the greenest energy is the energy you do not use.

Whilst improvements to the existing building fabric can improve the energy efficiency of a building, it needs to be considered as part of a whole building approach (see 4.1). A fabric first approach on its own does not take into consideration a building's context and other factors that can have implications for the introduction of energy efficiency measures. Effective energy efficiency interventions are also far broader than fabric thermal upgrades alone. They include:

- Repair and maintenance.
- Upgrading existing services.
- Using efficient heating technology with responsive controls.
- Installing new low or zero carbon technologies.

Interventions should be implemented in order of priority set out by the Energy Efficiency Hierarchy. This order of priority reflects not only the relative benefits, costs and technical risks of interventions but the 'three pillars of energy transition'. These are sufficiency, efficiency and renewables:

- First, reduce energy consumption in real terms (sufficiency).
- Second, minimise unavoidable energy use (efficiency).
- Finally, generate energy from 'renewables', also known as low- and zero- carbon technologies, when possible (generation).

A staged approach to retrofit that follows the Energy Efficiency Hierarchy helps to evaluate the options and structure the process of developing a strategy for the introduction of energy efficiency measures.

Stage 1 — Knowledge

As has been emphasised throughout this guide, the first step of any project should be the collation of knowledge about the building. Understanding the building's context, significance, condition and usage will inform decision-making on the best retrofit strategy at later stages.

Heritage context is key. Consider the existing condition and management of the building, using all relevant sources of information (see 5.1). Geographical context is also vital. A lack of consideration for the context of a building and its fabric could lead to irreparable damage or loss to heritage or could introduce new problems, reinforcing the perception that older buildings are an obstruction to, rather than part of, the energy solution.

Example: Geographical knowledge

A study of defects at Margam Castle in Port Talbot demonstrated that the north and east facades were mostly wet and struggling with accumulating organic matter. By stark contrast, the south and west facades had extensive issues with wind erosion of the stone. This had a significant impact on the planned cyclical maintenance strategy and the specification for repairs.

Above: Margam Castle

Stage 2 — Sufficiency

Eliminate unnecessary energy wastage and mitigate the impact of unavoidable energy use to reduce energy demand.

Repair and maintenance are critical to a building's performance. As wet built fabric has a higher thermal conductivity than dry fabric, prioritise identifying and eliminating sources of water ingress and saturation. Eliminating draughts by addressing unnecessary gaps and cracks can reduce heat loss through infiltration.

Improving the efficiency of a building through good maintenance and user behaviours will impact the type and scale of intervention discussed at a later stage in the hierarchy. For example, the size of any mechanical and electrical equipment may be smaller if demand is reduced, saving money and unnecessary disruption.

Simple measures such as window coverings (shutters or insulating curtains), low-flow sanitary fittings, LED bulbs, intelligent controls, hot water pipe insulation and spatial use can contribute to better energy performance and a more comfortable building. These are 'quick and easy' wins; they may not even require a Listed Building Consent and are likely to be more affordable, making them more accessible to owners or buildings with little scope for major intervention.

Encourage occupants to critically analyse their use of the building. General use of a space has a significant impact on resource use and experience of the building.

Stage 3 — Efficiency

Minimise unavoidable energy use by increasing a building's efficiency. Only after the previous stages have been considered is it appropriate to review possible improvements to the building's fabric by upgrading insulation and windows, undertaking airtightness measures and minimising thermal bridging. To ensure that interventions will not introduce new problems, it is essential that construction type and style are considered.

Measures also need to take into account the movement of moisture and air, the permeability of the existing and proposed materials, and their impact on heritage significance. Earlier considerations of the heritage context and addressing defects at Stage 1 will give identified interventions the best chances of success.

It is at this stage that low- and zero-carbon heating systems should be considered, such as heat pumps. Whilst thermal fabric improvements are important in order to reduce demand on heating systems, they can still be installed where this is not practicable or feasible in the context of a historic building. Heating systems will have a larger demand as a result, but they can be sized to operate effectively and still provide an effective route to reduced operational carbon.

Stage 4 — Generation

Generate energy from low- and zero-carbon systems to reduce emissions and demand on supply.
The accumulation of energy efficiency measures identified in the previous stages will support the appropriate and proportionate selection and implementation of low- and zero-carbon technologies, like solar panels.

Developing a strategy

Once all options have been identified, assess each measure against its impact on:

- Heritage significance and context.
- Building use and occupation.
- Energy reduction and carbon emissions.
- Occupant comfort, health and wellbeing.
- Climate resilience.
- Structural implications.
- Technical risks.

Above: Photovoltaic panels on the roof of a historic building

Top: Drip details have been added to the sill of this window to account for increased rainfall, improving the building's resilience to climate change impacts.

Bottom: Lead covers installed on overhangs protect the stone and carvings below from increased rainfall.

It is equally important to consider the risks of inaction alongside the risks of any particular intervention. Any new intervention should be designed and executed in such a way that it is of value immediately and in the future. It should also be designed to avoid prohibiting the installation of further energy efficiency measures in the future.

Interventions should use materials compatible with, and not detrimental to, the original material or construction (see 1.2 and 4.2).

As discussed in Chapter 3, modelling, especially when there is the risk of moisture accumulation and interstitial condensation, can help to provide an understanding of the fabric and system upgrades needed to meet any energy targets. Consider carrying out computer modelling of energy, heat transfer and moisture risk to better understand the implications of different measures.

When considering energy efficiency measures, it is important to consider the greenhouse gas emissions (both saved and emitted) in relation to the whole life cycle of the building. Consider both the carbon emissions that will be saved as a result of the improved operational energy performance, as well as the carbon emissions released as a result of the manufacture, transportation, installation and end-of-life disposal of the materials used during the project. The emissions associated with construction and retrofitting projects — the embodied carbon emissions — can be significant and, if not properly considered, could outweigh the long-term operational carbon savings.

Embodied carbon emissions can be minimised by eliminating new materials whenever they are not needed; reusing existing materials as much as possible; specifying durable, long-lasting, low embodied-carbon materials; and avoiding the over-specification of services. Consider commissioning a Whole Life Carbon Assessment, which weighs the upfront embodied carbon against the long-term operational carbon savings, to properly understand and compare different options. See the end of section 4.2 for more on embodied emissions.

Phased approach

Not all energy efficiency measures will be suitable for every building, and not all measures can, or need to be, executed at the same time. A phased approach may suit some building owners and occupants, especially if planned around an ongoing maintenance schedule.

However, each energy efficiency measure should be considered as part of a whole building approach to ensure each phase is contributing to the wider objectives and plan for the building. Consider potential risks and ensure that one measure does not adversely affect the outcomes and performance of another measure (see section 4.1).

The financial cost and payback of proposed energy efficiency measures

Various studies analyse the average costs of certain retrofit measures, such as the installation of internal/external wall insulation or the replacement of gas boilers with air source heat pumps. This is calculated either by looking at a price per m^2 or as an average building size and type, e.g. three-bedroom semi-detached home, and usually includes the cost of both materials and labour. Simple calculations can be used to estimate how many years it will take to make back the initial investments using the cost of measures and their ongoing maintenance, expected lifespan of the measures and anticipated annual energy savings.

More accurate calculations are also possible — for example, through energy modelling such as PHPP (see example in section 3.2) — to calculate the annual energy savings in kW. This can be converted into financial figures using current energy prices published by Ofgem or by specific energy supplier tariffs.

Resources

For more information on the energy efficiency hierarchy and financial payback see:

Historic England, *Improving energy efficiency through mitigation*

ECA, *Making the case for energy saving measures*

5.3 Legal and regulatory requirements

National Occupational Standards:
EEM01: K6
EEM02: K12, K13, K14, K15, K16, K17
EEM03: K8, K16

Key points

- How energy efficiency measures can change the appearance and character of traditional and protected buildings.
- Implications of legal and regulatory requirements.

Assessing implications of legal and regulatory requirements

Planning and heritage consents

Change in the built environment is managed through the planning system, and certain interventions may need planning consent. Listed Building Consent will be needed to make any changes that would affect the character of buildings that have been listed because of their special architectural or historic interest. Permissions are also required for works to buildings that are scheduled, in a conservation area or protected under another designation. See Chapter 1 for more information on heritage designation and values.

Energy efficiency measures such as the introduction of double glazing or external or internal wall insulation may have a significant impact on the character of an older and traditional building. For example, the measures may introduce new materials that are not compatible with the performance characteristics of the original building or that entail the loss or concealment of historic fabric and detail.

It is therefore imperative to determine the building's architectural or historical significance when proposing energy efficiency measures. To do so, undertake an assessment of significance and produce a Heritage Impact Assessment for submission with planning and Listed Building Consent applications.

Top: Listed Holyrood Park Lodge after considerable retrofit. It is possible to improve the energy efficiency of a building with minimal impact on its character and significance.

Bottom: Replacement windows in the upper story of this building not only perform very differently to the original windows on the ground floor but they also look considerably different and have a significant impact on the building's historic character.

Heritage Impact Assessment (HIA) for traditional and protected buildings

Heritage Impact Assessment is a structured process that ensures the significance of a heritage asset is considered when proposals for change are developed. It is a core part of the design process and tests whether your proposals are appropriate by investigating how they might impact the significance of the asset and ensures that what is important about your historic asset is sustained or even enhanced when you make any changes.

This iterative process considers options for each intervention and results in a heritage impact statement, which is submitted with heritage consent applications. This gives decision-makers the information they need to understand the reasons for your proposal and to weigh up the risks and benefits.

Understanding the asset and its significance is fundamental to a robust heritage impact assessment. See chapter 1 for more information on the values from which significance may be derived. Assessments of significance and heritage impact assessments should be conducted by a suitably qualified or experienced conservation professional. Assessments should be undertaken early and used to inform the design of any planned interventions. This will help to ensure that designs are appropriate and any impact to historic fabric can be avoided, mitigated or robustly justified.

Detailed guidance on heritage impact assessments in the context of the relevant planning policy is available from the statutory heritage bodies:

- Historic England
- Cadw
- Historic Environment Scotland.

Listed Building Consent (LBC) is administered by the local planning authority and is required for changes to both the interior and exterior of a building; early engagement with the local authority conservation officer is important. LBC is not required for maintenance and is unlikely to be required for like-for-like repairs that do not affect the historic character of the building. However, it is recommended that the Local Planning Authority and any local policy and guidance are consulted prior to making any repairs.

Requirements of building regulations

Building regulations are set legal standards for how buildings should be constructed to achieve a minimum level of performance and safety, and they include structural and fire safety requirements (the latter are also covered in relevant fire safety legislation). When planning energy efficiency measures, due consideration needs to be given to requirements set out in building regulations, which vary across the home nations.

It is important to be aware of implications for material choices, the performance of the fabric and vapour permeability, as well as potential impacts on the heritage significance of the property. Contact the local authority building control officer to establish whether approval for work is required. In consultation with building control, decide whether a full plans submission or building notice is the most suitable approach. Confirm appropriate approach to material selection and specification with the inspector.

Minimum standards for energy efficiency are set in Building Regulation Approved Document Part L: Conservation of fuel and power (there are different versions for England and Wales) and section 6 of Building Standards Scotland. These requirements can conflict with the requirements of traditional and historic buildings, particularly in relation to achievable U-values when using vapour permeable materials.

Works to traditional and historic buildings should comply with the energy efficiency requirements as far as reasonably practicable. However, work to listed buildings, buildings in conservation areas and scheduled monuments do not need to comply when doing so would unacceptably alter the dwelling's character or appearance. Similarly, for historic and traditional buildings with vapour permeable construction, the building standards in each of the home nations allows flexibility where the strict application of the energy efficiency requirements would cause long-term deterioration of building fabric and fittings.

If complying with the requirements of building regulations will result in the installation of measures that are incompatible with the existing building materials, a case should be made for an alternative approach.

Example: Vapour permeable insulation

Vapour permeable insulation tends to have a higher thermal conductivity than vapour impermeable insulation. This means that thicker build-ups are required to achieve the same U-value as a vapour impermeable equivalent.

Sometimes space does not allow for these thicker build-ups — for example, if there is a knock-on effect on the visual appearance of the building, like an increase in roof height. However, the use of vapour impermeable insulation could lead to unintended consequences like interstitial condensation and fabric deterioration.

In this instance, a case could be made to achieve the lowest U-value possible within the constraints of the existing building. Specialist advice will be helpful in making an assessment to ensure that any proposed measures have no adverse effect on the building fabric.

Wildlife protection

Many wildlife species are legally protected in the UK. The most likely of these to be encountered when planning or installing energy efficiency measures are bats and birds, both of which are commonly found in and around older and traditional buildings.

It is an offence to deliberately capture, injure, kill or disturb any bat species or to damage or obstruct access to a bat roost. Similarly, it is an offence to intentionally kill, injure or capture any wild bird, take or destroy their eggs or nest, or damage or block access to a nest while it is in use or being built.

Even minor works, such as treating timber, installing loft insulation, or replacing gutters, can disturb these species. Use of certain materials, such as woven membranes, should also be avoided near bat roosts as the bats can get caught in the filaments and die. Further advice on what to do if protected species are thought to be present can be found in the resource list at the end of this section. Advice may also be needed from an ecology consultant.

The Party Wall etc. Act 1996

Party wall legislation applies only to England and Wales and does not exist in Scotland or Northern Ireland. The Act provides a framework for preventing or resolving disputes in relation to party walls, party structures, boundary walls and excavations near neighbouring buildings.

Anyone intending to carry out work anywhere in England and Wales of the kinds described in the Act must give adjoining owners notice of their intentions. Further information about how the provisions of the Act might relate to the introduction of energy efficiency measures can be found overleaf.

Above: Alfred’s Terrace, Taff’s Well

Resources

Please visit the planning portal at www.planningportal.co.uk to process planning applications in England and Wales (planning and building regs) and www.eplanning.scot/ePlanningClient/ for applications in Scotland.

For government planning policy and supplementary guidance see the following:

Welsh government, *Planning guidance for the public*

Welsh government, *Technical Advice Note (TAN) 24: The historic environment*

Ministry of Housing, Communities and Local Government and Department of Levelling Up, Housing and Communities (England), *Planning Practice Guidance*

Historic England, *The planning system*, including Historic England published planning advice

Scottish government, *Planning Advice Notes (PANs)*

For information on obtaining a building warrant in Scotland and to apply see www.mygov.scot/building-warrant

For details of building regulations in England and the requirements for historic buildings, see:

Historic England, Regulations, Approved Documents and historic buildings

For information and detailed guidance on managing change in the natural environment and environmental considerations, visit the websites of the relevant national bodies:

Natural England

Natural Resources Wales

NatureScot

For more on specific regulations mentioned in this chapter see the following:

The Bat Conservation Trust

UK government, *The Party Wall etc Act 1996: Explanatory booklet*

Royal Institution of Chartered Surveyors (RICS), *An owner's guide to the Party Wall etc. Act 1996*

5.4 Justifying measures

National Occupational Standards:

EEM03: K17, K18

Key points

- Justifying proposed action above or below target U-values.
- Justifying why certain energy efficiency measures have not been selected.

Justifying action above or below target U-values

In some cases, energy efficiency measures may result in U-values below the set target. There are several technical reasons why achieving lower performance (higher U-values) might be necessary:

- To maintain the permeability of traditional construction and the relative thickness of these materials to achieve the required U-value, particularly where space constraints exist.
- To reduce internal moisture risk to an acceptable level or ensure the external wall is not cooled to a level where it is at risk of moisture accumulation or freeze-thaw (i.e. when installing IWI).
- To enable retention of internal or external features of heritage value.

Although less likely, achieved U-values can also exceed targets — for example, when there is a greater level of space for insulation than expected. However, it is imperative that thermal continuity is prioritised above maximising the U-value in any area — to reduce moisture risks noted above and prevent the creation of thermal bridges.

See 3.1 for details on U-values and their limitations for traditional buildings.

Justifying the selection of energy efficiency measures

Following the whole building approach outlined in section 4.1 will ensure your ability to robustly justify the selection of energy efficiency measures and help explain why other measures have not been selected.

Specific measures may be selected or discounted for any or all of the following reasons:

Compatibility with the fabric of an older or traditional building

For example, the selection of vapour permeable insulation and lime render, instead of vapour impermeable insulation and cement render, to reduce the risk of interstitial condensation and trapped moisture.

Compatibility with other energy efficiency measures in the works package or previously installed measures to avoid costly abortive works

For example, designing to install new insulation after the windows have already been upgraded could render the detailing of the window upgrade ineffective and require further costly works. A risk assessment could help to mitigate this (see 5.1).

Retaining (and enhancing, where possible) the significance of the building

For example, selecting sensitively designed secondary glazing rather than replacing existing historic windows to reduce the impact on the building's heritage significance or using the installation of EWI to reinstate missing architectural details, such as raised render bands.

Top: Carefully installed secondary glazing allows historic shutters to remain operable.

Bottom: The interior of a vernacular cottage has retained its original features, such as beams, following retrofit interventions to its walls and floor.

Cost of the works

For example, the selection of low-cost measures like draughtproofing and loft insulation instead of more expensive measures like insulating over rafters, which requires re-roofing work.

Obtaining consent for works

For example, selecting internal wall insulation (IWI) instead of external wall insulation (EWI) in a conservation area when EWI would impact the character of the surrounding area and therefore be less likely to gain planning consent. Installation of IWI still presents a technical risk and appropriate assessment is required.

Level of disruption

For example, installing roof insulation between and below rafters to coincide with essential, pre-planned roof upgrades. Carrying these out at the same time would limit overall disruption and abortive works.

Lower embodied carbon

For example, selecting materials with lower environmental impact when technically appropriate.

Resources

The following publications focus on managing change in the historic environment; they provide detailed guidance on assessing impact and justifying decisions and include case studies for the introduction of energy efficiency measures:

Cadw, *Managing change to listed buildings*

Historic England, Historic England *Advice Note 18: Adapting historic buildings for energy and carbon efficiency*

Historic England, *Historic environment good practice advice in planning 2: Managing significance in decision-taking in the historic environment*

Historic England, *Historic England Advice Note 2: Making changes to heritage assets*

Historic Environment Scotland, *Managing Change Guidance*

Chapter 6

Implementation and Project Management

Overview

This chapter covers the following topics:

- Preparing reports and plans.
- Requirements for the delivery of energy efficiency measures in a retrofit project.

6.1 Phasing works and communicating plans

National Occupational Standards:

EEM03: K10, K11, K14, K15

Key points

- Prioritising energy efficiency measures in a staged approach.
- Repairs required before installation of measures.
- Ongoing maintenance requirements to maximise the thermal performance of the building.

Above: Sowerby Bridge Library, West Yorkshire, undergoing works as part of the High Street Heritage Action Zone.

Prioritising and sequencing energy efficiency measures

As has been emphasised throughout this handbook, planning and implementing changes in stages is key to a successful retrofit. For example, adhering to the stages set out in 5.2 can help identify ‘easy wins’ that are relatively low risk and ensure that more intrusive measures are proportionate and considered in relation to their impact on other measures and on heritage significance.

By establishing the desired outcomes (short, medium and long term) and assessing what measures are needed to achieve these and how they interlink, it is possible to consider if and how works can be phased. More intensive phasing will require thinking beyond the building to a number of practical contingencies:

- **Budgets/funding**
  How much capital expenditure is available up front and how much might be available at a later date? Do the proposed measures offer value for money?

- **Quick wins**
  Are there easy, low-cost, low-risk measures or changes to occupant behaviour or building management that could be implemented early on?

- **Building occupation**
  Does work need to happen while the building is still being used?

Above: Access is a critical consideration when planning works, for example, if scaffolding is required. If so, it should be installed appropriately to avoid damage to historic fabric.

- **Disruption**
  Different measures have different levels of disruption. For example, a window can be replaced with minor disruption to a room, whereas adding internal wall insulation will require the removal and reinstallation of fixtures, fittings and finishes.

- **Timeline and time of year**
  Is the timescale realistic for the project, allowing sufficient time to prepare a detailed specification, obtain any required consents and complete the work? Will inclement weather impede progress?

- **Access**
  Are all areas of the building easily accessible? Will a scaffolding/crane/cherry picker be needed?

- **Need for preparatory works**
  Is work needed before a measure can be installed, such as repairs or the relocation of services?

- **Interactions**
  Do measures need to be installed together or in a particular order? Would the installation of some measures preclude the later installation of others or make subsequent installation more difficult? Would phasing introduce risks, such as condensation and mould, that would need to be mitigated against pending the implementation of a later phase of work?

- **Consent**
  Is planning or LBC required for any of the work? Does consent need to be sought from neighbours for access to shared spaces?

Repairs required before installation of measures

For energy efficiency measures to be effective, it is vital that the building fabric is in a good state of repair. Remedial works should be completed before energy efficiency measures are carried out. For example, installing solar panels on a roof that is not watertight or secure could cause further damage to the roof and lead to abortive work, wasted resources and higher costs. See 2.1 and 4.2 for more detail on building defects and repairs.

The importance of ongoing maintenance following the installation of energy efficiency measures

The main objectives of maintenance are to limit and slow deterioration; to ensure the measures continue to function as intended; and to ensure that they are able to withstand a changing climate (see 4.1). Inspections carried out at regular intervals, coupled with prompt action to pre-empt or remedy problems, can reduce the impact of defects and material degradation, especially relating to water ingress and the associated decrease in thermal efficiency of damp fabric.

Maintenance is usually cost-effective. The time and money spent on routine care, minor repairs and regular surveys will ensure that energy efficiency measures are achieving the desired outcomes. Good maintenance also helps to ensure the health and safety of building users and the public.

Maintenance plans should be proportionate to the size and complexity of the building. For large or complex buildings, a maintenance plan may form part of a comprehensive asset management plan. For smaller buildings, such as privately-owned dwellings, the plan might consist of a simple checklist to be used during an inspection. It is vital that maintenance requirements are communicated to occupants and that any maintenance plans, checklists or other guidance are provided.

Above: Vents can become blocked by debris over time.

Preparing and communicating reports and plans

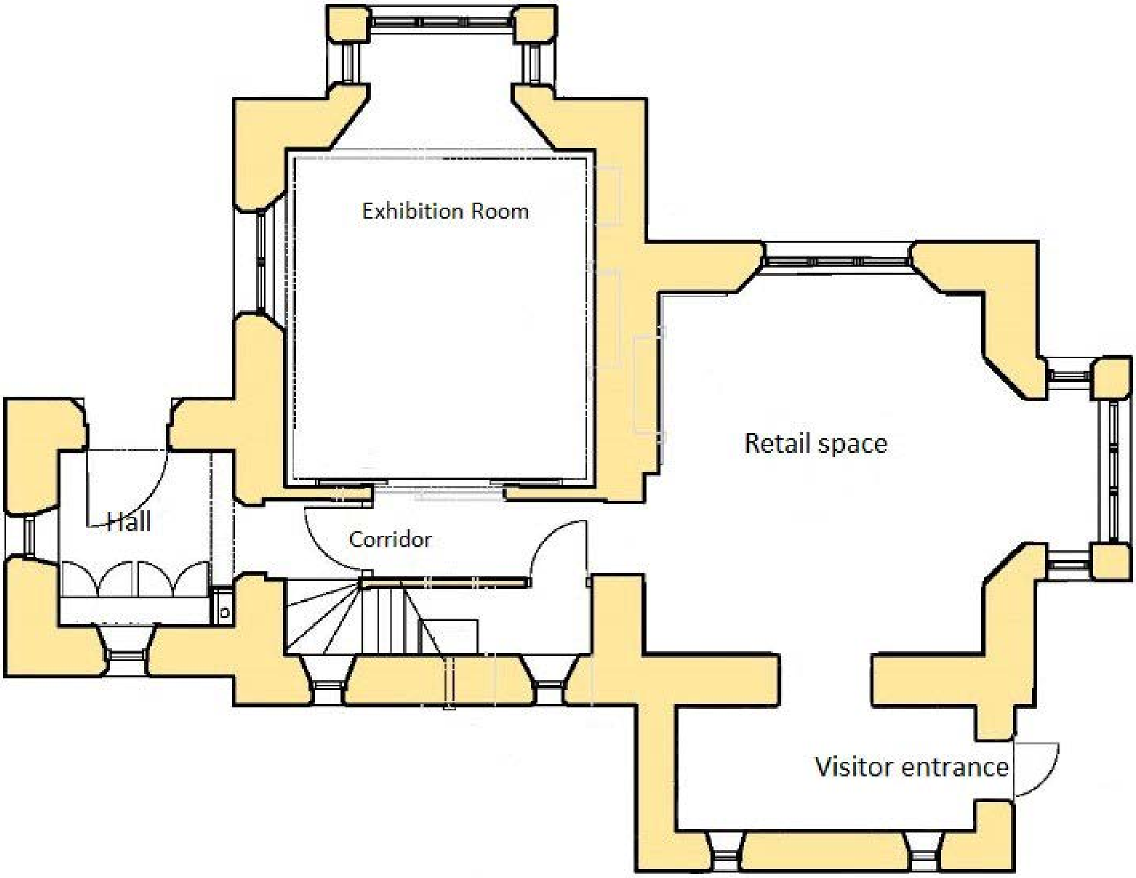
Another important part of planning is communicating your intentions to stakeholders. Aside from applications to the necessary authorities, when developing proposals for energy efficiency measures, a report should be produced to communicate to occupants what you are going to do, how you are going to do it and why. In order for an intervention to be successful, occupants must understand how to take advantage of the intervention. Include any relevant standards that are being met. The previous chapters of this handbook have covered the breadth of information that, when brought together, enables the design of suitable proposals and advice.

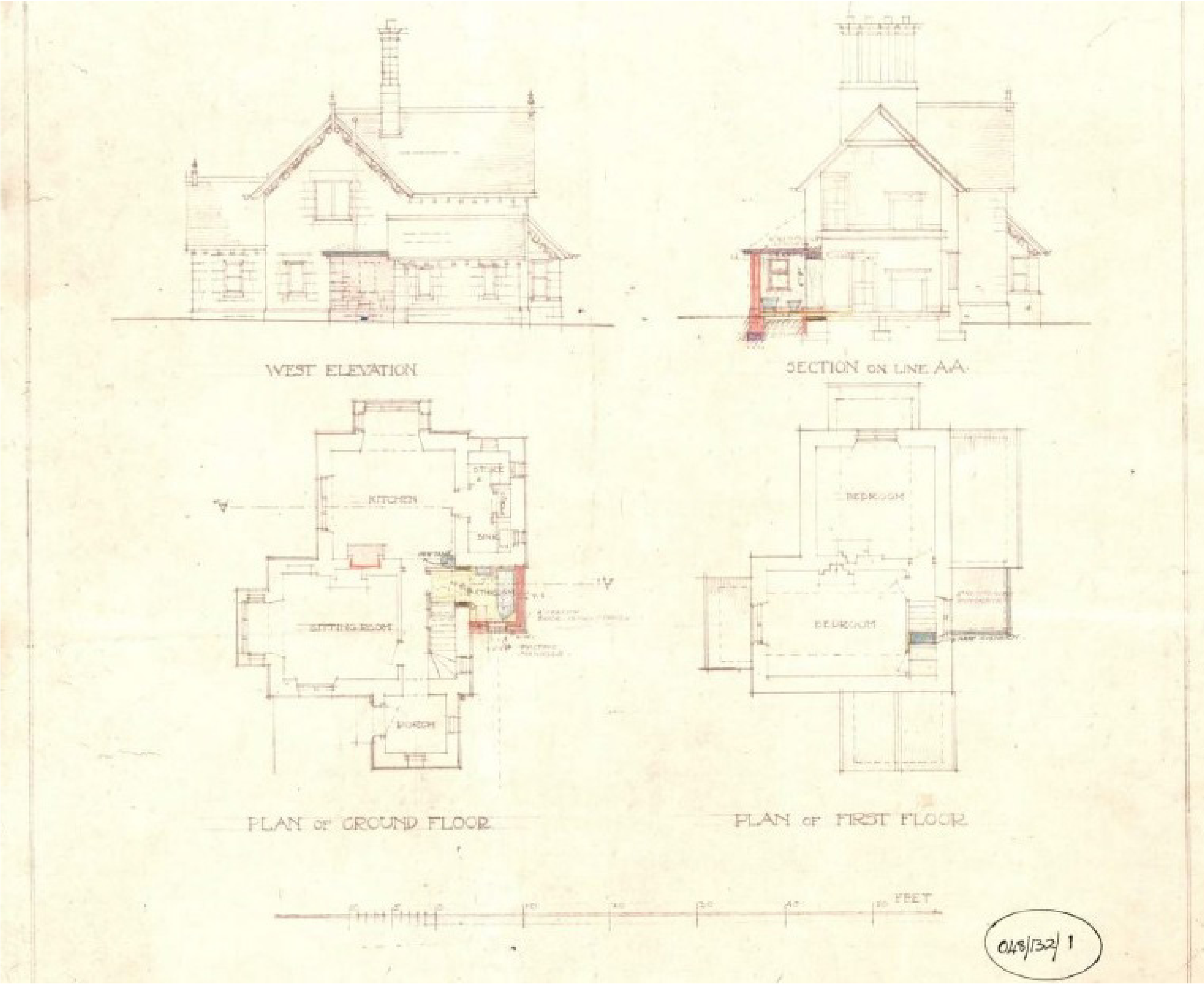
A report outlining proposals should include:

- Agreed intended project outcomes.
- Building context and existing services, including information regarding existing construction phases, materials and techniques, and heritage significance.
- Building and services condition report, including any performance issues.
- Outcomes of assessments, including energy modelling.
- A prioritised list of measures with estimated energy savings, costs of implementation and technical risk and mitigations.
- An implementation plan that outlines proposed timelines and impact on occupant use of the building.

Reports are important not only for planning and attaining permissions but also because they are an efficient way to communicate with occupants. Occupant engagement in the entire process is important, especially during the information gathering and design stages. The advice, the evidence on which it is based and the implication of proposed interventions should be clearly explained so that occupants know how any new measures operate and how their actions can impact the effectiveness of the intervention.

Below: Floor plans of buildings are vital.





Resources

The following are resources related to developing maintenance plans:

Cadw, *Maintenance matters!*

Historic England, *Maintenance plans for older buildings*

Historic Environment Scotland, *Maintenance of traditional buildings*

Above: Older drawings of elevations and floor plans can be useful.

Left: CAD drawings such as this can help visualise a building.

6.2 Project delivery

National Occupational Standards:
EEM03: K19, K20, K21, K22

Key points

- Requirements: packaging and sequencing of measures, repairs needed before installation, protection works, site issues, risk assessments.
- Roles and responsibilities in a retrofit project.
- Technical risks.

Requirements for the delivery of an energy efficiency project

Stages of an energy efficiency project

As seen in 5.2 and 6.1, interventions can be phased as part of a staged approach. Projects themselves should also be approached in stages to ensure their success:

1. **Starting from a position of knowledge**
The first step of any project should be the collation of knowledge and data about the building and how it is used. It is also important to find out what the client wants to achieve (see reasons for introducing energy efficiency measures in 4.1) and ensure there are clear project objectives from the outset. This will help inform and justify intended outcomes and measures. Consider also a strategy for client engagement — they must be kept informed at every stage throughout the project.

2. **Understanding the risks**
It is crucial to understand and mitigate the risks associated with the existing building, as well as any technical risks associated with potential energy efficiency measures.

3. **Identifying suitable measures**
Energy efficiency measures should be identified, compared and prioritised, with a clear plan for sequencing and phasing.

4. **Detail design**
In complex projects, professional advice should be sought, with drawings and a written specification required as a minimum. Designs should take into consideration: compatibility with existing fabric; impact on heritage significance; vapour permeability; adequate ventilation; thermal performance; usability; whole life carbon; existing and future climate change impacts; the need to ensure the resilience of the building and the energy efficiency measures; and compatibility with future phases of energy efficiency or climate adaptation improvements.

5. **Statutory approvals**
With some retrofit work, particularly involving a listed building or buildings in a conservation area, certain statutory approvals will need to be obtained prior to starting the work. The project team should advise on the need for statutory approvals and the timeframes involved in this process.

6. **Installation**
Find a contractor/installer who is familiar with the building and construction type and shows interest in the success of what is being proposed. Quality control is essential if the performance requirements of the brief are to be achieved. Site access and temporary works, including the protection of important building features, needs proper planning prior to commencing the work.

7. **Testing and commissioning**
Where new plants or services are being installed, commissioning and handover will be a key factor in the success of any energy efficiency measures. This will typically involve the testing of key systems to ensure they are operating in an efficient and integrated way. Commissioning should demonstrate that all metering and monitoring equipment are functioning properly. Thoroughly testing and adjusting this equipment will ensure that the whole system uses no more fuel or power than is reasonable and is operating as designed.

8. **Handover and handover advice to occupants**
It is essential that building users know how the installed energy efficiency measures work and understand their role in the smooth-running of any new systems. Plan to engage building occupiers in the handover process. Provide building users with a clear guide on how to use and maintain their building and any measures introduced to maximise efficiency and comfort.

9. **Ongoing monitoring and fine-tuning**
The continuous monitoring of any project outcomes will be key to understanding the impacts of any energy efficiency measures and helping to ensure their long-term success.

10. **Evaluation**
Compare the actual, monitored performance with the initial brief targets. On a small project, this might be meter readings, a review meeting with the team or short user interviews. Ongoing evaluation of a project will help ensure that the building is performing as intended and that users are operating the building in a way that ensures its optimum energy efficiency.

11. **Future maintenance and phased work**
Requirements for ongoing maintenance and repair should be documented as part of the handover process. This should include scheduling maintenance procedures and outlining the design life of the different installations and when they will require upgrades or replacement. In addition, any future phases of work required as part of the whole building approach should also be documented.

Requirements for the delivery of energy efficiency measures

Competency

The selection of a competent team to plan, design, manage and deliver energy efficiency measures is crucial, particularly for more complex projects involving the installation of multiple measures or listed buildings. Seek professional advice where appropriate.

Site operations can have a significant impact on the effectiveness of any building retrofit, therefore quality control processes should be a minimum requirement of any construction work. Contract documents should clearly set out what the aspirations of the project are, particularly in terms of performance, quality and safety. Building contracts which include performance and value-linked incentives based on monitoring should be considered.

Consultation

Planning for the delivery of energy efficiency measures should always be carried out with building owners and occupiers. Ongoing and thoughtful communication with the people who will be living in or using the building will be vital to ensuring that the project succeeds. Occupants should understand the crucial role they have to play in reaping the benefits of the retrofit, and they need plenty of time to plan for themselves — for example, if they will be required to vacate the premises.

A soft landings approach can help establish these channels of communication. It encourages collaboration between building designers, building developers/owners, the occupants, and operators of a building. It focuses on delivering buildings that are optimised to minimise energy use and maintenance costs and are comfortable and straightforward to use. For a soft landing:

- Effectively communicate the agreed project outcomes to all necessary stakeholders.
- Set up a process for reviewing designs with building occupants and managers.
- Identify risks to performance and how to mitigate these.
- Include a plan for advanced handover with the contractor and building occupants and managers, including user familiarisation, training and aftercare.

When discussing outcomes, designs and risks, explain which areas of the building will be affected, the level of disruption and time period for the work. Include information about repair works required in advance of the retrofit and any work planned for a later date.

Minimising risks

When works are being carried out, the contractor typically takes ownership of the site and is responsible both for delivering the employer's requirements and maintaining the health and safety of all people who may be affected by the works. Designers must ensure that proposals comply with all relevant health and safety regulations.

For complex projects involving multiple energy efficiency measures, a method statement should be produced by the retrofit installer. As a minimum, this statement should include a risk assessment for the proposed work; it should also include specific details about how the proposed design and installation will address any points of weakness (e.g. areas of water ingress and/or thermal bridging, see 2.1).

Historic buildings are particularly vulnerable to fire risk. This needs to be assessed at every stage, particularly during design and construction, with mitigation processes put in place.

Heritage protection

Careful consideration and planning should be given to the protection of existing features, particularly if the building is listed. Areas and features most at risk from the proposed building work should be identified, with a clear plan of how to mitigate these risks.

Example: Heritage protection

– Use of scaffolding will call for suitable protective measures, such as end caps to ensure that tubes are not rubbing against stone.

– A feature staircase might need to be sufficiently covered if there are large volumes of materials being moved around the building.

Roles and responsibilities

The roles of those working on the project need to be clearly communicated to all parties, including clients. These roles can vary, but there are broadly recognised roles for retrofit projects that are derived from PAS2035:

- **Retrofit coordinator** — oversees the project from inception to completion. They will direct the assessment, strategy, design, installation and evaluation phases. In PAS2038, this role is known as 'retrofit lead professional'.
- **Retrofit assessor** — responsible for the initial assessment of the building and data collection. They will make basic recommendations on the measures that could be considered.
- **Retrofit designer** — prepares the design package with sufficient information to inform effective installation. They will consider the interaction of measures to reduce technical risks.
- **Retrofit installer** — carries out the specified works.
- **Retrofit evaluator** — monitors and evaluates the effectiveness of intervention and provides feedback to the client and project team.

One person can hold more than one role in the retrofit process under PAS2035, assuming there are no conflicts of interest. For example, a retrofit evaluator who is undertaking further monitoring under BS40101 cannot also hold the retrofit coordinator role and will need to be entirely independent from all other roles.

See the introduction for an explanation of PAS and standards.

Glossary

Term	Definition
Adaptation (for climate change)	Adjustment to actual or expected climate and its effects to moderate or avoid harm or exploit beneficial opportunities.
Capillarity/capillary action	The movement of liquids in small spaces (capillaries) within materials against the force of gravity.
Carbon	Shorthand term for carbon dioxide (CO_2), which is a greenhouse gas and is the most prominent in causing climate change. The impact of the other four gases — water vapour (H_2O), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) — is often expressed as carbon dioxide equivalent or CO_2e.
Circular economy	A system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling and composting. The circular economy tackles climate change and other global challenges — such as biodiversity loss, waste and pollution — by decoupling economic activity from the consumption of finite resources.
Climate change	A change of climate that is attributed directly or indirectly to human activity, which alters the composition of the global atmosphere and is in addition to natural climate variability observed over comparable time periods. (United Nations Framework Convention on Climate Change, article 1)
Condensation	The change of state of water from a gas (vapour) into a liquid.
Conservation (for heritage policy)	The process of maintaining or managing change to a heritage asset in its setting in a way that sustains and, where appropriate, enhances its significance.
Decrement delay	The time it takes for heat to pass through an element. If a material has a high decrement delay factor, it will take longer for heat to pass through it.
Designated heritage asset	A World Heritage Site, scheduled monument, listed building, protected wreck site, registered park and garden, registered battlefield, or conservation area designated under the relevant legislation.
Dew point (DP)	The temperature to which air must be cooled to become saturated with water vapour. When warm air reaches a cold surface, DP will be reached and condensation will result. The location of the DP within the wall will change depending on conditions.
Embodied carbon	The carbon emitted over the whole lifecycle of a building, including during construction, maintenance, refurbishment and demolition. It considers carbon emissions released throughout the supply chain including extraction of materials from the ground, transport, refining, processing and assembly, and end of life.
Energy efficiency measures (EEMs)	Measures to reduce the amount of energy required for products and services.
Energy sufficiency	Measures to reduce energy demand by eliminating excess energy use and mitigating the impact of unavoidable energy use.
EPC	Energy Performance Certificate. EPCs provide a standardised energy or ‘asset’ rating for a building, based on the inherent energy performance of the fabric and systems within that building.
Exposure	The natural features of an asset’s position within the landscape that render it vulnerable to harm or damage. This includes but is not limited to exposure to rain. Approved Document C of the building regulations provides a map of the four exposure zones in the UK, based on exposure to wind-driven rain. The Environment Agency has published peak rainfall allowances maps for England.
‘Fabric first’ approach	The prioritisation of improvements to the existing fabric to reduce energy consumption before considering the introduction of low- and zero-carbon technology. Fabric improvements can improve the energy efficiency of a building, but they must be considered as part of a whole building approach to ensure all factors that have implications for the introduction of energy efficiency measures are considered.
Greenhouse gases (GHGs)	A gas that absorbs and emits radiant energy at thermal infrared wavelengths, causing the greenhouse effect. Primary greenhouse gases in Earth’s atmosphere are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Human generated GHGs are the primary cause of global warming and climate change.

Term	Definition
Heritage/historic asset	A building, monument, site, place, area or landscape identified as having a degree of significance meriting consideration in planning decisions, because of its heritage interest. Heritage assets are of two types: 'designated heritage assets' and 'non designated heritage assets'.
Historic environment	All aspects of the environment resulting from the interaction between people and places through time, including all surviving physical remains of past human activity, whether visible, buried or submerged, and deliberately planted or managed. The definition of historic environment varies across the NPPF, NPF4 and Planning Policy Wales.
Humidity	The concentration of water vapour in the air.
Hygroscopicity	The ability to absorb moisture from the environment and release it when environmental conditions allow.
Hygrothermal	Relating to the movement of heat and moisture through buildings.
Listed building	A building with heritage significance that is protected by law.
Listed Building Consent (LBC)	A type of planning consent required for proposals to make changes to listed buildings. LBC is administered by local planning authorities.
Mitigation (for climate change)	An intervention to reduce, absorb or remove greenhouse gases from the atmosphere with the primary function of limiting global warming to avoid the worst impacts of climate change.
National Planning Policy Framework (NPPF)	Sets out the Government's planning policies for England and how these are expected to be applied.
National Planning Framework 4 (NPF4)	The national spatial strategy that sets out spatial principles, regional priorities, national developments and national planning policy in Scotland.
Net zero	The reduction of greenhouse gas emissions by 90% or more compared to a set baseline year, with the remaining emissions balanced by absorbing or removing them. The UK's net-zero baseline year is 1990. The UK is committed to a target of net zero by 2050.
Operational carbon	The carbon associated with the in-use operation of a building. This usually includes carbon emissions associated with heating, hot water, cooling, ventilation and lighting systems, as well as those associated with cooking, equipment and lifts (that is both regulated and unregulated energy uses), but can account for any activities that expend carbon, for example the materials and processes involved in maintaining and repairing a building.
Overheating	Discomfort, and possible health risks to occupants caused by the accumulation of warmth within a building.
Payback	The time it takes to recover the cost of introducing energy efficiency measures through savings in energy usage.
Performance gap	The difference between the predicted or calculated building performance at the design stages of a project, based on modelling, and the actual measured performance, based on meter readings once the building is occupied. The predicted performance is based on modelling, while the actual performance is based on meter readings.
Permeable (materials)	Materials containing pores that are interconnected, creating pathways through which moisture can move in both liquid and vapour forms. They can take up moisture from their surroundings (absorption) and release it (desorption) in response to changes in the humidity of those surroundings.
Planning Policy Wales	National policy outlining guidance for making planning decisions in Wales.
Prebound effect	A phenomenon where less energy is used than had been assumed, leading to a performance gap due to the energy savings from introducing energy efficiency measures being lower than predicted.
RdSAP	Reduced Data Standard Assessment Procedure. The energy assessment procedure used for existing dwellings.
Rebound effect	A phenomenon where occupants change their behaviour following improvements of energy efficiency, for example, increasing comfort taking due to lower overall cost to heat their home. The energy usage used to calculate the performance of new measures will have changed, leading to a performance gap.
Resilience	The capacity to withstand or recover quickly from a hazardous event or change in climate while retaining functionality and/or significance.

Term	Definition
Retrofit	The addition of new technologies or features to an existing building to change the way it performs or functions. In this handbook, we use the term to refer to the improvement of an existing building to ensure it is responsive, resilient and well-adapted for our changing climate.
R-value	The measure of thermal insulance, expressed as m^2K/W.
SAP	Standard Assessment Procedure. The energy assessment procedure for newly built dwellings and dwellings converted from commercial to domestic via 'Change of Use'.
SBEM	Simplified Building Energy Model. The energy assessment procedure for existing non-domestic buildings.
Setting of a heritage asset	The surroundings in which a heritage asset is understood, appreciated and experienced. Its extent is not fixed and may change as the asset and its surroundings evolve. The definition of setting varies across the NPPF, NPF4 and Planning Policy Wales.
Significance (for heritage policy)	The value of an asset because of the sum of its heritage value(s). Significance can be derived from a place itself, its fabric, setting, use, associations, meanings, records, related places and related objects. The definition of significance varies across the NPPF, NPF4 and Planning Policy Wales.
Soft landings strategy	An approach for managing the transition of a project from implementation to occupation whereby the transition is considered from project inception.
Solar gains	The heating of an element or structure due to the absorption solar radiation.
Sympathetic	Designed in a sensitive or appropriate way. In a heritage context, this includes consideration of an asset's heritage values, setting, fabric and performance.
Thermal bridge	A point in an element or the building envelope that allows heat to pass through more easily. Also called a cold bridge.
Thermal bypass	The transfer of heat that bypasses the thermal insulation layer due to the movement of air across, within and behind the insulation.
Thermal comfort	The thermal satisfaction of a person in the surrounding environment.
Thermal conductivity	The ability of a material or building element to conduct heat.
Thermal inertia	The speed at which heat passes through a material, used to express a measure of the material's thermal mass.
Thermal insulance	A measure of the thermal resistance of a material based on its density and thickness. It is the opposite of thermal transmittance.
Thermal mass	The capacity of a material to hold heat.
Thermal transmittance	The ability of a material or building element to transmit heat.
U-value	A measure of the thermal transmittance of a structure, as single material or a composite, in standard conditions. It is calculated by dividing the rate of transfer of heat through the structure by the difference in temperature across it, expressed in W/m2K, watts per metre square Kelvin.
Vapour pressure	The pressure exerted by molecules of water vapour in gas form. This can exert considerable force — for example, enough to blister paint. Warm, moist air has a higher pressure than cold, dry air. A high moisture content will create a large amount of vapour pressure. Vapour diffuses through building materials at a rate proportional to the vapour pressure difference. If one side of a wall is much dryer than the other, the vapour will diffuse faster.
Ventilation	The movement and exchange of air.
Whole building approach	Considers a building's context to find balanced solutions that save energy, sustain heritage significance, and maintain a comfortable and healthy indoor environment. It also considers wider environmental, cultural, community and economic issues, including energy supply. It can help to manage the risks of maladaptation.

Appendix

National Occupational Standards

This table outlines where the principle content for each National Occupational Standard knowledge criteria (K) is covered in the handbook.

EEM01 Assess the age, nature and characteristics of older and traditional buildings

You need to know and understand...		Section
K1	Sources of information to help establish the age of older and traditional buildings.	1.1
K2	The architectural styles and characteristics of buildings.	1.1
K3	How U-values for building elements can be calculated and why the age building parts may impact on the default U-values used in core energy modelling methodologies.	3.1
K4	The relevance of building age in relation to the difference in performance characteristics between traditional and modern materials and construction methods.	1.2
K5	How heritage values are used to assess and describe the significance of buildings.	1.3
K6	Why and how statements of significance and heritage impact assessments are prepared and used.	5.3
K7	The range of current legislation and sources of official guidance relevant to built heritage.	1.3
K8	The necessity and context of applying a whole building approach.	1.3
K9	The key factors to consider when taking a whole building approach to the installation of energy efficiency measures.	1.3, 4.1
K10	Reasons for taking a whole building approach to the installation of energy efficiency measures.	1.3, 4.1
K11	The principles of conservation.	1.3
K12	How the principles of conservation are applied to older and traditional buildings in relation to the introduction of energy efficiency measures.	1.3
K13	The types of construction of older and traditional buildings, the materials used and how they differ from modern construction and materials.	1.2
K14	The how to identify local and regional variations of traditional buildings and materials.	1.2
K15	How the performance of traditionally constructed buildings differs to modern construction.	1.2
K16	The effect of the geographical location, climate, aspect, orientation and the differing exposure of individual elevations on the way older and traditional buildings perform.	1.2
K17	The interaction of traditional and modern materials and the consequences of using incompatible and poorly designed energy efficiency measures.	1.2
K18	The types and condition of water and space heating systems and the implications these have on the introduction of energy efficiency measures.	2.2

You need to know and understand...		Section
K19	The types and condition of controlled ventilation and the implications these have on the introduction of energy efficiency measures.	2.2
K20	The sources of uncontrolled air infiltration and the implications these have on the introduction of energy efficiency measures.	2.2
K21	The way of establishing and measuring the level of airtightness of older or traditional buildings.	2.2
K22	How to identify the common building issues and defects, and their causes.	2.1
K23	The implications of common building issues and defects for the introduction of energy efficiency measures.	2.1
K24	How building materials degrade and deteriorate over time.	2.1
K25	How alterations to the original construction affect the performance of buildings with particular reference to thermal performance, hygrothermal performance, overheating and thermal comfort.	2.1
K26	When there is insufficient knowledge or evidence present to make recommendations on the introduction of energy efficiency measures to older or traditional buildings.	2.1
K27	The range of specialists that may be needed when considering the introduction of energy efficiency measures to older and traditional buildings.	2.1
K28	The types of further analysis and investigation available.	2.1
K29	When and how to refer to specialists.	2.1

EEM02 Evaluate the options for introducing energy efficiency measures to older and traditional buildings

You need to know and understand…		Section
K1	The range of energy efficiency measures for building fabric including building maintenance and repair, airtightness, ventilation and insulation.	4.2
K2	The range of energy efficiency measures for building services.	4.2
K3	The suitability of materials and construction techniques for older and traditional buildings.	4.2
K4	How and why it is important to concentrate on the interfaces between corners, junctions and edges of building elements, and between the building fabric, building services and the occupants.	4.2
K5	The interactions and effects of energy efficiency measures in combination with each other.	4.2
K6	How building issues, defects, enabling works and the repairs required affect the choice of energy efficiency measures.	2.1
K7	The effect of moisture on the energy performance of traditional materials and construction.	2.1
K8	Factors that influence occupant behaviour in relation to energy use.	2.3
K9	The different methods of heat transfer — convection, conduction, radiation — in relation to the thermal comfort of occupants.	2.3
K10	How levels of energy use vary between traditional buildings due to occupant behaviour.	2.3
K11	The ways occupant behaviour impacts on moisture and humidity levels.	2.3
K12	The ways in which energy efficiency measures can change the appearance and character of traditional buildings and impact their significance.	5.3
K13	The content and role of the following types of relevant legislation, regulations, standards and guidance, and how they treat the requirements for energy efficiency measures for traditional and protected buildings.	5.3
K14	The requirements of planning and heritage consents for energy efficiency measures on traditional and protected buildings.	5.3
K15	When compliance with the technical requirements of the relevant national building regulations is required and when exemptions and special considerations apply.	5.3
K16	When an application for approval to a building control or other regulatory body is required for energy efficiency measures.	5.3
K17	How to obtain the necessary relevant legal and regulatory permissions.	5.3
K18	The technical risks associated with energy efficiency measures and enabling works.	4.3
K19	The potential unintended consequences of using poorly specified or unsuitable interventions or energy improvement measures.	4.3
K20	How and when to mitigate the risks.	4.3
K21	The development, use and limitations of energy modelling and evaluation tools for older and traditional buildings.	3.1

You need to know and understand...		Section
K22	The impact of using input assumptions, default recommendations and U-values on the energy efficiency rating and recommended energy efficiency measures.	3.1
K23	U-values, their sources and how they are calculated.	3.1
K24	How and why Psi-values are used.	3.2
K25	In what circumstances calculated or in–situ measured U-values should be used and the issues to be aware of, including the documentary evidence required.	3.1
K26	How to estimate the financial cost and payback of proposed energy efficiency measures for buildings.	5.2
K27	The range of thermal and moisture models, how they compare, their uses and limitations.	3.2
K28	How and why hygrothermal modelling is used.	3.2
K29	The range of calculations, testing and investigation techniques for assessing thermal and moisture risks.	3.2
K30	When and how proposed energy efficiency measures need to be adapted due to existing building structure, detailing and services, the heritage values and significance of buildings or technical risks.	2.1
K31	When and how adaptations are required to existing building detailing and services, and when energy efficiency measures cannot be recommended due to these factors.	2.1
K32	Key concepts and how they apply to evaluating the options for the introduction of energy efficiency and ventilation measures.	5.2

EEMO3 Advise on energy efficiency measures in older and traditional buildings

You need to know and understand...		Section
K1	The principles to follow in the whole building approach.	4.1
K2	When and how performance gaps occur when reductions in fuel use, fuel cost and carbon dioxide emissions are not as large as intended or predicted.	4.1
K3	The reasons for improving the energy efficiency of a traditional building.	4.1
K4	How and why it is necessary to establish the intended outcomes.	4.1
K5	Sources of information relating to specific buildings.	5.1
K6	What factors to consider when reviewing the recommendations for energy efficiency measures.	5.1, 5.2
K7	How to use a range of information sources to undertake a risk assessment for the proposed energy efficiency measures.	5.1
K8	How to undertake an assessment of significance and heritage impact, and prepare a heritage impact statement for traditional and protected buildings.	5.3
K9	When and why further information sources, testing and investigations should be used.	5.1
K10	Why and how to prioritise energy efficiency measures in a staged approach.	5.2, 6.1
K11	Factors to consider in relation to sequencing when installing energy efficiency measures in a staged approach.	6.1
K12	How the present and future impacts of climate change, and the need for climate change adaptation and resilience can affect the options for the introduction of energy performance measures.	4.1
K13	Common repairs and enabling works required before installing energy efficiency measures.	2.1
K14	Common occasional, regular or cyclical maintenance tasks which help to maximise the thermal performance of the building.	6.1
K15	The role and benefits of maintenance checklists and plans.	6.1
K16	How and when it is necessary to obtain legal and regulatory permissions relating to planning and heritage protection, and the national building regulations.	5.3
K17	How and why it is necessary to be able to provide a rationale for the recommended selection of energy efficiency measures.	5.4
K18	Factors to explain when providing a rationale for the recommended energy efficiency measures.	5.4
K19	How and why it is important to explain what is required to deliver the installation of the energy efficiency measures.	6.2
K20	How and why it is important to explain the roles and responsibilities in a retrofit project.	6.2
K21	How and why it is important to explain the common stages in a retrofit project to the building owner or occupier.	6.2
K22	How and why it is important to explain the soft landings strategy to ensure problems from the transition from construction to occupation are minimised and that operational performance is optimised.	6.2

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Above: Grade II listed lock-keeper's cottage on the Ashton Canal, Manchester.

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