Museums and Galleries

U-Value Guide

ARUP

Supported using public funding by ARTS COUNCIL ENGLAND

MDNW

Foreword

Museum Development North West (MDNW) is committed to promoting excellence, innovation, partnerships and organisational sustainability to enable museums to be resilient in challenging times.

The U-Value Guide and Heat Loss Calculator tool was produced by Arup in liaison with the Green Museums Northern Network and commissioned by MDNW using Arts Council England funding for the benefit of the museum sector. The production and dissemination of this guide and tool supports our commitment to enable museums to improve their environmental sustainability.

Museum Development North West

Museum and Galleries

U-Value Guide

Contents

Sheffield City Hall © Arup

Introduction

This guide was commissioned by Museum Development North West. It is aimed at museum and gallery staff to help you to identify opportunities to reduce building U-Values. These opportunities might include adding insulation during refurbishment and reducing air infiltration rates. The improvements are intended to reduce energy bills and carbon emissions. The guide should give you sufficient knowhow when you are involved in projects ranging from relatively minor fabric modifications up to major refurbishments.

Many museums and galleries are in heritage buildings and the guidance has a particular focus on how the structures of traditional buildings deal with various forms of moisture. It is important for you to understand the principles because traditional materials and systems behave differently from those found in modern buildings. A designer or contractor without the appropriate skills can make poor choices that can cause significant damage to buildings and collections. You need to be able to take an informed and critical approach when commissioning building improvements.

There are many potential building fabric related measures (often referred to as interventions) that can improve energy performance and sustainability and this guide should be used together with the Museums & Art Galleries Survival Strategies Guide, previously commissioned from Arup,[1] which includes a wide range of ideas to achieve more efficient buildings, not just in relation to fabric.

The thermal performance of museum and gallery space is very important for a number of reasons:

- Providing appropriate environmental conditions for artefacts and paintings
- Providing suitable conditions for staff and visitors
- Reducing the amount of energy needed to condition the space
- Reducing energy bills
- Minimising draughts
- Controlling infiltration and pollution
- Providing frost protection
- Avoiding condensation

Arup has developed a relatively simple calculation tool to accompany the guide in Excel spreadsheet format. This will enable you to calculate approximate existing U-Values and the potential reduction in U-Values and energy usage achievable from your improvement ideas. The tool is available to download from the Publications section of the Museum Development North West website.[2]

1 https://museumdevelopmentnorthwest.files.wordpress.com/2012/06/museum-and-gallery-survival-strategy-guide-printable.pdf
2 https://museumdevelopmentnorthwest.wordpress.com/publications/

KEY TERMS

Heat is lost from buildings in a number of ways. The primary ones are conduction, convection, radiation and infiltration. The majority of heat loss from a building is through conduction and infiltration, with some losses through radiation. A negligible amount of heat is lost through convection.

Conduction loss is the heat lost through the roof, external walls, lowest floors and windows, which form the thermal envelope of the building. Heat also transfers between rooms and between intermediate floors but it stays within the building. Metal window frames are good conductors of heat (they feel cold), whereas modern plastic window frames or high performance timber windows with thermal breaks are poor conductors of heat (and do not feel cold). In order to retain heat within a space, it is crucial to have good insulation and an appropriate level of airtightness to reduce the conduction losses.

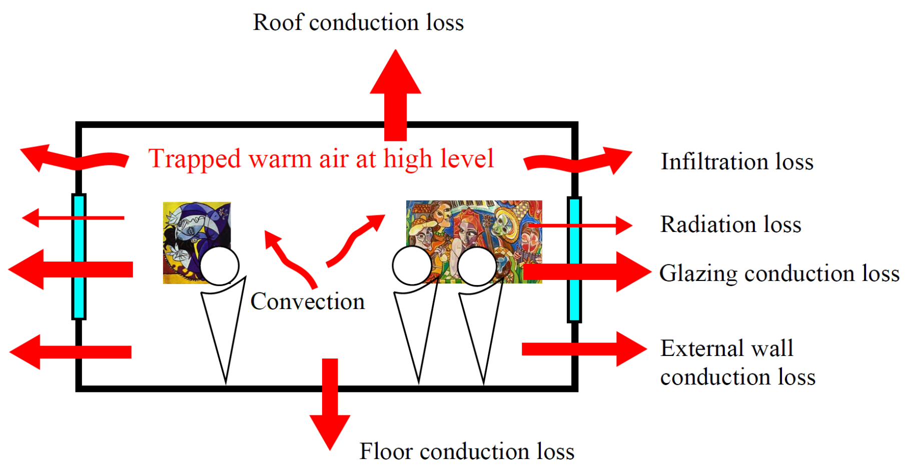
Convection heat loss from a building occurs when energy is transferred to the air inside the building from heat sources such as radiators, walls, people or sunlight. Warm air rises and transfers the energy again when it comes into contact with walls, ceilings, windows or building contents cooler than itself.

Thermal radiation. The hotter an object, the more thermal radiation it gives out. The best known example is the sun which is able to heat the earth through the vacuum of outer space. In a building most radiative losses are through windows and roof lights exposed to the sky.

Infiltration losses occur when air is able to pass through any gaps in the building fabric, allowing heated or cooled air to escape and to be replaced by infiltrated air from the external ambient environment. This incoming air will be at different levels of humidity and potentially polluted. Both are a particular cause for concern in museums and galleries.

The thermal performance of any material can be described in terms of its U-Value. U-Values are sometimes referred to as heat transfer coefficients, expressed in watts of energy transferred per square metre of surface area for each degree Kelvin[3] in temperature difference between the inside and the outside of the building. The units are abbreviated as $W/(m^2.K)$ but the notation is sometimes written slightly differently.

If you know the U-Values of different materials, you can compare their heat transmission performances against each other and calculate the heat loss from a space. A low U-Value means better thermal performance and a high U-Value means worse performance. For example, in comparison to typical building materials, a roof with loft insulation has a low U-Value and is good at resisting heat loss, whereas, single glazing has a high U-Value and loses heat rapidly.



Building heat loss diagram

3 A degree Kelvin is similar to a degree Centigrade but starting instead from -273.15C, the freezing point of nitrogen.

Section 1

Typical and target U-Values of building elements

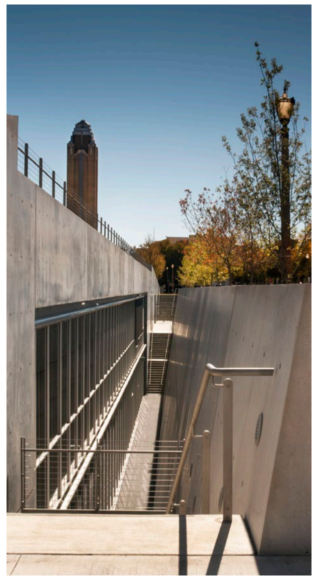
Context

The chart below gives an indication of how U-Value requirements for the construction of new buildings have changed from 1965 onwards. The table was developed for residential construction but the trend is similar for commercial and civic buildings.

The 1965 Building Regulations were the first to establish required, but modest, levels of thermal performance, although some basic standards were implied by building specifications in earlier codes and bylaws. In 1965 the basic norm was an uninsulated cavity wall and 25mm of mineral wool in roof spaces. This reflected a legacy of once cheap coal/coke and, more recently, relatively cheap electricity from coal-fired power stations. The standards were steadily tightened over time, notably in 1973 (the oil crisis), 1985 (the Building Act 1984) and 2006 (in response to climate change). The final entry shows how close current Part L requirements are to the very demanding Passivhaus standard, sometimes adopted for very low energy projects. The standards have probably now reached the practical limit achievable for new buildings.

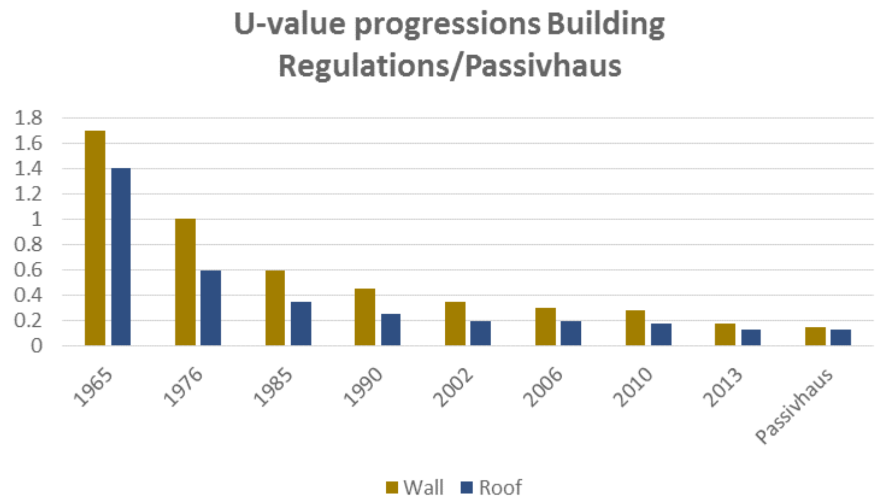
The main buildings of many museums and galleries often pre-date even the earliest of these regulations and have particular adaptation challenges in achieving improved thermal performance. The current Building Regulations recognise that older buildings cannot meet the same standards as new buildings and the required standards are outlined later in this section of the guide.

The following tables list approximate U-Values for different types of walls, roofs, floors and glazing. These values are provided because they are required inputs into the U-Value/heat loss calculator tool, which is provided separately as an Excel spreadsheet. This will enable you to gauge the existing thermal performance of the space or spaces that you are considering. The results will highlight which are the worst performing elements and will allow you to develop a refurbishment priority list.



Concrete external walls - Kimbell Art Museum, Texas

Arup © Nic Lehoux



UK U-Value progression over time / source: Arup Research

Types of insulation

A wide range of materials are used to provide thermal insulation. In general, only those more frequently specified are referred to here. Data for the comparative thickness of different types of insulation are shown in the table below.[1]

- U-Values are calculated based on 9" solid brick wall, internally applied insulation (with battens and/or air gap where appropriate) and 12.5mm plasterboard. Fixings and air movement are accounted for in calculated figures. All thicknesses are rounded to nearest 5mm.
- The choice of insulation material will also be influenced by considerations of available space (some materials require a substantial thickness), fire resistance, the need for vapour permeability and acoustic insulation.

Other products have continued to emerge since this table was published and it is important to keep an open mind. The Building Research Establishment has carried out studies of more advanced insulation materials.[2]

Stone external wall - City & County Museum, Lincoln

© Arup

Insulation type	Typical thickness to achieve U-Value 0.25 W/(m².K) (mm)	Environmental rating (BRE Green Guide)	Manufacturer/example (Arup research)
Plastic foams			
Foil-faced polyisocyanurate up to 32kg/m³	80-85	A	Celotex GA4000
Foil faced phenolic foam	75-85	-	Kingspan Kooltherm
Expanded polystyrene up to 30kg/m³	115-165	A+	Knauf ThermoShell – EPS Board
Wool and fibre			
Stone mineral wool (less than 160kg/m³)	150-160	B to A+	Rockwool
Glass mineral wool (up to 48kg/m³)	135-180	A+	Knauf Earthwool
Sheep's wool (25kg/m³)	150-215	A	Thermafleece
Cellulose fibre (dry blown 24kg/m³)	150-190	A+	Thermacel. Recycled paper, treated with borax against moisture/vermin
Wood fibre	145-225	-	Pavatex Pavadentro
Alternative products			
Hemp lime (monolithic)	260	-	Specialist contractors
Straw bale (monolithic)	175-235	A	Widely available

Insulation thickness variations to achieve a target U-Value
(By kind permission from The Energy Saving Trust)

1 Energy Saving Trust. 2010. CE71 Insulation materials chart: Thermal properties and environmental ratings
2 http://www.brebookshop.com/details.jsp?id=327120

External walls

The values in the table below refer to perimeter walls which are exposed to the outside air. The table includes several examples but construction types vary, particularly in older buildings. A chart later in this section of the report indicates ranges of values for varying materials and wall thicknesses.

If a building was constructed after 1920, it is likely that exterior walls will include a cavity. Cavities up to the mid-1980s were rarely insulated but, after more demanding regulations came into force in 1985, cavity insulation or insulating blockwork have been adopted. The amount of insulation has steadily increased to meet increased standards. If any refurbishment has been carried out, it will be important to check records of the building (drawings and any other documentation) in order to determine if cavity wall insulation or some other system of insulation has been installed.

Solid brick external wall - Imperial War Museum

By kind permission from Arup Associates © Andrew Putler

Construction Type	Typical thickness (mm)	U-Value W (m².K)
Stone walls		
Uninsulated stone walls	600	1.4
Insulated stone walls	700	0.7
Single leaf brick walls		
Brick leaf with plaster finish	250	2.1
Brick leaf with uninsulated cavity and plasterboard finish	300	1.4
Brick leaf with insulated cavity and plasterboard finish	300	0.6
Concrete walls		
Concrete block with plaster finish	200	3.0
Concrete block with uninsulated cavity and plasterboard finish	300	1.8
Concrete block with insulated cavity and plasterboard finish	300	0.7
Double leaf brick walls with cavity		
Uninsulated cavity	300	1.4
Insulated cavity	300	0.6
Brick and concrete block walls with cavity		
Uninsulated cavity	300	1.8
Insulated cavity	300	0.6

Wall construction and U-Values

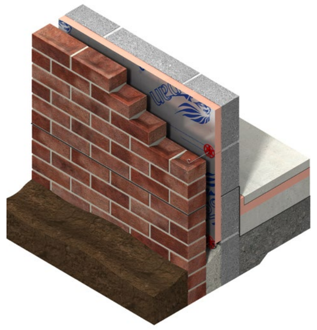
The above U-Values for uninsulated and insulated cavities are based on a 50mm cavity. Larger uninsulated cavities may result in somewhat larger heat losses.

Thicker insulation will reduce the U-Value of the construction. Mineral wool (often referred to by the dominant trade name 'Rockwool') was typically used for the earliest cavity insulation in new construction from the 1970s and later lightweight foamed concrete blockwork was sometimes used as an alternative. The most common current cavity insulation material in new build is probably polyisocyanurate or phenolic foam board with a foil facing layer, providing a good level of insulation that minimises loss of space. These products do not retain water or slump, as mineral wool can tend to.

This data is based on Appendix 3.A8: Thermal properties of typical constructions in CIBSE Guide A (2006).

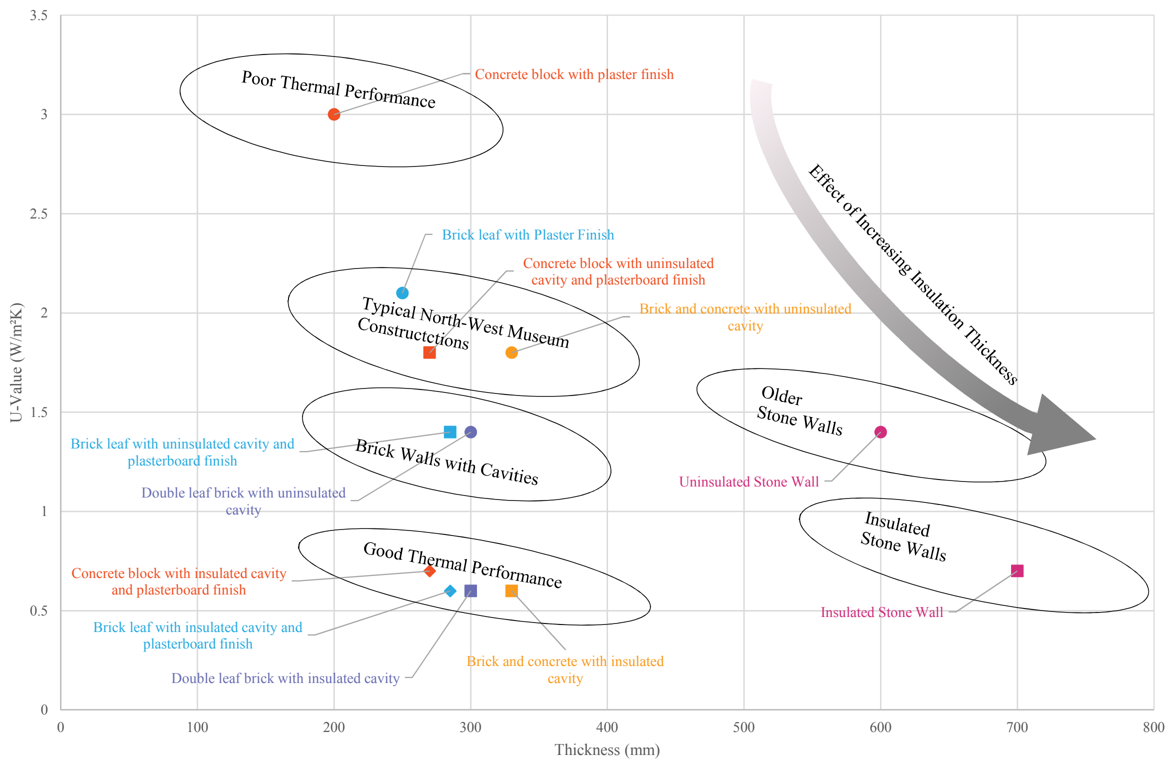
External walls continued

As the table of wall data makes clear, the range of U-Values is considerable, depending on wall thickness, the materials used and the extent of insulation incorporated. A comprehensive table incorporating all likely variants would be very long and cumbersome to use. Since only approximate U-Values are required to use the tool provided with this guide, the graph on the opposite page groups the approximate U-Values for different types of construction with and without insulation. This provides a visualisation of the way in which values range from higher/poorer to lower/better and it should help you to select an approximate value suitable to the wall that you are assessing.



Brick and block cavity wall with phenolic foam insulation board

By kind permission from and ©Kingspan Insulation Limited

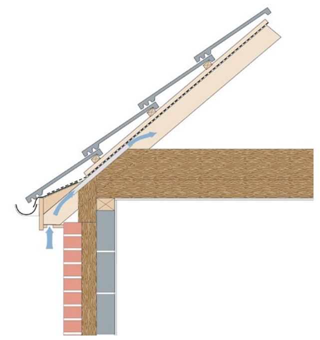


External walls: indicative thickness and U-Values graph, Arup

Roof

Up to 1965 roofs were rarely insulated and the 1965 UK standard only required 1 inch (25mm) of mineral wool quilt. Since that time mandatory levels of insulation have been driven by increased Building Regulations requirements. Unless other elements achieve in excess of current minimum standards, a roof in a new museum or gallery building or a major extension would be expected to achieve a U-Value of 0.25 W/(m².K). Subject to other design details, this could be achieved by installing 200mm of mineral wool quilt between and above ceiling joists, 8 times greater than the 1965 standard. In reality a higher standard of roof insulation is often targeted, as this is achievable at relatively low cost and can provide a greater degree of flexibility in relation to the performance of other elements, if required.

In relation to existing buildings, rather than new build extensions, a review of building records and visual investigation should be undertaken for refurbished projects to check whether the roof is insulated.



Glass wool insulated cold vented roof.

By kind permission from and © Knauf Insulation Ltd

Construction Type	Typical thickness (mm)	U-Value W (m².K)
Concrete flat roof		
Uninsulated	150	2.2
Insulated with polyurethane foam	350	0.3
Timber flat roof		
Timber decking with ventilated air space	40	2.4
Timber decking with polyurethane foam insulation	150	0.2
Timber pitched roof		
Uninsulated 12.5mm plasterboard ceiling	13	2.3
Insulated with 2-layer 300mm mineral wool quilt between and over ceiling joists	313	0.14

Selection of roof U-Values

This data is based on data from CIBSE Guide A (2006).

Ground or basement floors


Air brick

The base of the thermal envelope of a building is its lowest floor. This can be the ground floor, basement or a sub-basement or a stepped combination of these, where basements are smaller than the overall building footprint. Heat losses can be by conduction through a solid floor slab or a combination of conduction and infiltration through a floor suspended on joists or beams. It may be difficult to determine if insulation is present beneath a floor without a survey but if it is known that the ground floor is uninsulated, installing insulation would be a relatively quick win. This is reliant on how practical it is to obtain access (e.g. a timber floor with a void underneath).

A suspended floor will typically have air bricks at low level on the external walls of the building to ventilate the void beneath the floor. This is important as a preventative measure to reduce dampness and the likelihood of rot but it also provides a route for draughts and heat loss, particularly in windy weather, when the wind can cause an air pressure drop beneath the floor (the Venturi effect). Bear in mind that air bricks can appear at different heights in external walls, sometimes to provide ventilation at higher level within rooms or behind radiators. Simple air bricks are frequently positioned in the outside wall below the level of the floor to be ventilated, others may appear to be above floor level but are, in fact, cranked to take account of higher external ground levels.

Solid floors did not require insulation below the slab until the mid-1990s, so it is very unlikely that older floors would have insulation, and damp proof membranes were not generally introduced until the 1960s. Solid floors that are damp lose heat more rapidly than dry floors, and buildings with damp basements tend to have poor thermal performance. It is possible to introduce insulation above the slab but this requires careful design and specification and the loss of headroom needs to be considered, particularly at door openings. It is not appropriate to insulate on top of earth floors without a more fully worked out solution to provide a new floor and reference to Historic England guidance is provided later in this guide. Similarly it is not appropriate to insulate on top of traditional brick and stone flag floors as these are designed to be moisture permeable to allow the evaporation of water vapour.

Construction Type	Typical thickness (mm)	U-Value W (m².K)
Solid floor		
Uninsulated	200	0.75
Insulated (polystyrene)	250	0.25
Suspended floor		
Uninsulated	150	1.6
Insulated (glass or mineral wool)	150	0.4

U-Values of floors

Note that the U-Value for solid floors depends on the shape and size of the floor because of the cold bridging effect at the junction with walls. The values given above are typical figures.

This data is based on data from CIBSE Guide A (2006).

Glazing

The majority of museums and galleries are likely to either have single or double (air filled) glazing unless they have been refurbished recently. Unless existing windows and double glazing units have failed or are very old and performing poorly, installing replacement double glazing would have only a limited effect and may not be worthwhile.

When it is feasible and necessary, installing new high performance double glazing with a low emissivity (low-E) coating can improve the U-Value of windows considerably. A low-E coating reduces the amount of heat that is lost as radiation through the glazing and is commonly applied to the inner face of the outer pane of modern double glazing units.

However, many museums and galleries are listed or of historic interest and windows are a particularly sensitive heritage element. Conservation officers will understandably resist window replacement and the loss of historic glass because of the damaging impact on building character. Traditional glass contains irregularities, which allow for varied reflections and a shimmering effect when the glass catches the sun and the viewer passes the building. This is lost when modern float glass is used and when the heritage glass is removed, this is a permanent loss of building character.

Where the installation of replacement glazing is acceptable, it will not always be practical to install double glazed units in older windows because of insufficient depth in the frame and glazing bars. Other possible solutions are recommended elsewhere in this guide.

Construction Type	U-Value W (m².K)	
	Wood or PVC Frame	**Metal Frame**
Single	4.8	5.7
Double (air filled cavity)	3.1	3.7
Double (air filled cavity) + low emissivity (e) layer	2.7	3.3
Double (argon filled cavity)	2.9	3.5
Triple (air filled cavity)	2.4	2.9
Triple argon filled cavity)	2.2	2.8

Glazing U-Values

The figures in the table above are based on a 6mm gap between glazing panes, increasing this gap will improve the U-Value. Modern buildings may have a gap between panes of around 12-16mm.

This data is based on data from CIBSE Guide A (2006) and the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP2005).

Infiltration

Factors which increase infiltration rates:

- Increased infiltration rates are common in entrance areas and adjacent spaces due to doors opening and closing regularly and allowing outside air into the space
- Lack of effective draught lobbies, or revolving doors
- Poor wall/floor junctions
- Poor quality windows
- Air bricks
- Vents in walls

High rates of infiltration e.g. 1.5 air changes per hour (ACH) can be experienced in the entrance areas of old and modern buildings and lead to high energy consumption. Traditional buildings can have similarly high levels of air change overall because they have many paths through which air can pass. This was considered beneficial and desirable, so as to provide fresh air for the occupants but also so as to promote effective combustion and venting of toxic gases and smoke from open fires, stoves and gas-fired space heaters. When these forms of heating are no longer in use, there are opportunities to reduce the required number of air changes and to improve energy efficiency.

Building Type	Air permeability ($m^3/m^2.h$ at 50Pa)	Infiltration rates (ACH)
Unimproved building constructed pre-1900 Multiple air paths, likely to be cold and draughty	30	1 to 1.5
Unimproved building constructed 1900-1980 Leaky, cold draughts can be felt by occupants	20	1 to 1.2
Unimproved building constructed 1980-1992 Reasonable performance for an existing building	15	0.7 to 1
Unimproved building constructed 1992-2002 Good performance for an existing building	10	0.5
Building constructed 2002-2010 or later*	7	0.4
Newly constructed “air tight” building*	3	0.15

Typical infiltration rates

* Unlikely to be achievable for a retrofit without considerable cost and effort

Based on the infiltration rates given in CIBSE Guide A (2006). Air permeability is defined as the air leakage rate per hour per square metre of envelope area at a test reference pressure differential across the building envelope. The value used for UK Building Regulations is based on 50 Pascal (50 N/m^2). ACH – Air changes per hour. The amount of times per hour the volume of air in the space is replaced with outside air. The figures in the table above are based on a building area no greater than $500m^2$. For buildings with a floor area greater than this, the infiltration rate will be lower due to the reduced ratio of surface area (wall, roof etc.) to the volume of the space.

Building regulations part L – conservation of fuel and power

Target U-Values and regulations

This part of the Building Regulations sets out the minimum energy performance requirements and includes guidance on the required U-Values and the limiting values. The current regulations applicable to museums and galleries are summarised in Approved Document L2A for new build and Approved Document L2B for refurbishment schemes. The regulations are periodically updated and the current version is Part L 2013. These documents can be accessed via the following link:

http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/

Approved document L2B 2013 – refurbishment and small extensions

These regulations are most likely to apply to smaller day-to-day projects. They are open to technical interpretation and it is recommended to take appropriate professional advice. There is an interplay between building fabric and building services and integrated design solutions are usually required. For the purposes of preliminary strategic planning, the principles are simplified as follows.

The regulations are limited to those works that are ‘technically, functionally and economically feasible’. The economic test is based on simple payback within 15 years. There are also exemptions for listed buildings and buildings within Conservation Areas, where compliance would unacceptably alter their character and appearance and this issue is discussed further elsewhere in this document.

Renovation or replacement of thermal elements – regulation 23

This relates to proposed major building work to an external wall, a floor or a roof (a thermal element).

The rule only applies if the proposed building work relates to:

- a major renovation of the building, usually if the area to be repaired or refurbished is more than 25% of the total surface area of the building envelope, which means external walls, roof and the lowest floor levels
- or the renovation of more than 50% of the total surface area of the wall, floor or roof (thermal element)

If the U-Value of the element affected by the proposed works is higher than the threshold value in column (a) in the table below, the whole of it (not just the part being refurbished) needs to be improved to achieve a better U-Value than that shown in column (b), usually by adding insulation or by replacement with more efficient materials or systems. Major building work includes repair and maintenance work such as roof recovering, re-plastering walls or the replacement of windows and doors.

Upgrading retained thermal elements	U-Value W (m².K)	
	Threshold (a)	Improved (b)
Wall – cavity insulation	0.7	0.55
Wall – external or internal insulation	0.7	0.30
Floors	0.7	0.25
Pitched roof – insulation at ceiling level	0.35	0.16
Pitched roof – insulated at rafter level	0.35	0.18
Flat or roof integral (e.g. panellised roof systems) insulation	0.35	0.18

Minimum improvement levels - thermal elements

Example

A 60m² section of a 100m² cavity insulated wall is being refurbished. The area of the building envelope (total area of all external walls, roof and ground floor) is 600m². The area of the wall being refurbished is 60% of the external wall, and 10% of the total building envelope. As it is greater than 50% of the external wall area, if it has U-Value greater than 0.7W/(m².K), it should be improved to achieve a U-Value of at least 0.55W/(m².K).

Consequential improvements – Regulation 28

If the total useful floor area of the current building is more than 1,000m², additional rules apply. Useful floor area is broadly the Gross Internal Area (GIA) as defined in the RICS Code of Measuring Practice. The method of measuring GIA is set out in an appendix to RICS Property Measurement 2015.[1] The regulation applies where the proposed building work consists of or includes:

- an extension
- the installation of fixed mechanical or electrical heating or cooling systems (building services) for the first time
- an increase in the installed capacity of any building services

The required consequential improvements in energy performance would include all works necessary so that the building as a whole complies with the requirements of Part L. This incorporates consideration of the potential for a wide range of low or zero carbon technologies such as photovoltaic cells, biomass boilers and combined heat and power systems. In most instances it is very likely that the cost of upgrading the building and its systems to fully comply with Part L will be far from economically feasible at current energy prices. The best blend of affordable designs and specifications will be tested and agreed during design development.

1 http://www.rics.org/us/knowledge/professional-guidance/professional-statements/rics-property-measurement-1st-edition/

If a single room in a gallery is being refurbished, the area of the thermal elements in this room may only be a small percentage of the building envelope as a whole. In these circumstances consequential improvements are not required to meet Part L2B requirements. However, improving the element to meet the limiting fabric parameters is advantageous. It improves the ability to maintain acceptable indoor temperature conditions for occupants, artwork and artefacts and leads to lower energy consumption and reduced heating costs. Room by room incremental improvements will aggregate to reduce energy consumption substantially over time. It is probably more realistic to expect that improvements will be piecemeal, as funding and access permit, as part of a wider strategy.

Approved Document L2A 2013 – New buildings and larger extensions

Compliance with Building Regulations Part L2A is required for all extensions which are greater than 100m² and greater than 25% of the total floor area of the existing building.

For all new buildings, the minimum fabric performance must comply with requirements in Approved Document L2A and summarised in the table below.

This table also allows you to gauge the current performance of your museum or gallery compared to the latest standards.

It should be noted that these are minimum performance levels and in practice it is likely that the required performance will be better than the ratings indicated because of funding or other requirements. Public sector projects in particular are expected to set leading examples of sustainability and low energy design.

Limiting fabric parameters for new buildings (the lowest acceptable standard)	Less than or equal to U-Value W (m².K)
Roof	0.25
External wall	0.35
Floor	0.25
Windows, roof windows, roof lights and pedestrian doors	2.2
Vehicle access and similar large doors	1.5
High use entrance doors	3.5
Roof ventilators	3.5

A minimum air permeability of 10m³/m².h at 50Pa must also be achieved *

Limiting fabric parameters

* The majority of new buildings achieve an air permeability rate between 3 and 5m³/m².h at 50Pa

U-Values tool

It is important to be able to test the likely energy savings from your proposed alterations and interventions. Arup has developed a simple tool to help you do this. If you do not already have this, a free download is available from the Museum Development North West website in the publications section relating to environmental sustainability.[1] There is also a data checklist in Word format to help you to build up the information that you need to create the inputs for the tool. This is what the first worksheet of the tool looks like with some test figures inserted:

1 https://museumdevelopmentnorthwest.wordpress.com/publications/

ARUP

U-Value Guide

Heat Loss Calculator Tool

Part A - Existing Building

Part A of the tool is used to determine the performance of the existing space

Calculator tool guidance

1. Calculate the areas of the building elements exposed to outside
2. Determine the floor area of the room
3. Determine the height of the room
4. Determine the U-values of each building element based on the typical U-values provided in the guide
5. Input data into the table below

Input cells
Output cells

External design temp	-3.7	°C
Internal design temp	21	°C
Ground temperature	7	°C
Room area	100	m²
Average room height	3	m
Room volume	300	m³

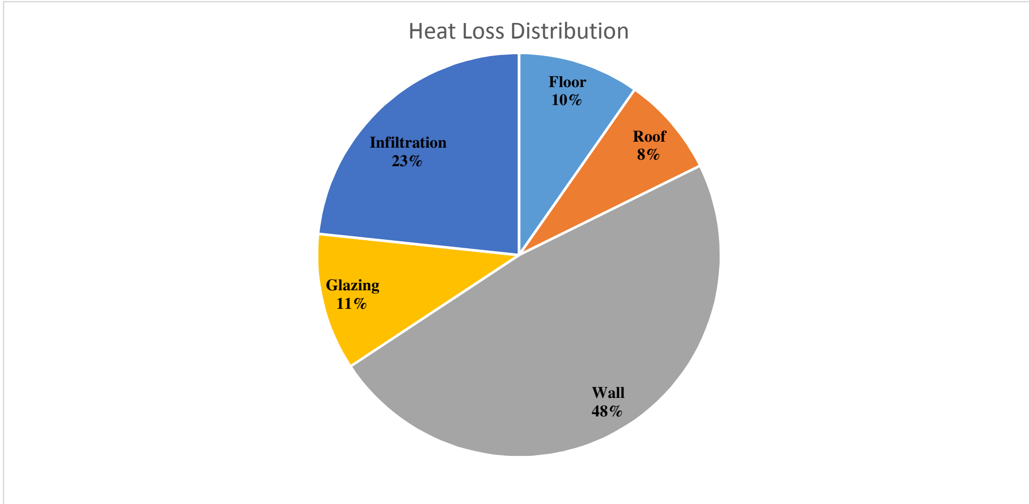
Selected outdoor winter design temperatures		
Manchester	-3.7	°C
Birmingham	-5.2	°C
London	-3.1	°C

	Construction	Area (m²)	U-value (W/m²K)	Heat loss (W)	Heat loss (%)
Conduction	Floor	100	0.75	1050	10%
	Roof	100	0.35	865	8%
	Wall	150	1.40	5187	48%
	Glazing	10	4.80	1186	11%
	Infiltration	300	1	2519	23%
		Volume (m³)	Rate (ACH)	Heat loss (W)	Heat loss (%)

Imperial to metric converter	
ft into m	
1	0.3048
ft² into m²	
1	0.092903
ft³ into m³	
1	0.0283168

Total peak heat loss	10807	W
	108	W/m²

W/m² output is useful for comparing spaces of different sizes



U-Values tool - existing building performance

The following steps show how to use the U-Values tool. Remember that it is only intended to provide very approximate and indicative results, so that you can get a feel for how effective and worthwhile your ideas may be.

- Measure the dimensions of the space or spaces that you intend to improve, following the instructions on the first tab of the tool and calculate the floor areas. Complete the tables in the data checklist
- Measure or estimate the thickness of the walls and look at the walls, roofs, windows, roof lights and floors, including cellars and basements to understand how it is constructed. Fill in the data checklist
- Using the data checklist information together with the tables and wall U-Values chart in Section 2 of the guide, estimate the approximate average U-Values of the different elements of the external walls, roof, floors and windows/roof lights (the thermal envelope). Estimate the likely number of air changes per hour for the building, as it stands
- You will need to average the U-Values if the elements of the space that you are assessing contains more than one type of construction. For example there may be some areas of suspended timber floor and some solid floors. There may be 3 different types of window. A simple average is likely to give a skewed result. You will need to calculate a weighted average to reflect the relative proportions of the different elements
- Complete the green input cells in the Part A – Existing Building tab of the tool
- Using Section 4 and 5 of the guide, work out which intervention measures you think may be practical and suitable for improving the various parts of the thermal envelope
- Fill in the green input cells in the Part B – Existing Building tab of the tool. The tool also contains some fixed figures and built-in calculations

You should now have some results. Review them to see whether they appear to make sense and, if not, check back and see where you might have gone adrift. An example of the results for a refurbished building is shown below.

It does not matter if your results are not perfect. The process that you have been through should have clarified your ideas and your understanding about how the U-Values of your space might be improved. This will form a basis for developing your project and will provide a useful starting point for developing your project brief.

ARUP

U-Value Guide
Heat Loss Calculator Tool
Part B - Refurbished Building

Part B of the tool is used to determine the performance of the refurbished space and compare against the existing space

Calculator tool guidance

1. The floor area, room height and fabric areas are assumed to be the same as those pre refurbishment
2. Determine the U-values of each refurbished building element
3. Input data into the table below

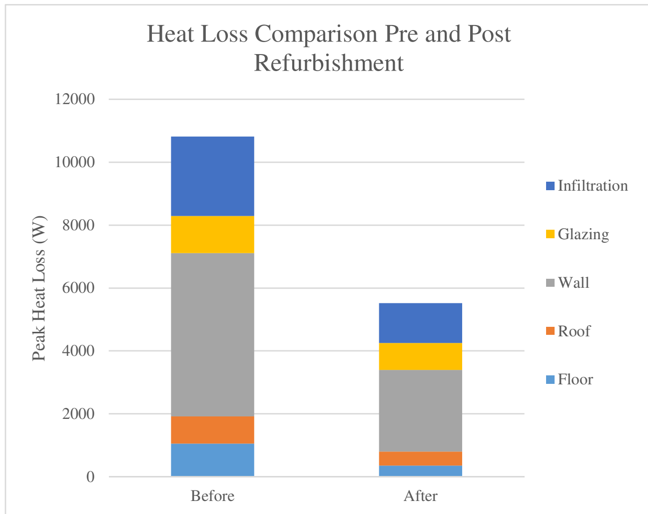
Input cells
Output cells

External design temperature	-3.7	°C
Internal design temerature	21	°C
Ground temperature	7	°C
Room area	100	m²
Average room height	3	m
Room volume	300	m³

		Area (m²)		U-value (W/m²K)		Heat loss (W)		Heat loss (%)		Saving (%)
	Construction	Before	After	Before	After	Before	After	Before	After	
Conduction	Floor	100	100	0.75	0.25	1050	350	10%	6%	6%
	Roof	100	100	0.35	0.18	865	445	8%	8%	4%
	Wall	150	150	1.4	0.7	5187	2594	48%	47%	24%
	Glazing	10	10	4.8	3.5	1186	865	11%	16%	3%

	Before	After	Before	After	Before	After	Before	After	Saving (%)
Infiltration	300	300	1	0.5	2519	1260	23%	23%	12%
	Volume (m³)		Rate (ACH)		Heat loss (W)		Heat loss (%)		

Peak heat loss for whole building before and afer refurbishment		Before	After	Saving
	W	10807	5512	49%
	W/m²	108	55	



U-Values tool – indicative improvements in performance

Section 2

Case study: Bolton Museum gallery refurbishment

Bolton Museum

Bolton Museum was opened to the public in 1947 and forms part of the Le Mans Crescent Civic Centre. Bolton Museum is run by Bolton Council, the local authority. The museum houses an art gallery, Egyptology gallery, history centre and a local history gallery. The local history gallery, telling the story of Bolton, had a significant refurbishment in 2010.

As part of the refurbishment various energy savings opportunities were identified and integrated into the project. These included: zone control of the heating system, thermal insulation fitted to concealed windows and skylights, improved air tightness, replacement of lighting systems and refurbishment of the exhibit display cases.

The existing but concealed windows and skylights in the gallery resulted in significant heat loss with an estimated U-Value of 5.4 W/m²K. Installing insulation reduced the estimated U-Value to 0.2 W/m²K and the infiltration rate was also reduced by re-sealing the windows.

The first graph below shows the distribution of heat loss from the space before the insulation was installed. The concealed skylights, concealed windows and infiltration losses were all significant contributors to heat loss.

Owner

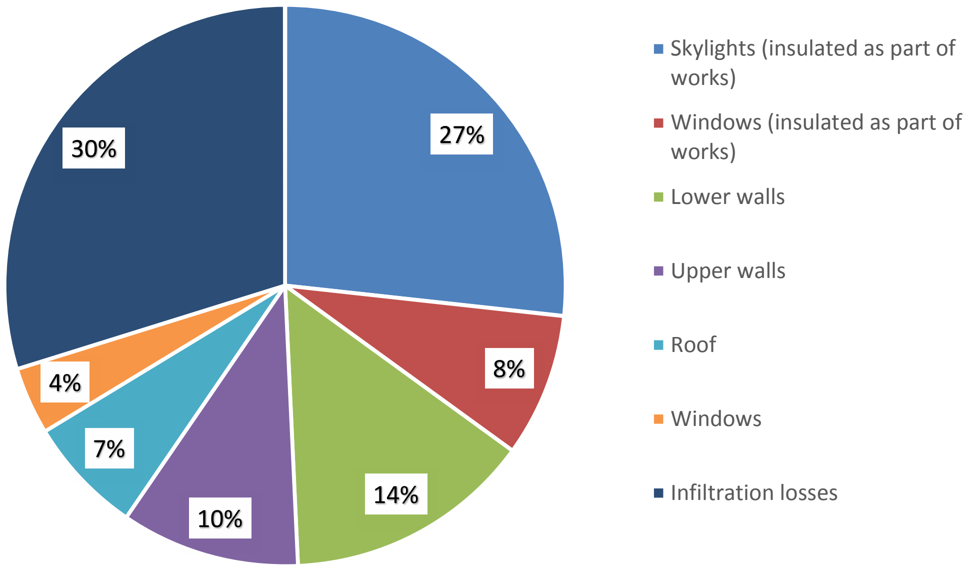
Bolton Council

Project Value

Not separately identified. Part of a larger project

Funding

Information not available



Heat loss distribution before the refurbishment works

The second graph highlights the significant reduction in calculated peak heating demand of approximately 44%.

The difference between the two bars shows the total calculated reduction in peak heat loss before and after the refurbishment. A reduction in peak heat loss has an impact on the annual energy consumption, and the gallery space benefited from lower utility costs and improved gallery temperature control.

Contacts for more information

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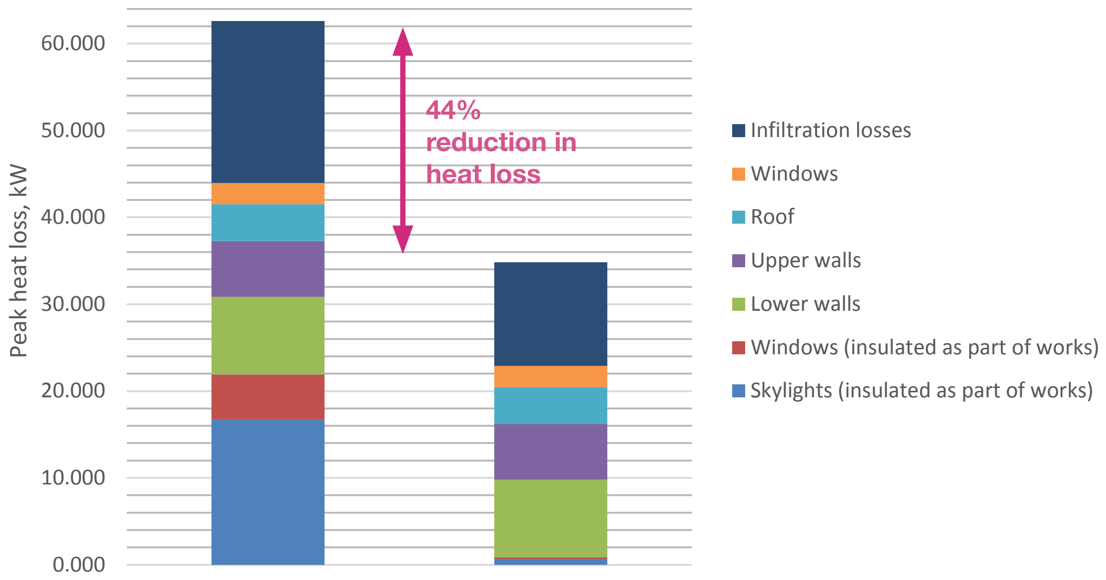
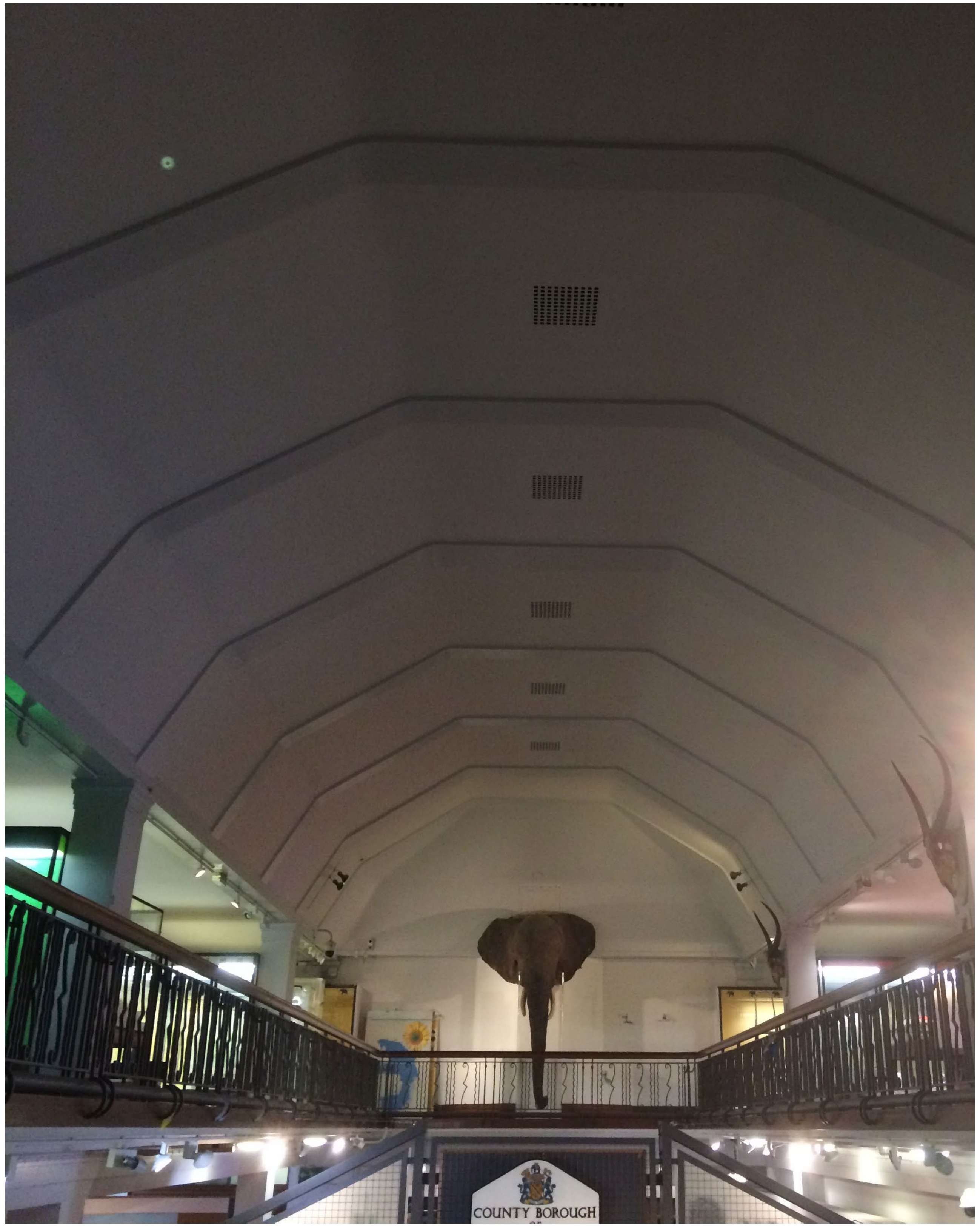
tim.whitley@arup.com



Comparison of heat loss before and after insulation of windows and skylights



Bolton Museum

Key considerations for refurbishment

Ownership of the building

If you occupy the building as a tenant, it is important to gain permission from the landlord before any modifications are made to the space. It would be prudent to have preliminary discussions as soon as outline ideas have been worked up, so that obstacles or objections can be identified as early as possible.

Listing of the building

If a building is listed as being of special architectural and historic interest, this is likely to limit what modifications can be made to certain elements. As a starting point, review the details of the list entry in the National Heritage List for England. Different restrictions may apply to different elements. Bear in mind that the list entry includes a short statement about the character of the building and will not identify the significance of all building elements. Further investigation and assessment will be required and the hierarchy of significance is explained in more detail in the next section of the guide. For example, if a historic building has been previously extended, the entire building is normally included within the listing, but the extension may not be considered to have any significant heritage value. However, attitudes to later extensions can change and the 20th Century Society continues to encourage Historic England to list notable modern buildings.

Proposed changes to later extensions can have a significant impact on the setting of heritage buildings and on Conservation Areas and it would be prudent to discuss all proposed changes with a certified building conservation professional and, once the preferred approach is established, with the local conservation officer and, if necessary Historic England. Some related issues are touched on below.

Grade II buildings represent 92% of the total list and proposed changes are generally less sensitive. In the case of Grade I and Grade II* buildings, the conservation officer is likely to wish to consult Historic England. Listed Building and Conservation Area Consents are likely to be required for any significant changes. It is likely to be very difficult to justify works to improve U-Values, which would be apparent and considered to have an adverse effect on the heritage value of architectural elements of the building. This is a relatively complex and subtle area and it is important that the professional team have directly relevant experience.

The degree of flexibility in obtaining consent for the adaptation of any heritage building will depend on the significance of building elements affected. All historic buildings have been through repairs, changes and alterations throughout their lives and it is good practice to commission a statement of heritage significance to guide designers and to inform heritage professionals during the consent process. Please check, there may already be an existing statement, prepared for an earlier project. The consent process is not black and white and is very much a matter of professional opinion on both sides, which is why it is important for the museum or gallery to instruct its own heritage adviser, both to inform the team and to explain, justify and negotiate consent for the proposed interventions.

Heritage statements and impact assessment

The National Planning Policy Framework incorporates established guidance on historic assets and the heritage value should be graded using the following hierarchical levels.

Exceptional

An asset important at the highest national or international levels, including scheduled ancient monuments, Grade I and II* listed buildings and World Heritage Sites. The NPPF advises that substantial harm should be wholly exceptional.

High

A designated asset important at a national level, including Grade II listed buildings and locally designated conservation areas. The NPPF advises that substantial harm should be exceptional.

Medium

An undesignated asset important at local to regional level, including buildings on a Local List (non-statutory) or those that make a positive contribution to a conservation area. May also include less significant parts of listed buildings. Buildings and parts of structures in this category should be retained where possible, although there is usually scope for adaptation.

Low

Structure or feature of very limited heritage value and not defined as a heritage asset. Includes buildings that do not contribute positively to a conservation area and also later additions to listed buildings of much less value. The removal or adaptation of structures in this category is usually acceptable where the work will enhance a related heritage asset.

Negative

Structure or feature that harms the value of heritage asset. Wherever practicable, removal of negative features should be considered, taking account of setting and opportunities for enhancement.

There may already be an existing statement, prepared for an earlier project, so it is worth checking. It may not be ideal for the current purpose but it may be better to build on this rather than starting again from scratch.

The final Heritage Statement will summarise the significance of the building and its various elements and will provide a Heritage Impact Assessment. Usually this will outline the proposed changes to the building and provide a commentary on their impact and any mitigation measures adopted. For example, interventions which are easily reversible without material damage to the historic fabric of the building are preferred. They leave scope for their replacement in the future by new and more discreet technologies or finishes. For example, high performance secondary glazing improves U-Values but allows existing historic window frames and glass to remain in situ, without significant detriment to the external appearance.

Conservation plans

The conditions for consent may include the preparation of a Conservation Plan for the building to provide for the future maintenance and conservation of the building and its most significant heritage elements. This is an important tool for the future management and maintenance of the building and should form part of the statutory Health and Safety File. It is very useful for curators and building managers to have a clear statement of the significance of the various elements of the building. This enables their future conservation to be planned into maintenance and fitting out work.

Overheating and cooling requirements

Improving the U-Values and reducing infiltration will reduce the amount of heating needed in winter. However, this may increase the overheating risk and the cooling requirement in summer. If a lot of heat is generated in the space (e.g. from traditional filament lighting or direct sunlight) and the U-Values have been improved, the heat will take longer to escape, increasing the risk of overheating. Conversely, if little heat is generated and it is hot outside, insulation and improved airtightness will limit how much external heat will enter the space during each day, reducing the risk of overheating and the need for cooling.

Key considerations to avoid overheating include adequate ventilation, solar shading (e.g. blinds, solar control films, solar control glazing) and lighting efficiency. Inefficient traditional lighting can be a significant contributor to heat gains and LED lighting offers significant energy efficiency improvement.

Best practice lighting guides are now available but this is a technically complex area requiring specialist advice. There are a number of factors involved including:

- Tendency for some lamps to fade over time, despite an otherwise long life
- Selecting a colour balance appropriate to the items to be displayed
- Colour rendering capability of the lighting system
- Susceptibility of displays to fading in ultraviolet light
- Whether it is important to fade or brighten lighting
- Importance of achieving appropriate contrast between background and display lighting
- Flexibility to incorporate rapid changes in control systems, increasingly accessed via tablets and other hand-held devices
- Need to accommodate rapid reconfiguration of lighting displays for changing exhibitions and events

Manchester Art Gallery Lighting

Arup has provided technical advice on lighting to Manchester Art Gallery over a number of years, enabling the Gallery to procure replacement LED and other lighting combined with other measures. Actual energy savings of up to 35% have been realised and the heat load generated by lighting has reduced even more significantly.

With kind permission of Manchester City Art Gallery, © Shamus Dawes

Location and orientation

Buildings located in different regions experience considerable variations in climatic conditions. In cold regions, heating energy typically predominates energy consumption. By contrast, London's climate is significantly different from that in Edinburgh, experiencing more days of high ambient temperature and elevated levels of humidity. Climate conditions need to be taken into account when comparing total energy use for buildings and the tool makes some provision for this.

It is possible to assess a building's expected annual energy consumption using a technique known as a Degree Day Analysis. This involves working out the number of days in a year that heating will be required, based on the outside temperature. When the outside temperature is lower than a given base temperature (usually the temperature that the inside of the building is heated to), that represents a day that the building will be heated. It is then possible to use the number of degree days and the U-Values to estimate energy usage. This process can be complicated and assistance should be obtained from a specialist when a project develops beyond preliminary feasibility stage. The location of the building, whether it is sheltered or exposed and its orientation are all relevant. For example, southern and western elevations frequently exposed to driving rain have a very different thermal performance when compared with northern elevations. Heating energy use will increase in cooler parts of the building, for example where there is no free heating from direct sunlight and increased energy demand can be mitigated by measures to improve U-Values.

Ventilation rates, outside air and moisture control

If a space is naturally ventilated, with no mechanical ventilation system, the openings to the space (mainly windows and doors) will provide fresh air, along with the air leaking in through infiltration. So if the infiltration is reduced, it is important to consider how outside air will get into the space for ventilation and to provide air movement to prevent the space from becoming stuffy. This is also an important consideration for moisture control of airborne humidity, dampness and condensation.

The calculation tool associated with this guide will assist in determining the improvement in infiltration. If the improved infiltration rate is likely to be below 0.5 ACH, additional ventilation may be required and advice should be sought.

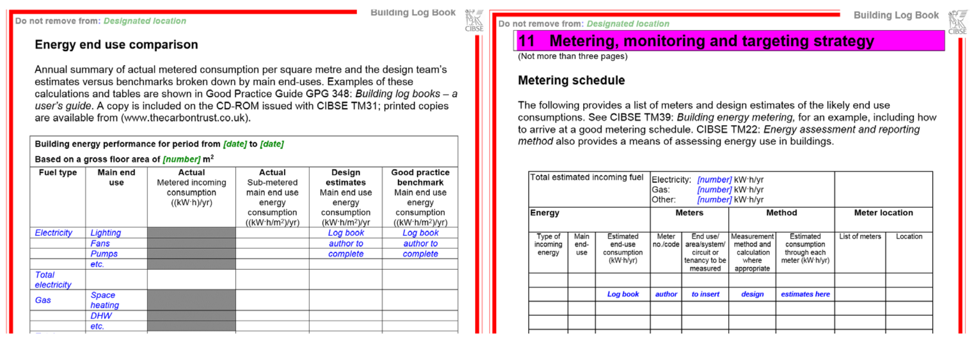
BMS and system controls adjustment

Improving the thermal performance of the space will alter how the heating, cooling, ventilation and humidity control systems operate to provide suitable conditions. These are often centrally controlled by an electronic building management system (BMS). These vary in their complexity. A simple system may be similar to a domestic time clock with a wall mounted thermostat which controls when the boiler pumps operate to distribute hot water to the heating system. This could be refined by providing thermostatic radiator valves (TRVs) on each radiator. TRVs monitor the surrounding air temperature and adjust their output to achieve the temperature set-point. This is not always the best solution for larger spaces and a full BMS system can have a suite of controls and sensors to control gallery conditions including ventilation and cooling systems. At the very least BMS systems will need to be re-set and optimised at the completion of a refurbishment project. The building services and BMS system should be reviewed as part of proposed fabric improvements projects. This is important to establish further opportunities for energy saving measures and to assess the need for additional controls and changes as a result of the proposed works.

Keep records

Keeping records of the refurbishment will help inform any future works and enable day-to-day operation to be adjusted to suit changing seasonal conditions. These records are typically kept in the Operation and Maintenance manuals (O&M) which contain instructions and specifications for the building and its systems.

The other key record is the Building Log Book. This covers how a building is intended to work and how it should be maintained and serviced. It also provides a means to record the energy use and maintenance of the services within the building. Log books provide a simpler and more easily accessible summary of the key information about a new or refurbished building. Provision of adequate information via the Health and Safety File/O&M manuals has been a statutory requirement since 1994. Building Log Book information has been a statutory requirement under Part L of the Building Regulations since 2006.



CIBSE format of building log book

Image

Sample pages from CIBSE's building log book, showing the information covered and suggested ways of recording energy usage. The log book is a summary document written in an easily understood style for facilities managers, building operators and non-technical readers. It is a management tool for running the building. This guide, and other templates are available to non-CIBSE members from http://www.cibse.org/Knowledge/CIBSE-TM/TM31-Building-Log-Book-Toolkit

Monitoring energy and utility bills

After the refurbishment has been completed, how do you know if the space is using less energy and providing improved conditions for the exhibits and occupants? Keeping track of utility bills before and after a refurbishment is simple and easy, although it is surprising how often this information is not available. If the utility bills relate to the whole building, and not just the refurbished space, it may be difficult to see the impact of the refurbishment in isolation. Where practicable energy sub-meters should be installed for the separate zones of the building for at least a year, and preferably longer, before the start of refurbishment works. The heating requirement will vary year on year depending on whether it is a mild or severe winter. If you don't know what your energy costs are now, how will you know whether your project has been successful?

If it is not possible to keep a detailed record, then simply note the conditions in the space before and after the refurbishment. For example, can a comfortable temperature be maintained with the radiator valves turned down? Does the space take less time to get to a comfortable temperature? Are there fewer draughts coming into the space?

If possible, log the temperature and relative humidity for the space before and after the refurbishment. This can be carried out with data logging equipment. The data can then be analysed using Degree Day Analysis which takes into account the severity of the winter and provides a fair annual comparison.

A basic table for recording temperature and humidity before and after refurbishment is shown below.

- By recording the internal and external conditions, it will be possible to make a fair comparison of the change in performance of the building
- The longer conditions are measured for, the more accurate the results will be.
- This data can later be compared to the energy bills for the building

Location: Gallery One
Year: 2008

Date	Day	Time	RH (%)	Temp (°C)	Dehumidifier on? Y/N	Heating on? Y/N	Notes	Weather	Outside Temp (°C)	Initial
8/4	S	02:00	41	12	N	Y		Rain	4	DE
8/4	S	08:00	43	16	N	Y	Setting up exhib.	Rain /sun	7	EH
8/4	S	14:00	42	17	Y	N	Setting up exhib.	Rain /sun	10	NY
8/4	S	20:00	56	16	N	N	Press photos	Rain	6	EH
9/4	M	02:00	50	11	Y	Y		Clear	3	EH
9/4	M	08:00	56	16	Y	Y	Open for season	Clear	4	DE

Temperature and humidity log

Traditional construction

Traditional building materials and methods function differently from their modern equivalents. For example, solid masonry walls constructed with lime mortar and finished with lime plaster or render are designed to absorb moisture during damp or wet conditions and to expel it by evaporation when in drier conditions. If the building is well constructed and maintained, this system regulates the moisture content to keep it below levels at which decay and rot can occur.

Moisture can arise from a number of sources:

- UK southwesterlies carry rain clouds, mainly from the Atlantic. These prevalent winds result in driving rain that can saturate western and southern elevations
- The action of wind, rain and sun on these elevations accelerates the decay of windows and masonry
- Dampness in the ground rises up through solid walls. This occurs by capillary action if there is no physical damp proof course. Damp proof courses began to be used in late Victorian construction but only became widely used from the 1920s
- Dampness in the ground also evaporates through brick and stone flag floors
- Human beings breathe and sweat, producing surprising amounts of water vapour, which combines with steam from cooking and washing

The majority of traditional buildings have been repaired and altered over their lives using modern gypsum plasters, cement pointing/renders and concrete. These are usually unsuitable and can prevent traditional materials and systems from performing as they should. Concrete floors with waterproof membranes displace moisture to the surrounding walls, increasing levels of dampness. Waterproof renders trap moisture in walls and encourage it to rise higher. Cement pointing is not water permeable and is hard and inflexible. It prevents walls from drying out as effectively as lime mortar and can result in damage to softer surrounding masonry by freeze/thaw action.

Listed Building Consent relates to materials and systems as well as to the finished appearance of repairs and alterations. It is important that works to traditional building elements are specified by an experienced and certified building conservation professional, to avoid the risk of unintended long-term damage. These issues are explored in more detail later in this guide.

Consider possible next refurbishment steps

Improving the U-Values and building airtightness can greatly improve the performance of the space and the energy efficiency. There are several further refurbishment steps which can be explored, including measures to improve the ways in which the building is used and operated, efficient plant, control strategies, lighting systems, and relaxing overly narrow temperature and relative humidity set points. These are outside the scope of this guide but it is recommended that a rounded energy conservation strategy is developed to incorporate a range of the most cost effective measures. These can be implemented progressively as funding and cyclical maintenance opportunities permit.

Relevant questions to ask

These questions can be put to engineering consultants, architects, building surveyors and contractors, as appropriate, to gain an understanding of the proposed refurbishment works:

- Which section of Part L of the Building Regulations is the refurbishment working towards?
- What U-Values are you designing to for each of the elements in the refurbishment?
- What measures have you adopted to minimise thermal bridging?
- What infiltration rate are you targeting?
- What methods will you use to reduce infiltration and draughts?
- How will this infiltration rate be measured?
- Will the environmental conditions of internal spaces be more stable?
- What measures have been included to maintain stable conditions?
- What impact will the refurbishment have on the ventilation and the relative humidity? How will this be managed?
- Will the BMS/controls systems be adjusted as part of the works?
- Who is producing the EPC and the DEC certificate?
- How have the areas to be refurbished been prioritised? (Refer to calculation tool results)
- How much energy will be saved?
- What is the payback period for the various elements of the works?
- What provision is being made for outside/fresh air?
- Are the proposed insulation systems for external solid walls vapour permeable, with no vapour barriers?
- Where internal wall insulation is to be installed and the ends of timber joists or beams are embedded in solid external walls, what is the strategy for dealing with the increased risk of dampness and rot in timber?
- Are the proposed plaster/render and paint systems for insulated solid walls water vapour permeable, to allow the building to ‘breathe’ by permitting the passage of water vapour through them and the proposed insulation?
- Is lime mortar and lime plaster specified for works to walls of traditional construction?

Listed or Conservation Area buildings

- Have the proposals yet been discussed with the local conservation officer or Historic England?
- Who is proposed as the certified building conservation professional?
- Is there an existing statement of significance for the heritage asset?

Below are links to RICS and RIBA certification schemes for building conservation professionals.

http://www.rics.org/uk/join/member-accreditations/building-conservation-accreditation/

https://www.architecture.com/FindAnArchitect/FindaConservationArchitect/FindaConservationArchitect.aspx

Section 4

Understanding what is practically achievable

Introduction

There is now widespread acceptance that even extensively refurbished existing buildings are unlikely to achieve the very efficient levels of thermal performance of new buildings. Reflecting this, Part L of the Building Regulations sets somewhat less demanding targets for alterations to existing buildings.

Nevertheless older buildings can perform surprisingly well, especially those with thicker walls.[1] With intelligently designed adaptation they can do even better. This includes heritage buildings, although some potentially very effective measures, such as external wall insulation, would have too damaging an impact on character to be appropriate or acceptable. Listed buildings and buildings in Conservation Areas are exempted from Part L energy performance requirements, where compliance would unacceptably alter their character and appearance. This leaves a lot of scope for debate and professional opinion, so expect some vigorous discussion of your proposals, preferably represented by your own expert.

Methods for improving U-Values are well established, although materials and techniques continue to develop. Many measures were not specified in the past because buildings were operated at lower temperatures or because fuel was cheap but also for cost reasons since improvements were not mandatory. Making these adaptations to existing buildings is somewhat more difficult than providing them in a new building but it can and should be done.

However, buildings vary greatly and it is essential to choose the right solution. Buildings are designed with elements, materials and systems that are intended to work together to provide a healthy and protected environment. When changes are introduced, buildings perform differently. Unsuitable materials and ill-informed changes can cause defects to develop. Well-considered designs and specifications can enhance the performance of buildings without creating new problems.

Many of the issues and specification options are explained clearly with illustrations in the excellent free guides prepared by David Pickles for Historic England. Although these guides relate specifically to historic building types, they cover principles and solutions applicable to a lot of museums and galleries. The advice set out is worth considering for each of the key elements referenced. Links are provided to online documents if there is a relevant Historic England guide:

https://historicengland.org.uk/advice/technical-advice/energy-efficiency-and-historic-buildings/

1 Baker P. Glasgow. 2011. Historic Scotland Technical Paper 10: U-Values and traditional buildings.

Potential for energy savings

How much energy and carbon can be saved very much depends on the acceptability of possible building adaptations. Tackling only the building fabric improvements will normally produce lower levels of savings than a more comprehensive strategy. A utilitarian 1960s building is likely to be much more adaptable than a Grade I listed Palladian mansion. In Arup's experience older buildings with little insulation and containing traditional building services and controls can reasonably be expected to be adapted to achieve average energy savings of up to 50% but this is a range with wide variations. This indicative average assumes that co-ordinated improvements are also made to building services installations and controls and how the users operate the building.

Return on investment

The return on investment usually diminishes rapidly once the most practical and effective interventions have been implemented. This is because each intervention reduces the amount of energy consumed and although every subsequent effective intervention should continue to reduce the total energy bill, the quantum of the bill grows smaller every time. Later interventions produce much lower savings in cost, kilowatt hours and carbon emissions. This makes it harder to justify the investment on cost saving grounds alone, unless energy prices rise rapidly. It remains important to contribute to national carbon reduction targets as part of a long-term strategic plan, which is discussed further below. The design life of the different interventions should also be taken into account in calculating investment return. A window might require replacement after 20 years but insulation could potentially last for 100 years or more.

Energy sources and building design

Older buildings in the UK as late as the 1830s were frequently designed to operate at lower temperatures than modern buildings and it may be appropriate to continue this approach as part of the operational strategy. After about 1840 and the advent of the railways, designs began to change. Coal, and later coke, became more plentiful and much easier to distribute. This reduced prices, allowing many buildings to be heated throughout, to much higher temperatures and for longer periods. Energy conservation was not a priority. In the second half of the 20th Century heating systems were gradually converted to burn fuel oil and, from the mid-1970s, piped North Sea natural gas. A laissez-faire approach to energy conservation continued until at least 1976 when the Building Regulations standards began to recognise the lessons of oil price shocks.

Putting savings in proportion

Museums and galleries are not a single building type and it not possible to provide general guidance about the proportion of heat losses for the different elements of the building. Neither is it possible to generalise about the relative improvements that might be achieved. Museums and galleries range from conversions of existing buildings, such as individual houses or cotton mills, to very large purpose-built municipal buildings, across a wide spectrum of building styles and periods. The table below compares some very broad estimates of elemental losses arrived at in published information for a low-rise commercial building and the average UK house.

The variations in proportionate energy losses illustrate the considerable differences. This reinforces the importance of calculating the likely U-Values and the potential reductions that might be achieved from insulating them. It is very unwise to rely on doubtful rules of thumb or generalisations that may have come from an entirely different building type.

Building Element	Commercial Building *	Average UK House **
Walls	9%	33%
Roof	22%	8%
Floor	8%	9%
Windows and glazing	26%	20%
Ventilation and air infiltration	35%	25%
Other	-	5%
Totals	**100%**	**100%**

Disparate nature of proportional heat losses

* Commercial Building [2]
** Average UK House [3]

2 https://www.carbontrust.com/media/19457/ctv014_building_fabric.pdf
3 https://www.gov.uk/government/statistics/united-kingdom-housing-energy-fact-file-2013
(UK Housing energy fact file: 2013, refer to Table 6n 2011)

U-Values tool and establishment of base data

The U-Values tool accompanying this guide, explained in Section 2, should provide a good starting point to develop your ideas and to clarify what might be practically achievable. You know your building and should be able build on this knowledge in conjunction with an analysis of the energy consumption data from at least 3 previous years' energy bills. This information also arms you to counter over-optimistic or misguided recommendations from designers, manufacturers and contractors.

Strategic planning

It is highly unlikely that comprehensive improvements to thermal performance will be achieved as a single project, unless a museum or gallery receives unusually high levels of funding and is prepared to close for some or all of the works. Work to building fabric can be very disruptive, although work in roof spaces and external works can often be carried out while the building remains operational. In most cases, however, it is likely that improvements would be undertaken by room, by wing or by floor and this guide enables you to make assessments at this level as well as for the entire building. Improvements should ideally be incorporated as part of regular changes in displays or cyclical re-fits.

For this reason, it is important to develop a long term retrofit plan for the building fabric, integrated with a complementary building services strategy. The plan should be reviewed and updated at least once a year, with a running record of progress against objectives. Government-led market incentives, technologies and legislation will change and it should be expected that the retrofit plan will also change over time. It is also essential that managers and staff are aware of the key objectives and the reasons behind them.

Funding is usually impossible to predict except over short periods and a clear incremental plan for the improvement of the building and its services will inform funding bids with a narrative linking the works to reduced operating costs and carbon emissions.

Users of this guide are reminded that Museum Development North West commissioned Arup to provide advice on a wide range of potential measures to improve environmental performance. The related Survival Strategies guide is provided on the website in the Publications section.

https://museumdevelopmentnorthwest.files.wordpress.com/2012/06/museum-and-gallery-survival-strategy-guide-printable.pdf

It is strongly recommended that this document and the Survival Strategies guide should be used together in developing strategic plans.

Climate change adaptation

The main emphasis in this guide is to improve U-Values and reduce energy consumption but the wider context must also form part of strategic planning. Reduced energy consumption will contribute to carbon reduction targets but it seems clear that the targets set by the Climate Change Act 2008 will not be met. As a result buildings will experience more extreme weather events, probably in the North West greater incidence of driving rain and flooding, although summers are also expected to be warmer. You should incorporate suitable adaptive and preventative measures into your strategic retrofit plans, based on flood risk assessments and experience of which areas of your buildings are prone to water penetration.

Examples might include:

- Prioritising elevations that are regularly saturated by driving rain
- Installing additional rainwater gullies and downpipes to prevent parapet or valley gutters from overflowing and flooding the building
- Solar shading to windows and roof lights known to cause overheating

Teamwork for the right solution

Retrofit is rarely as straightforward as works designed from first principles in a new building, so careful thought and skilled design is required to marry the right intervention with the existing fabric. Sometimes the best answer does not present itself straight away, and a number of iterations are required. This is where collaborative team work pays off, by drawing on the skills and experience of the client, the design team and the contractor. If at all possible you should procure the main contractor in a way that allows key staff to be involved early in the design development process. Contractors have a practical grasp of materials, their cost and how to incorporate them in the building. All concerned may have ideas from other projects.

Section 5

Selecting the right interventions and materials

Introduction

This section of the guide outlines what might be achievable for different building elements, together with some recommendations and warnings about specification and materials. This is an introduction and overview, some links are provided to more detailed guidance. These links and other policy and information sources are collected in a single section towards the end of the guide.

External walls

Improvements to performance will depend on opportunities to install wall insulation, externally, internally or in a cavity. This should be combined with measures to reduce the infiltration rate. Designing and specifying the correct solution for the insulation of external walls is not straightforward and developing the right answer will come out of investigation and discussion.

The following two guides are relevant and between them cover the issues and potential options for a wide range of building types but with an emphasis on heritage buildings. They clearly explain the way that solid walls are designed to "breathe" by temporarily absorbing rain and moist internal air, until conditions change and they can later dry out. This natural modulation and regulation of moisture is a key system in the effective operation of the building.

https://content.historicengland.org.uk/images-books/publications/eehb-early-cavity-walls/heag083-early-cavity-walls.pdf/

https://historicengland.org.uk/images-books/publications/eehb-insulating-solid-walls/

There are only a limited number of timber-framed historic museum and gallery buildings in the North West and, to keep this guide reasonably short, the issues are not reviewed here. You are recommended to look at Historic England's short guide.

https://historicengland.org.uk/images-books/publications/eehb-insulating-timber-framed-walls/

Cavity wall insulation (CWI)

CWI can provide useful savings and is cheap to install but it is less effective than installing insulation to the internal or external wall face (100mm of wood fibre insulation or equivalent). Cavities are relatively rare in buildings constructed before about 1920. Their likely existence can often be deduced by examining the bonding pattern of the bricks and the overall thickness of the wall.[1] Usually the bricks in the external leaf are laid lengthways in "stretcher bond" to enable the creation of the cavity, rather than including bricks laid end on as "headers" bonded into the adjacent leaf of brickwork. However, care should be taken in assuming that the presence of headers always infers that the wall has no cavity. Sometimes "snapped headers" were used in the outer leaf of cavity walls to create a more interesting pattern.

In existing buildings, CWI is inserted through a grid of holes, normally drilled in the outer leaf of brickwork and made good afterwards. Blown or injected CWI is a relatively low cost solution but it is normally significantly less effective than comprehensive insulation systems applied to the face of the wall.

Potential issues:

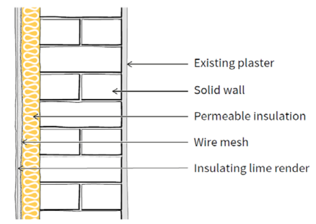
- Although there are many building owners who are entirely satisfied with CWI, there are still some controversies
- Urethane foam insulation may be unsuitable in some locations
- In some cases CWI has been associated with accelerated decay of wall ties
- Fibre insulation can retain water in some circumstances, resulting in increased moisture levels in walls and a resultant loss of thermal performance
- Such an outcome would be particularly unacceptable for museums and galleries with collections susceptible to higher levels of humidity
- Wet fibre insulation can hold moisture against joist ends and increase the risk of timber decay

It is important to take informed professional advice.

1 http://www.designingbuildings.co.uk/wiki/Cavity_wall

External wall insulation (EWI)

Many museums and galleries are in much-loved heritage buildings. It is rarely likely to be acceptable to install an insulated cladding system that obscures the main external elevations that give the building its character. There may be opportunities to install external wall insulation in more utilitarian modern buildings or to secondary elevations of lesser significance in heritage buildings. Carefully designed rain screen cladding or insulated render systems can provide an opportunity to transform the perception of a building and to conceal a poor quality, damaged or unattractive external wall. There would be an impact on character, as the render will appear new and the windows would be deeper set, but a good designer with heritage experience should be able to make a case for Listed Building Consent.



Vapour permeable external insulation to a solid wall

With kind permission from and © Historic England

Where EWI is acceptable and appropriate, and where the wall has an unfilled cavity, it should be practicable to use proprietary systems incorporating plastic foams. Often these are finished in painted cement render but perforated metal rain screen systems are also available.

It is strongly recommended that solid wall buildings should be insulated using a water vapour permeable insulation system such as wood fibre board or hemp lime composites with a vapour porous lime render and lime or clay based paint system, so as to permit the absorption and evaporation of rain and water vapour. This will help any vapour trapped in the wall to escape to the exterior, instead of accumulating and increasing the risk of damage to the building fabric. Advice should be obtained from a certified conservation professional and careful detailing will be required to achieve a good design aesthetic. The cross-sectional sketch adjacent indicates the method to be adopted.

If there is an existing filled cavity and a decision is taken to install EWI as an additional measure, it may be better to use a vapour porous system if there is any concern that the cavity fill is damp. If an impervious EWI system is installed any moisture in the cavity would either be trapped or would tend to be drawn into the interior of the building.

Potential issues:

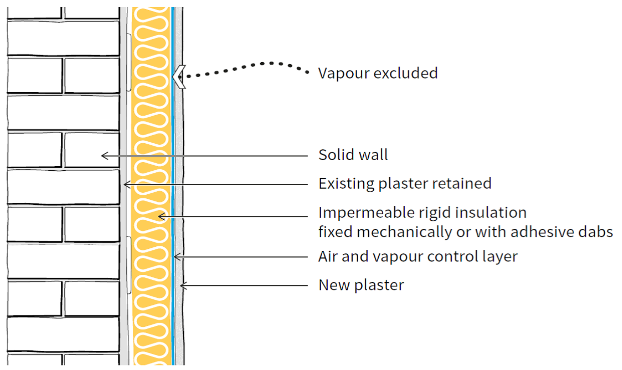
- Similarly, if surveys identify that the external skin of existing cavity walls is damp, it may be appropriate to use a vapour permeable insulation rather than trapping moisture in the wall
- Rainwater pipes, gullies and soil pipes will need to be removed and repositioned. The costs can be significant
- Careful detailing will be required around window and door openings, possibly using a more slender high performance plastic foam or calcium silicate board in these areas to reduce cold bridging
- If window frames are narrow this may be difficult to achieve
- Once window reveals have been insulated, future window replacement may be more difficult

Internal wall insulation (IWI)

IWI can be very effective provided that it is acceptable to lose a little floor space. It requires careful detailing and is disruptive, normally requiring that heating, power and data services, as well as skirtings and architraves are removed and reinstated. If the budget is more generous, it may even be possible, using skilled craftsmen, to remove, adapt and reinstate wainscoting and other timber panelling to permit the installation of internal wall insulation but this will depend on the specific circumstances and negotiations with the heritage professionals dealing with Listed Building Consent. It would not normally be appropriate to obscure decorative plasterwork or to replace heritage plasterwork.

However, in more modern buildings, or in simpler spaces in older buildings, it may well be possible to apply an insulation system. This can be carried out using modern, high performance polyisocyanurate or phenolic foam insulation. This is available as foam backed gypsum plasterboard panels incorporating a vapour barrier.

Correct specification and workmanship are very important, as there are significant risks in relation to damage from condensation mould and even consequent timber rot occurring behind foam, polystyrene or mineral/glass wool insulation. Installing a layer of internal insulation causes the dew point at which water vapour condenses to move closer to the inside face of the original wall. This surface is likely to be significantly colder in a traditional solid-walled building than in a modern building. Warm air is able to carry a higher proportion of water vapour than cold air and the water vapour cannot be absorbed by impervious insulating material. Instead it will condense on the cold surface of the wall. This concealed dampness can cause timber rot as well as damage to fabric from condensation mould.

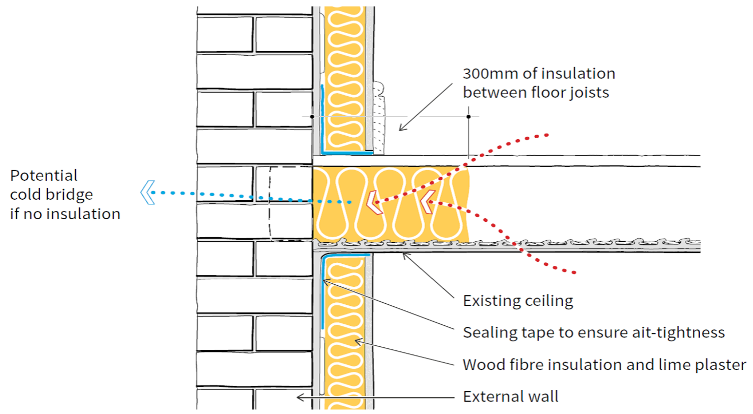


Impermeable internal wall insulation to a solid wall

With kind permission from and © Historic England

There are also health risks and risks to exhibits and contents if the mould spores are present in the air. As a result, impermeable insulation materials of this type require a vapour barrier (a layer of plastic or foil) on the cold side of the insulation, to prevent what is known as interstitial condensation. The sketch below indicates the approach to be adopted.

As in the case of external insulation, because of the increased risk of interstitial condensation, it is strongly recommended that solid wall buildings should be insulated using a permeable insulation system such as wood fibre board with a vapour porous lime or clay plaster and paint system so as to permit the absorption and evaporation of water vapour. The drawback is that a greater thickness of natural material is required to achieve a significant improvement in U-Value, perhaps 100-150mm of wood fibre board. This reduces internal space somewhat. The sketch below indicates the approach that might be adopted, including insulation between floor joists perhaps 1 metre deep from the perimeter to reduce the risk of cold bridging, condensation and rot, where timber beam ends remain set in the wall.



Vapour permeable internal wall insulation to a solid wall

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Capillary active insulation

The use of capillary active insulation such as calcium silicate board should also be considered, particularly in circumstances where condensation mould has already been a problem. Although the thermal resistance value of calcium silicate is much poorer than phenolic foam (0.059 W/m²K against 0.020 W/m²K), it has a number of other advantages.

- It allows the open diffusion of moisture, dispersing any moisture
- At 30-50mm is much less bulky than wood fibre board
- Its natural alkalinity resists mould growth
- It is fully bonded to the existing plaster enabling a more gradual thermal gradient through the wall
- Condensation forming at the junction of the original wall surface and the insulation is absorbed, dispersed and later evaporates into the room
- This vapour permeable system is particularly well suited to solid external walls, which rely on vapour permeability to function correctly
- Calcium silicate board is also relatively slender and is well suited to insulating window reveals and other areas of cold bridging
- A tapered board is available, which can be useful in making the transition to cornices and decorative skirtings

It is very relevant to museums and galleries, as it helps to provide passive modulation of humidity inside the building, absorbing water vapour from the air and gradually releasing it when the building is less densely occupied. This approach has only recently become more recognised in the UK, although Calsitherm board, the main product currently available, has been manufactured in Germany for 20 years. It is not suitable for use externally.

http://www.ecologicalbuildingsystems.com/UK/Products/Calsitherm-Climate-Board

Potential issues:

- Closed cell foam insulation systems specify the use of a vapour barrier but poor workmanship is quickly covered up. It can be difficult to achieve an effective seal at floor level and around electrical outlets and trunking. It is also easily breached during later alterations by those unfamiliar with the requirement for maintaining the integrity of the vapour barrier
- Some foam insulation manufacturers specify screw fixing to pre-installed timber battens, creating a significant air gap and increasing the area of wall that can be reached by moist air when the vapour barrier fails
- Particular care should be taken to design internal wall insulation to reduce or eliminate cold bridging. Window and door reveals, internal masonry walls connected to external walls and timber joist ends embedded in external walls are particular areas of risk
- It may be necessary to insulate around timber joists embedded in the external walls, as shown in the sketch or, if acceptable, cut them back and install stainless steel joist hangers to allow the insulation to be continuous between floors
- Vapour permeable insulation materials such wood fibre board and calcium silicate board will not work effectively when applied on top of non-permeable paint finishes or gypsum plaster, which would first need to be removed
- If this is not practical or acceptable for heritage reasons, the insulation may need to be terminated above and below the floor joists to limit the risk of rot, which arises because internal wall insulation will tend to increase the impact of cold bridging adjacent to joist ends, increasing the levels of moisture within the wall
- Loss of thermal mass. Insulating the internal face of external walls reduces the capacity of the building to use its dense structural elements (thermal mass) to provide passive regulation of internal temperatures
- However, if the building has internal masonry walls, heavy plaster ceilings and solid floors, the loss of exposed thermal mass in the external walls would have a lesser impact
- Reduced air infiltration is particularly pertinent to buildings in England and Wales with drystone external walls, constructed in un-mortared slate or stone. Internal insulation would reduce infiltration but the condensation risk needs to be properly considered and understood

Roofs

As might be anticipated, different types of roof construction require different insulation solutions. Ease of installation also varies considerably.

Flat roofs

Insulation is best installed to flat roofs when the roof covering is due for replacement. Even in heritage buildings, adding insulation to flat roofs is often relatively uncontroversial as most flat roofs are only visible from a limited number of viewpoints, often at some distance. The insulation itself is concealed by the roof covering.

It is also possible to install insulation on the surface of the roof above the waterproofing layer but Arup advises against this approach, as the system makes it much more difficult to inspect roof coverings to find the source of roof leaks. It is also common to weight insulation installed above the waterproofing layer with pebbles and beach stones to prevent its being dislodged by high winds. This would cause a change in appearance, as well as increasing the load imposed on the roof structure.

If a flat roof is not due for recovering, and if interior finishes are relatively simple, it may be possible to install insulation at ceiling level in the rooms beneath. However, this option may be unacceptable, even though readily reversible, if the rooms contain elaborate plaster cornices and/or ceiling roses. It may also be impractical to install insulation if there is a service void with services suspended from, or attached to the roof structure.

Ceilings can also be insulated within rooms by mechanically fixing calcium silicate board. This material is outlined in more detail in the section on internal wall insulation but it is particularly useful to absorb water vapour from rising warm air, providing a natural means of regulating internal humidity. However, it has poorer thermal performance than modern foam insulations.

Some more advanced technologies, such as phase change materials can be used at ceiling level to absorb rising heat energy for later discharge but they have not yet been widely adopted and are relatively costly. In many instances where heat gain is an issue in particular spaces, ventilation and extraction may be lower cost solutions until prices become more competitive.

For further information, the following Historic England advice may be useful:

https://historicengland.org.uk/images-books/publications/eehb-insulating-flat-roofs/

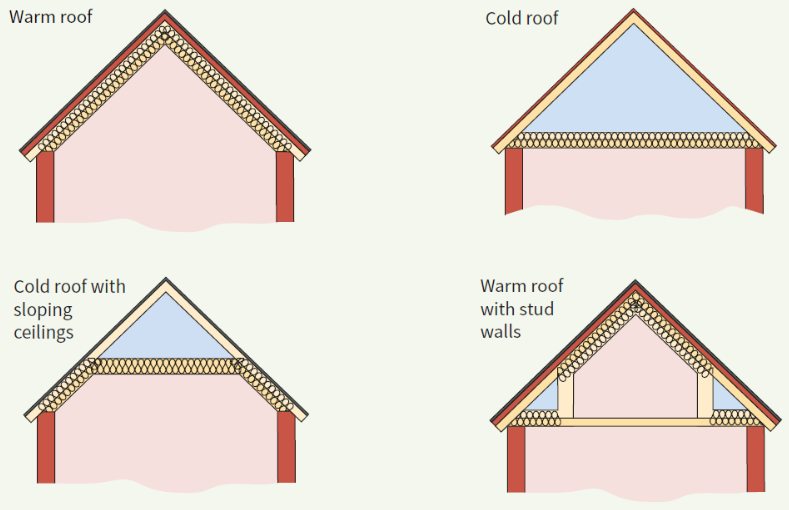
Pitched roofs

Pitched roofs can be either warm or cold depending on where the insulation is positioned. The illustration indicates the difference, which depends on whether it is intended to use the roof space for storage or accommodation, rather than as a maintenance zone.

Fitting insulation in attic spaces within pitched roofs of heritage buildings is not usually controversial, as they are concealed from public view and the insulation is readily removable. Glass wool and mineral wool quilting are commonly used. Alternatively wood fibre board, sheep's wool or cellulose insulation can be used, if a more natural material with greater vapour permeability is required for heritage roof structures. If space is restricted, foam boards can be used.

Warm Roofs and Cold Roofs

In this guidance the term 'cold roof space' or 'cold roof' is used to describe a pitched 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 sloping rafters, so that the whole of the volume under the roof can be heated and used. Some buildings have combinations of these two arrangements.



Insulating warm and cold roofs

With kind permission from and © Historic England

Potential issues:

- In cold roofs, where sarking felt or another impervious membrane is installed beneath the roof covering, it is important to provide ventilation at the eaves to avoid the build-up of moisture in the roof timbers
- Insulate pipework and tanks in cold roofs, if they will be above the new layer of insulation to be installed
- There are sometimes hard-to-access areas of void space surrounding lantern lights and specific design solutions will be required to introduce insulation
- In some circumstances vapour barriers are required and specifications should be prepared by experienced professionals familiar with the type of building to be treated
- Loose fill cellulosic fibre insulation usually made of recycled paper can blow around and drift in draughty roofs, reducing the effectiveness of insulation. This is not a problem in less draughty locations and when cellulose insulation is in solid batt form. The UK market leader for this product is Warmcel (http://www.warmcel.co.uk/)
- If recessed light fittings penetrate the ceilings of the rooms immediately below the roof space be insulated, ventilated airspace should be provided around the fittings in accordance with the manufacturer's specifications to reduce the risk of overheating, which has caused fires. However, this can result in heat loss through fittings. LED fittings can be vented into the room subject to manufacturers' guidance
- Insulation works should be combined with draught sealing, particularly around loft hatches, access doors and penetrations for pipes and wires. Winds blowing through roofs can create a pressure drop (the Venturi effect), which draws warm air out of top floor rooms

For further information, the following Historic England advice may be useful:

https://historicengland.org.uk/images-books/publications/eehb-insulating-pitched-roofs-rafter-level-warm-roofs/

https://historicengland.org.uk/images-books/publications/eehb-insulating-pitched-roofs-ceiling-level-cold-roofs/

Floors

There can be benefits in insulating the floors in heated rooms, at the base of the thermal envelope. They might be at ground floor or in basements or a combination of the two, depending on the layout of the building. There might be an unheated basement below a ground floor heated room and it may be beneficial to insulate the floor of the heated room.

Different types of floor construction require different solutions. The loss of heat through suspended floors can be substantial because the air temperatures below the floors are likely to be similar to external air temperatures. Solid floors without a void behave differently because ground temperatures fluctuate much less than air temperatures. Heat losses tend to be much less than through floors with an unheated void. It is also worth bearing in mind that warm air rises and heat would tend to be less concentrated at floor level. Improvements in the U-Values of floors yield proportionately lower benefits than equivalent improvements in walls, roofs and windows. There is an exception in the case of underfloor heating.

Suspended timber floors

It is often possible to insert insulation between floor joists, subject to being able to obtain access to the space beneath the floor. Even if there is insufficient space to install insulation a proportion of the boards can be taken up to provide access. As can be imagined, if only the thickness of a floorboard separates the heated space from a cold void beneath, a significant amount of heat can be lost through this route. Provided that insulation can be installed relatively easily, this can be a cost-effective measure although the cost will be higher if pipes, wires and ducts need to be demounted and reinstated.

It should be noted that a high proportion of overall heat loss through timber floors is likely to result from infiltration and air leakage. This is greatly increased in windy weather because of air bricks which are essential for ventilating the floor void to prevent the build-up of moisture in the timbers. Draught proofing the floor should be dealt with as a priority, even if it is not practical to insulate the floor.

Potential issues:

- It is difficult to lift floorboards without causing some damage. This may be unacceptable in heritage buildings and should be discussed with a joinery specialist and building conservation professional to establish the practical limitations and the likelihood of obtaining Listed Building Consent
- Vapour barriers are likely to be required in accordance with manufacturers' recommendations
- Water pipes below the insulation should be insulated to reduce risk from frost damage
- It is essential to maintain ventilation of the floor void to minimise the risk of timber rot. Air bricks should be unblocked and additional air bricks inserted if the original provision is assessed to be inadequate

For further information, the following Historic England advice may be useful:

https://historicengland.org.uk/images-books/publications/eehb-insulation-suspended-timber-floors/

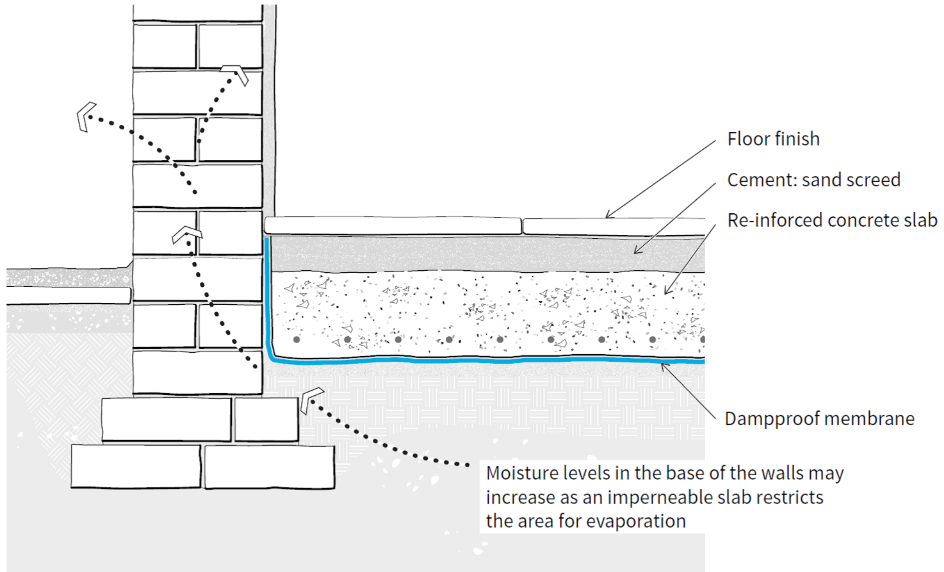
Suspended solid floors

It is also worth insulating concrete or vaulted brick floors with unheated basements beneath. Heat loss is slower than for suspended timber floors and payback is likely to be take longer but once installed it should benefit the building for many years. It will be most cost-effective to insulate the underside of the floor slab, where it is accessible in the cellar or basement space beneath. The cost will be higher if a lot of pipes, wires and ducts need to be demounted and reinstated and these costs will need to form part of the assessment of viability.

Insulating on top of existing floors is also feasible but can have significant knock-on implications, particularly in relation to the height of doors, which would need to be cut short, and door openings, which may not be high enough. There are also safety issues at stairs as a result of reducing the height of the first tread. It would be necessary to provide a robust floor above the insulation layer and floor coverings appropriate to the area to be treated. In most cases the overall cost is likely to be greater than insulating below the floor. The retention of attractive original hard floor finishes such as tiles, mosaic, terrazzo or wood blocks may also rule out this option.

Concrete floors with no void

This form of construction was used increasingly from the 1850s, particularly in civic, commercial and industrial buildings. Insulating on top of original concrete floors is feasible in many buildings but the door and headroom issues raised in the previous paragraph are applicable. Where insulating above the floor slab is not practicable, it is also feasible to break up and remove existing concrete floors, excavating sufficiently to install insulation below the new floor slab, although such an approach could be prohibitively costly and disruptive. However, if the existing floor is causing damp problems in adjacent walls or is badly damaged, such a project may be worthwhile. The sketch below indicates the way in which replacement floors can be the cause of problems. The impervious slab has replaced a former suspended timber floor, causing moisture in the ground to rise up the adjacent walls by capillary action, instead of being dispersed by evaporation in the ventilated sub-floor area.



Potential increased dampness from solid floor installation

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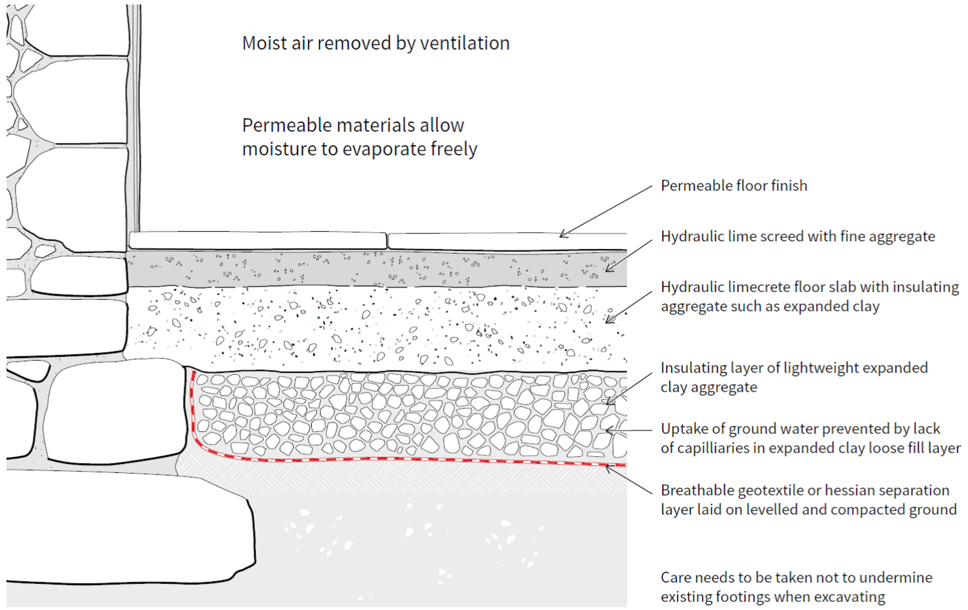
As indicated in the sketch, traditional brick or stone walls would commonly not incorporate a damp proof course and displaced moisture can rise through the wall to as much as a metre above ground level. Injected chemical damp proof courses are often recommended as a solution but there is little evidence that they work. You should seek the advice of a certified building conservation professional.

If the external walls have no damp proof course it would be appropriate to consider a more natural solution, such as a limecrete slab containing an expanded clay insulating aggregate. The sketch below shows how this would work for a stone wall.

For further information, the following Historic England advice may be useful:

https://www.historicengland.org.uk/images-books/publications/eehb-insulating-solid-ground-floors/



Vapour permeable solid floor in a traditional building

With kind permission from and © Historic England

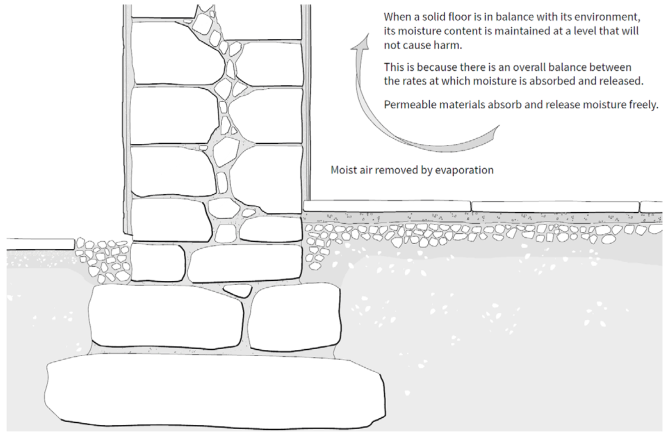
Stone flag and brick floors

The Historic England advice referred to in the previous paragraph is relevant to these types of floors. Installing insulated solid floors in traditional buildings with solid walls constructed with lime mortar and finished with lime plaster carries potential risks and complexities. Buildings of this type have usually been subject to multiple alterations over their long lives, some of which may have created problems, rather than solving them.

In buildings of this type, original solid floors were laid to be vapour permeable using stone flags with lime mortar joints, brick or even tamped earth. The principle is that, provided external ground levels are lower than internal floor levels, dampness in walls and floors should be quite limited, as water should naturally drain away from the building. Any residual moisture will evaporate through the walls and the floor. The sketch below shows how this works.

Potential issues:

- As we have seen in this section of the guide, ground and basement floors have great potential for decay as a result of damp problems
- Damp walls and floors have much poorer thermal performance than those that are relatively dry. Maintenance is as important as improvement
- There are often problems caused by earlier alterations, arising from a poor understanding of relatively subtle traditional building systems
- A survey should be carried out by a certified conservation professional to establish whether any remedial works are necessary, before developing any ideas for insulated solid floors in traditional buildings
- Could there be a cracked drain or other concealed defect that is causing the problem?
- Have external floor levels been raised above internal floor levels?
- Is the revised ground level too high and/or does it fall towards the building?
- It is essential that the building elements should be allowed to function as originally intended, so as not to undermine the effectiveness of proposed energy efficiency improvements



Moisture control in traditional floor and wall construction

With kind permission from and © Historic England

Glazing and windows

Although some museums and galleries operate from relatively small former houses, many are freestanding civic or industrial buildings, frequently with large windows and roof lights. In these buildings the heat loss through glazing is often a much greater proportion of overall heat loss than for houses. This provides an opportunity for substantial improvement, including reducing air leakage and infiltration.

Different solutions apply to different types of window and, at the most comprehensive, will involve complete replacement with modern, thermally broken window frames incorporating draught strips and high performance, argon filled, low emissivity double or triple glazing. This would address both U-Values and infiltration very effectively. High quality trickle ventilators can provide controlled natural ventilation, when mechanical ventilation is not provided.

High performance secondary double glazing can be particularly effective, allowing the retention of period windows. The air gap between the two sets of windows can provide an additional thermal barrier, particularly on sunny elevations. Careful design is required as well as an active maintenance programme to see that the glazing and the air gap are cleaned and decorated.

At a more modest level, existing windows could be overhauled, draught-stripped and fitted with internal polycarbonate secondary glazing. Reflective and tinted plastic films can also be useful in reducing heat gains in sunny rooms, as well as reducing ultra-violet light damage to collections.

Consider high performance timber, aluminium alloy or timber/aluminium composite windows, which combine some key benefits of both and do not require regular re-painting. UPVC windows are rarely suitable for civic buildings of character.

It is also worth amplifying the advice in the first part of this guide in relation to heritage buildings. Windows are one of a handful of key features that shape our perception of the external character of a building. Prior to the development of float glass, window glass was not completely flat and the variations lend much interest and character to a building, changing subtly according to point of view, time of day and intensity of light. Historic glazing is unique to each building and irreplaceable. Conservation professionals will usually vigorously resist its removal. Even where no heritage glazing remains, conservation officers are likely to favour repair over replacement of windows in listed buildings. It is often easier to obtain consent for secondary glazing, an alteration that can be reversed without compromising the original heritage window.

Roofs in museums and galleries traditionally incorporated roof lights or lantern lights and treatment will depend on the policy adopted in relation to daylighting and collections. A handful of manufacturers make simple double glazed replacement ‘heritage’ roof lights with improved thermal performance.

If the glazing of a large linear roof light or lantern lights is to be permanently obscured, and is accessible for re-glazing from outside, it may be preferable to install an internal insulated timber frame. This could be adjacent to the glazing and would enable the installation of foam insulated plasterboard with a vapour barrier, incorporating a suitable ventilation system. The solution would be reversible, if daylighting requirements change in the future. This is normally preferable to installing an insulated suspended ceiling, which would remove air volume important in coping with visitors. It would also detract from the architectural character of the space.

For further information, the following Historic England advice may be useful:

https://historicengland.org.uk/images-books/publications/eehb-draught-proofing-windows-doors/

https://historicengland.org.uk/images-books/publications/eehb-secondary-glazing-windows/

In relation to the suggested low-cost secondary acrylic single glazing see:

https://www.spab.org.uk/downloads/warmer_bath_june2011.pdf

It is also covered in a free to download briefing guide to windows and doors:

https://www.spab.org.uk/downloads/SPAB%20Windows%20Doors_low%20res.pdf

Infiltration

Reducing infiltration rates has great potential to reduce heat losses at relatively low cost, as has been mentioned in the external wall section. The infiltration of dust, pollution and moist external air are also reduced. Other projects designed to improve U-Values are also likely to reduce air infiltration. These will include window replacement and the insulation of walls, suspended floors and roofs. The following opportunities can also greatly reduce infiltration:

- Draught lobbies to external doors and professional draught stripping to windows. In heritage buildings planar glass lobbies can provide a discreet, modern and reversible solution
- Metal framed windows tend to twist, leading to draughts and significant infiltration losses. Self-curing silicone sealants provide effective and discreet gap sealing tailored to each window treated
- Chimneys are less likely to be in use and can usually be stopped up, provided that some ventilation is retained. Such stoppers should be removable for maintenance
- There are usually many small openings around skirtings, pipes, architraves, ducts, conduits and so on and identifying them can be worthwhile but laborious. Modern sealants are relatively discreet, increasingly long lasting and can usually be removed in the future without damage, if required

Potential issues:

- Older buildings were not designed to be airtight and an over-zealous retrofit could have adverse consequences
- Internally generated humidity from visitors and other sources such as catering hot water boilers will not escape so readily if the building is better sealed
- If collections are sensitive to humidity, mechanical extraction may need to be provided or display cases fitted with localised environmental control
- Heat gains from lighting and visitors can no longer escape so quickly and may require mechanical extraction at significant capital cost. Appropriate automatic controls will be important
- Operating the fans on such systems increases energy usage and it will be important to carry out realistic calculations and strike a balance between energy saving and increased energy consumption
- There might be inadequate supply of air for stoves or open fires. This can be hazardous, with a risk of carbon monoxide poisoning
- Other issues resulting from reductions in the frequency of air changes might include condensation mould growth, lingering food and body smells, poor air quality and overheating, particularly for large groups in relatively small rooms

The design team needs to strike the right balance between reducing infiltration and still providing sufficient ventilation and the removal of stale or moist air. This requires co-ordinated designs for both the building fabric and the building services.

Next steps

After you have carried out your preliminary study, you should have a reasonable sense of what is practicable for your building and which initiatives look most promising.

Your assessment and reasoned ideas should form part of a preliminary brief for a potential professional team. You know your building better than any external party. It will be important to draw on the skills of your internal team. Their accumulated knowledge and your ideas for the future are very valuable and need to be captured as early as possible.

Now you are ready to discuss your ideas with designers, heritage advisers and cost consultants before developing them further, and moving towards funding applications. Depending on workload, many advisers should be willing to attend a workshop to discuss your ideas at no charge. This would be on the basis that, if their initial advice is satisfactory, they would be asked to submit a competitive tender, if the project goes any further. This approach can save a lot of abortive thinking and work.

Once you have developed your ideas in this way, it is recommended that you should commission a formal assessment of U-Values and the likely impact of the long list of potential improvements that you have identified. This will enable you to test ideas and assumptions, so as to establish a reasoned short list of interventions that will form part of your project brief

Section 6

Case study: Greater Manchester Police Museum

Form of construction and indicative U-Values

Heritage issues

Recommended interventions

Results and key lessons

Greater Manchester Police Museum

Owner
Greater Manchester Police
Project Value
Not yet costed
Funding
Internal

The Greater Manchester Police Museum is a traditional mid/late 19th Century two-storey building, listed Grade II and was formerly the Newton Street Police Station. The elevations are in red brick with sandstone dressings and a Welsh slate roof. It has principally timber sash windows and includes a covered internal courtyard with a fully glazed roof. The main building is of four bays to the front elevation with a deep rectangular plan. There is a smaller outrigger and yard to the rear.

The front section of the building is understood to have been constructed in the latter part of the 19th Century as the Manchester weights and measures office, with large sliding sash windows. The rear block was constructed earlier as the police station and holding cells to a standard design used in other stations elsewhere in the city and appears to have had extensive alterations and reconstruction, particularly at first floor level, probably carried out at the same time as the construction of the front, Newton Street block.

This building is characteristic of many small 19th Century buildings that have later been used for museum purposes and the building elements present problems of thermal performance common to a range of traditional buildings. The thermal envelope has been examined in the same order used in the earlier sections of this report. The U-Value calculations are based on dimensional measurements on site, reasonable assumptions and the indicative performance values of individual materials and elements provided in this guide.

Form of construction and indicative U-Values

The indicative U-Values identified are approximations based on benchmark data and reasonable professional judgement.

External walls

The walls are of solid, load-bearing brick construction with no cavity. All walls are plastered internally apart from the cell block. Wall thicknesses and estimated U-Values vary:

- Front, side and cell block elevations (c.720mm) U-Value 1.0W/m²K
- External walls to charge office and courtyards (c.400mm) U-Value 1.4W/m²K
- Side and rear walls to first floor courtroom (c.330mm) U-Value 1.6W/m²K
- Weighted average for all external walls U-Value 1.17W/m²K

Roofs

The roofs are pitched and covered in Welsh slate. Ceilings are principally lath and plaster with a borrowed light over the main staircase and a long twin pitch ridge light over the rear courtroom. This is effectively a room within the roof. The roofs and roof spaces are understood to be uninsulated.

- Estimated U-Value 1.90W/m²K

Ground or basement floors

The building has a full basement, apart from the building areas beneath the internal courtyard and bays 1 and 2 of the Newton Street elevation (primary and secondary police offices). Floors are concrete on the ground floor and in the basement either stone flags or concrete slabs. The floor construction could only be established by intrusive investigation and it is assumed that no insulation has been installed beneath any of the floors. The rear cellar beneath the police cells is unheated and the ground floor is treated as the base of the thermal envelope in this area. The concrete floor of the police cells is supported by brick vaults. The estimated U-Values are as follows:

- Ground floor police cells area 0.5W/m²K
- Ground floor primary and secondary police offices 0.5W/m²K
- Basement areas 0.5W/m²K

Glazing

All of the windows and roof lights are single glazed. Most windows are large and of timber sliding sash construction and appear to have been painted closed, although it is likely that air leakage paths remain around some of the sashes or high level pivot lights. The U-Value of the lantern light over the courtyard has not been calculated because this area is not heated.

- Estimated U-Value of single glazed windows and roof lights 4.8W/m²K

Infiltration

This building was not designed to be airtight and there are numerous routes in older buildings for warm air to be displaced by colder air from outside.

- Typically a building of this nature might generate 1.0 air changes per hour

Heritage issues

The building is listed Grade II and maintaining the external appearance of the building from public vantage points is critical to its character and perception. Doors, windows, brickwork, stone dressings and the visible slopes of the roof are key elements. Internal finishes that contribute to the perception of historic character will also be sensitive. Examples include plaster cornices, original joinery, the volumes of internal spaces, staircases, original floors and any special features. If there is no existing statement of heritage significance, it is strongly recommended that one is commissioned before the designs for any proposed interventions are developed. This will inform the design team and the heritage professionals dealing with Listed Building Consent.

It would be reasonable to assume that it is unlikely to be acceptable to make any material change to the appearance of the spaces that define the character of the building and its former use. For example, the cells have painted brick walls and the character would be changed by installing insulation and providing a smooth plaster finish. It would be more acceptable to install insulation in the roof space and in the basement below the cell block. These areas are not of unusual significance and are unvisited by the public. Insulation can be removed quite easily, if improved technologies become available and this quality of reversibility is often a key consideration in granting consent for alterations to heritage buildings.

Recommended interventions

Recreated police court, first floor above cell block

External walls

External wall insulation would unacceptably change the character of the building.

For the same reason internal wall insulation is not realistically achievable in most areas. The disadvantage of not being able to insulate the external walls is mitigated by the 720mm thickness of the brickwork on Newton Street, Faraday Street and the cell block wall on Little Lever Street. Brickwork of this thickness is estimated to have a U-Value of 1.00 $W/m^2.K$. This assists the building in retaining heat energy and reduces the potential benefit of installing installation.

However, it should be possible to insulate the interior of the rear wall and both return walls of the courtroom (the return wall to Faraday Street is in the storage space behind the false wall) with a capillary-active insulation material such as 50mm of Calsitherm calcium silicate board or equivalent, finished with proprietary lime based plaster and permeable paint. It is assumed that the walls have the original lime plaster and the acrylic paint surface should be removed or scarified to increase vapour permeability in advance of the works. Tapered calcium silicate boards are available if this provides a neater junction with the wall panelling. If a greater level of funding is available, the panelling could be demounted and the treatment continued to floor level, after which the panelling could be reinstated.

http://www.ecologicalbuildingsystems.com/docs/CALSITHERM-CLIMATE-BROCHURE-MARCH-2015.pdf

Roofs

Install 300mm of glass or mineral wool to the main roof areas including the area above the borrowed light on the main staircase, which should be painted out to match the ceiling.

The courtroom appears to have a gypsum plasterboard ceiling, which would not be vapour permeable and unless the existing plasterboard were to be stripped, installing calcium silicate board would be of limited effectiveness. Instead the existing ceiling should be lined with pre-formed foam-insulated plasterboard panels, mechanically fixed to the rafters and incorporating a vapour barrier. Space is limited and it is likely that 62.5mm board would be the most appropriate product, providing 50mm of insulation.

Ground or basement floors

The ground floor foyer and police offices have solid floors with some original finishes. It would not be practical to install insulation because of the knock-on impact in changes in level that this would create and the loss of character involved. The cellar beneath the police cells is unheated with few building services installations. The vaulted brick ceiling could be insulated relatively easily and cheaply using mechanically fixed glass wool or mineral wool batts.

The basement floors comprise some areas of original sandstone flags and others where it is assumed that concrete floors have been laid without insulation. Installing insulation above the slab would be disruptive and of limited benefit, taking into account the relatively good existing U-Value of the solid floors.

Glazing

Secondary double glazing is feasible but expensive. The window frames would be relatively substantial and intrusive in appearance because of the very large size of the majority of the windows. Although relatively easily reversible in the future, the appearance of the secondary glazing would result in loss of internal architectural character. It may be difficult to obtain Listed Building Consent.

A compromise solution that has been accepted by conservation officers would be to install secondary single glazing to all main windows in clear acrylic panels with slender magnetic perimeter fixings. This approach is explained in a downloadable SPAB Briefing – Windows & Doors.[1]

It is recommended that the cord operated centre pivot windows at high level should not to be secondary glazed. Instead they should be overhauled, draught-stripped and maintained as primary ventilation. The toilet windows, which are later additions, should be replaced with new high performance double-glazed timber windows in a sympathetic style.

A secondary timber frame should be installed beneath the modern twin pitch glazed roof light over the courtroom and it should be insulated with calcium silicate panels or 62.5mm polyurethane foam insulated plasterboard panels, as daylight is not required in this area.

Infiltration

There is no mechanical ventilation system and some ventilation is required for health and wellbeing. However, for a small museum of this type with limited visitor numbers during the majority of its operating hours, it would be acceptable to reduce the number of air changes to 0.5 per hour. However, a suitable number of windows in each room should be made operable to provide additional ventilation on demand. The following measures would assist in reducing infiltration:

- Installation of draught proofing to windows, external doors and loft hatches
- Installation of the recommended secondary single glazing
- Replacement high performance toilet windows
- Draught stripping and keeping closed the doors into the covered yard
- Installation of a draught lobby to the main double doors into the covered yard
- Gap sealing generally and blocking the ventilation route from the cellar into the cell block

1 https://www.spab.org.uk/downloads/SPAB%20Windows%20Doors_low%20res.pdf

Results and key lessons

The results in the chart show the approximate projected savings generated by the recommended improvements to insulation and the halving of the air change rate. The two are linked: works to improve insulation usually reduce air infiltration.

ARUP

U-Value Guide
Heat Loss Calculator Tool
Part B - Refurbished Building

Part B of the tool is used to determine the performance of the refurbished space and compare against the existing space

Calculator tool guidance

1. The floor area, room height and fabric areas are assumed to be the same as those pre refurbishment
2. Determine the U-values of each refurbished building element
3. Input data into the table below

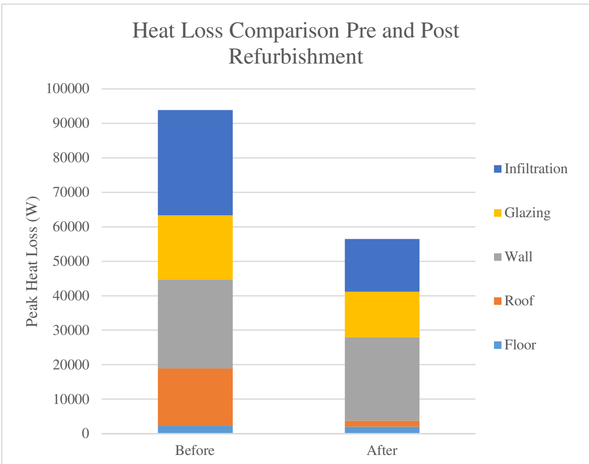
Input cells
Output cells

External design temperature	-3.7	°C
Internal design temerature	21	°C
Ground temperature	7	°C
Room area	997	m²
Average room height	3.65	m
Room volume	3634	m³

	Area (m²)		U-value (W/m²K)		Heat loss (W)		Heat loss (%)		Saving (%)
Construction	Before	After	Before	After	Before	After	Before	After	
Conduction: Floor	321	321	0.50	0.45	2247	2022	2%	4%	0%
Conduction: Roof	356	356	1.90	0.20	16707	1759	18%	3%	16%
Conduction: Wall	893	893	1.17	1.10	25807	24217	27%	43%	2%
Conduction: Glazing	157	157	4.80	3.41	18614	13233	20%	23%	6%

	Volume (m³)		Rate (ACH)		Heat loss (W)		Heat loss (%)		Saving (%)
	Before	After	Before	After	Before	After	Before	After	
Infiltration	3634	3634	1	0.5	30522	15261	33%	27%	16%

Peak heat loss for whole building before and afer refurbishment		Before	After	Saving
	W	93897	56491	40%
	W/m²	94	57	



Indicative improvements to U-Values

The key lessons are as follows:

Heritage limitations

The Grade II listing and the remaining, extensive historic architectural features limit the scope for fabric retrofit measures to improve U-Values.

Walls

The heritage significance of the majority of the walls means that it is not feasible to install insulation in most places but some limited benefit could be gained by installing wall insulation in the courtroom. This measure could reduce the total estimated heat loss through the walls by up to 6% but this only represents an overall saving of 2% of current energy costs. This would be a relatively expensive and disruptive project and is unlikely to be a worthwhile investment at current energy prices.

The 700mm thick brick walls to the main street elevations are already relatively efficient insulators (1.0 W/m².K) and limit heat loss, offsetting the 40% poorer performance of the rear walls.

Roof

Heat losses through the roof could be reduced by up to 90% at relatively low cost but the calculated heat losses are only 16% of the total, so the overall impact is lower. Nevertheless this is a worthwhile investment.

Floors

There are limited opportunities to improve the performance of the floors. Heat losses through solid floors with no void beneath are generally quite low and usually not worth the cost and disruption involved in improving insulation, unless floors are very damp or defective. However, it is relatively easy to insulate the brick vaults in the unheated cellar beneath the cell block without disruption and this would probably be worthwhile.

Windows and glazing

It is not practical to replace windows or to install double glazing except in the toilets because of the heritage significance of the existing windows. Relatively low cost acrylic secondary glazing together with insulating the roof light over the court room could reduce energy losses through windows and glazing by up to 30%. It will also assist with reducing infiltration losses.

Infiltration

Reducing infiltration could cut heat related losses by up to half at relatively low cost.

Overall impact

On a simplistic assessment the recommended interventions to improve U-Value could potentially reduce heat losses by up to 38% after setting aside the proposal to insulate the exterior walls of the courtroom. However, the overall effect would be somewhat less because combining interventions would achieve less than the sum of the individual savings. Nevertheless, substantial additional savings are likely to be achievable by carrying out the building services and operational changes outlined in the next paragraph.

Other interventions

This guide has a specific focus on U-Values but a fully considered project would combine the fabric related measures with appropriate building services and other improvements. Examples might include the following and a full survey is likely to suggest others:

- As far as possible lighting should be replaced over time with LED fittings, wherever practicable and appropriate
- The gas-fired boiler appears to be relatively efficient but there may be significant benefits from improved heating controls, with consideration of zoning to limit heating to where it is needed
- Solar control film coupled with roller blinds fitted with reflective film on the rear surface may be of benefit in reducing heat gains in the front, ground floor display area
- Guidance and training for museum staff in the efficient operation of the building, following improvement

Indicative improvements to U-Values

Greater Manchester Police Museum

Case study: The Whitworth

Summary of outcomes

The Whitworth

Owner

The University of Manchester

Funding

Heritage Lottery Fund as part of a larger project.

By the time the first Whitworth Institute building was completed in 1908 it had already assembled two of the world's great collections: British watercolours and drawings, and world textiles. The gallery became part of the University of Manchester in 1958 and was extended and adapted in the late 1960s to support the gallery's burgeoning reputation for modern art. The RIBA award-winning Sculpture Court was added in 1995. The Whitworth nevertheless began to run out of space as its popularity increased. A £15 million project, completed in 2015 doubles the gallery's public space, extending into its surrounding park. A new Collections Centre has been created and the original spaces have been sensitively refurbished. A sustainable energy strategy underpins the latest project, utilising ground source heat pumps and photovoltaic panels.

It is too early to provide any effective analysis of the energy performance of the refurbished and extended gallery but this brief note discusses the effect of earlier energy efficiency works undertaken in 2009.

Roofs

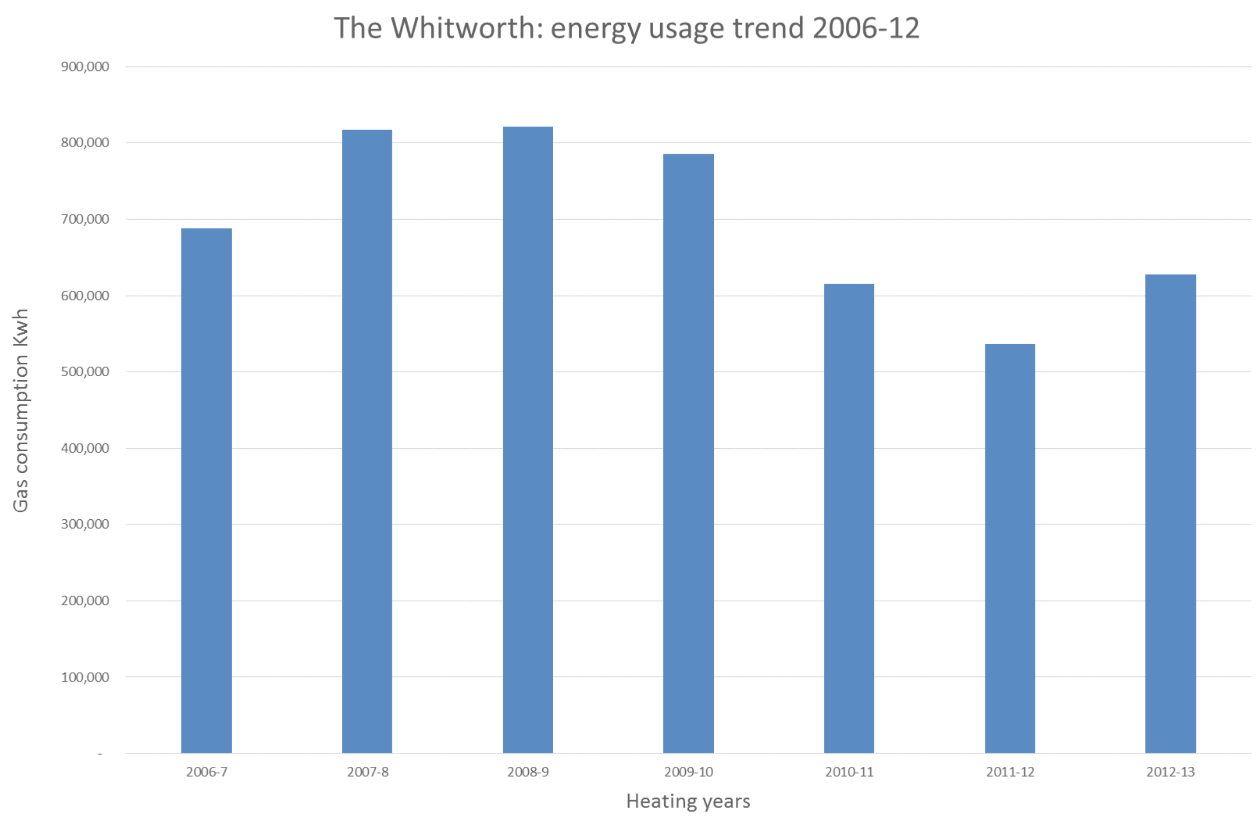
The building suffered from high levels of heat loss by convection and by conduction via the very extensive areas of single glazed roof lights over gallery spaces. The funding was applied to install multi-layer foil insulation to improve the thermal performance of the glazing and adjacent roof slopes. The insulation was installed above a suspended ceiling utilising an existing access gantry system. It was not possible to obtain information on the product used or the specification.

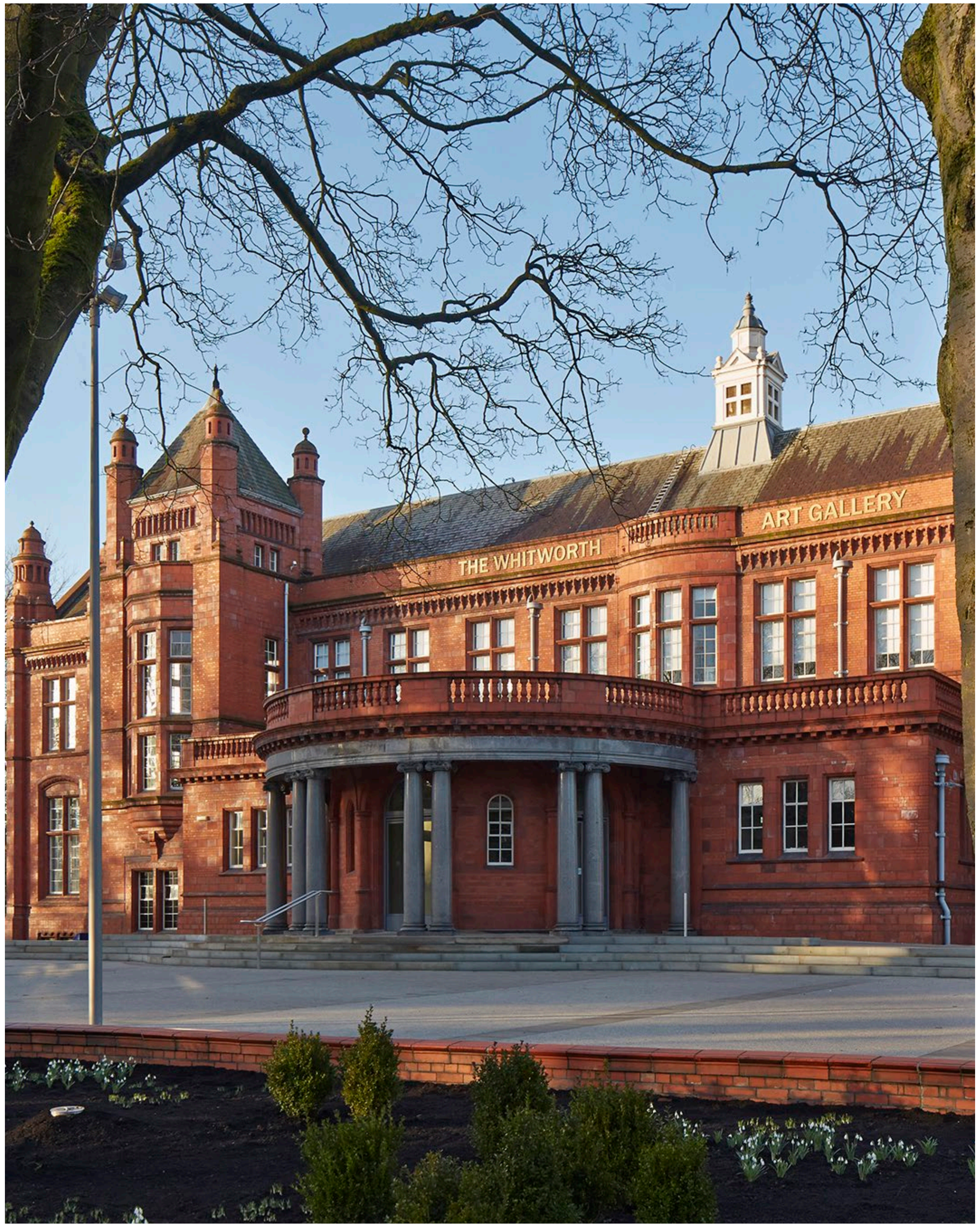
Summary of outcomes

The Whitworth monitors energy usage by monthly meter readings. The trend in annual gas consumption in kWh is shown in the graph below.

Annual energy consumption varies as a result of the way the spaces in the buildings are utilised from year to year but it is reasonable to assume that there was reasonable consistency over the period shown. The Whitworth held exhibitions and the other spaces in the buildings were occupied by staff and researchers. The relative mildness or severity of the weather is likely to have been the main determinant of energy usage.

The trend in energy usage can be arrived at by averaging the consumption in the years before the installation of the insulation (2006-10 778,000 kWh) and comparing this with the average consumption for the subsequent period before the major works were undertaken (2010-13 593,000 kWh). There is an average reduction of about 24%. It is not possible to state that the entirety of this saving results from the insulation project but it seems likely that the investment has made a very substantial difference.





The Whitworth

Case study: Norton Priory

Norton Priory

Norton Priory, the most excavated monastic site in Europe and home to the internationally significant twice-life-size statue of St Christopher, closed its museum in late 2014. This enabled the replacement of the previous outdated and poorly performing building. The new museum, gallery and café incorporate and protect the conserved Grade I listed 12th Century undercroft, providing more than 60% of additional display space. The much larger new building increases the museum's annual energy consumption but overall the building is radically more efficient.

Owner

The Norton Priory Museum Trust

Project Value

£4.5 million

Funding

Heritage Lottery Fund: £3.7m

Further support was provided by Arts Council England, The Wolfson Foundation, Foyle Foundation, Granada Foundation, the Garfield Weston Foundation and Halton Borough Council.

Predicted U-Values

Roofs: 0.18 W/(m².K)

New walls: 0.25 W/(m².K)

Existing stone walls (listed, uninsulated): 1.2 W/(m².K)

Ground floor 0.25 W/(m².K)

Windows: 1.8 W/(m².K)

Building services installations

Outside the scope of this study but it is understood that the building will be largely naturally ventilated with a pellet-fired biomass boiler and underfloor heating.

Design and construction

Architect: Buttress Architects, Manchester

Mechanical Engineer: Silcock Leedham, Leeds (Part L assessment)

Contractor: HH Smith & Sons Ltd. Manchester

Lessons learned

Tendering in 2013-14 took place during a rapid rise in construction workloads. The winning tender was over budget as a result and value engineering measures included a reduction in the higher than threshold levels of insulation originally proposed. However, the impact on energy usage is expected to be minimal, given the relatively demanding standards required by Part L2A 2013. At the time of writing the building has only recently been occupied, so it is still too early to assess the operational outcomes.

Section 9

Sources of strategy and guidance

Sources of strategy and guidance

There is a growing body of information about retrofit and measures to improve energy efficiency and some useful sources are provided here. Key information and links are provided to the strategy pages of the National Museum Directors' Council. This information is particularly relevant and should be considered and checked for alignment when developing retrofit strategies and funding bids.

Building Regulations – Part L

An overview of the applicability of Part L is provided in Chapter 2 of this guide. Links in context are provided to the Approved Documents.

NMDC

The National Museum Directors' Council recognises that museums need to approach long-term collections care in a way that does not require excessive use of energy, whilst recognising their duty of care to collections.

There is general agreement within the international museums community that it is time to shift policies for environmental control, loan conditions and the guidance given to architects and engineers from the prescription of close control of ambient conditions throughout buildings and exhibition galleries to a more mutual understanding of the real conservation needs of different categories of object, which have widely different requirements and may have been exposed to very different environmental conditions in the past.

Bizot Green Protocol

The Bizot Group of the world's leading museums agreed the Bizot Green Protocol in 2015. NMDC adopted these standards and hope they act as guidance for the rest of the museum sector. The text is reproduced below.

1. Guiding Principles

Museums should review policy and practice, particularly regarding loan requirements, storage and display conditions, and building design and air conditioning systems, with a view to reducing carbon footprints. Museums need to find ways to reconcile the desirability of long-term preservation of collections with the need to reduce energy use.

Museums should apply whatever methodology or strategies best suit their collections, building and needs, and innovative approaches should be encouraged. The care of objects is paramount. Subject to this:

- environmental standards should become more intelligent and better tailored to specific needs. Blanket conditions should no longer apply. Instead conditions should be determined by the requirements of individual objects or groups of objects and the climate in the part of the world in which the museum is located

- where appropriate, care of collections should be achieved in a way that does not assume air conditioning or other high energy cost solutions. Passive methods, simple technology that is easy to maintain, and lower energy solutions should be considered
- natural and sustainable environmental controls should be explored and exploited fully
- when designing and constructing new buildings or renovating old ones, architects and engineers should be guided significantly to reduce the building's carbon footprint as a key objective
- the design and build of exhibitions should be managed to mimimise waste and recycle where possible

2. Guidelines

For many classes of object containing hygroscopic material (such as canvas paintings, textiles, ethnographic objects or animal glue) a stable relative humidity (RH) is required in the range of 40-60% and a stable temperature in the range 16-25°C with fluctuations of no more than ±10% RH per 24 hours within this range. More sensitive objects will require specific and tighter RH control, depending on the materials, condition, and history of the work of art. A conservator's evaluation is essential in establishing the appropriate environmental conditions for works of art requested for loan.

Publicly Available Specification 198 (PAS 198)

Following publication of NMDC guidelines and an investigation by the AHRC/EPSRC Research Cluster, the British Standard Institute consulted on and published Publicly Available Specification 198: Specification for managing environmental conditions for cultural collections. This standard reflects research conducted since the publication of environmental guidance for museums, libraries and archives in British Standard 5454 (2000). The PAS 198 suggests users:

- Evaluate the sensitivity of their collection in response to temperature, relative humidity, light and pollution, recognising that different materials react in different ways to agents of deterioration
- Think holistically and put in place an environmental strategy appropriate for the collection (and which takes into account the expected lifetime of the collection)
- Make decisions about suitable environments on the basis of the significance, condition, use or display of those specific objects

http://shop.bsigroup.com/ProductDetail/?pid=000000000030219669

NMDC guiding principles

NMDC developed a set of guiding principles for rethinking policy and practice with the aim of minimising energy use in 2009. The guidelines were developed in consultation with UK conservators, ICON and the National Trust among others.

NMDC members agreed to commit to these guidelines, signalling a move towards a less energy intensive approach to collections care. The guidelines were accepted by the European Bizot Group of major museums at their May 2009 meeting.

The full NMDC guiding principles for reducing museums' carbon footprint:

http://www.nationalmuseums.org.uk/media/documents/what_we_do_documents/guiding_principles_reducing_carbon_footprint.pdf

The paper presented by Sir Nicholas Serota, Director of Tate, to the Bizot Group in May 2008:

http://www.nationalmuseums.org.uk/media/documents/what_we_do_documents/serota_bizot_paper_may08.pdf

The 2008 paper on environmental conditions in museums by Mark Jones, Director of the V&A:

http://www.nationalmuseums.org.uk/media/documents/what_we_do_documents/mark_jones_museums_climate_change_nov08.pdf

Currently conservation principles in relation to internal environments vary considerably across the world. This leads to challenges in relation to international loans and travelling exhibitions. The Bizot Green Protocol and PAS 198 could form the basis of an emerging European Standard.

Museum Development North West

This U-Value Guide and its accompanying calculation tool and checklist are available to download free of charge from the Museum Development North West website via links provided in the Publications section:

https://museumdevelopmentnorthwest.wordpress.com/publications/

In 2011 the Renaissance North West group of museums and art galleries, then part of the (now abolished) Museums, Libraries & Archives Council produced Preserve the Past, Protect the Future, a green guide with case studies drawn from round the region:

https://museumdevelopmentnorthwest.files.wordpress.com/2012/06/greenmuseums_v5.pdf

At the core of this green guide is Museums & Art Galleries Survival Strategies, a guide commissioned from Arup for reducing operating costs and improving sustainability. It should be used in conjunction with this U-Value Guide:

https://museumdevelopmentnorthwest.files.wordpress.com/2012/06/museum-and-gallery-survival-strategy-guide-printable.pdf

Historic England

Historic England has reissued the extensive energy efficiency guidance previously prepared by English Heritage and links are provided below to some selected titles but there are several others in the same area of the website.

The main guide to Part L, Energy Efficiency and Historic Buildings is lengthy and, in places, somewhat technical but it provides excellent, and fairly accessible, further explanations of many of the principles inherent in the design and functioning of older buildings. Traditional building methods often evolved over many centuries and respond to local environments and available building materials. The elements of such buildings work together in relatively complex ways to create balanced, habitable environments, provided that the occupiers use them with common sense. The inappropriate application of modern materials and systems can prevent and has prevented buildings from working as they were designed.

General and Part L Guidance

https://historicengland.org.uk/advice/technical-advice/energy-efficiency-and-historic-buildings/

Walls

https://content.historicengland.org.uk/images-books/publications/eehb-insulating-solid-walls/heag081-solid-walls.pdf/

https://www.historicengland.org.uk/images-books/publications/eehb-early-cavity-walls/

https://historicengland.org.uk/images-books/publications/eehb-insulating-timber-framed-walls/

Roofs

https://historicengland.org.uk/images-books/publications/eehb-insulating-pitched-roofs-rafter-level-warm-roofs/

https://historicengland.org.uk/images-books/publications/eehb-insulating-pitched-roofs-ceiling-level-cold-roofs/

https://historicengland.org.uk/images-books/publications/eehb-insulating-flat-roofs/

Floors

https://historicengland.org.uk/images-books/publications/eehb-insulation-suspended-timber-floors/

https://www.historicengland.org.uk/images-books/publications/eehb-insulating-solid-ground-floors/

Windows and glazing

https://historicengland.org.uk/images-books/publications/eehb-draught-proofing-windows-doors/

https://historicengland.org.uk/images-books/publications/eehb-secondary-glazing-windows/

SPAB

The Society for the Protection of Ancient Buildings was involved with Bath City Council in the development of this guide, primarily as a means of collecting advice and experience of thermal improvements to Georgian houses in Bath. This provides a reference source but also sets out the interventions that are more likely to be acceptable to Historic England and the local planning authority. Many of the lessons learned and the ideas set out are applicable to a much wider range of traditional buildings elsewhere:

https://www.spab.org.uk/downloads/warmer_bath_june2011.pdf

There is also a free to download briefing guide to windows and doors:

https://www.spab.org.uk/downloads/SPAB%20Windows%20Doors_low%20res.pdf

Your climate/Arup – Low Carbon Heritage Buildings

Arup was commissioned by the Climate Change Partnership for Yorkshire & Humber to prepare a building user guide and case studies to help owners and users of heritage buildings to reduce carbon emissions and save energy. The guide sets out key principles and explores potential retrofit measures in five case studies:

http://yourclimate.github.io/pages/low-carbon-heritage-buildings/

The Old House Eco Handbook

Notwithstanding the title, this 2013 handbook by Marianne Suhr and Roger Hunt is particularly helpful in explaining how older buildings work. It develops practical retrofit proposals for a range of traditional construction types and is recommended by SPAB, from whom it is available:

https://www.spab.org.uk/online-shop/process/product-details/?product_code=O8

Glossary

A/C
Air conditioning

ACH
Air changes per hour. The number of times per hour the volume of air in the space is replaced with outside air.

Air permeability
Measure of how much air can pass through a material. Measured in $m^3/m^2.h$ and normally specified for UK Building Regulations at a particular pressure differential of 50Pa.

Ambient air
External air in the environment surrounding the building.

BMS
Building Management System. A computer-based control system which controls and monitors the heating, ventilation, cooling, lighting and other systems in a building or complex. All of these systems can also be controlled manually. This is especially useful in a large or complicated building and good modern systems are web enabled, allowing them to be accessed and monitored remotely.

Building fabric
In the context of this report, walls, windows, roofs, floors and any other elements which form the thermal envelope of the building.

Building Regulations Part L
The Building Regulations set out the statutory requirements for construction projects in England and Wales. Part L of the Building Regulations sets out the requirements and guidelines for the consumption of fuel and power in buildings. Relevant parts of the regulations are explained in this guide.

Building services
The mechanical, electrical and public heath installations in a building.

Capillary active insulation
A permeable interior insulation system designed to redistribute and conduct accumulated moisture to areas with lower moisture content. This helps to control moisture balance and to reduce the risk of damage from rot or condensation mould.

CIBSE
Chartered Institution of Building Services Engineers. CIBSE provides industry guidance for building services design.

Cold or thermal bridging
A cold or thermal bridge is an element of the building or part of an element that has a higher rate of heat transfer than the elements or materials surrounding it. Examples include metal window frames that are not thermally broken and internal masonry walls connected to external walls. These colder areas are at increased risk from condensation, corrosion and mould growth.

Colour rendering
The ability of a light fitting to show the true colours of a space compared to natural daylight.

Control system
The installed system which operates the boiler pumps and other equipment in the building. This can be as simple as a thermostat on the wall or a fully automated building management system (BMS).

DEC (Display Energy Certificate)
This requirement relates to buildings occupied by a public authority, where from July 2015, the total useful floor area of the building exceeds $250m^2$ and which is frequently visited by the public. The certificate is to be displayed in a prominent place clearly visible to the public and shows the relative level of energy efficiency of the building.

Degree day analysis
Degree day analysis allows the energy consumption over a period of time to be calculated and takes into account weather effects on energy consumption for a given geographical region. This means energy consumption between years can be compared fairly.

Dew point
The atmospheric temperature, which varies according to pressure and humidity, below which water droplets can begin to condense.

FM
Facilities Management.

HVAC
Heating, Ventilation and Air Conditioning.

IAQ/IEQ
Indoor Air Quality/Indoor Environmental Quality.

Infiltration
Infiltration losses occur when heated or cooled internal air is able to pass out of the building through any gaps in the fabric, to be replaced by external air at ambient temperatures and levels of humidity. The air entering the building also tends to carry dust and other pollutants.

Interstitial condensation
Condensation from the water vapour carried by warmer, moister air deposited on colder surfaces in the interstices (intervening spaces) such as those occurring behind insulation. These spaces are not necessarily large gaps but frequently a zone within the wall where the dew point is reached and condensation takes place.

kW
Kilowatt. The measure of instantaneous energy consumption.

kWh
Kilowatt hour. The standard unit of energy consumption, used for energy bills. The amount of energy used over a period of time.

O&M
Operation and Maintenance.

Passivhaus
A demanding low energy performance standard for new buildings developed in Germany that emphasises high levels of thermal insulation, airtightness, mechanical ventilation and heat recovery and the beneficial use of sunlight for heating.

Relative humidity
%RH is a measure of how much water vapour is in the surrounding air compared to its capacity and this varies depending on temperature and pressure. Warm air can usually support more water vapour than cold. Gallery spaces often require relative humidity control in order to preserve exhibits.

Thermal bridging
See entry “Cold or thermal bridging”.

Thermal envelope
The ‘skin’ of the building that contains the heated or cooled air and provides protection from the infiltration of ambient air. It also provides a barrier against penetration of rain, wind, dampness and pollution. It normally consists of roofs, external walls, windows and the lowest structural floor level immediately above the foundations.

Thermal mass
The ability of a material to absorb and store heat energy. Dense materials such as concrete, stone, bricks and tiles need more energy to raise their temperature. Lighter materials, such as timber or plastic foams do not store much heat energy and have relatively low mass. Denser materials, having absorbed heat energy yield it up again by convection when internal temperatures fall. The reverse effect is seen when dense thermal elements lose temperature overnight, providing so-called free cooling until the temperature of the thermal mass rises close to internal air temperature.

Treated areas
Those areas of a building that are actively heated or cooled.

U-Value
The thermal performance of any material can be described in terms of its U-Value. This allows the heat transmission performance of different materials to be compared and the heat loss from a space to be calculated. A low U-Value means better thermal performance and a high U-Value means worse performance. For example, in comparison to typical building materials, 300mm of glass wool loft insulation has a low U-Value and is good at reducing heat loss, whereas, single glazing has a high U-Value and allows heat to be lost rapidly. U-Values are sometimes referred to as heat transfer coefficients, expressed in watts transferred per square metre of surface area for each degree Kelvin[1] in temperature difference between the inside and the outside of the building. The units are abbreviated as $W/(m^2.K)$ but the notation is sometimes written slightly differently.

1 A degree Kelvin is similar to a degree Centigrade but starting instead from -273.15C, the freezing point of nitrogen.

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