EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

Summary Guide

for Local Decision-makers

Technical guidance on energy efficient renovation of historic buildings

(D3.6 - Summary results e-guide for local governments /
Technical guidance on energy efficient renovation of historic buildings)

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SEVENTH FRAMEWORK PROGRAMME

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0 Executive Summary

Today the refurbishment of existing buildings to very low energy demand is possible and economically feasible. This is an area with huge potential for action, also for historic buildings. The main issue to be addressed is: how to **balance building protection requirements with the need for optimised energy efficiency**. There are many available strategies and technologies that can be applied to reduce energy demand and switch to sustainable energy solutions, also to historic buildings. This requires close cooperation between experts who deal with historic buildings, energy / building experts. (architects, engineers, craftsmen) and the owners of the building - to find a win-win solution for all.

However, **local leaders who need to make informed decisions** also need to understand what is possible / not possible in this context of historic buildings and monuments. Why? Decisions about energy efficient retrofit can (should) ideally be linked to the broader municipal strategy, e.g. the Urban Master Plan and Sustainable Energy Action Plan (SEAP).

This guide offers a **brief summary of technical solutions for local decision-makers** on the energetic retrofit of historic buildings as identified and used in the 3ENCULT project. Each solution has a short description, an indication of their general replication potential, and some challenges or issues to be considered *(an extensive technical guide is also available)*.

The **3ENCULT project** (**Efficient Energy for EU Cultural Heritage)** is funded through the 7th Framework Programme (FP7) of the European Commission (EC). It bridges the gap between the conservation of historic buildings and dealing with climate protection. While this may seem like a contradiction in terms, it is clear that historic buildings have a higher chance of “survival” where energy efficiently retrofitted.

3ENCULT demonstrates that it is **feasible to reduce energy demand by between 75 and 90 percent**. This of course also depends on each unique case and its heritage value.

The 3ENCULT research activities are accompanied and stimulated by the involvement of eight case studies in different countries and climatic zones, from different historic eras. In each case study an **assessment of the needs** was made and then **suitable strategy or technical solutions were selected** for delivering the building energy retrofit. The aim is to ensure that the project results are relevant to the majority of the European built heritage /with residential and social functions) in urban areas. The main focus in this guide is on the building envelope, windows, ventilation, passive and active energy efficient solutions.

Figure 1: Warehouse City, Potsdam (Germany)

Figure 2: Public Weigh House, Bozen/Bolzano (Italy)

1 Introduction

It is useful to consider the whole building when dealing with renovation, as illustrated by the image.

This will help improve the understanding of all problem areas and ideally find an integrated approach towards solving these.

This was the approach taken in the 8 case studies of the 3ENCULT project.

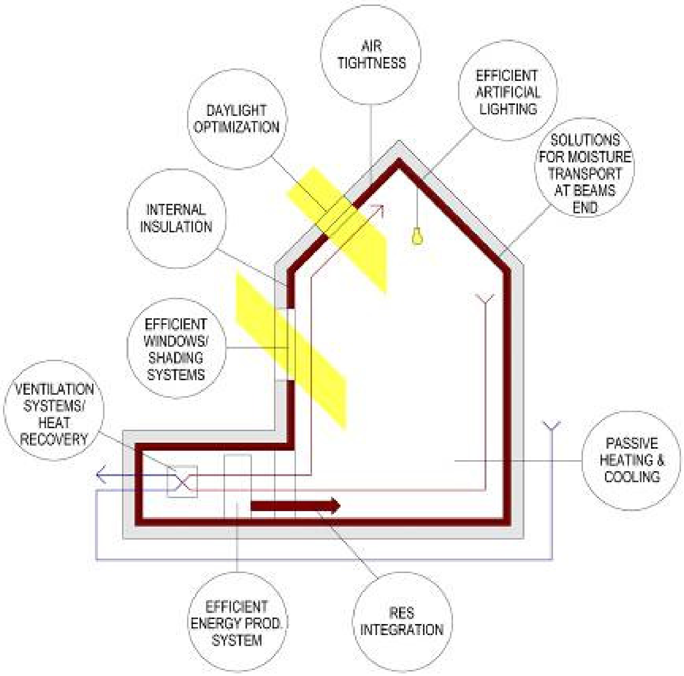

Figure 3 : Passive and active energy retrofitting solutions

Why address historic buildings and energy?

Historic buildings are the trademark of numerous European cities, towns and villages - a living symbol of Europe’s rich cultural heritage and attractive inner cities. The culture and history are major elements drawing tourists from all over the world to Europe. Many historic buildings are being lived in, used as working space or museums hosting precious collections. Some are listed as cultural heritage[1]; others have aesthetic, cultural and/or historic value.

To be defined as a “historic building”, a building must be old enough to have been studied by historians or archaeologists, it must retain its historic physical integrity and it must be significant to be considered as historic by either reflecting important aspects of history, or representing distinctive characteristics of a certain architectural style or building type from the history, or having the potential to yield information to our understanding of the past[2].

Each building uses energy - for electricity, space and/or water heating or space cooling. Typically, historic buildings have a high level of energy inefficiency, due to the way they were constructed (design and material used). Thus energy costs are often high. Further, energy use and energy wasted contribute to the release of greenhouse gas emissions (GHGs).

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[1] **Cultural Heritage** is an expression of the ways of living developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expression and values. Cultural Heritage is often expressed as either Intangible or Tangible Cultural Heritage. [*ICOMOS, International Cultural Tourism Charter. Principles And Guidelines For Managing Tourism At Places Of Cultural And Heritage Significance*. ICOMOS International Cultural Tourism Committee. 2002.]

[2] Georgia Department of natural resources webpage http://georgiashpo.org/faq_what_makes_a_property_historic

Therefore it is important to look at historic buildings from a value perspective (intrinsic building value, historic value for the community, for posterity) as well as from an economical (cost, maintenance) and environmental perspective. The latter refers to the impact of the building on the environment – e.g. through use of energy and water. This combination is complex and addressing the joint task of conservation and energy efficient retrofit requires a multi-disciplinary approach and team.

Focus on several key issues

In the EU27 14 percent of buildings were constructed before 1919 and 26 percent before 1945. Although only a certain amount of these buildings are protected (i.e. listed buildings), they have historical significance and should still be treated with care.

From past to future – it is important to consider:

- Preserving the historic building (also in this context consider the impact of climate change on buildings – more intense rainfall, flooding, droughts, heat waves, rising sea level)
- Reducing the impact on climate change (i.e. reducing ´greenhouse gas emissions)
- Keeping maintenance and energy costs reasonable (also considering that energy costs are rising).

Why do buildings have a higher chance of survival when energy efficiently retrofitted?

- Buildings are properly maintained and managed as living spaces (or used space),
- Their focus is on user comfort (or comfort of heritage collections) yet maintain historic interests,
- Structural protection is supported (relevant when considering the impacts of climate change),
- Such buildings have reduced energy needs, also lower energy bills.

Buildings considered as one of the main energy consumers in the urban context[3]. The energy demand of buildings in Europe is as high as 40% of the total energy demand. Creating buildings equipped with sustainable energy solutions is the key to achieve more energy efficient and more environmental friendly buildings[4].

Sustainable energy is defined as: "Energy production or consumption of electricity, heating and cooling, which has no or limited impacts – compared to fossil fuels or nuclear energy – on human health, the functioning of local and global ecological systems and the environment. Sustainable energy is the combination of energy savings, energy efficiency measures and technologies, as well as the use of renewable energy sources, such as solar energy (passive and active use), e.g. solar thermal, photovoltaics, wind-, bio-energy, geothermal energy, small hydro power, wave and tidal power, as well as hybrid systems. Its objective is to provide energy security (sufficient, safe, affordable) for the present and future generations."[5].

[3] Troi, A., Historic buildings and city centres – the potential impact of conservation compatible energy refurbishment on climate protection and living conditions, Proceedings of the International Conference Energy Management in Cultural Heritage, 6.-8.4.2011, Dubrovnik, 2011

[4] Tomás, N,, Carvalho, A., Coelho, D., Renewable Energy Integration in Buildings: A Case Study in Portugal, International Conference on Renewable Energies and Power Quality (ICREPQ'10), 23th to 25th March, Granada (Spain), 2010

[5] Source: Your LG Action Guide - to local climate and sustainable energy action - http://www.lg-action.eu/?id=8186

Role of local governments

Local governments can play a central role in this process. This could include any of the following roles:

- **own or maintain a large number of buildings,** probably also historic buildings (even listed monuments);
- **shape local strategy and policy** (e.g. sustainable development, climate protection, job creation, ..);
- **deal with urban planning and updating the urban master plan**;
- **outline and enforce building regulations** (also protection and maintenance of monuments and all other buildings that are not classified but have a cultural value);
- **plan the sustainable energy transition in the community** (e.g. Sustainable Energy Action Plan);
- **reducing energy demand in municipal buildings and switching to renewable energy**, e.g. green electricity; and
- **encourage the local community to engage in the sustainable energy transition** (stakeholder action).

Addressing sectorial aspects such as promoting tourism, where cultural heritage can be a substantial contributor to the local economy, also falls within the mandate of the local government.

Guide focus

The role of this guide is to share the latest innovative technical solutions developed in the 3ENCULT project with local government representatives - providing inspiration and ideas, triggering discussion and interaction between the public and private sector.

Specifically aimed at local decision-makers who are not necessarily experts on sustainable energy and buildings, the guide will help to inform local leaders who are involved in municipal decision-making processes relevant to the built environment, urban planning, the energy sector as well as tourism and sustainable economic development.

Building the low-carbon future of your community also means applying innovation to, and protection of, your city´s past. Take a look at the range of technical solutions for historic buildings, and explore options in your own context

Below we explore:

- The solution and the problem it aims to address
- The range of solution options (there may be multiple options)
- Challenges when dealing with this issue and potential solutions
- Brief cost – benefit analysis
- Brief replication indicator – is this a good idea for historic buildings?
- Value for building conservation

2 Baseline assessment for your renovation

It is essential to remember that **every historic building is unique**: there are no ready-solutions which fit all. However, there are standards activities which should be done, starting with an assessment of renovation needs.

When starting to plan an energy retrofit for your historic buildings it is crucial to **explore a series of key points**:

i. What is the reason behind the renovation project?

- What will the purpose of the building be? The building could change function and adapt – with a new role and potential for use.
- Is the building part of a bigger transition programme for the city or area?

ii. What regulations need to be followed for the protection of the historic building?

- Is this a listed monument? Or any specific relevant regulations? What limitations to interventions (what and why)
- What are the optimal renovation options? approaches for potential opportunities of energy innovation

iii. It is important to make the most out of this investment – also by considering: the economic and social impact when planning. Is this being done?

iv. Are you involving appropriate people in the process? Joint discussion with the historic building expert (monument protection agency) and experts on sustainable energy solutions for buildings have to take place thorough the process in order to identify and discuss the specific situation, explore and select appropriate technologies.

In this process you should consider:

- **Value of building:** evidential value, historic value, aesthetic value, communal value
- **Period of construction:** roman, romantic, gothic, liberty, modern, etc…
- **Construction materials used:** concrete, wood, bricks, clay, steel, etc…
- **Public interest** - landmark, social meeting point...

3 Smart solutions for your historic building

Many of the solutions listed below have been studied and (further) developed as part of a retrofit intervention of a specific building – i.e. in a 3ENCULT case study. These solutions are the results of a joint dialogue between researchers, energy experts, industry representatives and building conservationists.

It is important to keep in mind that every heritage building is unique and that not all solutions are replicable one-to-one.

Building energy solutions can be divided into two main clusters:

- passive solutions (resulting from design and change in user behaviour)
- active energy solutions, meaning improving energy efficiency (technologies) and generating renewable energy for electricity, space and water heating or space cooling.

Figure 4: Case studies overview

It is important to keep in mind that the applicability and the results of the application of a certain solutions depend on:

- type of building,
- use of the building
- climate
- materials
- national and local regulations on heritage protection
- energy planning
- funds available

Nonetheless solutions might be adaptable to different needs and adopted in specific cases, after discussion with all relevant stakeholders and especially with experts in conservation.

The solutions are grouped into **five areas of intervention** (building envelope, windows, ventilation, active and passive solutions), all of which are interlinked.

3.1 Building envelope

The building envelope is defined as "the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation."[6]

The Intergovernmental Panel on Climate Change (IPCC)[7] defines the thermal envelope as: "The term 'thermal envelope' refers to the shell of the building as a barrier to unwanted heat or mass transfer between the interior of the building and the outside conditions."

3.1.1 Insulation

Insulation is a **layer of material applied on the inside or outside of the wall**, in order to reduce the loss of heated or cooled air, as well as to ensure excess heat or cold does not gain access to the building. The aim is to ensure thermal comfort for the building user and the purpose it is used for.

When discussing energy efficiency in historic buildings one of the first issues usually addressed is insulation. Regardless of construction materials used, the climate and period of construction of the building, the first focus when conducting an energy efficiency retrofit is to **avoid energy waste** (loss of heat, etc.). Insulation further contributes significantly to reduce emissions. The benefit of a well-insulated building is typically reflected in an increase of the real-estate value of the building, and of the attractiveness as a living / working environment.

Two main options are available: internal and external insulation.

- **External insulation** means thermally insulating the building envelope with insulation boards – in most cases with expanded polystyrene (EPS), mineral wool/rockwool, or phenolic – which afterwards covered with external grout and reinforcements.
- **Internal insulation** is often used when you are limited with the options on changing the building facade (its external appearance), e.g. where there is stucco or bricks, or where you change the proportions of the building as external insulation adds several centimetres to the facade (not useful if there is for example a frontage). Internal insulation, often the only viable option in historic buildings, can be particularly advantageous in temporarily occupied rooms (meeting rooms, churches, schools, banquet halls, etc.) where energy-efficient heating will be guaranteed significantly faster.

Typical problems with insulation:

The issue of **moisture accumulation** - due to temperature difference between the inner and outer wall, allowing water vapor to diffuse into the construction – can potentially cause mould and moisture damage.. This can be addressed by using:

- **diffusion brake interior insulation** and
- **diffusion-open, capillary-active interior insulation systems**

Cost / benefit: The costs of classic interior insulation systems depends on the insulation type and thickness, and varies between €60 and €240 per square meter, including personnel costs. The solution developed in 3ENCULT is called iQ-Therm with the components iQ-Fix, iQ-Tex, iQ-Top and iQ-paint. It needs around €75, up to €150, depending on the thickness of

[6] http://www.c2es.org/technology/factsheet/BuildingEnvelope

[7] http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch6s6-4-2.html

the insulation. At high performance the insulation has small thickness, leading to more usable living space and less space consumption. In comparison to conventional insulation, the time for workmanship could be reduced remarkably by 25 percent, which supports acceptance by processors. The product is sturdy, construction-tolerant and provides a sustainable solution.

Use and replicability:

Insulation
Use in Historic Building
Not Suitable●●●●○Suitable

Conservation: Sustainable functioning of the construction has the highest priority of energy-efficient renovations of listed buildings. The protection against moisture is the first priority, followed by heat protection. Some constructions are very sensitive. Therefore, monitoring of energy-efficient renovation is useful..

Practical example:

Figure 5: Interior insulation system iQ-Therm after installation.

A heat flux and temperature sensor is mounted on the insulation surface. The final finish consists of the moisture buffering plaster iQ-Top, which has a reinforced textile called iQ-Tex and the diffusion open paint iQ-paint.

3.1.2 Air tightness

Air tightness should be considered as one of the key topics when renovating. The aim is to **avoid unwanted ventilation heat (or cooling) losses** that impair thermal comfort, cause structural damage (condensate) to the historic construction and poor air quality.

Improving air tightness in historic and listed buildings can be challenging, because there are restrictions to the application of certain solutions and as the substance of the buildings does not allow the use of standardised measures. A particular challenge to air-tightness is represented by the application of internal insulation in presence of pre-existing wooden beams. The potential increase of moisture due to the insertion of the insulation might damage the beams, and, at same time, the air leakages, due to the cracks in the beams, might decrease the air-tightness and the effectiveness of the insulation itself. This could result into rising heating demand and structural damage.

3ENCULT explored how to efficiently proceed with this integration, and has collected useful tips through a series of experiments – using a spreadable paste and a special non-woven material. Compared to just using adhesive tape when sealing the gap, the **use of both materials decreased the volume leak flow for the small sample beam by up to 77%.**

Cost/benefit: Costs for the different methods depend greatly on the respective building circumstances. Labour costs for implementation might exceed the cost of materials.

Use and replicability: Choosing a method for sealing wooden beams must still be done on a case-by-case basis for the following reasons:

Insulation boards in combination with vapour retarder sheet	Capillary active internal insulation with fine plaster
Use in Historic Building	**Use in Historic Building**
Not Suitable●●○○○Suitable	Not Suitable●●●○○Suitable

Capillary active internal insulation combined with an air tight layer
Use in Historic Building
Not Suitable●●●○○Suitable

Conservation: Intact wood beams may be retained if interior insulation is used, in which case they must be integrated into the concept for air-tightness. The solutions investigated are suitable to this purpose. It is necessary to expose the wood beam sections completely near the area to be sealed. The solutions have to be investigated in relation to the specific case.

Practical example: In the case study Public Weighhouse, Bolzano, interior insulation will be installed in part of the exterior wall. Depending on the insulated area, the insulation will be penetrated by old ceiling joists. At this point air-tightness sealing between the air-tightness layer of the interior insulation and the joists will be crucial.

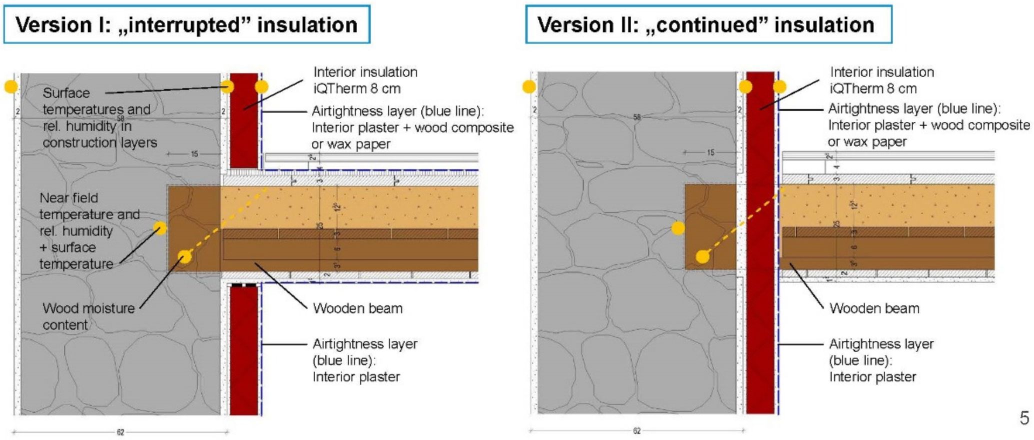


Figure 6: Detail section ceiling/exterior wall: two different solutions for the airtight connection between exterior wall and ceiling (with wooden beams) will be implemented in the "test room" of the case study: "interrupted" insulation and "continued" insulation. The "interrupted" version could be recommendable in cases where only one floor or one part of the building will be refurbished, or in cases where the wooden ceiling can´t be opened (advantage of the "interrupted" version: less invasive and laborious. Disadvantage: thermal bridge - higher energy losses, must be proved in detail from the point of view of the building physics.

3.2 Windows

Windows are critical element of the building both in terms of comfort (cold draft risk, radiation losses), hygiene (moisture, mould) and air-tightness, and they represent a challenge to the **thermal envelope**. Often in modern passive-oriented buildings the problem is addressed through the installation of air-tight windows combined with the introduction of ventilation systems. Often ventilation would not be an option for historic buildings, as it would raise conservation issues.

Most frequent obstacles are represented by the **incompatibility of the frames with sizes and weight of the glass panes**. The larger width of air-tight window frames does not correspond with the filigree historical structures and triple glazing, necessary to provide a quality insulation, is commonly too heavy and too deep for historic frames.

The light reflecting properties of *Insulated Glass Units (IGU)*[8] does not correspond to the **appearance of historical glass**, and it is most often not compatible with monument protection criteria. Furthermore, historical windows are usually parted in many sections, and replicating this partition system with a newly constructed window leads to a very high fraction level of the frame and to increased spacing, which causes additional thermal losses and reduce solar gains.

The 3ENCULT research team developed a series of recommendations, such as **separating the thermal insulation layer from the external glazing of the window**. This will help maintain the external "original" appearance, while the internal triple glazed insulation layer will enhance comfort, hygiene and air tightness.

[8] IGU's are two lites of glass separated by an isolated air space to improve the thermal performance of the windows by providing a thermal break between the two lites.

Cost/benefit: Costs depends on the specific case. Coupled windows allow for the cheaper solution, as the layers are directly connected to each other. Box windows allow more flexibility in the design of the external layer, and the larger depth of the frames constituting the window allow for an easier installation than casement windows. An additional 4th glazing improves the thermal properties and raises the temperature of the glass edge.

Use and replicability: Especially in historical buildings, the installation situations of windows should be designed, aided by two-dimensional heat flow analyses, to optimize installation thermal bridge and to avoid problems of mould and condensation. For this, tools like Therm are recommended.

The new window, called "smartwin historic", should combine high energy efficiency and respect the aspect of the original window and preserve the general appearance of the cultural heritage building.

"Smartwin historic"- a window system, not a window type

"Smartwin historic" is not a window type, but a window system, based on two prototypes:

- a compound window basis,
- a box window basis
- both with two layers

The outer layer is the part respecting the requirements for the historic aspect: slender frames, number of sashes, mullions, transoms, single glazing with glass produced with ancient methods (as required by the architects or the conservators), glazing bars, mouldings, color, putty… can be reproduced in this window part.

The inner layer is the main energy efficient element with triple glazings, insulation, gaskets and fittings able to support the weight of the glazings.

For the inner window, toughened glasses and krypton fillings can reduce the thickness of the triple glazing (22 mm instead of 48 mm) with nearly the same U_g value.

smartwin historic – coupled window	smartwin historic – box window
Use in Historic Building	**Use in Historic Building**
Not Suitable●●●●○Suitable	Not Suitable●●●●○Suitable

Conservation: The criteria listed by conservators - mainly the respect of the aspect of the old window concerning the material (generally wood) and the measures of the frames and profiles, mouldings, historic glazings (often small glass fields with glazing bars, mullions, transoms, number of sashes, colors, putty, fittings) and high energy efficiency made possible by triple glazings with low emissivity coatings, argon or krypton filling, warm edge spacers, fittings able to support the weight of heavy glazing and requiring thicker and broader wooden frames, get into conflict. The solution to this conflict is a combined window.

The recommended *smartwin historic* solution gives the possibility to combine the two, keeping the historical habitus of the window and achieving comfort and hygienic standards of a modern window.

Practical example: For case study 1, the Public Weighhouse of Bolzano, one of the aims was the development of a conservation compatible highly energy efficient window. In the 1950s-60s, new windows have been installed on the building, which from the conservator's should be replaced by reproduction of historic windows. As there are no documents or information available on the type of the original window, the conservator proposed to develop a new prototype using as basis windows typically used in the region during the baroque period, both for appearance (division and proportion) and function.

Aim:

- Enhancement of the existing energy efficient “passive house” window in order to fulfill the demands of a historic protected building

Approach:

- Based on the individual demands of the case study: adaption of the “passive house” window to the special conditions of the historic building
- Strong collaboration during the development process with the conservation office. Every design step/interim solution was accompanied and evaluated by the conservator.
- Installation and testing of a coupled window prototype in one room of the building, where also internal insulation will be installed. The room will be temporarily heated up during the cold season.

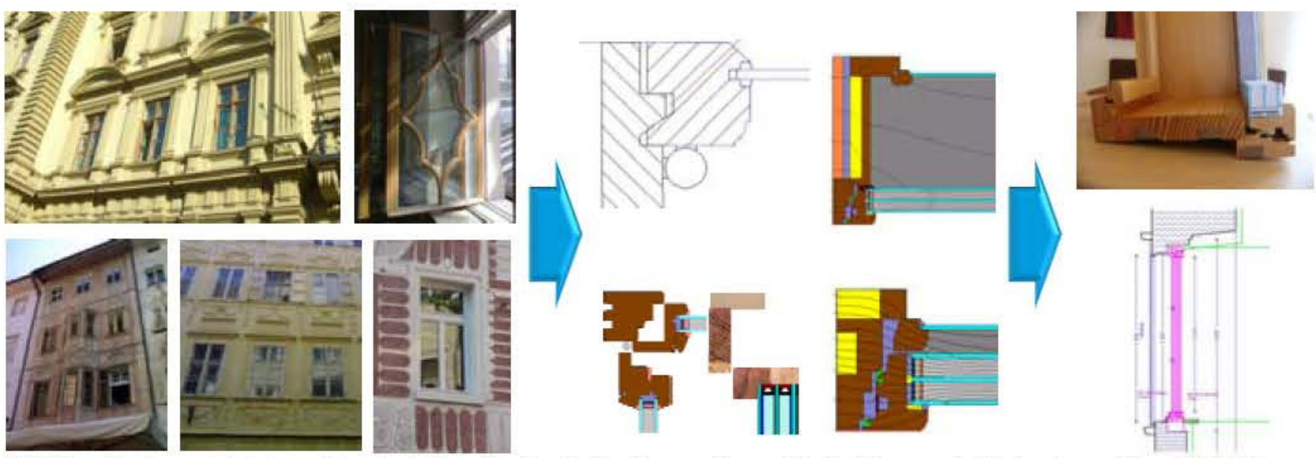


Figure 7: Development of window prototype starting from the state-of-art (problems and demands), taking into account original and new solutions (Figure 7a). Design and realization of first model (Figure 7b). Adaption of window into building (Figure 7c)

Figure 8: Installation of new conservation compatible highly energy efficient window prototype in case study

3.3 Ventilation

Ventilation is a crucial element to consider during the design and refurbishment of a building as it affects not only the building itself - **regulating the level of humidity in the structure** - but also relevant to the **health and comfort of the occupants**. There are several typologies of ventilations that can be implemented, active and (almost) passive solutions. The 3ENCULT consortium investigated innovative ideas on how to apply and integrate ventilation in historic buildings.

3.3.1 Passive ventilation

Passive ventilation (window ventilation) can be very effective especially for night ventilation in order to avoid overheating in summer time. The flow rate, which can be achieved strongly depends on the area and location of the openings (cross flow, stack effect etc.). Within the PHPP, a tool is implemented to quantify these effects. Within the 3ENCULT case study CS5 (NMS Hötting), the flow rate was measured with tracer gas and compared to the calculated values. In one class room the box type window was refurbished to the original version, opening to the outside (outer glazing) and to the inside (inner glazing). This way, enhanced passive ventilation was achieved, which works even in case of the shading device is in place.

3.3.2 Heat recovery systems

Controlling humidity in existing buildings is essential, and the integration of heat exchangers in historic buildings requires special attention and not-invasive intervention. Lately ventilation through heat-recovery has become more efficient in terms of energy consumption and air quality.

Among the possible integration options explored, 3ENCULT focused on **wall integration** and on the **"active overflow principle"**. The latter works as a mixing ventilation approach using corridors and staircases as distribution zones. For protected buildings, this is a big advantage compared to decentralised systems with two openings per room (in and outflow) to the outside (impacting on the building structure).

Within the 3ENCULT project, this existing ventilation principle was transferred to non-residential use (school buildings). A special **active overflow prototype** was constructed by ATREA, which is tested in the school NMS Hötting, in Innsbruck. The prototype as shown below (Figure 4) consists of a ventilator and silencers. The box on the left side of the photo shows the air inlet, the air distribution duct is at the right hand side, a textile hose will be connected for air at this part.

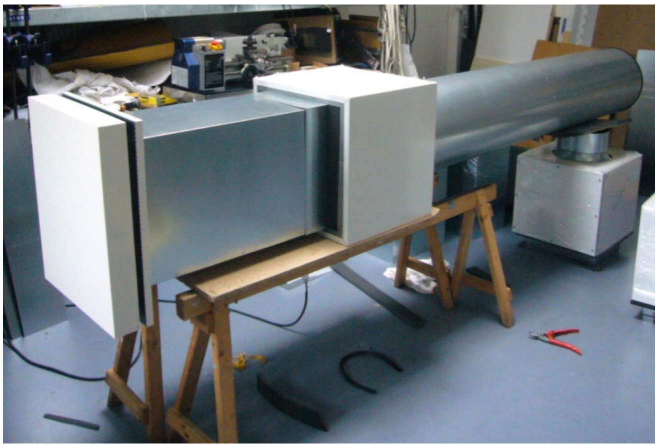


Figure 9: Active overflow system, prototype manufactured by ATREA

It is necessary to adapt the decentralized ventilation systems available on the market to the needs of a heritage building, as most systems are constructed for integration in the ceiling. In order to avoid long ducts, the unit should be placed close to the window, which is not ideal for an efficient use of daylight and it significantly affects the appearance of the room.

High efficient silencers as well as low sound emission of the fans are necessary to achieve the strict regulations for noise prevention in school / public buildings.

Costs/benefits: The system tested in 3ENCULT is in a prototype phase at the moment, for this reason the costs are much higher than regular standard ventilation systems. If the proof of concept is positive, the system can help to save costs for installation and ductwork (horizontal and vertical supply air distribution).

Figure 10: Combined window and ventilation system designed by architect Michael Tribus, (window company: WOLF artec)

Use and replicability: A prefabricated window/ventilation unit as shown in Figure **Error! Reference source not found.** is not applicable in most historic buildings. The heat exchanger as well as the duct system has to be tailor-made to the specific geometry of the individual building. As this system will never be a mass product, the price compared to prefabricated solution will be higher. The system was developed especially for school buildings, but could be adapted for most historic buildings with different use, such as office buildings.

The ventilation effectiveness of the active overflow principle compared to standard systems is lower due to the principle of the corridor used as an air mixing zone. Therefore this system should be restricted to application for cultural heritage buildings or other buildings strictly protected for architectural reasons.

Wall Integrated Heat Exchanger	Active Overflow
Use in Historic Building	**Use in Historic Building**
Not Suitable●●○○○Suitable	Not Suitable●●●●●Suitable

Conservation: For most listed buildings, external insulation as well as any other interventions at the façade may not be applied.

In those cases, the decentralised heat recovery system is not a suitable solution in the cultural heritage context.

When using a heat exchanger, the energy efficiency strongly depends on the quality of the central heat exchanger as well as the electric efficiency of the fans. The pressure drop is rather low, because of the missing supply air ducts.

In case of internal insulation, the thermal bridge problem calls for a ventilation system to reduce indoor air humidity. The active overflow principle is a minimal invasive system without any interventions in the façade, which can help to preserve the building structure and to prevent any humidity problems.

Practical example: In Innsbruck, at the Neue Mittelschule Hötting - a historic building and 3ENCULT pilot project - a new minimally invasive ventilation system for school buildings is being tested. The dual aim of this system is to preserve the architectural value of the building while guaranteeing scholars´ comfort.

3.4 Lighting

From an architectural point of view lighting is a means to express and underline the desired character of the rooms and buildings, which is defined both by the overall architect's design and by the special user requirements corresponding to the room utilizations.

The user consciously and subconsciously defines specific requirements to the lighting solution depending on the activity (e.g. in administrative buildings the key element is functionality according to ergonomics, whereas in residence and tourism aesthetical and emotional aspects are in the foreground).These requirements define the subjective 'visual comfort', which is characterized by

- Luminances (i.e. absolute levels and ratios)
- Shadowiness (i.e. direct and indirect illumination)
- Spectral distribution (e.g. color temperature, Color rendering, etc.).
- Surface materials which change the primarily emitted light until it hits the retina
- Illuminances (i.e. absolute levels and ratios)

Besides these requirements defined by needs of human beings, materials resp. surfaces (e.g. pigments in frescoes) define specific requirements to the lighting solution (both day- and artificial). Physical and chemical reactions triggered by electromagnetic radiation may accelerate deterioration of materials.

Artificial lighting systems are today mainly dominated by traditional light sources (halogen, CFL, etc.). However, the future of the artificial lighting will be LED (light-emitting diode) technology, thanks to its ever increasing efficiency, small geometric size and increasing colour rendering abilities.

In 3encult an illumination concept was developed, that is able to fulfil the human and material requirements. The luminaire 'wallwasher', that can be installed in a non-invasive way provides on the one hand an optimized visual scenery, on the other hand it should slow down the deterioration process that any material undergoes in its natural (or artificial) environment.

Prototype of pipe-type luminaire

The pipe with 60mm in diameter could be hang from rope/cable

Figure 11: Prototype of pipe-type luminaire,

The geometric, visual, energetic and optical requirements were defined together with local experts in Sala degli Stemmi - a huge frescoed room in Palazzo d'Accursio / Bologna.

Figure 12: Demonstration at an Italian fair for 'restaurateur'. Shown are 4 designs of the wallwasher. One of them emits 6400K, the other 2700K.

Costs/benefits:

The luminaire will be relatively more expensive than other wallwashers, which do not deliver comparable performance. The luminaire 'wallwasher' provides:

- a unique homogenous luminance distribution on the illuminated wall (ratio 1 to 4)
- the best colour rendering due to LED choice
- the unique possibility to remake of historic incandescent illumination (2700K).
- glare free illumination:
    - precise cut-off (vertical, approx.. 90°)

- precise lateral cut-off (approx. 90°), which removes the illumination problem at top walls of room.

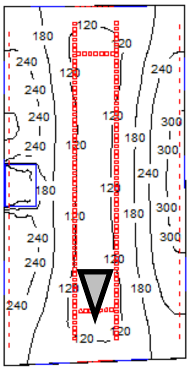


Figure 13: Top-view of luminaire position (rectangular layout)

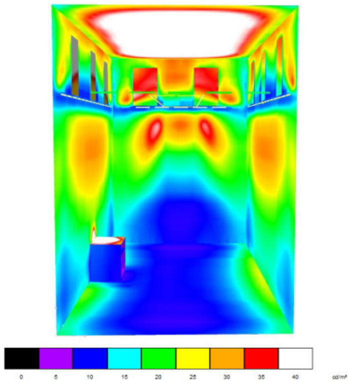


Figure 14: Pattern at front faces

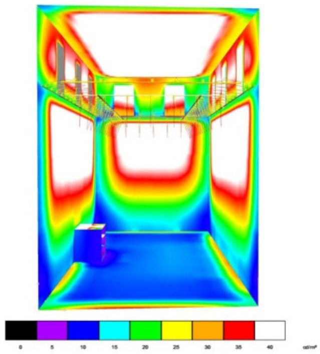


Figure 4: No pattern due to lateral cut-off

- Minimal installation efforts (anchors and rope-bearing, stand mounted, put on floor or cornices, shown in Figure 14)

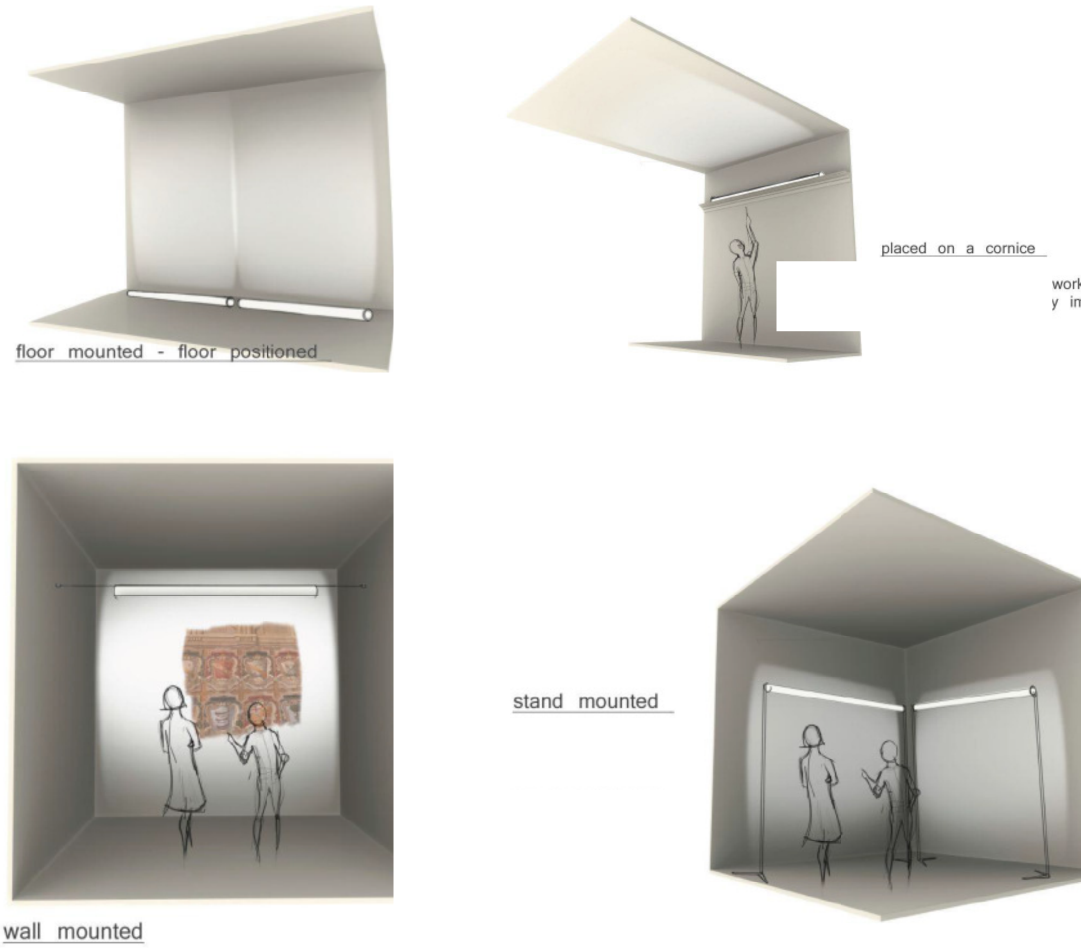


Figure 5: Different installation possibilities

- Minimized impact on materials (e.g. molecules or pigments) due to spectral composition of light source (LED). Which could even be adapted if a particular risk to specific colours/materials is known.
- Optimized efficiency due to the optical design of the reflector (at neutral white (CCT 4000K) the efficiency is about 90lm/W).

Use and replicability: Sala degli Stemmi represents a common room category for listed buildings: its dimensions are enormous, the exhibition is the room itself i.e. the frescoes on the walls, etc.

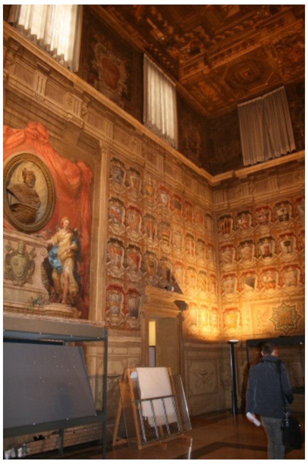


Figure 6: Actual lighting solution: inhomogeneous

Figure 7: Wall as object of demonstration

The 3encult wallwasher allows appropriate illumination of this kind of room with its lateral and vertical cut-off characteristics. The mechanical realization of the luminaire allows it to be mounted on a bearing rope structure (only a few screws are needed) or to be hidden on top of existing cornices. The colour temperature can be adjusted by choosing the proper LED type or choosing a tuneable LED chip. For very specific conservator requests, the correlated colour temperature could be even very warm (2400K) for particular incandescent remakes.

The wallwasher can be used to illuminate:

- halls
- corridors
- facades
- art pieces in museums

when high visual homogeneity and comfort is required besides minimal installation efforts.

The luminaire is not limited to the pipe-type design. The core of it, the so called light-engine, could also be included in any other casing. So the luminaire is widely applicable also in suspended ceilings etc.

Conservation:

In many articles showing illumination guidelines for art pieces and historic surfaces it is often recommended to keep the 50lx threshold. But with the physical processes that cause fading/damage in mind, the single photometric luminance of 50lx is not enough: on the one hand it's the physical value of energy per wavelength, i.e. radiant flux with the spectral distribution of the light source that must be considered, on the other hand it's the spectral sensitivity of surface materials (i.e. materials react differently to daylight exposure, see Figure 13)).

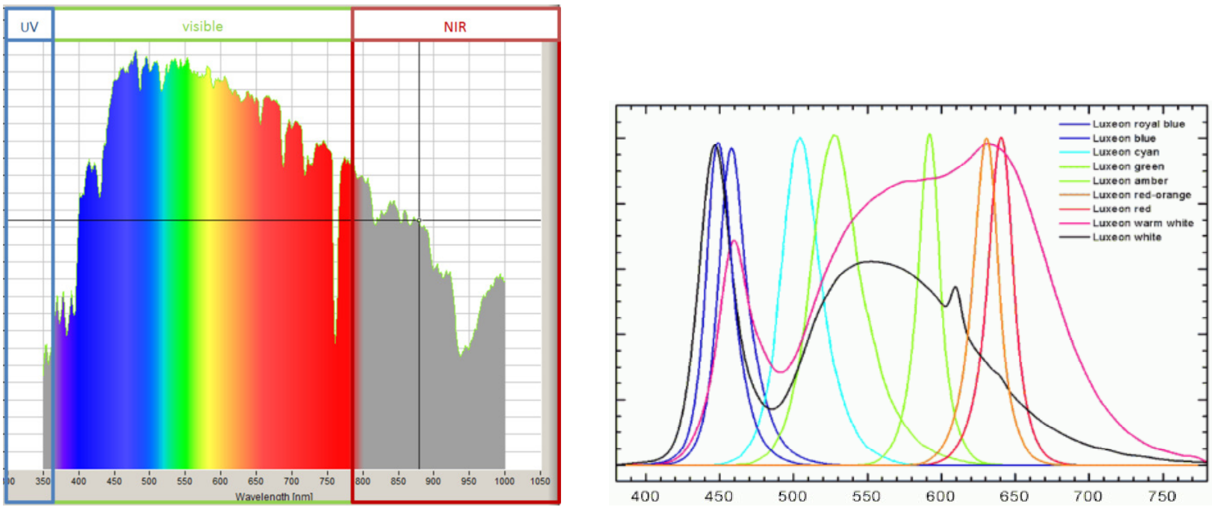


Figure 8: The spectral power distribution of daylight and many different LEDs. Together with Figure 13 the overall damage potential is calculated. LED light sources do only emit in the visible part of the spectrum. (UV … ultra violet, visible, NIR…. Near Infrared)

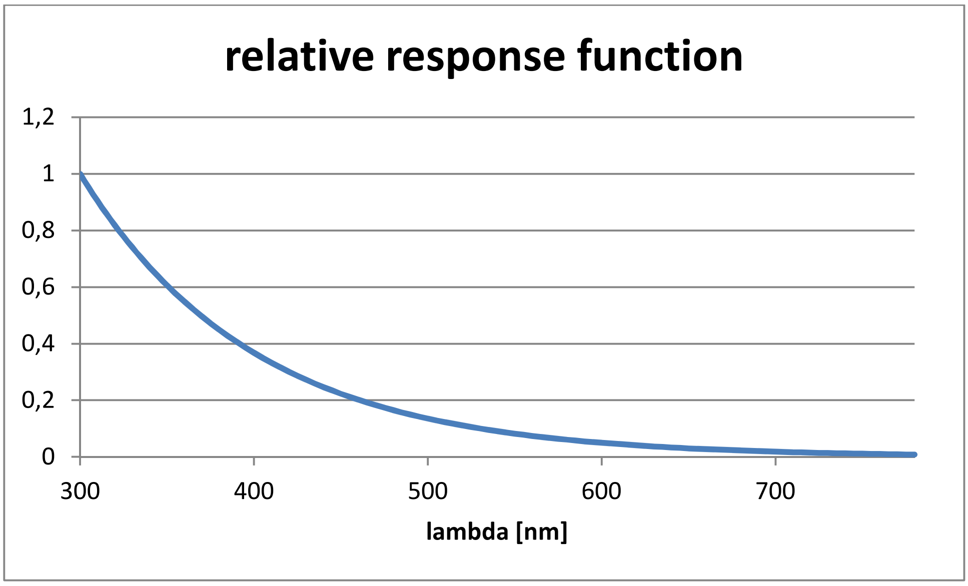


Figure 20: Standard - model for damage potential. It means that at a wavelength of 300nm the damage potential is one. At 400nm it’s 0.4 and at 700nm it is close to zero. If current materials are specifically investigated a more detailed model should be used.

The ICOM[9] writes that one can stick to the long existing recommendation of 50lx for sensitive paintings on paper and 150 lx for any other basis, but you have to consider the problems that come along with this low illumination levels, for example ‘older’ people will have problems with the resulting luminance levels. With general knowledge of minimum luminance of 10 –

[9] ICOM – International Council of Museums, Running a museum: a practical handbook, I. –. I. C. o. Museums, Hrsg., Paris, 2004, pp. 78-79

20cd/m² the recommendation of 50lx for paintings with reflectivity of approx. 0.3 is too low. The illumination at the surface of the materials must be in the range of approx. 160 luxes. If the particular behaviour of the materials is known (i.e. specific wavelength dependencies) the LED/reflector could be chosen according to this and then an additional filter could be applied.

3.5 Passive energy efficient solutions

A passive design solution intends to achieve a suitable indoor environmental comfort condition and integrate this into the built environment by making the design layout responsive to a number of parameters, which are originated from the architectural configuration of the buildings, constructive and finishing materials, and optimal management of envelope components. Passive solutions need an integrated process with architectural design that can be applied to both new buildings and refurbishments.

Most of the historic buildings have been designed to include passive solutions when there were no possibilities to implement active solutions, however, nowadays the buildings have gained new functions in terms of usage which restricts the application of passive solutions. Another feature common to most historic buildings is the very high mass of the constructive components that have both structural and architectural functions. High thermal mass components, such as stone-made walls, allow passive solar gain in winter and take less energy to keep cool in summer. These kinds of materials can absorb, retain, or store the heat produced by sunlight. There is a difference between the absorber and thermal mass. Although they often form the same wall or floor, the absorber is an exposed surface whereas storage is the material below or behind that surface.

3encult project explores the most efficient solutions for the comfort conditions, the energy efficiency, and the cost savings by exploiting the potential of thermal mass combined with a smart ventilation system.

Stated that the solutions are strongly dependent on the building architecture, it is not possible to define a product or a general solution.

In multi-objective optimization, a solution may fit to a certain case, but may not be applicable to another. The decision should include a set of parameters which are mentioned below:

- the position of the thermal insulation, on the interior side or on the exterior side
- the insulation material
- the insulation thickness on the interior side and on the exterior side
- the window type (double or triple glazing)
- the setback heating and cooling temperatures
- the summer night ventilation air changes
- the night internal and external temperature difference making available the fixed ventilation rate

Different combinations of the listed parameters should be tested with simulation software (for example Energyplus).

It is impossible to define the best solution that meets all the needs, the designer always has to decide which need he/she wants to target and which solutions are really feasible in each case. In the following part we propose general recommendations for 3 climate conditions, which analyse the results of the simulations carried out for a reference room, defined on the basis of Waaghaus features.

3.5.1 Best solutions for Bolzano/Bozen climate

During summer, the best comfort conditions are guaranteed by a high rate of ventilation air changes. The night ventilation reduces the internal temperature of air and walls, and therefore the sensible and latent cooling load decreases. The effect of the night ventilation is higher when the insulation is positioned outside rather than inside, because of the big thermal mass of the stone walls in direct contact with the fresh flow of night air. In fact, the interior side of the stone wall directly facing to the inside of the room decreases its temperature rapidly thanks to the effect of the night ventilation. On the contrary, the walls with interior insulation keep their temperature higher because they are not directly exchanging trough convection through the air flow. For the comfort conditions it is always better to cool also at night during the non-occupancy period. During winter, a substantial thickness of external insulation and triple glazing windows are the best solutions to reduce the heating sensible and latent load. However, the use of the internal insulation guarantees acceptable comfort conditions during summer if combined with a high rate ventilation system. It has lower costs compared to the external insulation and does not affect the heating load during winter as much.

3.5.2 Best solutions for Bologna climate

As in the climate of Bolzano, in Bologna the summer comfort conditions are strongly influenced by the ventilation air changes: the higher the ventilation rate, the lower the PMV and the cooling load. Also in this case, the effect of the night ventilation is higher when the insulation is positioned outside than inside. Like in the case of Bolzano, it is better for the internal comfort to cool also during the non-occupancy period. Obviously a longer period of cooling corresponds to a higher cooling load, but the setback temperature (that means the minimal set point temperature of the system during the non-occupancy period) does not have as great an influence as the ventilation rate. This means that we can strongly reduce the cooling load by just increasing the air changes and also without cooling at night. A substantial thickness of external insulation and the triple glazing windows reduce the heating sensible and latent load during winter, but the solution with interior insulation has lower costs (approximately the half) and works sufficiently good in summer.

3.5.3 Best solutions for Palermo climate

In Palermo, the influence of the external or internal insulation is not important because the heating load is almost zero for every solution. This means that a non-insulated building will save a lot of money without increasing its heating energy demand. The summer night ventilation is the most important parameter; a high number of air changes (more than 10 ac/hour) are needed in Palermo to reach comfortable conditions. In this case too, it is better for the internal comfort, to cool also during the non-occupancy period. Also in this case a longer period of cooling corresponds to a higher cooling load and the setback temperature is not as influential as the ventilation rate. Moreover, managing the ventilation in order to reduce the cooling energy is better than having more hours of ventilation with a hotter entering airflow rather than having less hours of ventilation with a lower entering airflow.

3.5.4 Conservation issues

The aspects connected to the cultural heritage are related to the possibility to add insulation on the exterior façade of the historic building and the possibility to have a ventilation system during the summer period. In 3encult, it has been analysed both the influence of the insulation position and the best way to handle an external airflow (air changes and minimal delta T for activation).Constructive solutions have not been truely proposed, but recommendations have been given for the exploitation of the thermal mass in three different climates. In every building the designer should investigate the ventilation flow, the naturally exploiting building features from constructive and architectural point of view, or the mechanical through a non-invasive system.

As a generic rule of thumb, the interventions with historic buildings should be non- invasive and removable. Therefore, most of the time, in historic buildings it is impossible to put the insulation on the exterior part of the walls. Also the windows with low transmittance can be installed only if they don´t alter the aesthetic value of the façade. The natural ventilation is usually more preferable than the mechanical one because it is not necessary to have invasive installations.

Passive heating and cooling solutions		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●●Suitable	Expensive●●●○○Cheap	Low●●●○○High

3.6 Active energy efficient solutions

An active solution involves machines and appliances which directly make use of fossil fuel or renewable sources to generate needed energy to keep the level of comfort in the building at a desired level.There are different alternatives for heating and cooling system usage in building renovation. In order to assess which systems are more convenient for historic building renovation, available systems can be grouped in five main categories:

- Generation system (both for heating and cooling)
- Ventilation system
- Emission system
- Control system
- Renewable energy systems

3.6.1 Generation systems

The ***generation systems***, identified include: boilers (gas boilers, condensing boilers, biomass boilers), heat pumps (ground heat pumps, air-water, water-water, absorption chillers, adsorption chillers), micro co-generation (micro combined heat and power - CHP), Variable Refrigerant Flow (VRF) systems and solar panels.

- **Gas boiler systems** are the most common and traditional systems with an efficiency that ranges from 80 % to 95 %. They are most commonly used in situations where high supply temperatures needed.

Traditional Gas Boiler		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●●●Cheap	Low●●○○○High

- A **condensing boiler** has similar components of a gas boiler but it also makes use of the heat produced (latent heat) during the operation of the boiler, which otherwise would be lost. For this reason condensing boilers have a higher efficiency (>100 % with heat recovery) than a traditional gas boiler. Low supply temperatures are the optimal conditions for this kind of boiler systems.

Condensing Boiler		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●●○Cheap	Low●●●○○High

- **Biomass boilers** are not widely used for commercial applications. Their energy efficiency is lower compared to condensing boilers.

Wood Fired Biomass Boiler		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●○○○○Suitable	Expensive●●○○○Cheap	Low●●○○○High

- A **closed loop ground heat pump** is a shallow geothermal energy system that provides heating and cooling energy to buildings. The heat pump either dissipates the heat taken from the building into the ground (cooling mode) or takes the heat stored in the ground to circulate in a secondary cycle to heat the building (heating mode).

Ground Heat Pump (closed circuit)		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●○○○○Cheap	Low●●●●●High

- A geothermal **open loop heat pump** uses ground water extracted from underground aquifers through boreholes for cooling and heating. In a open loop system the extracted groundwater is used for heating/cooling purposed and then either re-injected to the ground or used as WC flushing.

Ground Heat Pump (open circuit)		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●○○○○Cheap	Low●●●●●High

- **Air condensed heat pumps** operate with electricity. It uses external air to condensate the refrigerant to be used in the process.

Heat Pumps (air condensed)		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●○○Cheap	Low●●●○○High

- **Water condensed heat pumps** are working with the same principle except the refrigerant is condensed by circulated water. They have a higher efficiency compared to air condensed heat pumps. Water is cooled with cooling towers.

Heat Pumps (water condensed)		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●○○○Cheap	Low●●●●○High

- **Absorption heat pumps** (chillers) are less efficient than traditional chillers. They are more convenient for district heating systems or solar panel systems where there is “free” source of heat for the entire year.

Heat Pumps (absorption)		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●○○○Cheap	Low●●●○○High

- **Micro co-generation** is a system where both heat and electricity is produced – combined heat and power (CHP). Instead of burning fuel just for heating space or water, a portion of energy is transformed into electricity while the rest is used for heating.

Micro Co-generation (CHP)		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●○○○○Cheap	Low●●●●○High

- **Variable refrigerant flow (VRF) systems**, also known as variable refrigerant volume (VRV) systems, are multi-split direct exchange systems in which an outdoor system is connected to indoor systems. One advantage is that the different indoor systems can operate in different modes, meaning while one system heats a part of the building another can cool a different part.

VRF System

Use in Historic Building	Cost	Energy Efficiency Improvement
Not Suitable●●●●●Suitable	Expensive●●●●○Cheap	Low●●●○○High

3.6.2 Ventilation systems

The considered ventilation systems are; mixed ventilation systems, all air systems, and natural ventilation.

- **Mixed ventilation systems** use mechanical ventilation to provide fresh air and to control internal air quality and humidity while the heating and cooling loads are treated directly in the ambient with local units.

PRIMARY AIR-Mixed ventilation system		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●●○Cheap	Low●●●○○High

- In an **all air systems**, air is used both to control internal air quality and to balance heating/cooling loads.

PRIMARY AIR-All air ventilation system		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●●○○Cheap	Low●●○○○High

- Natural ventilation can be used for both free cooling and fresh air supply. Many different possible solutions can be investigatedto assure natural ventilation in buildings.

Natural Ventilation		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●●●Cheap	Low●●●○○High

3.6.3 Emission systems

The considered emission systems in buildings are; radiators, radiant (Floor/Ceiling), fan coils, chilled beams, CAV (Constant Air Volume), VAV (Variable Air Volume), FSS (Floor supply system).

- **Radiators** are the most common and traditional emission system. They generally release heat 70% by convection and 30% by radiation.

Radiators		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●●●Cheap	Low●○○○○High

- **Underfloor heating /Radiant floor** works by passing low temperature hot water through pipework embedded in, or attached to, the floor. Heat is radiated from the floor and heats surfaces and objects in the room or space above.

Underfloor Heating/Radiant floor		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●●●○Cheap	Low●●●●●High

- **Chilled ceilings** are simple static cooling solutions in which chilled water fed panels in the ceilings.

Chilled Ceiling		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●●○○Cheap	Low●●●●●High

- **Chilled beams** can also be an alternative solution for cooling. These are water cooled finned tubes which use natural or induced convection to cool rooms. Chilled beams have a higher convective cooling component than chilled ceilings therefore they can cope better with high cooling loads. This is a relatively new technology, for this reason the use of chilled beams are not common.

Chilled Beams		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●○○○Cheap	Low●●●●○High

- **Fan coil** units are the most common air conditioning systems in many parts of the world. The reasons for this popularity are relatively low installation costs, proven technology, flexibility of use, ability to deal with high heat loads, simple local control and reduced plant space.

Fan Coil Unit		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●●○Suitable	Expensive●●●●○Cheap	Low●●●○○High

- The **constant air volume** systems are preferably used in buildings with homogenous and high internal loads. The inlet air is mixed with ambient air and extracted through an air-vent. For this kind of system it is important to control and design the position of the air-vents in order to assure good air quality and homogenous thermal conditions in the ambient air.

Constant Air Volume (CAV) – all air system		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●●○○Cheap	Low●●○○○High

- **Variable air volume** (VAV) is an all-air system with air supplied at a constant temperature with modulation of supply volumes to match the room sensible load. VAV is primarily to provide cooling and requires supplementary systems for heating typically perimeter heating or terminal re-heat.

Variable Air Volume (VAV) – all air system		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●○○○Cheap	Low●●●○○High

- In **floor supply system (FSS)** the air vents are installed at floor level and the air is extracted from the wall or the ceiling. This kind of ventilation system assures a good control of internal thermal conditions and a high air quality, it can be also used for free-cooling.

Floor Supply System (FSS) – all air system		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●●○○Cheap	Low●●●○○High

3.6.4 Control systems

The efficient use of the control / regulation and monitoring systems of a building is also crucial when dealing with building renovation. In order to reduce energy consumption of the building sensors and thermostats could be used to optimize the operation of the control/regulation and monitoring systems.
The deployment of control systems is not a huge task in a historic building since it only needs to be added to the Building Management System software. However, the major concern here is the installation of the Building Management System and the monitoring system in historic buildings. Due to the lack of these systems in historical buildings, there is a need for the setup of such a system. This is the main challenge to be faced with historic buildings because of the difficulties in wiring.

Control Systems		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●●●○Cheap	Low●●○○○High

An example for the deployment of the control systems is the Industrial Engineering School of Bejar, where two control systems are installed.

First of all, there is a lighting control system based on occupancy levels and lighting values. In this case, if a presence sensor sends a signal that the lighting level of the room is less than the established comfort level, the appropriate lighting circuit is switched on. As it is shown in Figure 4, there are six circuits that are set on/off depending on the presence and light level. Thus, the unnecessary use of luminaries is avoided and consumption is decreased.

Secondly, the HVAC systems are controlled in order to reach comfort levels in the rooms. In this case, the additional installation of a hardware gateway is required in order to translate communication protocols. There exists a fixed timetable function of the usage of the demonstrator in combination with the temperature value and presence sensors. Thus, if the time is within the "ON" time slot and the presence sensor sets an occupied value, the temperature pattern displayed in Figure 5 is followed. This means if the room temperature is higher than 25ºC the HVAC system is used as cooling system and if the value is under 22ºC, it is commuted to heating mode. Between 22ºC and 25ºC is the dead band, where the systems are switched off because the comfort level is reached, and the energy consumption of these systems is avoided.

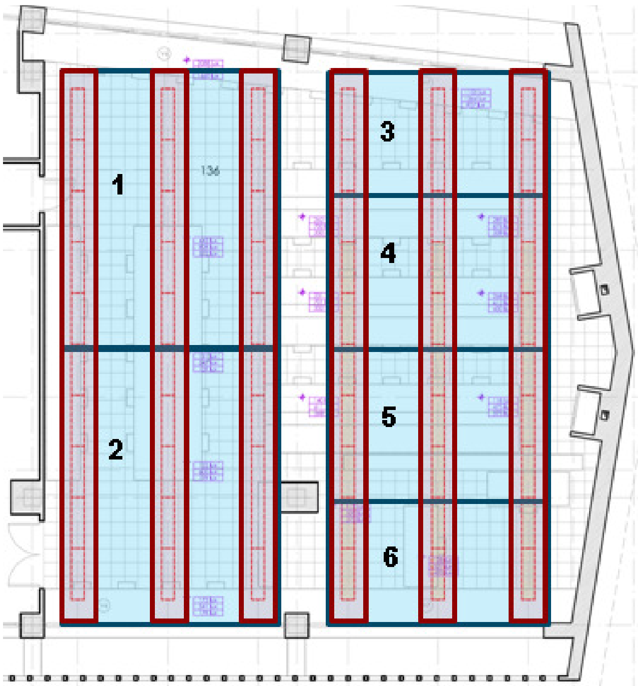


Figure 21: Distribution of the lighting circuits

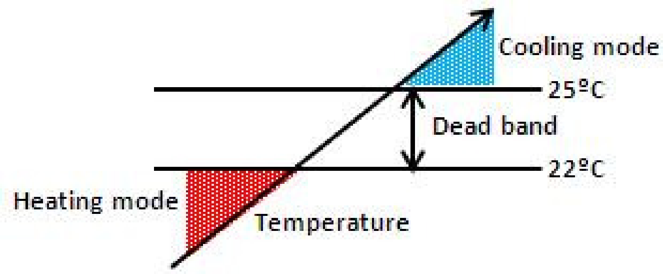


Figure 22: Temperature pattern for the HVAC control

3.6.5 Renewable Energy Systems Integration

The **integration of renewable energy systems** in historic buildings is an option to be considered – switching from fossil fuels to production of own, decentralised, clean energy. Another point which makes renewable energy systems integration in historic building renovation important is that these facilities generally require less maintenance than traditional systems.

From the point of view of the integration in historical buildings, the **aesthetic aspects are very important**. Thus, it will be necessary analysing the interest and character of the building and its surroundings, how to design and place the equipment to protect the character and appearance of the historic building.

Deciding which **technology is best suited** to one building depends on many factors. Some questions have to be taken into account like available budget, if the system will be used for space heating, hot water and/or electricity, if the system should be fully automated or manually controlled, if the visibility and the aesthetic aspects are very important. Checking and obtaining permissions early in the process may also be needed.

Two main categories are addressed: electricity (power) generation systems and thermal energy generation systems.

Electricity (power) generation systems:

- The term **building integrated photovoltaics (BIPV)** refers to integrating photovoltaic (PV) elements into the building envelope, establishing a symbiotic relationship between the architectural design, functional properties and economic regenerative energy conversion (Odersun, 2011[10]). BIPV offers an alternative to conventional rooftop PV installations. They can be used in all parts of the building envelope and offer high efficiencies (especially in Nordic countries where the angle of the sun is low). BIPV could also add value to the aesthetics of the building and both roofs and façades can be used – a flexible technology that can be tailor-made to suit any part of

[10] Odersun, 2011, Manual for BIPV Projects.. Available: http://www.odersun.com/uploads/pdf/Odersun-BiPV%20Manual-110902-EN-Download.pdf [Accessed 18 March, 2012].

the envelope. However, regarding historical buildings there are often regulations for such interventions in the building.

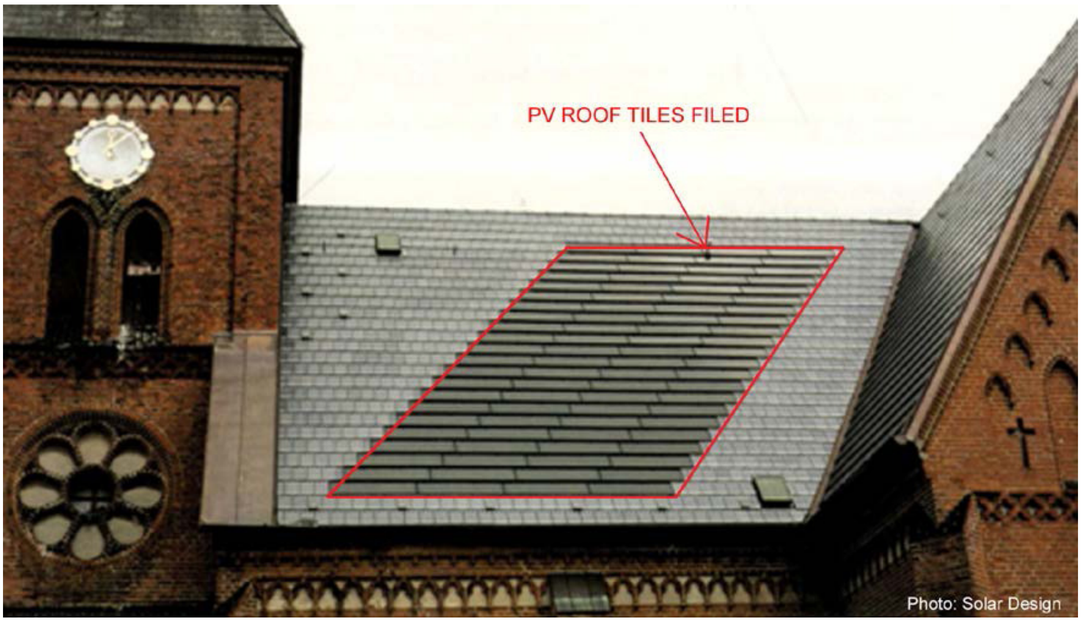
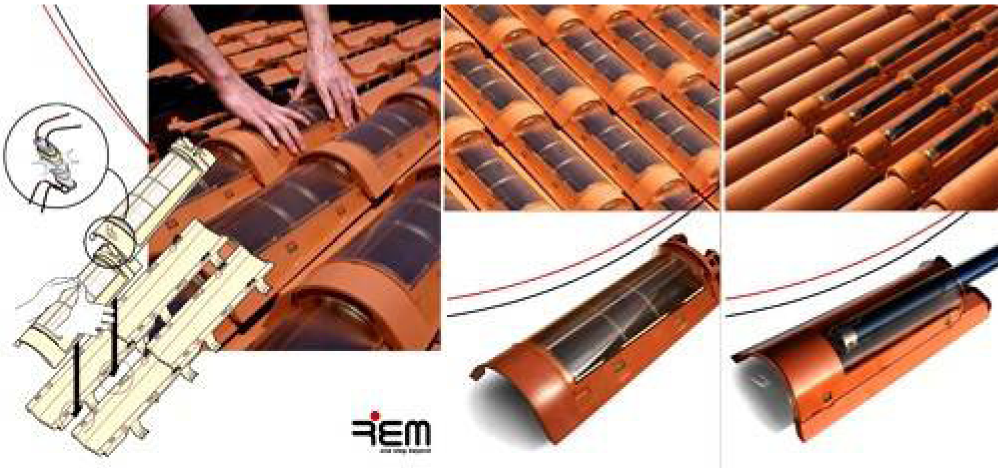


Figure 23: Architectural integration of PV on the roof of a Church, Carlow, Germany

The example above illustrates the Church in Carlow, Germany. Here limited intervention was allowed without altering the historical appearance of the church - as stipulated by the monument protection authority (Hermannsdorfer and Rub, 2005[11]). PV modules were produced to match the shape and the colour of the roof tiles of the church and then integrated to a part of the roof.



Transparent and semi-transparent PV integration into the building facade as well as skylights, atrium and greenhouse glass use with semi-transparent PV glazing can create an aesthetical mosaic and add the culture of saving energy to that of cultural heritage – as illustrated below.

[11] Hermannsdorfer, I. & Rub, C. 2005. *Solar Design,* Berlin, Jovis Verlag GmbH.

Figure 249 : Example of PV atria integration and example of glass substitution by PV glass with shading properties (a-Si, left picture)

It's also possible to integrate the PV in the blinds and sliding shades.

A new semitransparent photovoltaic glass with the thermal isolating properties required for windows, atria, skylights, double skins and curtain-walls has been developed by the 3ENCULT partner Grupo Unisolar / Soliker (G1S). The photovoltaic material deposited on the glass is paired down or removed by a laser, making the glass translucent and enabling it to generate electricity at the same time. As a result of this procedure, the brightness of the glass is decreased, allowing for solar control. Up to 40 percent semi-transparency is possible. The outer appearance is the same as a standard glass used for windows, making it suitable for historical buildings.

Another possibility is to integrate heat recovery properties into ventilated façades to offer double advantages for the buildings. Apart from the PV energy production, the air is heated up, flows up and is introduced in the building and ventilated façades works as a chimney in this concept. Opaque or semi-transparent PV devices can be used in ventilated facades, double skin and curtain walls depending on the visual requirements.

Solar Photovoltaic		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●●○○Cheap	Low●●●○○High

- A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy, and thus produces **wind power**. Building-mounted wind turbines will often not be permitted on historic buildings. This is most likely due to their visual impact; however the installation process or any vibration could also affect the building fabric. For these kind of turbines a structural survey of the building is necessary to ensure that it can support the proposed installation without subsequent damage to the historic building. This makes free-standing mast-mounted turbines more viable for many historic properties.

Building conservation specialists are also often concerned with the reversibility of any work done to a historic building. As a wind turbine's lifespan is shorter than that of the building, removal and replacement options should be considered during the initial installation.

The basic requirements of these systems include space to install the turbine, suitable site conditions (free of obstacles), adequate wind speed (above 5-6 m/s), back-up electricity source and space for this back-up source. Turbines must also be sited in a reasonably exposed location. They work best at a height where wind speeds are high and where there are no obstructions from buildings, trees or other features that would cause turbulence.

Figure 10: Wind turbine fixed to a historic building.

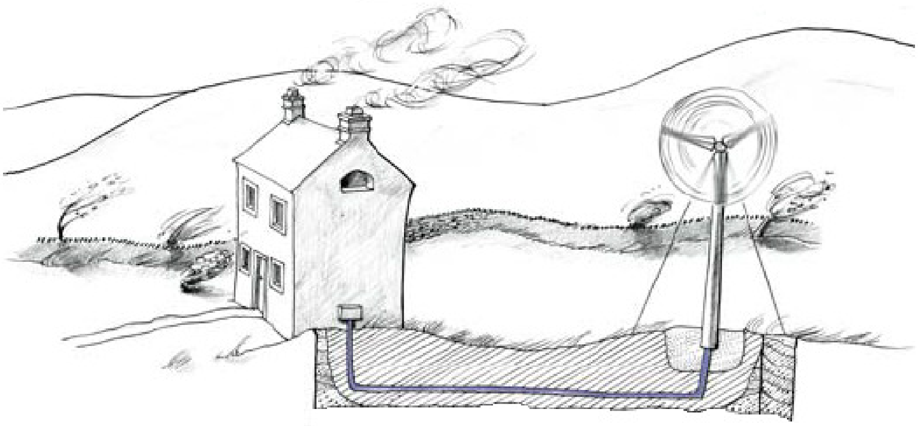


Figure 11: Scheme of a wind turbine away from the building.

A wind turbine away from the building can be mounted on a pole or in a latticework tower. The support and the location should be high enough to avoid the effects of turbulence. The pole or tower requires proper foundations depending on the weight and height of the turbine and on the soil conditions. The turbine is connected to the building through a cable, which is usually necessary to bury (Figure 9).

Before excavating, both for foundations and for cabling, it is important to assess the possibility of buried archaeology on the site.

Many accredited installers recommend monitoring the wind speed in the proposed site for at least one year as part of the decision-making process.

A wind turbine may not be viable where typical wind speed is below 4,5 m/s, since the amount of energy generated would not justify the capital cost.

Wind power		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●○○○○Suitable	Expensive●●●○○Cheap	Low●●○○○High

- **Hydropower** technology needs some basic requirements to work; like a nearby source of running water with a relatively consistent flow, a back-up electricity source and space for it.

  Micro hydro systems are one of the most reliable, durable and cost-effective renewable energy options available. They provide a steady, predictable source of electricity, run very efficiently and can cost less than other electricity generation technologies. If a property is situated near a suitable water source, hydropower could be the best source of renewable electricity.

  In some cases, hydro power offers an excellent opportunity to enhance the character of a historic building. Many old mills or former mill sites are given some formal protection through listing. Historic mill sites may provide suitable locations for new hydroelectric installations, although consideration needs to be given to the archaeological impact of any new works (Figure 22).

Figure 12: Historic mill utilized for a modern hydroelectric scheme.

A hydro system may have a visual impact on the landscape. This can be minimised by sensitive site selection (without compromising the performance of the system), and by design measures, such as burying the penstock, and using an existing outbuilding to house the turbine and other equipment where possible.

Original building fabric is considered important to the cultural value of a historic building. As such, installation of hydro systems and associated cables should minimise loss or damage of this original fabric. In most cases this should be negligible, as the majority of the works are external.

Building conservation organisations are often concerned with the reversibility of any work done to a historic building. As a hydro system's lifespan is shorter than that of the average building, removal and replacement options should be considered during the initial installation so that lose or damage of original fabric can be kept to a minimum.

Hydropower		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●○○○Cheap	Low●●●○○High

Thermal energy generation

- **Biomass (boilers)** and **geothermal (heat pumps)** solutions have been discussed in Section 3.5.1.
- **Semi-transparent solar thermal panels** are another innovative alternative for building renovation. Both sides of the collector are covered by a Transparent Insulating Material (TIM) patented by G1S. This simultaneously enables thermal insulation and transparent properties. It is designed for façades where the angle of the plate can have 45º and the ambient light passes through it - also for use in atriums and skylights.

Semitransparent solar thermal panels		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●●○○Cheap	Low●●●○○High

- **Semitransparent and colored PV solutions** can be provided enabling solar control of the spaces and fulfilling the aesthetic desires of architects and conservators and providing thermal insulation and electricity generation. The a-Si thin-film devices can replace other passive constructive elements, complying with their requirements in terms of security, aesthetic, thermal and electrical insulation, water proofing and solar control. They can be used for semitransparent ventilated façades, double skins, skylights, atria, canopies, louvers, etc.

a-Si semitransparent PV Panel		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●●○○Cheap	Low●●●○○High

- **Solar semitransparent double glazed isolating PV window** are mainly used in atrias and as curtain walls in other some type of buildings, where solar and thermal control is required. No thermal isolation is applied, though it improves the thermal behavior of the spaces. Although it is considered under the thermal energy generation solutions, semitransparent double glazed isolating PV windows also generate electricity, turning the solution into a hybrid thermal-electricity generating solution.

a-Si semitransparent double glazed isolating PV window		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●●○○Suitable	Expensive●●●○○Cheap	Low●●●○○High

- **Solar thermal collectors (panels)** are used for domestic hot water (DHW), radiant floor, radiators or heat pumps. The collectors need a tilting angle of around 45º for optimal behaviour, depending on the latitude.

Solar Thermal Panels		
Use in Historic Building	**Cost**	**Energy Efficiency Improvement**
Not Suitable●●○○○Suitable	Expensive●●●○○Cheap	Low●●●○○High

Conservation: Aesthetic concerns are important in historic building renovation, but other important points also need to be considered – especially where and when to use renewable energy systems. An important early step is - working with preservation professionals - to identify the character-defining features and the potential location for a renewable energy system. This will help to ensure that the system does not negatively impact other key features, such as aesthetics. Further, it is advisable to contact the local planning and building control departments at an early stage and confirm if any permission is needed. If a building is not listed but lies in a protected area, planning constraints may be placed on external alterations. Such areas include Conservation Areas, World Heritage Sites, Areas of Outstanding Natural Beauty and Scheduled Monuments. Other permissions may be needed where a proposed installation could have an environmental or archaeological impact. This last point will be very important when a geothermal installation is planned.

4 Brief conclusions

Historic building protection and energy efficiency are becoming a more effective combination that they have ever been and thanks to technology and the advancements of research, bridging the gap between them becomes easier and more efficient.

There are many solutions available that can be taken into consideration and adapted case-by-case to the single historic building, and more are being researched. Local governments approaching the challenging task of protecting their cultural heritage, and of ensuring that it plays and active part within the life of the community, should necessarily consider energy efficiency in the start-up phase of their planning.

When starting to plan an energy retrofit for historic buildings it is crucial to **explore a series of key points**:

i. What is the purpose agreed upon for the building and who will be the final user? Always considering the building role when part of a bigger transition programme for the city or area.

ii. Keep in mind what regulations need to be followed for the protection of the historic building

  - Is this a listed monument? Or any specific relevant regulations? What limitations to interventions (what and why)

iii. It is important to make the most out of this investment – also by considering: the economic and social impact when planning.

iv. Joint discussion with the historic building expert (monument protection agency) and experts on sustainable energy solutions for buildings have to take place thorough the process in order to identify and discuss the specific situation, explore and select appropriate technologies.

Indoor environmental analysis are a fundamental precondition, and need to be discussed with the experts who need to be involved thorough the process. This may include: thermography, Ground Penetrating Radar testing, Blower Door Tests, Heat flow meter measurements; Hygrothermal monitoring with the use of wireless sensors (WSN); "Spot" measurements of expressive parameters of the Hygrothermal, visual and acoustic comfort; Psychrometric and lighting maps material compatibility.

It is important to keep in mind that every heritage building is unique and that not all solutions are replicable one-to-one, therefore the applicability and the results of the application of a certain solutions depend on:

- type of building,
- use of the building
- climate
- materials
- national regulations on heritage protection
- funds available

Nonetheless solutions might be adaptable to different needs and adopted in specific cases, after discussion with all relevant stakeholders and especially with experts in conservation.

Once decided what actions are possible on your unique building, consult experts (including your own local government relevant departments!) and find the optimal energy efficient solution:

- Energy efficiency do not always come from the newest technologies – explore with conservator if historic techniques can be reapplied to the building (e.g.: cooling , shading)
- Innovative technologies / techniques are not always the more expensive, especially when it comes to refurbish an historic building, where different materials are used.
- Even when the costs are higher, don't forget to look at the larger picture: energy saving means not only less emissions for your community but also less costs. Discuss with the experts what the feasible options for the building are: investment recovery time might surprise you, especially if you can utilize renewable energy.

The city of the future is "**smart**": reduced energy demand and emissions, better quality of life and less costs both economic and for the environment. Investing in energy efficiency has become increasingly urgent in order to respond to the steep growth curve of energy prices, and **energy security** is a main item in European agendas. European cities past can play a proactive role in their future and energy-saving oriented renovation can help to "adapt" the irreplaceable heritage of cities to a continuously changing world. Councils have the possibility to take the lead in the developing strategies that allow community to protect these cultural and economic assets.

An attractive and lively historic urban fabric can contribute not only to the quality of life of the community, but also enhance local and regional economic competitiveness, creating a better environment for businesses and tourist sector. The facilitation towards a stronger economy would be able to create employment in the EU, alongside with inclusive social and environmental policies, which would themselves drive economic growth even further.