WINDOWS

Guidelines for renovation of historic buildings

Franziska Haas, Eurac Research

INTRODUCTION

These guidelines are intended to explain to interested owners as well as professional planners the fundamental steps towards the concept definition for a sustainable renovation of a historic building providing a basis for further planning and implementation.

There are many reasons to renovate a building: The Property does not get warm properly, there is a draught through old windows, heating bills are high; and often there is decay or damage to the masonry or roof that triggers renovation. In addition, there is the awareness that climate change is happening and that we can all do something for our environment by saving energy and using existing material resources.
However, if the building that is to be renovated is historic or traditionally built, many questions immediately arise.

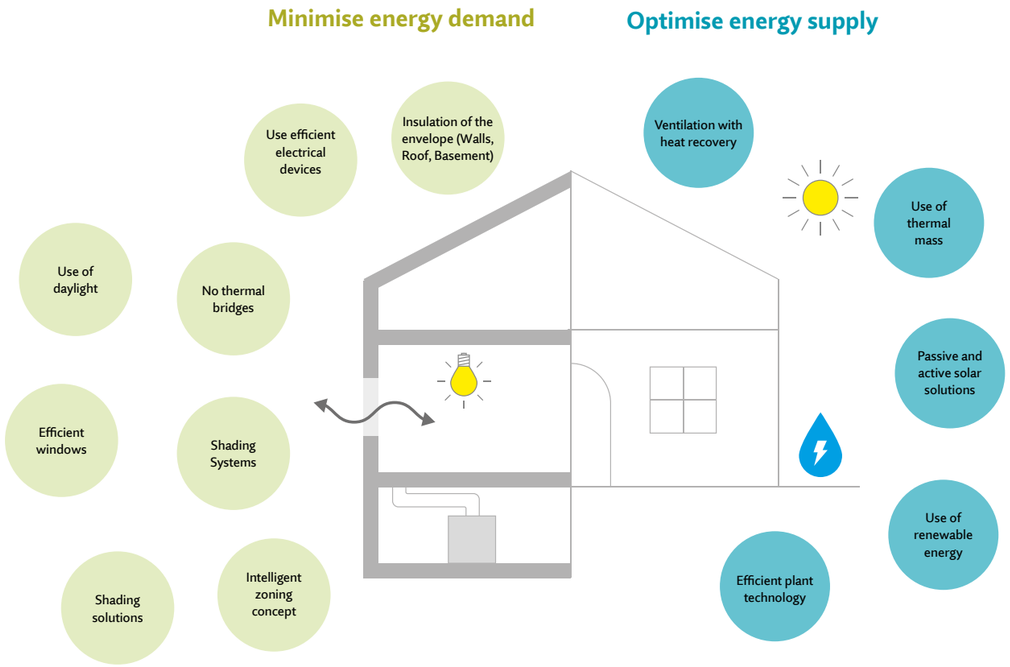
- *Does my building have a special cultural value and how can I preserve it?*
- *Do I have to observe the requirements of monument protection?*
- *Is modern living comfort possible within the old walls?*
- *Are new renovation solutions suitable for the old building fabric?*
- *Whom do I best ask for advice?*

However, historic buildings do not only include the large universally recognised monuments, such as churches, castles and monasteries. It is the many traditional residential and agricultural buildings that characterise the Alpine landscapes and towns. They are intrinsically linked to their environment, built using local building materials and local craftsmanship. And yet each one of them is quite individually designed. Many of them are not protected, and yet it is just as important to preserve them.

What does energy-efficient actually mean?

Energy-efficient renovation can reduce the energy consumption and operating costs of a building. At the same time, however, it can also improve living comfort and thus increase the market value of a property. Energy efficiency measures therefore contribute to the preservation of the building structure by ensuring its usability in the future. Through energy-efficient refurbishment, you therefore make a major contribution to the preservation of building culture as well as to environmental protection. However, it is important to consider the special legal, physical and design conditions in old buildings - this is the only way to plan sustainable renovations.

EXAMPLE: The renovation of a historic wall can be beneficial for several reasons. In addition to the preservation of the historic wall and thus also of the building, with the renovation also the energetic property can be improved, what increases the living comfort at the same time because of a higher surface temperature. With this discomfort inside the rooms is prevented, because annoying draughts are avoided and the perceived room temperature increases.



Integrated Design

Energy renovations must always be planned holistically. This means that the entire building is considered from the very beginning. Individual measures, such as the replacement of windows, are always examined in interaction with all other components. The associated additional planning effort and the higher investment costs at the beginning of a project are often a barrier for many people. A thorough planning phase usually saves more money than it costs during the later implementation. Details and structural component joints are clarified in advance. Expensive construction delays, unattractive "tinkering solutions" and structural damage are avoided. Renovation steps that are staggered over several years can be coordinated through detailed planning in such a way that the investment costs become more reasonable, but the measures do not interfere with each other. Even with limited financial resources, it is worthwhile to invest in planning in order to obtain cost certainty and to take the most effective steps first.

EXAMPLE: The retrofit of historic windows must be part of an overall concept. If the window is regarded as a singular building element without considering the connection to the wall and the threat of thermal bridging there, condensation and mould formation can easily occur in the reveal. In addition, the expected humidity in the room, which can be ensured by manual or mechanical ventilation, is a crucial factor. Some solutions for insulating the reveal that would work in dry rooms will cause damage in more humid rooms.

For holistic design, the principle should always be followed of first saving as much energy as is reasonable and possible and covering the remaining demand with renewable sources.

Is energy-efficient renovation worthwhile?

It is difficult to determine the right moment for an energy retrofit. However, if maintenance measures are to be carried out anyway (e.g. new roofing) or a change of use is planned (e.g. conversion of the utility part into living space), then the opportunity for a sustainable refurbishment should be taken. All measures should also be examined with regard to their follow-up costs. The sooner I have to replace a solution, the more costs arise. In most cases, repair proves to be more cost-effective than complete replacement. When implementing renovation measures, importance should therefore be given to their reparability and maintainability in order to save high follow-up costs for a complete renewal, but also to preserve material resources.

The path from idea to concept

A renovation should be well prepared in any case. Before planning starts, the conditions of the building, one's own ideas and the general framework must be clarified. The time and effort invested in the preparation phase and conceptualisation will avoid later changes to the plan and unforeseeable costs.

1. Project idea: inspiration through examples

At the beginning of every renovation project are the initiatives and ideas of the building owner, usually prompted by the desire for change.
Inspiration from examples that have already been implemented can provide a wide range of ideas. The HiBERatlas, in which many examples from the Alpine area are documented, can help here.

2. Partner: energy renovation is teamwork!

The preparation, planning and implementation of an energy-efficient refurbishment involves a wide range of aspects, from special technical challenges and complicated permission procedures to the application for subsidies.

The building owner can reduce the workload considerably by commissioning an architect. Only in cooperation with an experienced designer can a holistic design concept be implemented. In the course of planning, other experts are involved, depending on the objectives and the existing building. If the building is a protected building, contact should be made with the relevant heritage protection authorities at an early stage.

> The municipalities often offer advisory services for building owners who are planning to renovate.

3. Framework Conditions: Possibilities and limits

From the beginning of the planning process, the client and the architect should agree on the existing framework conditions:

- *Which regulations must be observed for the planned renovation? (The balance of Building regulations, energy saving regulations/ monument protection/ landscape protection).*
- *What is the available budget?*
- *What subsidies may be available?*
- *Which renewable energy sources are suitable and available?*

4. Analysis: getting to know the building

The basis of any planning on historic or traditional buildings is the survey and documentation of the existing situation. The following information should be collected:

- *General building information*
- *Documentation of the building's structure and components (survey, construction details)*
- *Building history and cultural-historical significance*
- *Condition of the building, damage, and environmental impacts*
- *Conservation possibilities and limitations*
- *Assessment of building use, functionality*
- *Assessment of energy performance and existing indoor climate*

f the building is a protected building, the heritage authorities can help with the historic specification and heritage value assessment. If it is not a protected building, a comparison with other buildings of the same typology can be informative.
Experienced experts should be consulted to assess the condition of the building, especially when it comes to the analysis of damages. Incorrect assessments lead to incorrect repair and implemented measures being short-lived.

EXAMPLE: If a wall is to be insulated despite the presence of moisture, this will always lead to destruction and mould. However, in order to dry out the masonry, one must know exactly where the moisture is coming from, so a horizontal barrier will prevent rising damp from the ground, but not the condensation of air moisture in the interior. Incorrect masonry drying measures can cause high costs without having a positive effect.

5. Concept: Define your own targets

Based on the knowledge of the initial situation and one's own wishes, the objectives for the renovation can be defined, as well as suitable measures that can be considered for achieving these objectives. This concept forms the basis for an architectural renovation design. The concept should answer the following questions:

- *What should be preserved of the structure and substance? Appropriate repair and conservation measures*
- *What energy level and comfort level do I want to achieve? Suitable solutions for energy upgrading and systems technology*
- *Which building-ecological aspects are important to me? Suitable local and natural building materials*
- *Which functional requirements should be met? Suitable architectural design measures*
- *How important is it for me to support the local economy? Suitable craftsmen and products*
- *What time frame do I plan for my renovation? Decision for a complete renovation or a step-by-step approach as part of an overall concept*

Dagmar Exner, Eurac Research

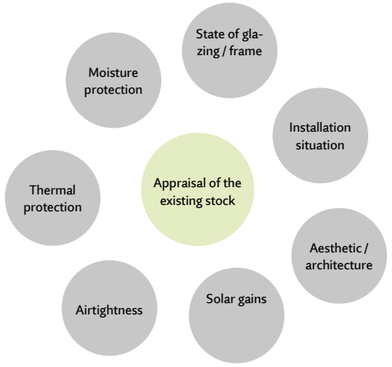
WINDOWS

This guideline summarises the most important points to be considered when renovating a historic window and should provide interested owners with the basic procedure. Architects, planners, and energy consultants can use these guidelines to understand the fundamental technical requirements and the approach to take with historic material.

Windows are inseparable components of the building envelope. They significantly shape the building from architecture point of view – and in a historic building, this aesthetical value is complemented by the value of perhaps still preserved original material and the witness to the creative will, construction rules and craftsmanship of earlier epochs. They structure the façade and contribute to the architectural expression by giving a vertical and horizontal rhythm to the building. Windows are complex building components and fulfil a multitude of tasks such as lighting, thermal insulation, sound insulation, ventilation, solar gain, and sun protection. All these demands on the building component have led to the development of various characteristic systems over time.

Building efficiency legislation has triggered replacement of traditional windows in recent times. However, maintenance, repair, and retrofit of existing windows should be considered, not only for heritage protection reasons, but also with resource efficiency in mind. At the same time, the windows must meet the demands of today's living comfort and energy efficiency, so it is necessary to consider factors in preserving the substance and appearance on the one hand and improving energy efficiency on the other. The choice between careful repair of frame and glass, constructive energy optimisation with varying degrees of intervention in the substance, or a complete replacement with replication can only be decided for each individual case. For a sustainable solution, it is essential not only to consider thermal and hygrothermal aspects, but also to apply appropriate validation procedures to avoid long-term damage, as inappropriate window replacements or upgrades can ruin or degrade the historic value of the building and, in addition, cause hygrothermal related problems, like condensation and thermal bridges.

1 Appraisal of the existing stock



In order to determine the situation for the refurbishment of a window, two basic points must be distinguished:

- **the technical composition and condition of the window**
- **Its cultural and heritage values of the window assembly**

1.1 First check of the window to be upgraded (technical observation)

To verify the performance of a window, it is necessary to know and understand the typology, the required functions, and the actual state of the window. Usually, the window serves primarily as an opening in the building envelope to let in light and air and to allow a view to the outside. As well as being openable, the window must provide protection against cold, rain and wind, and acoustic noise.

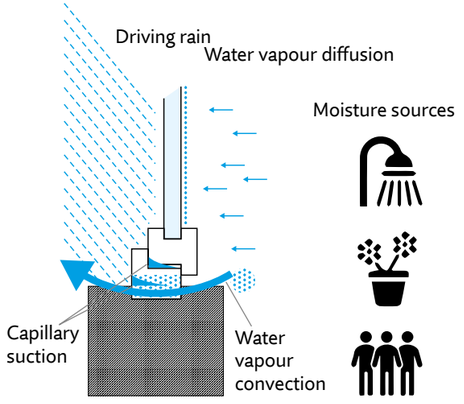
1.1.1 Overall condition - stability verification

Because of weathering or condensation, service life and lack of maintenance, the window construction can be impaired or damaged. Thus, the condition of all parts of the window (glazing, sashes, casements and the window frame) should be assessed with regard their stability, damaged areas, or cracks. Also, the condition of the coating and the glazing putty should be checked, as well as the functionality of all movable parts of the window and the fittings.

1.1.2 Moisture Protection

The main problem of any building is moisture. Whether it is rain, rising damp, or sources of moisture inside the building, any kind of moisture load poses a major problem for the building and its components over time. On windows, standing water on the surfaces or water that penetrates the window construction can lead to permanent damage from rot and to mould growth. Windows are exposed to moisture on the outside as well as on the inside:

- **Moisture load from the environment:** Water droplets, driven by wind pressure and air flow (driving rain), can penetrate the window construction and the window-wall connection through open joints and cracks. In this context, the condition of the window must be checked. Is the window construction, coating, and glass fixing intact? How are the joints? The water must be drained out of the building component in a defined manner by constructive measures. To protect against driving rain, joints should be made driving rain-proof by constructive or structural measures such as drip edges, additional deflector profiles (weather bars), flashings, deep installation position in the wall or by using suitable sealing systems. Besides driving rain, water can be introduced into the construction via capillary suction without external influence (wind pressure). Capillary joints - narrow joints between two building components - must therefore be avoided to prevent undefined water ingress.



Moisture load:

- from the outside (driving rain, capillary suction)
- from the inside (moisture transport: diffusion + convection)

- **Moisture load due to moisture transport from the inside to the outside:** In addition to the obvious moisture loads from the environment, moisture transport mechanisms (water vapour convection and water vapour diffusion) occur due to different temperatures and relative humidity levels between the interior and exterior. Water vapour convection is caused by the air flow from the warm to cold side with condensation on cooler surfaces via unsealed or leaking joints. Large amounts of water can enter the construction through this air flow. Water vapour diffusion occurs in many materials when there are differences in water vapour partial pressure and is caused by the differential climate between inside and outside. Diffusion processes are much slower than convection processes and the amounts of moisture are considerably smaller. They should anyhow not lead to a long-term increase in material moisture.

1.1.3 Thermal Protection

In historic buildings, the window often represents a weak point with insufficient thermal protection. Due to the high heat losses through the window construction, the interior surface of glazing and frames, as well as the adjoining reveals or parapet are significantly colder than the room temperature. Due to this temperature difference of the surfaces, the room climate is perceived as uncomfortable. If, in addition, there are high humidity loads in the interior (high relative humidity), the moisture condenses on the window, especially on the glazing surface or in the reveals, or reaches a very high relative humidity and can thus lead to mould growth.
The thermal transmittance, U-value, expresses how much heat is lost through the window. At a window, as an inhomogeneous component, the U-value depends on the thermal transmittance of the individual elements and their share of the total area. For the development of individual retrofit solutions, it is therefore crucial to look at these components in detail - from the frame over the glass surfaces to the glazing bars - to understand, where the solution can start and to quantify the influence of the measure on the overall energy efficiency of the window. For historic window with two window layers, like coupled and box-type windows, both window layers and the intermediate space are considered for the U-value calculation. As it is the biggest part of the window, the overall performance is highly influenced by the efficiency of the glazing. Special attention must be paid in this context to the thermal bridge of the wind-wall-connection. This thermal bridges at the adjoining reveals or parapet can be determined with the help of a thermal imaging camera.
But it is not only heat that is lost through the window. The sun brings light and heat into the room through the window. Depending on its orientation, solar gains are generated through the solar radiation on the surface and through the transparent component, which have a positive effect on the energy balance (especially in winter).

To reduce energy losses and structural damage, the windows should be as airtight as possible and impermeable to driving rain, condensation should be prevented and any moisture that occurs should be safely drained away

1.1.4 Airtightness of windows

While the airtightness of current windows is very high, historic window constructions are often leaky. However, increased airtightness of the window is necessary for several reasons: It prevents warm moist air from penetrating into the construction, condensing there and leading to moisture damage. At the same time, improving the airtightness is essential for energy saving, by avoiding unwanted ventilation heat losses. Lastly, it has a positive effect on comfort by preventing the influx of cold air. Thus, to reduce energy loss and damage to the construction, the windows should be as airtight as possible.

New sealed windows however require adapted ventilation behaviour. To ensure indoor air quality and to decrease indoor air humidity even with high joint tightness, a minimum air exchange is necessary. This can be achieved through natural window ventilation or (controlled user-independent) mechanical ventilation. In case of natural ventilation, it is recommended to ventilate the rooms for five to ten minutes every two to three hours (if possible, open opposite windows), especially immediately after periods of high humidity, such as after showering or cooking.

When developing a retrofit measure for windows, it is crucial to consider not only the thermal performance of the window itself, but also the connection window-wall and the energy balance of the whole building – to optimize the heat losses and, most importantly, to assure sufficient internal surface temperatures to avoid condensation and mould growth.

The following table summarises the different factors for the technical assessment of a window:

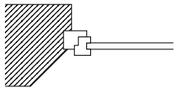
	Error indicator	Examination by
Overall condition - stability verification	Damaged parts of glazing or rotten wood construction, cracks, defective coating or glazing putty, malfunctioning window sashes or fittings	Handicraftsmen, architect > Visual inspection, Windows list
Moisture Protection	Flaking coating, rotten parts of wood construction, water traces on surfaces, mould growth in the reveals	Building physics, architect > Visual inspection, Moisture measurement
Thermal Protection	High energy demand, cold glazing surfaces, mould	Building physics, architect > Infrared thermography
Air tightness	Draughts, air infiltration, not well closing window sashes	Air tightness testing by air tightness test, infrared thermography; “candlelight” or “paper” test

1.2 Determine the historical values of the window

The most common four historic window types in the Alpine region are single windows, coupled windows, box-type windows, and the winter window as its variant. What they all have in common is a slim and delicate construction. The construction principle differs in terms of number of window layers and the different ways in which these layers are connected. The glazing bars made of wood or lead were not only a design element, but they also served a structural purpose.

Historic windows need a retrofit project that considers the historic, aesthetic and material values and the state of conservation. Conservation aspects must be considered at the same level as thermal performance and the need of comfort for the users.

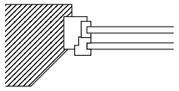
Single window



...consists of one window plane with single glazing and, like all other window types, can have one or more sashes.

Uw-value old: 4,8 W/m²K

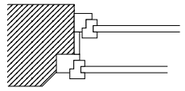
Coupled window



...consists of two adjacent window layers that are directly connected to each other but can be separated for cleaning purposes.

Uw-value old: 2,6 W/m²K

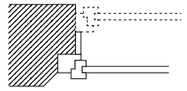
Box-type window



...has two window layers connected by a wide wooden frame (box). The double structure is reflected in the view.

Uw-value old: 2,4 W/m²K

Winter window



...are a variant of the box-type windows: in winter, an additional window layer is placed on the outside. It can be substituted in summer with a shutter.

Uw-value old: 2,4 W/m²K

Before starting with the enhancement of existing windows, a holistic concept for the whole building façade must be elaborated in tight collaboration with the conservator or architect. This overall window concept is based on a detailed acquisition and evaluation of every single window during an interdisciplinary on-site inspection, describing window typology, state of conservation, construction, materials, installation, surrounding framing (profiled stone frame etc.), type of window sash, glazing, wood joints, fittings, and additional

The wooden construction of historic windows is very fragile and thin, while the optic of the typical new windows is often broader. Traditional mouth-blown historic glazing has a different reflection and mirroring compared to modern glazing.

equipment such as window shutters etc. From the façade concept emerges which (part of) windows and additional equipment must be retained and repaired, and which parts can be replaced, as well as the position of the original/new window or respectively the position of an additional new second window layer and how to treat the surrounding framing (reveals, profiled stone frame).

It is important to know typical characteristics of local historic windows. In general, two aspects of the original appearance of historic windows are crucial: (i) the original proportion between glass area and sash bars and window frame and (ii) the optic appearance of original historic glazing. Originally, the wooden frames, impost and sash bars were very fragile and thin, possibly moulded, while the optic of the typical new windows is much broader. Exchanging historic single glazing with double-glazing changes the look to the façade because of different reflection and mirroring, caused by

- convex or concave deformation of the glass pane through expansion and contraction of gas between the two glass layers
- different surface finish of flat modern float glazing compared with traditional mouth-blown historic glazing and
- more regular reflection if subdivisions are not any more glass-dividing (and thus not causing different glass inclinations).

In order to conserve the aesthetic value and the craftmanship, any retrofit measure should alter as little as possible the existing historic material. Heritage assessment distinguishes solutions with impact on the interior and exterior appearance and addition of new or replacement of existing components. For every window construction it can be decided only individually which is the best retrofit solution.

2 The redevelopment process

2.1 Increasing the energy efficiency

To improve the energy efficiency of a window, additional measures must be added. To enhance the airtightness, a surrounding seal on the window itself and window-wall connection can be added. To improve thermal transmittance, the single glazing can be substituted with high performance glazing and depending on the window typology, a better performing window layer can be added or one of the existing layers or window sashes can be substituted. Based on the heritage assessment it can be decided, which parts of the window can be replaced or added, and the position of an additional new second window layer can be defined and thus if the measure has an impact on the internal or the external appearance of the window and facade. If it is not possible to enhance the historic window construction due to major damage or if there are no requirements from preservation point of view, the replacement of the entire window construction with a new energy efficient window can also be considered.

Historic box-type windows have a Uw-value of around 2.4 W/(m²K), coupled windows around 2.6 W/(m²K), windows with early insulating glazing have a Uw-value of around 1.7 W/(m²K). The table shows that the addition of a second layer of windows can significantly improve the thermal transmittance and that with the installation of multiple glazing (in one of the of the window levels), you can achieve a Uw-value that is close to that of new windows commonly used today.

In the following, possible retrofit measures to enhance the energy performance of the window are presented, structured according to their invasiveness from small intervention to a profound intervention in the substance and appearance of the component. In the schematic drawings, the addition (orange) and the replacement (green) of components are differentiated by color. The solution approaches refer to the four historical window typologies most found in the alpine space: single, coupled and box-type windows, as not all renovation solution is applicable to every typology.

Typical U-values of different window types and renovation solutions

	Single window			Coupled window	Box-type window (distance 150 mm)			
	Singles glazing	Additional pane (coated)	Special insulation glass	Singles glazing, each layer	Singles glazing, each layer	Coated glazing (inside)	Insulation glazing (inside)	Triple glazing (inside)
Solution comparison								
Glazing layers	3	3-15air-4	3-4kry-3	3-30air-4	3;4	3;4	3;4-12-4	3;4-12-4-12-4
Ug-value [W/(m²K)]	5,7	2,1	1,9	2,8	2,8	2,2	1,1	0,7
Uw- value [W/(m²K)]	4,8	2,1	2,2	2,6	2,4	1,9	1,3	1,1

U-values of different window typologies and retrofit solutions. Source: Holzfenster im Baudenkmal, Arbeitshefte der VDL, 2017

2.1.1 Low impact on the appearance

Repairing window

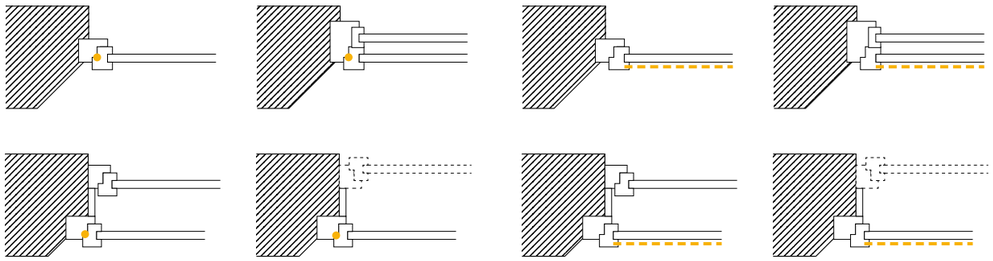
After assessing the condition of the historic window, and as a basis for all further measures, the preserved parts of the window must be repaired to guarantee their functionality and durability. The maintenance and external upgrading include the repair of smaller defects and the replacement of larger damaged areas in the wood, as well as the replacement or repair of damaged glass, the renewal of the protective coating and, if necessary, the renewal of brittle and cracked putties, as well as the adjustment of the fittings. This renovation includes all conservation measures to improve durability and does not alter the window construction. It does however also not improve its physical and thermal properties.

Inserting a sealing strip

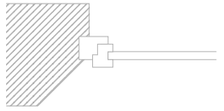
Leaks in windows can occur both within the window construction as well as at the window-wall connection. The correct wall connection must always be ensured first. When sealing windows, a distinction is made between gluing in and milling the seal. When milling in, one or more slots are milled into the window frame between the sash and casement frame and sealing strips are inserted. The use of a high-quality seal is recommended to guarantee a functioning seal especially if the frame is slightly warped. This measure does not improve the U-value of the construction, nevertheless it reduces heat losses caused by convection and suppresses draughts, which has a positive effect on the room comfort. In many cases, this solution can be easily integrated into the historical window construction, only minimally interfering with the substance, and hardly changing the window appearance. This measure can be applied to all four mentioned window typologies.

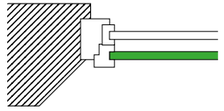
Addition of foils to the glass

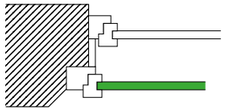
Films are used mainly to upgrade historical glazing regarding requirements for breakage resistance. By coating the existing glazing with foils, the historic glazing can be enhanced to safety glass. By using insulating or heat protection films, the thermal properties can be improved at the same time. Depending on the film, the appearance of the window however may be altered in terms of colouring or transparency.

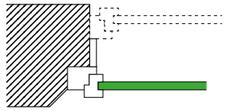


Replacing inner glass
(with vacuum and insulation glazing)
This method applies for constructions with several window layers, such as coupled or box-type windows. The historical window construction and the glazing of the outer window sashes are preserved and restored, while the inner glazing is replaced by insulating or vacuum glazing. If necessary, this allows to replace defective historic glass on the outside with recovered glass from the inside. From an energy and economic point of view and if conservation requirements allow, it is advantageous to do the replacement of the inner glazing without sash bars. Since insulating glazing has a larger cross-section than single glazing, the rebate usually must be enlarged, or the thickness of the inner frame must be increased on the outside with an additional wooden strip. At the same time, a sealing is inserted at the inner window layer. With this solution the heat transfer coefficient of the glass (Ug-value) can be significantly improved while the external historical appearance is maintained completely. It must be ensured that the existing fittings can bear the additional weight of the new glazing.

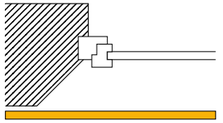


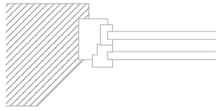


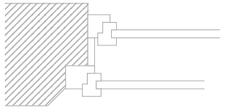


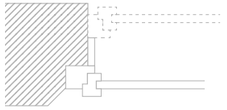


Adding an additional glass layer on the inside of the outer wall
This solution is suitable for single windows. A new room-high glass layer is attached to the inside of the outer walls, covering both the walls and the windows, which is hardly visible from the outside. The solution has a considerable influence on the U-value of the windows and on the comfort. A variant of this solution is to separate unheated or less heated rooms with historical windows (such as a staircase) with an additional glass level.

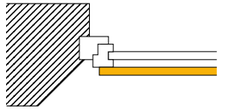


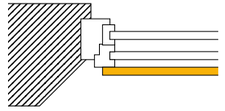


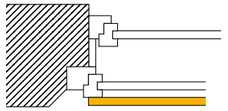


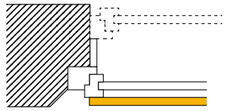


Extra layer of glass on the inside
In this solution the existing glazing is not replaced, but a further layer of insulating or vacuum glazing on the inside of the existing window casement is added. The thermal properties are thus improved by the additional glazing, and slightly also by the air layer created between the two glass panes, and the outer historical glazing is maintained. Adding panes creates additional weight, so the load-bearing capacity of the existing fittings must first be checked. Both visually and constructively, the use of the thinnest possible and therefore lightest possible glass on the inside of the existing frame of the historical window construction is preferable. To be able to clean the inside of the outer pane, the additional window construction must be able to be opened. Thus, this solution turns an existing single window into a kind of coupled window. There are industrially prefabricated solutions for this extra glass layers.

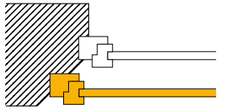


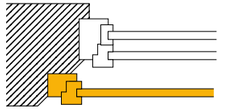


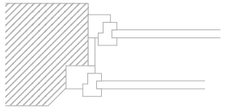


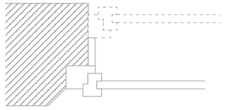


Addition of a new window layer (on the inside)
This solution is only applicable to constructions with one windowpane, such as single or compound windows. Behind the historical window construction, another window layer is installed, consisting of high performing double or triple glazing. The single window is thus extended to a kind of box-type window, whereby the window layers do not necessarily have to be connected to each other. The advantages of this retrofit measure are the good airtightness, which can be easily achieved, the avoidance of moisture problems, when installed correctly and the possibility of improving the thermal bridge at the window-wall connection. The outer, historical window plane remains almost untouched and can thus be preserved completely.

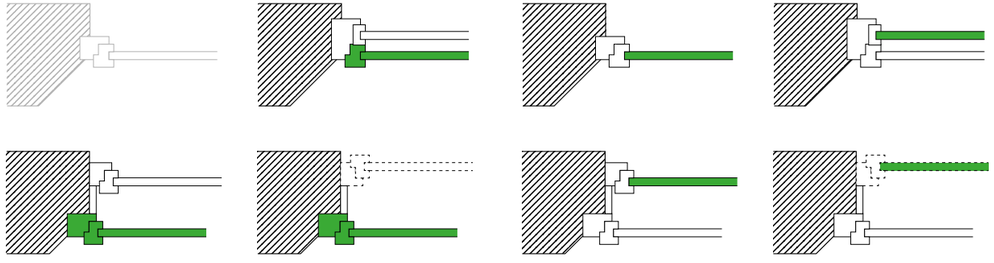






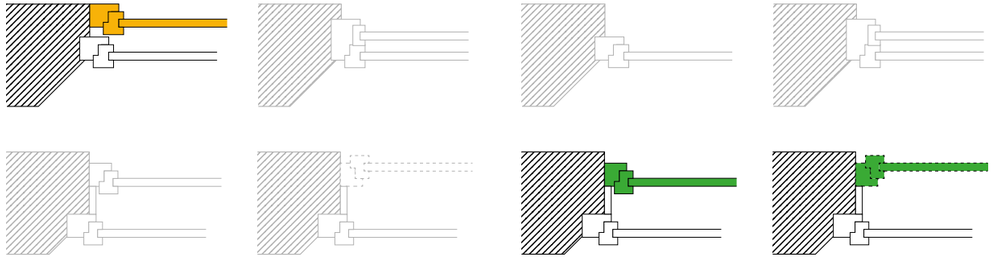


Replacing the window sashes or window layer (on the inside)
This method is mainly used for box-type windows, in rare cases also for composite windows. The historic inner window layer is completely replaced by a new energy-efficient window construction. In the case of the box-type window, this solution allows to improve the thermal bridge of the window-wall connection by adding an insulating layer in the window reveal.



Replacing outer glass (with vacuum and insulation glazing)
Replacing the external glazing is generally only considered in rare cases, for example, if the historical glazing is damaged or if existing standards require the use of safety glazing. Also, in case of single windows, replacing the glazing is a possible intervention to significantly improve energy efficiency. After removing the window putty, a new insulating or vacuum glazing is installed. Care must be taken in the selection of the new glass to meet both visual and structural requirements. Existing frames, sash bars, transoms and skylights should be maintained and repaired. For coupled window, it is also possible to install triple glazing instead of the two single glazing layers - in this case the two window sashes are joined permanently.

Addition of a new window layer (on the outside)
A new window layer is added to the outside of the existing window. This solution is rather an exception in the historical context and is mainly used when the preservation of the inner appearance is more important than that of the outer façade. Special attention must be paid here to addressing the building physics requirements.



Replacing the window sashes or window layer (on the outside)
The replacement of the outer, historical window level with a new construction is only recommended in individual cases. Apart from the fact that this represents a considerable intervention in the substance, the altering of the external appearance can be minimized with sensitive planning.

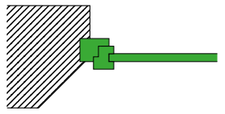
2.1.4 Impact on the whole window

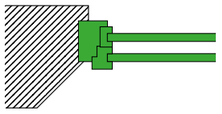
Substitution of the window with a replica

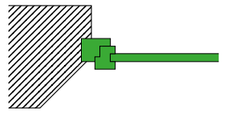
If the maintenance and repair of the historical window construction is not possible due to major damage, can only be achieved at disproportionately high cost, or if there are no requirements for its preservation from preservation point of view, the replacement of the entire window construction can also be considered. The new window should be based on the historical model and correspond to it as far as possible in its material, constructional and aesthetic quality. The proportions, thickness of frame and sashes, the number and shape of the skylights, sash bars and transoms as well as the material, coating and other design characteristics must be considered in the design of the new window. By using energy-efficient glazing and, if necessary, a more energy-efficient construction of the frame, heat losses can be significantly reduced so that the new window meets today's standards.

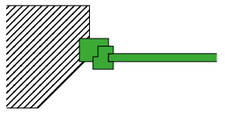
Substitution of the window

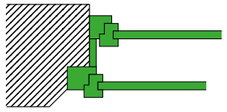
Existing windows can be replaced by new, mostly industrially produced windows. However, this should only be the case if the existing window construction cannot be repaired. The new windows can deviate considerably in their design from historical models but should nevertheless be characterized by a high design standard. The new windows are generally much more energy-efficient and typically have a U-value improved by 70-80%, which sometimes justifies the replacement also from resource efficiency point of view.

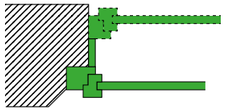


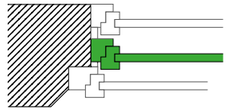


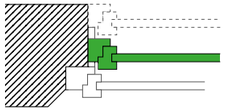












3 Planning information

3.1 Building physics aspects of window renovation – planning advises

All measures on the window must be aimed at improving the structural-physical properties, this means on the one hand improving the thermal properties and airtightness, but at the same time minimizing the risk of condensation and mold on the window itself and the adjoining wall construction.

As stated above, in historic buildings, the window usually represents a thermal weak point, which in winter - depending on the outside temperature and the amount of moisture in the interior - regularly leads to condensation on the inside of the windowpane. Therefore, historic windows often have even devices for collecting and draining off condensation, such as gutters or drawers underneath the window construction.

3.2 Airtightness and condensation risk

Besides the reduction of thermal heat losses, the use of better insulated glass panes in window renovation leads to warmer surface temperatures and thus results in less condensation on these. In addition, the warmer surfaces raise the indoor comfort by preventing cold air downdraughts. In parallel, the improvement of airtightness through the installation of seals on the window itself and in the connection to the wall has a positive effect on the reduction of ventilation heat losses and thus on the energy balance, it prevents damage to the construction and improves indoor comfort by avoiding unwanted infiltrations.

In a modern household however, there is generally much more moisture than it was the case with traditional use (more use of shower, more drying clothes etc.). In view of the reduced air exchange described above and the fact that more moisture is produced in a modern household, it is therefore important to pay attention to thermal bridges around the window in connection with window retrofit (see chapter below).

For reasons of keeping the construction free from damage, it is moreover essential to ensure that the connection of the window to the wall is professionally airtight to avoid the inflow of room air through the joint into the construction and thus a possible build-up of condensation in the building component.

In the special case of multi-layer windows, such as coupled, box-type or winter windows, and for all solutions with an additional high performing layer on the inside, the moisture behavior in the space between the panes must be considered. Here it is important, to locate the airtightness layer (circumferential sealing) at the inner window layer in order to prevent warm room air from flowing into the interspace and condensing on the colder outer panes.

3.3 Thermal bridges around the window

A thermal bridge is an area with a significantly higher heat flow compared to the surrounding surface and can thus cause higher heat losses. Generally, a thermal bridge occurs either at corners and edges of homogeneous building components (geometric) or where different building components join. Thermal bridges at the window are therefore unavoidable, both at the window itself, e.g., in the area of the glass-frame connection and in the area of the window-wall connection.

When better thermally performing windows are installed, the thermal bridge problem in general worsens, because in practice the weak points shift away from the window, which used to be the area with the lowest insulating effect. In winter, low temperatures on the inside of the windowpane cause visible condensation, especially around the edges - the user knew he had to ventilate. This indicator function of the window does not apply to today's constructions, since the weakest areas in terms of thermal insulation are no longer the window, but usually thermal bridges in places that are difficult to see (e.g., room corners, window reveals, sills, surfaces behind furniture).

When retrofitting a window, special attention must be paid to the thermal bridge of the wind-wall-connection. This applies to the connection points in the reveals or the area of the sill/parapet, especially if the window retrofit is not accompanied by insulation of the exterior wall. To prevent the formation of mold at the connection points between the uninsulated wall and the renovated window, it makes sense to carry out calculations on possible condensation in advance. In most buildings worthy of historical preservation, no exterior insulation may be installed. The installation of insulation around the window reveal however is a countermeasure to raise the surface temperature. In order to raise the surface temperature on critical surfaces, one

solution therefor can be partial internal insulation in the reveal/parapet area, e.g., with a thin layer of insulating plaster (see illustration). It may also be necessary to improve other building components or to adapt (natural) ventilation strategies.

- Improved airtightness of windows and higher internal humidity levels in modern households lead to higher condensation risk on cold surfaces.
- Better insulated windows could worsen the thermal bridge problem in the sense of condensate appears in less visible parts of the construction.
- Thermal bridges are not only a risk for condensation, but can also cause high energy losses and thus relativise the energy improvement of the window.

It is therefore recommended to plan the construction details precisely and to pay attention to their accurate execution: airtight window-wall connection, as well as to exclude critical surface temperatures with the help of thermal bridge calculations in accordance with the applicable standards.

3.4 Energy balance of the building

In general, windows are only ONE part of the building and, from an energy point of view, the area of the windows in historic buildings in relation to the total heat-transferring envelope is usually small. Therefore, the entire energy refurbishment concept of the building envelope must always be considered to achieve efficient thermal measures. Window replacement alone reduces losses via the window surfaces and unpleasant draughts by eliminating leaks. Only additional insulation of the building envelope brings another significant increase in energy savings and living comfort. Thus, at best, individual measures should not be planned only for the window, but a sustainable energy concept should be developed for the entire building. In general, there are two aspects to consider in renovation planning:
(i) How big is the influence of the windows on the overall energy balance?
(ii) How can an adapted use make minimal interventions justifiable?

Conservation and energy enhancement of existing windows are a reasonable alternative to the substitution with new windows. Between the maintenance and replacement of the window - there is a whole range of solutions, which show that good functional values can also be achieved by renovating windows.

Checklist – refurbishment of historic windows

Existing stock:

- Determine the overall condition and stability of the existing windows
- Moisture protection (check water traces on surfaces, state of coating, wooden parts, mould growth in reveals etc.)
- Thermal behaviour (window and glazing typology)
- Air tightness (check infiltrations, not well closing window sashes, non-existent sealing etc.)

Checkpoint 1 – stock analysis:
An accurate examination of the existing situation is the basis for any planning and a necessity for estimating the expected costs of the intervention!

Heritage aspects:

- What is the protection level of the building?
- Is there already some information about the window typology available?
- What heritage values are associated to the windows?
- Is the glazing historic?
- Special craftsmanship / workmanship?
- Typical windows of the time and/or territory?

Checkpoint 2 – heritage analysis:
Study the windows and their history (photos, project plans etc.) and identify the elements worth preserving (consult in case a conservator).

Goal – define the targets you would like to achieve:

- Quality of indoor environmental comfort
- Reduction of energy consumption – improvement of energy efficiency
- Future use of the building?
- Holistic retrofit concept for the whole building?
- Design requirements
- Financial aspects

Checkpoint 3 – the targets:
The targets for the final result must be clearly defined. This saves time, money, and misunderstandings.

Planning – get your team:

- Legal aspects > What am I allowed to do? (Monument protection, building law clarifications)
- Heritage office / Historian
- Architectural concept
- Energy efficiency concept
- Building physicists / Envelope consultant
- Special Knowledge of craftsman
- Consult expert for funding possibilities

Checkpoint 4 – integral planning:
All stakeholders must work together. The overall concept must be considered from the beginning. Find out about examples that have already been realised, get information from practical experience. Find suitable companies and craftsmen who know how to deal with historic windows.

The choice of right (energy efficiency) measures:

- Repair and maintenance of the existing parts of the window
- Solve possible moisture issues: Driving rain protection (on the surface, constructive protection), minimize internal sources (ventilation strategy)
- Consider a holistic sustainable retrofit planning for the whole building
- Choose the right measures for energy enhancement of windows considering the technical function and the preservation of the historic values of the window (impact on the external/internal appearance, heritage value).
- Choose the right solution that fits to the local climate and typology of window, considering the impact of the solution the energy balance of the whole building

Checkpoint 5 – Energy enhancement

- A sustainable energy concept should preferably be developed not only for the windows but for the entire building.
- Retrofit of existing windows should be considered, not only for heritage protection reasons, but also with resource efficiency in mind.
- When improving energy efficiency of a window, there are mainly three aspects to consider: (i) minimize ventilation heat loss/leakages, (ii) improve the heat transfer coefficient, (iii) maintain solar gains (in winter).
- Better insulation value of the window does not improve the air tightness and vice versa.
- Minimise sources of moisture and remove remaining moisture through regular ventilation or, ideally, through controlled mechanical ventilation with heat recovery.
- Solve thermal bridges around the window.

Energy enhancement of windows helps to reduce energy costs and leave a better ecological footprint, but also contributes significantly to a higher level of living comfort.

The implementation:

- search for experienced craftsmen
- time planning and coordination with other crafts
- obtain construction quotes for cost clarity
- check for a proper workmanship, especially for sensitive details

Checkpoint 6 - Execution control:
Careful control of the construction is necessary to achieve the planned goals and to ensure a sufficient quality of the execution. For this reason, it is even more important to work with companies that already have experience and good references. The cheapest offer in this context is usually not the best and can lead to hidden costs or undesirable outcomes during the construction.

Publisher: Posoški razvojni center

Authors: Dagmar Exner, Franziska Haas
Photo: Darius Richter, EURAC Research, Historic Environment Scotland, Michael Tribus, Stefan Hitthaler, Trimmel Wall Architekten ZTGmbH

July 2021


eurac research
SITES & CITES REMARQUABLES
Energieinstitut Vorarlberg
universität innsbruck
Posebni razvojni center
SUPSI
teamblau