

# HERITAGE 2016

## 5<sup>th</sup> International Conference on Heritage and Sustainable Development

Edited by  
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Cover photo: Terreiro do Paço, Lisbon (Photo credit: Tourism of Lisbon)

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ISBN 978-989-8734-13-6

Published by  
Green Lines Instituto para o Desenvolvimento Sustentável  
Green Lines Institute for Sustainable Development  
Av. Alcaldes de Faria, 377 S 12  
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<http://www.greenlines-institute.org>

1<sup>st</sup> edition, July 2016  
300 copies

Dep. Legal

Printed by  
Gráfica Vilaverdense – Artes Gráficas, Lda  
Parque Industrial de Gême – Lote C1  
4730-392 Pico de Regalados, Portugal

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# Windows and renovation: The case of 19<sup>th</sup> century ordinary housing in Switzerland

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**ABSTRACT:** This contribution examines the original features and renovation strategies for windows of ordinary late nineteenth and early twentieth century residential buildings in French-speaking Switzerland. The aim is to compare the energy performance of different interventions, as well as assessing their architectural impact. Three types of intervention strategies are compared: adapting windows with single glazing to insulated glazing; replacing existing windows for new timber windows; adding a second window with insulated glazing in front or behind the original window. For each type of intervention, the architectural and thermal insulation impact are compared using the same criteria, drawings at the same scale and by calculating heat transfer coefficients.

## 1 INTRODUCTION

Ordinary residential buildings dating from late nineteenth century and early twentieth century are an essential part of the European built environment. Today, it is important to address the comfort of residents through renovations improving the buildings' energy performance. Nevertheless, strategies aiming for a drastic reduction of energy consumption – such as outside insulation currently applied to new buildings – are often incompatible with their original architectural character. Considering the absence of systematic protection measures, that could sometimes be too restrictive, ordinary buildings are often at risk of being completely disfigured, namely through interventions concerning the windows. An apparently simple procedure such as window renovation can induce important changes to buildings. Not only are the aspects to consider often contradictory, but several strategies are not well-known. It is therefore essential to contribute to research concerning historic windows and to make public alternative solutions to their replacement<sup>1</sup>.

## 2 METHODS

We first identified four types of original nineteenth century windows: windows with single glazing, windows combined with storm windows (*fenêtres d'hiver*), paired double windows (*fenêtres à caisson*) and joint double windows (*fenêtres couplées*). The joinery techniques used were examined by looking at building manuals of the time and by conducting metric surveys in situ. Each type of original window was then drawn at the same scale to make comparison easier, and their heat transfer coefficients estimated.

Secondly, we examined three different types of interventions that improve the windows' energy performance: adapting original windows with single glazing to insulated glazing; adding a second window with insulated glazing in front or behind the original window; replacement for

old-style new timber windows. The interventions were examined in collaboration with joiners to observe the construction processes. As with the types of original nineteenth century windows, we compared the energy performance and architectural impact of the interventions by producing drawings at the same scale and by estimating heat transfer coefficients.

### 3 THERMAL INSULATION REQUIREMENTS

In Switzerland, the energy performance of entire buildings or of specific building components is regulated by the *SIA 380/1 (2009), L'énergie thermique dans le bâtiment*. These regulations specify the methods of calculation and the required thermal insulation values. They are legally binding in most Swiss cantons.

According to the SIA 380/1 (2009) regulations, the heat losses through the windows are measured according to the  $U_w$  variable, which stands for the average heat transfer coefficient through the opening in the wall. To determine the  $U_w$  value it is necessary to apply the ISO 10077-1 (2006) regulations. The latter take into account: the heat transfer coefficient ( $U_g$ ) and the net surface of the glazing ( $A_g$ ); the heat transfer coefficient ( $U_f$ ) and the net surface of the frames ( $A_f$ ); the linear heat transfer coefficient due to the combined thermal effect of the glazing, the spacers, the frame and the perimeter of the glazing ( $l_g$ ). The average  $U_w$  value is then calculated according to the following formula:

$$U_w = \left( \sum U_g A_g + \sum U_f A_f + \sum \Psi_g l_g \right) / \left( \sum A_g + \sum A_f \right)$$

For double windows, the ISO 10077-1 requires the calculation of separate values for each window ( $U_{w1}$  and  $U_{w2}$ ). The  $U_w$  value of the set would then be calculated according to the following formula (ISO 10077-1, 2006: Art. 5.1.2):

$$U_w = 1 / \left( \frac{1}{U_{w1}} - R_{si} + R_s - R_{se} + \frac{1}{U_{w2}} \right)$$

$R_{si}$  and  $R_{se}$  are internal and external surface resistances.  $R_s$  accounts for the thermal resistance of the air-gap between the two windows. In common cases,  $R_{si}$  is 0.13 m<sup>2</sup>K/W and  $R_{se}$  is 0.04 m<sup>2</sup>K/W.

Two procedures can be followed to justify a building's compliance with the SIA 380/1 (2009) regulations. The procedure based on localised performances (*performances ponctuelles*) requires certain coefficients of heat transmission for each renovated component. This method is mostly applied to smaller interventions aiming to renovate only a few building components, such as the windows. In this case, the  $U_w$  of each window should be equal or inferior to 1.3 W/m<sup>2</sup>K. The procedure based on global performances (*performances globales*) requires an energy balance of the transformed areas. This method is generally applied to more significant renovations of entire buildings or of a large part of a building. This method allows for less demanding  $U_w$  values of each component, since the insulation can be divided amongst the various building components.

To evaluate the energy performance of the different windows analysed, the  $U_w$  values according to the ISO 10077-1 (2006) were calculated for a window of 1.00 x 2.00 m. The thermal value of the frames ( $U_g$ ) and of the spacers ( $\psi_g$ ) was obtained through finite element analysis software, Flixo<sup>2</sup>. This method allows for an equivalent evaluation of all window types, both of one original single-glazed window and of double windows.

## 4 ORIGINAL TYPES OF WINDOWS

### 4.1 Window with single glazing

The double-casement window with single glazing (Fig. 1) was the most common in Swiss residential buildings dating from the nineteenth or early twentieth century. Throughout the centuries, this type of window was adapted depending on the possibilities of manufacturing glass,

timber frames and metal hinges. Thanks to the development of insulated glazing, this window is still evolving today, thus being adapted to technical progress and to new energy, acoustic and security demands. The fixed window frames and the casements were usually 35 to 45 mm thick and 60 to 70 mm wide. The fixed frames were placed against the interior side of the wall and their size was slightly smaller than the masonry void. As a result, they were hardly visible from the outside.

The airtightness of the window stiles was often insured by a nut hinge stile. The horizontal elements of the frame (rail, sill) and the casements were usually fitted with a rabbet joint (L-shaped groove). To close the casements, the manuals of the time mention several options: for instance, stiles with a half-round groove (*à geule-de-loup*), ogee stiles (*en doucine*) or feather edge stiles (*en sifflet*) (Rondelet, 1802-1818: 420; Barberot, 1912 [1895]: 525). Windows of ordinary residential buildings in French-speaking Switzerland mostly had half-round grooves, probably due to its increased airtightness.

The glazing was formed by panes of drawn or blown glazing 2 mm thick, which was assembled with an open rabbet. Between the windowpanes there were glazing bars to support and seal the glass on each side.

#### 4.1.1 Energy performance

The theoretical  $U_w$  value of a window with single glazing is approximately  $5.0 \text{ W/m}^2\text{K}$ , calculated according to the 1007-1 regulations (2006). The calculations show that the element with the worst energy performance is clearly the single glazing, with an  $U_g$  value of  $5.9 \text{ W/m}^2\text{K}$ . It is responsible for 90% of heat loss; the other 10% pass through the timber elements.

The lowest temperature on the interior surface of the window is between the glazing and the frames. If there are no radiators below the windows, there is a risk of condensation when the outside temperature is below  $8^\circ\text{C}$ .

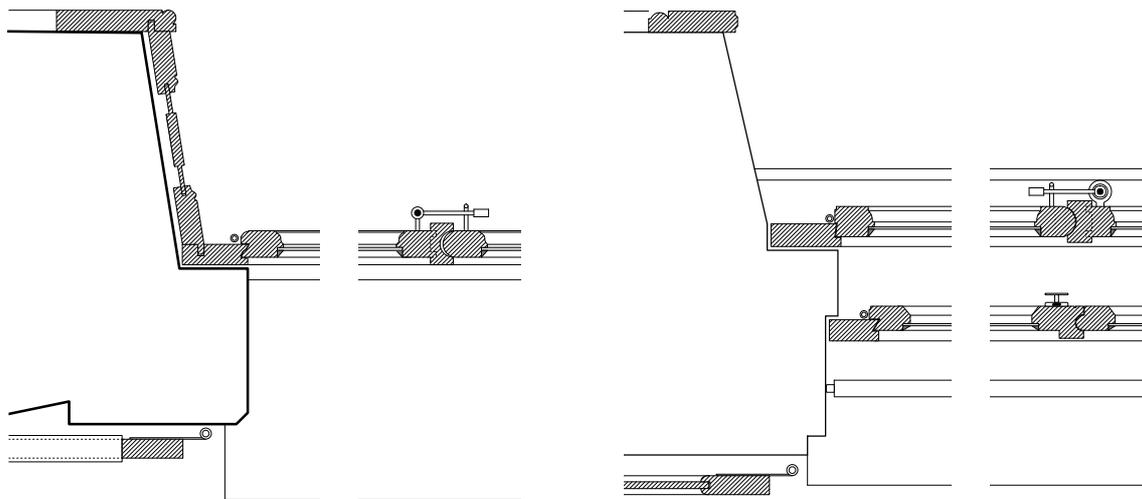


Figure 1. Window with single glazing | Figure 2. Window combined with a storm window

#### 4.2 Window combined with a storm window

The storm window, the paired double window and joint double window are all developments where two single-glazed casement windows were combined to create a more performing element.

To double the window, the simplest solution was to place a storm window on the outside of the main single-glazed window (Fig. 2). The storm window was also a single-glazed casement window that could be removed during the summer months. It was similar to the main interior window, allowing the joiners to use the same fabrication tools. Nevertheless, it was usually considered less important. As a result, it generally had simpler detailing, was made with less noble

wood, such as painted spruce, and was often fitted with a cremone bolt instead of an es-pagnolette bolt. Furthermore, the window was usually placed within the opening, either against a small recess in the stone or by attaching the fixed frame to the wall. It was connected with hooks to the interior window.

#### 4.2.1 Energy performance

Adding a second window reduces conduction heat losses by around 40% when compared with one single-glazed window. We can estimate the combined  $U_w$  value of the two windows at around  $2.3 \text{ W/m}^2\text{K}$ . However, it is difficult to correctly evaluate the influence of the space between the two panes in the calculation. In fact, the air exchange between the three areas (inside, between the panes and the outside) depends on several factors, such as the connection between the frame of the storm window and the masonry, wind exposure or the airtightness of both windows. It is important to note that it is necessary to have an air exchange between the inter-window space and the outside to limit the risk of condensation during the winter.

#### 4.3 Paired double window

The paired double window (*fenêtre à caisson*) was also composed of two windows with an air-gap in between (Fig. 3). A common fixed frame was placed against the sills allowing the second window to be placed on the inside of the main one, with which it formed a set. The hinges of each window were attached to the common frame that formed a case between the windows. There are a few well-preserved examples in French-speaking Switzerland, even though this type of window was more common in Germany, Austria and German-speaking Switzerland.

Constructively, the window on the outer side was identical to the window with single glazing examined. Since the interior window was protected from the bad weather by the latter, it no longer had a weatherboard and the rabbets had detailing similar to a conventional frame. This probably meant that the interior window could be removed during the summer months, similarly to a storm window.

#### 4.3.1 Energy performance

The energy performance and the risk of condensation of the paired double window are similar to the window combined with a storm window. We estimated a theoretical  $U_w$  value of around  $2.4 \text{ W/m}^2\text{K}$ . Sufficient air exchange through the outer window is essential to avoid mould formation.

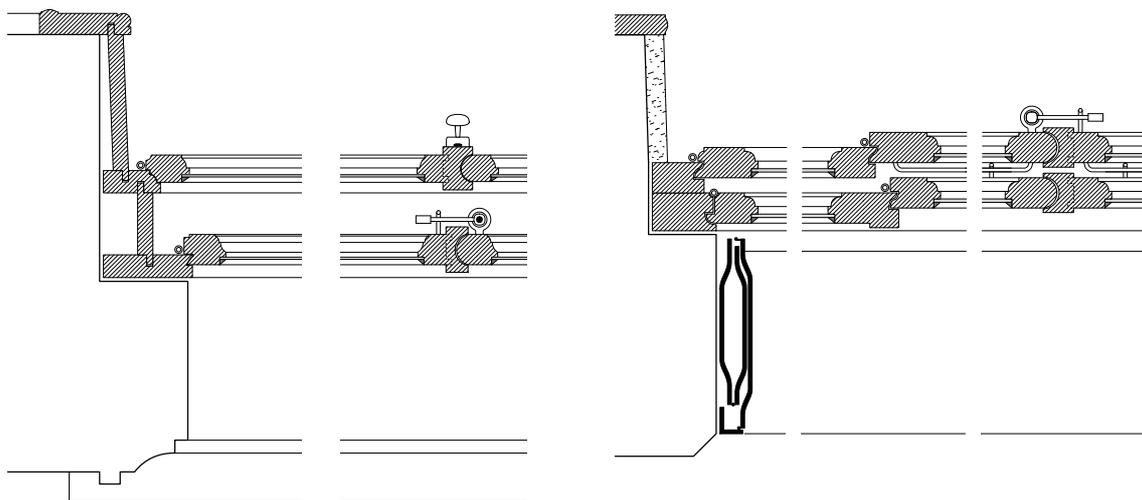


Figure 3. Paired double window | Figure 4. Joint double window

#### 4.4 *Joint double window*

The last type of nineteenth century window examined in this study is a type of double window comprising two windows joined together by several hooks so that they opened simultaneously (Fig. 4). Even though it was used only occasionally, we can still find joint double windows in some buildings. Constructively, we could consider the joint double window as a development of the paired double window, but also as a precursor of the window with double-glazing that started being used around the 1930s. Several new elements were necessary to open both windows at the same time. First, the windows were brought together so that the second window was placed on the inside, next to the first one. Secondly, to limit the space occupied when the casements are open, the outer window was conceived differently: the interior extremities of the frame and of the casement were aligned with the lift-off hinges. As a result, there was a distance of only 2 cm between the windows. Only the interior window had an espagnolette bolt to open and close the window. This type of window was easier to use all year round without taking it up and down between the summer and winter months.

##### 4.4.1 *Energy performance*

The energy and physical performance of the joint double window is similar to the two previous types examined. The calculations according to the ISO 10077-1 regulations determine a  $U_w$  value of 2.3 W/m<sup>2</sup>K. As in the previous examples, there is also a risk of condensation.

## 5 INTERVENTIONS

Original nineteenth century windows with single glazing are often in quite good condition. Nevertheless, they no longer comply with the residents' comfort expectations or with current energy performance demands. Before deciding to systematically replace the original windows by new ones, it is important to consider their architectural value and the possibility of transforming them to comply with today's expectations. We examined three intervention strategies to improve the windows' energy performance. A first option is to adapt the original windows to insulated glazing, which significantly preserves their substance. Secondly, in case of replacement, the original windows are taken down and new windows are placed instead. A third option is to preserve the original window as it was and to add a new second window in front or behind it.

### 5.1 *Adapting original windows with single glazing to insulated glazing*

The renovation of windows by replacing the original single glazing with double insulated glazing is a procedure perfected for the restoration of protected buildings. In French-speaking Switzerland and, particularly, in Geneva, this method is carried out by several joiners that have perfected this technique throughout the years.

The procedure consists of replacing the single glazing with double insulated glazing (Fig. 5). When the window frame is completely renovated, the airtightness is also improved by adding rubber bubble gaskets around the edges of the moveable framework.

Before renovation, it is essential to ensure that the elements that are kept are in good condition, that is, the wooden frames and the metal lift-off hinges. The hinges have to be strong enough to withstand the weight of the new glazing, on average 25 Kg per frame rather than the previous 8 Kg.

The first stage of the work consists of removing the old single glazing and of cleaning the glazing rabbet. Secondly, the latter is adapted to place new insulated glazing around 20 mm thick. If the geometry of the window frame allows for it, the existing glazing rabbet is deepened by 2 to 5 mm. Afterwards, the exterior surface of the wood is cleaned and a new layer of timber – usually in oak – is glued to the original one. This new layer of wood thickens the windows and ensures that the glazing rabbets are deep enough. To place the rubber gaskets it is also necessary to make grooves on the edges of the casements.

The final protection layer (paint, woodstain or varnish) is ideally carried out before placing the glazing and the rubber gaskets. This ensures that all the timber elements are protected, even those that are covered by the putty afterwards.

### 5.1.1 Energy performance

Since the timber framework of the windows is thicker, its  $U_f$  value after renovation is slightly lower than that of the original one. They are usually fitted with double insulated glazing, with 12 mm spacers and two glasses 4 mm thick. Today we can find such glazing with  $U_g$  values of  $1.0 \text{ W/m}^2\text{K}$ , allowing for an average  $U_w$  value of  $1.4 \text{ W/m}^2\text{K}$  for the renovated window. Keeping the physical separation between the glass sections adds around  $0.1 \text{ W/m}^2\text{K}$  per glazing bar to the  $U_w$  value. Even if the  $U_w$  value does not comply with the localised performance method of the SIA 380/1 (2009), its performance would be enough in more generalised renovations according to the global performances method.

### 5.1.2 Future perspectives

This type of intervention preserves the substance of the window frames and most of the windows' appearance. It is mostly applied in the renovation of protected buildings, but is now being increasingly used in more ordinary buildings as well. Nevertheless, the transformation work cannot be automated and is done by hand, which implies a cost similar to a new industrial timber window.

The perspective that vacuum insulated glazing with  $U_g$  values of  $0.6 \text{ W/m}^2\text{K}$  could soon become widely available could make this type of renovation even more common and economically interesting. This would allow for  $U_w$  values of  $1.2 \text{ W/m}^2\text{K}$ , which would easily comply with today's regulations.

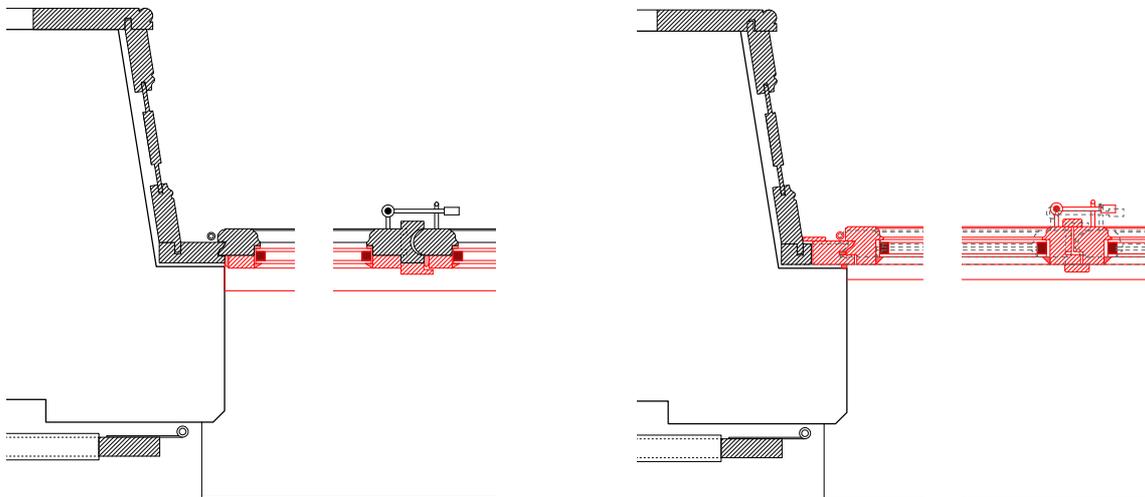


Figure 5. Original window adapted to insulated glazing | Figure 6. Old-style new window

## 5.2 Replacing existing windows

When renovating old buildings, the energy performance of the windows is very often addressed by completely replacing them. The windows that are most used are industrial windows with timber, timber-aluminium or plastic frames, that is, the same types of window found in contemporary buildings. Nevertheless, there are also some cases in which old-style new windows are chosen.

The replacement of old windows usually takes place in a similar way independently of the type of window installed. The old casements are systematically taken down and eliminated while the work done to the fixed frame is more variable. The latter is sometimes taken down completely to place the new frame, or sometimes cut without damaging the woodwork of the sills. The new window is then placed where the former frame used to be.

The production of new industrial windows usually takes place in automatized factories. The industrial frames are conceived for variable sizes and uses, particularly for windows up to 6 meters square applied to contemporary buildings. Today, with the generalized use of insulated tri-

ple glazing, the fixed window frames and the casements can have three times the size of the old ones, in order to support the glazing weighing over 100 Kg and up to 45 mm thick. As a result, the new windows drastically change the perception of the façades and of the interior spaces.

### 5.2.1 *Old-style new window*

Old-style new windows were conceived as a reinterpretation of the old windows, either by using similar materials (spruce or oak) or detailing (Fig. 6). They were developed by joiners as a response to a demand for windows adapted to historical buildings. The aim is to keep, at least to a certain extent, the proportions and the detailing of the old windows in a new window that responds to today's energy demands. Since this is a small market, the windows are hand-made or made in a semi-industrial way.

The old-style new windows have some of the technical detailing of the old windows. As such, the glazing is usually placed with an open rabbet and silicone putty, the casements are attached to the frame by lift-off hinges and they have an espagnolette bolt and a nut hinge stile (*feuillure à noix*) to keep the window airtight. The casements are slightly thicker, allowing for a deeper rabbet to place the insulated double-glazing. The weatherboard of the fixed window frame is made of timber or aluminium. Finally, rubber gaskets are placed around the perimeter of the casements to ensure their airtightness.

The old-style new window has a general appearance that is often close to the old nineteenth century windows through the use of similar techniques, some of the detailing and, mainly, a similar proportion between the glazed and timber surfaces.

#### 5.2.1.1 Energy performance

The similarities between the original renovated window and the old-style window also imply that they have similar energy performances. As such, the theoretical  $U_f$  value of the frame is 2.2 W/m<sup>2</sup>K and that of the entire window  $U_w$  1.5 W/m<sup>2</sup>K. These values are due to the narrow frames, which are not much more insulating than the ones of old windows. The heat loss could nevertheless be reduced if the frame was not directly applied to the wall, but insulated by 5 to 10 mm of PUR foam or another insulating material. This would reduce the estimated  $U_w$  value to 1.4 W/m<sup>2</sup>K.

As in the case of original renovated windows, the windows could only comply with the global performances method of the SIA 380/1 (2009). Special permission would be necessary in a more localised renovation.

#### 5.2.1.2 Future perspectives

The materials used, and the size of the frames of the old-style new window allow for an appearance that is close to the original windows whenever their renovation is not possible. Since the old-style new windows are produced in small series with few automated methods, their price is still higher than industrial windows, which are made in large quantities in an automated way. While in protected buildings this extra cost can easily be justified, in more ordinary buildings planners sometimes have to consider other solutions. Nevertheless, this procedure shows how heritage and architectural demands can be taken into account while responding to today's comfort demands.

### 5.3 *Adding a second window with insulated glazing in front or behind the existing window*

The concept of the paired double window can be used to add a new window on one side or the other of an existing window. This strategy has the advantage of completely preserving the old window, and combining it with the energy performance of contemporary ones. Even though this approach could be considered more restrictive for certain users, it could also produce new spatial features and improve acoustic insulation, thus largely compensating the functional inconvenience of opening two windows.

#### 5.3.1 *New window on the outside of the existing window*

A new storm window placed on the outside of the existing window will act as a thermal barrier and protect the latter from the elements (Fig. 7). Unlike the old storm windows that were taken down during the summer, the new windows are permanently assembled and attached. Techni-

cally, all types of new windows can be used as storm windows even if, architecturally, some types could fit in better with the original façade than others. The new window can either be placed against a small recess in the stone or by attaching it to the fixed frame to the wall. There is usually a distance of around 5 to 15 cm between the windows.

The main reason in favour of placing a new storm window is the fact that the old window can be kept, even when it is not in very good condition, as well as the coherence of the interior detailing that defined nineteenth century bourgeois housing. On the outside, the new window will define the appearance of the façade. The fixed window frames will be systematically visible and the proportion between the glazing and the moveable timber framework will depend on the type of window. For this study, we examined a new old-style window with double-glazing, which has a glazing/timber proportion close to the original windows, as well as a similar appearance.

### 5.3.2 Energy performance

Keeping the main window in place improves thermal insulation by at least 20%. By adding a new storm window with insulated double-glazing, we could reach  $U_w$  values of  $1.2 \text{ W/m}^2\text{K}$ , or  $0.9 \text{ W/m}^2\text{K}$  with insulated triple glazing.

The main problem of this solution is the interruption of the insulation plan. There is a risk of condensation at the intersection of the splays and the frame of the storm window. To avoid condensation it is important to allow for air exchange between the inter-window space and the outside, and limit the air exchange with the inside. This can be controlled by limiting the airtightness of the new window and by placing new rubber gaskets on the existing interior window.

### 5.3.3 Future perspectives

Even if it is not commonly applied, the strategy of placing a new storm window manages to combine energy, heritage and architectural demands, if one can accept the changes to the outside of the buildings. It would also be quite feasible to reverse this type of intervention, making the old windows visible again should technological progress allow for it. In the meantime, they would remain protected behind the new storm windows.

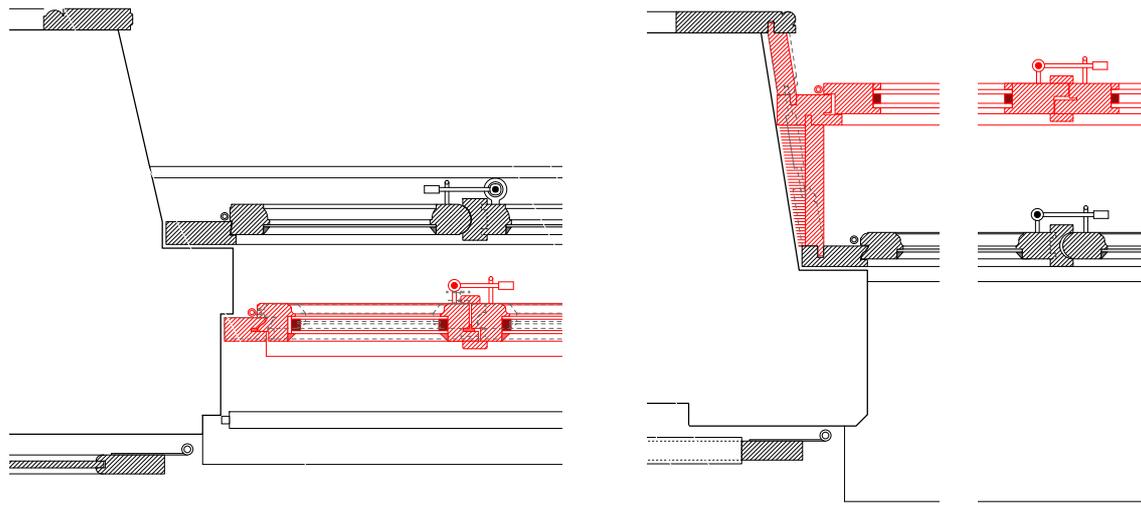


Figure 7. New window on the outside of an existing window | Figure 8. New window on the inside

### 5.3.4 New window on the inside of the existing window

A new second window can also be placed on the inside of the existing window to form a new paired double window (Fig. 8). This intervention strategy preserves the outside appearance of the façades, and the second window is hardly visible from the outside. The transformation consists of adapting part of the old window frame to receive a joint frame and, then, the new window. The latter would have insulated glazing and airtight rubber gaskets. Since the new window is not exposed to the elements, it can have a simpler design than an industrial window: the

weatherboard is not necessary and the rabbets can be simplified in relation to industrial ones, which have chambers to collect water.

In this case, only the outer window is exposed to weathering and must prevent rainwater infiltration. Its paintwork, putties and weatherboards would have to be revised and renovated if necessary. The airtightness of the old window should not be improved, so that humidity values remain balanced.

Adding a second window on the inside partially changes the interior appearance of the opening, forming a space that can be used in several ways. The design of the new window could also draw on the typical character of nineteenth century residential buildings to find a new spatial balance. This intervention has the added advantage of not changing the amount of natural light since the glazing surface does not decrease.

### 5.3.5 *Energy performance*

Placing a new window with insulated glazing on the inside of the existing one can also be interesting from a thermal point of view. The new set of two windows allows for a good insulation of the splays, thus moving the hot-cold limit to the inside. The intervention makes it easier to combine with a global interior insulation of the building.

The thermal calculations show that a  $U_w$  value of 1.1 W/m<sup>2</sup>K can be reached, representing a 30% improvement in relation to one single glazed window. However, it is important to note that the temperature between the two windows will be close to the outside temperature, and can thus be quite low. To keep the hygrometric balance, it is important to place the airtight barrier (rubber gaskets) on the interior window. This is quite easy to do on the new window and avoids transforming the existing one.

### 5.3.6 *Future perspectives*

Globally, turning one single glazed window into a paired double window is an intervention strategy that easily combines energy performance and the preservation of original characteristic elements. It is a solution that is seldom applied in French-speaking Switzerland and that would deserve to be more well-known.

## 6 FINAL REMARKS

This study showed that window renovation is not only conditioned by energetic or acoustic issues, but that other issues should be considered as well: integrating contemporary elements into a historical façade; combining older noble materials with synthetic modern ones; replacing detailed original timberwork by mass produced products; doing away with good quality elements in good condition due to new regulations without considering their value; addressing the future of new windows when the technology of glass production evolves and the market can produce thin and light insulated glazing.

The comparison of different intervention strategies also showed that there are two types of window manufacturing. First, the traditional joiners, who can repair and transform existing windows with careful manual work. Secondly, companies that produce large quantities of factory products and that can offer industrial quality windows at a low price. Usually, traditional joiners work in the restoration field on protected buildings, while the industrial manufacturers work on new buildings or in the renovation of buildings built after the Second World War.

In the case of historical buildings that are not protected, both types of production are applied, even though neither can completely satisfy the demands of this type of work. While the first have solutions that most respect the built heritage but that are more expensive, the second offer economically interesting products that are less adapted to existing buildings.

Due to cost issues, lack of knowledge concerning alternative solutions or high energy performance demands, the old original windows are almost systematically replaced by new industrial windows without an evaluation of other options such as the renovation of an old window or adding a second window to the existing one.

As such, we could consider whether there could be a market for industrial windows adapted to historical buildings. This would require building owners and architects to be aware of the implications and create a demand for this type of product. On the part of companies, it would re-

quire taking initiatives where they use their expertise to make new products adapted to this type of ordinary building.

Finally, it is important to note that renovating existing late nineteenth century buildings also implies other issues – structure, acoustics, network, equipment, etc. – that may have less of an impact on the exterior of the buildings, but that are just as complex and sensitive as window renovation. To preserve this less acknowledged heritage, it is important to draw on former building methods and to identify renovation strategies to reply to contemporary building regulations while preserving the original qualities of the buildings.

## ENDNOTES

1. This work is based on the ReHAB research project on window renovation conducted by Luca Ortelli, Pierre Zurbrügg, Catarina Wall Gago and Georgine Roch at the *Laboratoire de Construction et Conservation* of the *École Polytechnique Fédérale de Lausanne*. Its completion would not have been possible without the support of the *Stiftung zur Förderung der Denkmalpflege*.

2. With the Flixo program it is possible to create bidimensional thermal models and to determine the thermal transmissions with a finite element model (Thun: Infomind [[www.flixo.com](http://www.flixo.com)]). Used version: Flixo 7).

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