



# **D5.6 - Techniques/components for windows retrofit and the manufacturing design of the needed components II**

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Authors	A. Miglioli (ZH), L. Maestri (ZH)
Contributing Partners	POLIMI
Reviewers	F. Leonforte, R. Adhikari (POLIMI)

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# 1. Executive summary

This document is an update of the Deliverable 5.5 on the windows retrofit process. More in detail, it contains a focus on films that can be applied on glazing, designed to enhance thermal/visual performances of existing windows. This analysis is also oriented towards the selection of the most suitable low-intrusive component/technique for the retrofit of the first case study in Milan.

Two additional releases of this document are scheduled by month 19 and 27. The subsequent deliverables will include further specifications and/or modifications according to the results of the first testing activity in the case studies and the future development during the project.

## 2. Technical specifications and guidelines

Generally speaking, in the whole-life environmental perspective, the replacement of the existing windows is more expensive than the retrofit, not only from a sustainable point of view but also from an economic point of view. However, sometimes the window replacement is mandatory if the components are heavily damaged to be repaired or cannot be disassembled or modified.

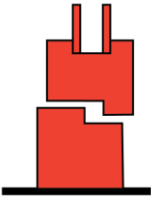
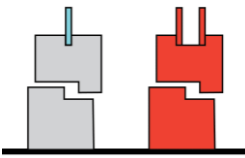
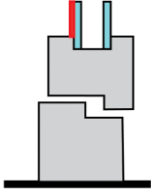
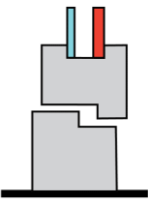
Commonly, to define properly the solution to improve the window's performance, it is necessary to verify their current conditions through a detailed inspection, thereby collecting the information on the main window characteristics and state of conservation.

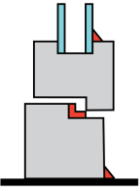

In detail, different intervention levels may be defined according to the state of window systems to be recovered. Currently, they may be grouped as follows:

- overall window system substitution;
- add a secondary window;
- add a film on glazing;
- glazing substitution;
- adding a new glass pane;
- improvement of weatherstrips;
- insulation of the shutter box.

These interventions levels imply different technical solutions, according to the technology of the existing windows installed in the building.

In the next section, all above mentioned intervention solutions are described in detail. Figure 1 shows their pros, cons and feasibility issues for the different window technologies.

Solution	Advantages	Disadvantages	Implementation difficulties		
			Wooden frame	PVC frame	Aluminum/ metal frame
<p><u>Overall window substitution</u></p> 	<ul style="list-style-type: none"> <li>• high thermal and acoustic insulation;</li> <li>• draught-proofing;</li> <li>• solar gains can be increased or reduced.</li> </ul>	<ul style="list-style-type: none"> <li>• high cost;</li> <li>• high embodied CO<sub>2</sub> emissions;</li> <li>• existing windows must be dismantled;</li> <li>• loss of artistic/cultural value of the existing window (in listed buildings).</li> </ul>	Masonry where the existing window is anchored must be recovered.		
<p><u>Add a secondary window</u></p> 	<ul style="list-style-type: none"> <li>• high thermal and acoustic insulation;</li> <li>• draught-proofing;</li> <li>• solar gains can be reduced;</li> <li>• maintenance of artistic/cultural value of the existing window (in listed buildings).</li> </ul>	<ul style="list-style-type: none"> <li>• high cost;</li> <li>• high embodied CO<sub>2</sub> emissions;</li> <li>• possible decrease in visibility;</li> <li>• reduction of window sill space.</li> </ul>	Verify available space for the new window installation.		
<p><u>Add a film on glazing</u></p> 	<ul style="list-style-type: none"> <li>• solar gains can be reduced;</li> <li>• glare from sun can be avoided;</li> <li>• The low-e films are able to reduce the thermal losses;</li> <li>• low cost.</li> </ul>	None	Bad application can leave bubbles on the glass surface. The durability of the component must be analyzed in detail if the film must be applied on the external side.		
<p><u>Glazing substitution</u></p> 	<ul style="list-style-type: none"> <li>• improved thermal and acoustic insulation;</li> <li>• solar gains can be reduced;</li> <li>• windows must not be dismantled;</li> <li>• maintenance of artistic/cultural value of the existing window (in listed buildings).</li> </ul>	<ul style="list-style-type: none"> <li>• implementation process takes longer time than substitute the whole window.</li> </ul>	Verify the available space to add the new glass. A new stop profile is necessary.	Verify the possibility to disassemble the frame and the available space to add the new glass. A new stop profile is necessary.	Verify the possibility to disassemble the frame and the available space to add the new glass. A new stop profile is necessary.

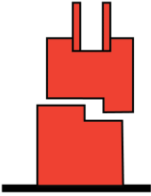
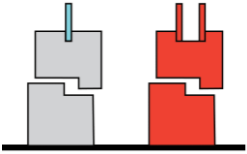
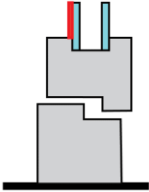
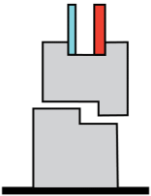
<p><u>Improvements on weatherstrips</u></p> 	<ul style="list-style-type: none"> <li>• reduce thermal losses;</li> <li>• draught-proofing.</li> </ul>	<p>None</p>	<p>None</p>
<p><u>Roller shutter box insulation</u></p> 	<ul style="list-style-type: none"> <li>• reduce thermal losses;</li> <li>• avoid mould problems on the wall.</li> </ul>	<p>None</p>	<p>Insulation solution must not require disassemble the box and the roller.</p>

**Figure 1.** Main intervention categories for windows retrofit

Figure 2 shows a rough evaluation of the intervention costs of the different options for the energy requalification of windows. It should be noted that the prices refer to the Italian market and may undergo variations according to market fluctuations and the specific contexts of European countries.

An update of such evaluation will be provided in the next releases of this deliverable.



Solution	Description and cost range
<p><u>Overall window substitution</u></p> 	<p><i>Wooden frame:</i> 420 - 700 €/m<sup>2</sup>  <i>PVC frame:</i> 405 - 660 €/m<sup>2</sup>  <i>Aluminum/metal frame:</i> 630 - 890 €/m<sup>2</sup>  <i>Biobased frame:</i> 600-800 €/m<sup>2</sup></p> <p>NOTE: The prices indicated consider a double glazing</p>
<p><u>Add a secondary window</u></p> 	<p><i>Wooden frame:</i> 330 - 780 €/m<sup>2</sup>  <i>PVC frame:</i> 320 - 740 €/m<sup>2</sup>  <i>Aluminum/metal frame:</i> 500 - 1000 €/m<sup>2</sup></p> <p>NOTE: The prices indicated consider a double glazing</p>
<p><u>Add a film on glazing</u></p> 	<p>Reflective film: 25 - 32 €/m<sup>2</sup>                      Selective film: 70 - 80 €/m<sup>2</sup>                      Low emissivity films: 35 - 100 €/m<sup>2</sup></p> <p>Skilled labor accounts for about 20 - 40 €/m<sup>2</sup>, to be assessed case by case, based on the degree of difficulty and the amount of work required.</p>
<p><u>Glazing substitution</u></p> 	<p><i>Wooden frame:</i> 300 - 400 €/m<sup>2</sup>  <i>PVC frame:</i> 150 - 250 €/m<sup>2</sup>  <i>Aluminum/metal frame:</i> 400 – 550 €/m<sup>2</sup></p>

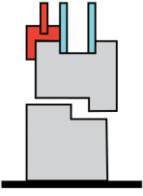
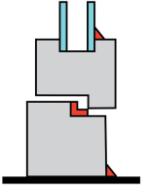
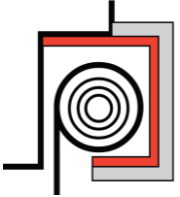

<p><u>Adding a new glass pane</u></p> 	<p>100 – 150 €/m<sup>2</sup></p>
<p><u>Improvements on weatherstrips</u></p> 	<p>50 – 250 €/each</p>
<p><u>Roller shutter box insulation</u></p> 	 <p>Solution with 2 components one of 500 mm of development + rigid base of 240 mm: 50 €/m</p> <p>Solution with 1 component of 790 mm development: 54 €/m</p>

Figure 2. Reference costs for each type of retrofit intervention

## 2.1. Overall window substitution

In some cases, the window elements cannot be recovered or modified, leading the overall windows substitution the only possible option. In particular, usually it occurs when:

- frame damages are too serious to be repaired;
- the window system cannot be disassembled in base elements (i.e., in case of mono-block plastic frame);
- the system integrity and performance may be compromised while modifying its elements;
- quality and performance of all window elements are too poor.

Obviously, this intervention represents the worst case in terms of resource waste reduction, therefore, following two possible solutions may be investigated to reduce the environmental impact:

1. The first one is useful when the window is directly anchored to the masonry (even if it is quite unusual). In this case, the fixed frame may be kept and reused as a substructure for the new window. This avoids damaging the masonry when removing anchors. Moreover, masonry recovery takes time (that may cause delay in windows installation for few days) and results in a significant cost increase.
2. The second one is to disassemble windows elements in an accurate way to dispatch them in a recycling process.

*Circularity issues:* in the removal process of the existing window, there is a huge opportunity to recover materials that can be sorted and sent to recycle/reuse processes: in this case it is suggested to track the amount (volume/mass) of the specific materials sent to recycle/reuse. The procurement of the new windows should include, in the technical specification, requirements concerning the use of recycled materials or re-manufactured elements and the easiness to disassemble in recyclable parts the new windows at the end of their service life.

*Maintenance issues:* the procurement specifications should include the request for the manufacturer to provide a maintenance and use manual. The installation of the new window should be verified with a design review process to check the accessibility and maintainability features of the windows (for instance to allow for an easy cleaning of the glazed parts or lubrication of the moveable hardware). The easiness to repair/replace the parts with a shorter life span (gaskets, mosquito-net, etc.) should be demonstrated by the manufacturer/supplier.

A further improvement in terms of performance can be obtained by adopting innovative frame materials (Fig. 3), such as Biopolyurethane. This material, already tested by INDRESMAT, is able to achieve optimal thermal performance, with a U value (of the frame) equal to  $0.8 \text{ W/m}^2\text{K}$  while ensuring a very low embodied energy compared to traditional solutions.



**Figure 3.** Example of the Bio-PUR window frame

## 2.2. Add a secondary window

A secondary window is a fully independent system installed in the windowsill. Such solution generally allows to maintain the original window unaltered in the original position, which is of particularly important in listed buildings with cultural or artistic significance. While the new system installed can be openable, fixed, or removable. The main advantages obtained from the addition of a double window system can be summarized as follows:

- reduction of thermal losses through the contribution of the existing window and the new one, which can be a double or triple glazing systems with low U-value and low-emissivity glass (Low-E);
- improvement of acoustic insulation provided by the secondary window system (single or double glazing);
- draughts caused by air infiltration through the existing window can be eliminated by the secondary system, which has more efficient perimeter sealing;
- solar gains can be reduced through the secondary window system which can have a specific treatment;
- the addition of the new window in the external position has a positive effect in terms of protection of the old window from the external agents and subsequent extension of the expected service life of the existing window.

*Circularity issues:* in this case, the total amount of materials that is saved by the decision to avoid the removal of the existing window, should be accounted. The procurement of the new windows should include, in the technical specifications, the requirements concerning the use of recycled materials or re-manufactured elements and the easiness to disassemble in recyclable parts the new windows at the end of their service life.

*Maintenance issues:* the addition of the second window should be carefully verified to avoid any interference with the existing one. The possibility to open and clean the two windows should be assured. The procurement specifications should include the request for the manufacturer to provide a operation and maintenance manual. The installation of the new window should be verified with a design review process to check the accessibility and maintainability features of the windows (for instance to allow for an easy cleaning of the glazed parts or lubrication of the moveable hardware). The easiness to repair/replace the parts with a shorter life span (gaskets, mosquito-net, etc.) should be demonstrated by the manufacturer/supplier.

Figure 4 shows a typical example of a secondary window system.



**Figure 4.** Example of secondary window system implementation

### 2.3. Add a film on glazing

A low-cost and efficient solution to improve the window performance consist in the application of specific film on the glazing surfaces. However, before to select the proper component for the windows pane, the compatibility of the product with the glass should be verified. Windows films, according to the manufacturer specifications, can be generally applied on the interior or exterior side of the window, with the results to obtain different performances, as summarized in the Table 1.

<b>Interior Window Film:</b>	<b>Exterior Window Film:</b>
<p>Protection from Wear and Tear: Interior window films are generally more protected from the sever weather, reducing the risk of damage from external factors.</p> <p>Ease of Installation: Installing window film on the interior is usually easier and less complex than applying it to the exterior.</p> <p>Improved Aesthetics: Interior films may provide a more polished appearance as they are not exposed to external elements that might cause damage or reduce the film's clarity over time.</p> <p>Easier Maintenance: Interior films are easier to clean and maintain since they are not exposed to outdoor pollutants, dust, and other debris.</p>	<p>Protection from UV Rays: Exterior window films are more effective at blocking UV rays and solar heat before they enter the building. This can result in better heat rejection.</p> <p>Durability: Exterior films are designed to withstand harsh weather conditions, making them more durable over time. They are less susceptible to scratches and damage.</p> <p>Increased Energy Efficiency: By blocking sunlight before it reaches the glass, exterior films can be more effective in reducing solar heat gain, leading to improved energy efficiency.</p> <p>Reduced Interior Glare: Exterior films can be more effective in reducing glare since they stop the sunlight before it enters the building, preventing reflections on the glass.</p> <p>Technical Installation: Exterior film installation is usually more complex and requires professional expertise. It may involve more specialized equipment and techniques.</p>

**Table 1** – Performance features of interior and exterior window film

Due to the high level of energy performance that must be achieved in RE-SKIN, the exterior application has been analysed in detail.

In general, they can be described according to their features and advantages, as follows:

- **Glare reduction films**  
Glare reduction films, also known as anti-glare or anti-reflective films, are designed to reduce glare from external light sources, such as sunlight or artificial lighting, that can cause discomfort and visual strain most in office spaces. The reduction of intensity is provided thanks to the diffusing and scattering of the incoming light preventing from excessive brightness or reflection that can make hard to see screens and displays.
- **UV Blocking films**  
UV blocking films, also known as ultraviolet (UV) protection films or UV window films, are designed to block and reduce the transmission of harmful ultraviolet rays (UV-A and UV-B). Prolonged exposure to sunrays, in fact, can be detrimental to human health causing damage to skin and eyes and damage valuable objects such as furniture and work of art causing the fading of the surface. UV blocking films can also contribute to energy efficiency by reducing the amount of direct sunlight and heat entering a space.  
UV blocking films are generally available in transparent and clear options. This allows for the preservation of the aesthetic qualities of windows while still providing effective UV protection. These films are virtually invisible, allowing visible light to pass through while blocking UV rays.
- **Spectrally selective films**  
Spectrally selective films, also known as spectrally selective window films, are designed to control the transmission of specific portions of the solar spectrum while allowing other wavelengths of solar radiation to pass through.  
These films are designed to provide specific benefits related solar radiation reduction, and thus energy efficiency and comfort. To stop some portion of the Infrared radiation helps to keep indoor spaces cooler in hot weather, reducing the need for air conditioning and improve energy efficiency. Spectrally selective films are commonly used in commercial and residential buildings, and other applications in order to reduce the amount of solar radiation transmitted by the glass, without compromising the quantity of light. They offer a balance between solar control and visible light transmission making them a versatile choice for window treatments in various climates and environments.
- **Security window films**  
A security window film is a type of protective film that is applied to glass window in most buildings and vehicles to prevent the glass to be shattered into many pieces when broken. This film is typically made of a strong, flexible material like polyester and is designed to adhere to the surface of the glass. Security window films are engineered to make glass more resistant to impacts. In the event of a breakage, the film helps hold the glass together and

this feature is especially important in the case of accidents, vandalism, or natural disasters. Following the UNI 7697 standard the security glass is mandatory in the following cases:

- Internal side – when the glass is positioned at least one meter from the floor level.
  - Inside and outside – if the glass is positioned less than one meter from the floor level.
  - Inside and outside – in all the different types of doors, of any height, when the glass surface extends from the ground.
  - Risk of falling – when there is the possibility of falling and in any case at heights greater than 4 meters from the building floor.
- Low-e films  
 These are a type of window films designed to enhance the energy efficiency of windows by reducing the emissivity of the glass. Emissivity refers to the ability of a surface to emit radiant energy. Low-E films function by reflecting a significant portion of infrared (IR) radiation, which helps to maintain a more consistent indoor temperature. In general, Low-E films are engineered to maintain a high level of visible light transmission. Low-E films find their best application in residential and commercial buildings; they are particularly efficient in cold climates while they are not suitable in hot climates.

Table 2 provides a summary of the key features together with the suitable context application are provided.

WINDOW FILMS TYPOLOGY	KEY FEATURES	SUITABLE APPLICATION
<b>GLARE REDUCTION</b>	Solar glare reduction Enhance visual comfort Improved indoor visibility	Desert Zone High-altitude region Areas with water reflection Snow-covered regions Urban areas with skyscrapers
<b>UV BLOCKING</b>	Filtering harmful UV rays Protection against UV-induced damage Preservation of furniture and interiors	Sunny Coastal Areas Museums and Art Galleries Historic Buildings and Churches Residential and Offices
<b>SPECTRALLY SELECTIVE</b>	Selective control of sunlight Heat reduction without compromising natural light Enhanced energy efficiency	Hot Climate Regions Residential and Offices Hospitals and Healthcare Facilities
<b>SECURITY</b>	Glass reinforcement against impacts Reduced risk of glass shattering Protection against theft and intrusions	Seismic Regions Public Buildings Tornado-Prone Regions High-Crime Areas



<b>LOW-E</b>	Improved thermal insulation Reduction of heat loss in winter Reduction of heat gain in summer	old Climate Regions Extreme Temperature Zones
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**Table 2** – Key Features and suitable context application of different types of solar control films

The market is largely dominated by several multinationals. In the following table some of the major window film companies in the world have been listed with their website and products (Table 3).

COMPANY	WEBSITE	PRODUCTS
<b>3M COMPANY</b>	<a href="http://www.3m.com/windowfilm">www.3m.com/windowfilm</a>	Sun control, privacy & protection, and improved comfort & security for Automotive, Residential and Commercial applications
<b>SAINT-GOBAIN SOLAR GARD</b>	<a href="http://www.solargard.com/">www.solargard.com/</a>	Film solutions for automotive, commercial, and residential applications such as Sun control, Low-E, Safety and Security, and Decorative films
<b>LLUMAR</b>	<a href="http://www.eastman.com">www.eastman.com</a> <a href="http://www.llumar.com/">www.llumar.com/</a> <a href="http://www.vista-films.com">www.vista-films.com</a>	Solar control, Energy-saving, Safety, and Decorative window films Filter films, Transparent window films, Automotive Paint Protection film for cars
<b>JOHNSON WINDOW FILMS</b>	<a href="http://www.johnsonwindowfilms.com/">www.johnsonwindowfilms.com/</a>	Window films for Automotive, Residential and Commercial applications
<b>MADICO WINDOW FILMS</b>	<a href="http://www.madico.com/">www.madico.com/</a>	Protection, safety, security, and decorative window films for Automotive, architecture, healthcare, and aerospace industries

**Table 3** – Major manufacturing companies of different types of solar control films

Since RE-SKIN project aims to reduce the energy consumption of the buildings, the film categories which enhance the thermal performance of glazing are analyzed in detail hereafter.

In such respect, a preliminary market analysis of the solar control film and low-e film have been carried out.

Regarding the solar control films, the values reported in the Table 4 have been derived from an analysis of the data included in the technical specifications provided by the manufacturers. These documents contain reference parameters for various glazing systems, as well as the guaranteed performance after the application of the film. By comparing the performance of the elements, both with and without the window films, it is possible to determine the characteristics of the product itself.

Company	Product	G-value (SHGC)	$\tau_v$	Uv Block	Weight g/m <sup>2</sup>	Roll Dimension	Cost Euro	Warranty
3M Corporation	PR 70 EXT	0.557	0.797	0.384	80-90	n.d	75 €	10 years
Saint-Gobain Solar Gard	LX 70	0.523	0.789	0.273	80-90	n.d	n.d	15 years
Llumar	XHE 70 ER HPR	0.395	0.656	n.d	80-90	152cm x 30m 152 cm x 7,7m	145 €	10 years
Johnson Window Films	SUN 70	0.581	0.753	0.303	80-90	152cm x 30m 152 cm x 7,7m	20 €	Lifetime
Madico Windows Films	NOVA 70	0.628	0.764	0.303	80-90	152cm x 30m 152 cm x 7,7m	n.d	Lifetime

**Table 4** – Features of the commercial solar control films applied on the external layer of the glass

Regarding the LOW-E range, the specific parameters of the products also derive from the comparison of the glazing system with and without the application of the window films. Given the high effectiveness of Low-E films in terms of transmittance, the performances for both single clear and double-clear configurations have been reported in Table 5.

Company	Product	G-value (SHGC)	$\tau_v$	Type	U-Value	Weight g/m <sup>2</sup>	Roll Dimension	Cost Euro	Warranty
3M Corporation	AMBER 35 ALL SEASON	0.400	0.354	clear	0.814	80-90	152cm x 38.2m	115.00 €	15 years
				Double clear	0.885				
Saint-Gobain Solar Gard	Eco LUX 70	0.700	0.785	clear	n.d	80-90	n.d	n.d	15 years
				Double clear	n.d				
Llumar	VE 50 SR CDF	0.743	0.671	clear	0.756	80-90	152cm x 38.2m	155.00 €	10 years
				Double clear	0.915				
Johnson Window Films	SAWPNS15	0.400	0.157	clear	n.d	80-90	152cm x 38.2m	11.87 €	Lifetime
				Double clear	n.d				

**Table 5** - Features of the commercial low-e films applied on the internal layer of the glass

*Circularity issues:* The advantage of this solution is to avoid the replacement of the existing glazing and this could be accounted highlighting the amount of glass saved. Information on recyclability of the polymeric film shall be requested to the manufacturer/Supplier.

*Maintenance issues:* information on expected service life of the film shall be requested in the tender process to the bidders. Considering that the life span of the films is normally shorter than the window life span, the possibility to access easily the windows, should be verified in order to replace the film. The procurement specification should include the request for the manufacturer to provide instruction for cleaning and maintenance of the film.

## 2.4. Glazing substitution

Windows with wooden frames are the most suitable to be repaired and improved, but in many cases modifications on metal and plastic frame are also feasible.

However, if the existing windows will be maintained, it is necessary to reinforce those parts of the window decays characterized by no longer function as per requirements.

Wherever possible, modifications should be carried out in-situ, particularly when the frame cannot be easily removed without damaging either the window or the surrounding walls. In detail, the main repairs that could be necessary for wooden profile are:

- re-secure the open joints by cramping, gluing, re-wedging and pinning, in order to avoid the moisture to enter and cause decay;
- spliced repairs should be made by cutting out rotten wood and splicing or scarfing-in timber inserts which are shaped to obtain the maximum strength and to match the existing profiles;
- cleaning and repairing/replacing missing or broken items;
- when necessary, small areas with material losses can often be filled with wood dust mixed with epoxy resin or polyester resin.

For aluminum or PVC frames, the steps are similar and even simpler, since these materials are not subjected to rot. Thus, the tailored cutting of existing profiles just implies the reconfigurations of the gaskets. If the quality of the current glazing system is poor, glazing substitution solution may provide a significant thermal performance improvement. It is worth to notice that in timber frame windows, this action must consider some limits due to the frame structure. Specifically, the available glazing thickness must be considered, together with its weight. The glass thickness increase also causes a modification in the glass stop profile. For a limited thickness, the current stop profile may

be recovered, by reducing its section; however, reducing its width at less than 20 mm is not recommended, since the anchorage may not be safe.

For wider glazing system, a new glass stop profile should be designed such a way to anchor it to the vertical side of the frame. In this way, this profile may also cover the existing frame and provide a new finishing. This mechanism may be useful for restoring frames with damaged or lacking finishes. In addition, the profile may be coupled with rigid insulating elements to increase the frame thermal resistance.

Among the large number of glazing options (meeting the previous requirements), designers should also consider the most suitable ones according to the climatic zone of building site.

*Circularity issues:* in this case, the amount of materials that is saved by the decision to avoid the removal of the existing frames should be accounted.

*Maintenance issues:* replacement of the glazing system does not significantly impact the maintenance characteristics of the existing windows. A periodical check should be made on the glass stop systems if they have been reduced in size. Another check should be made on the geometry of the windows considering the increased weight of the glass that the frame must bear.

The most significant solutions among the ones under study in RE-SKIN, are presented in the Figs. 5-7, according to the different material profiles.

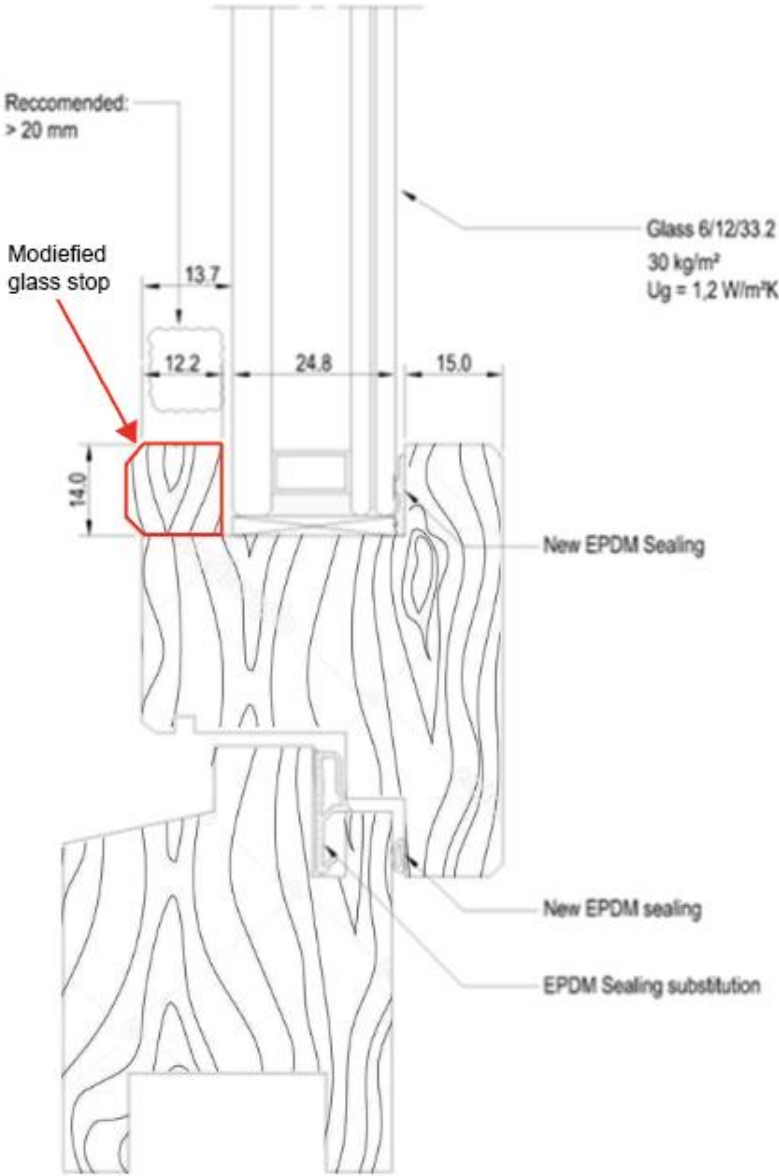


Figure 5. CASE 1 - Glazing substitution on a wooden frame

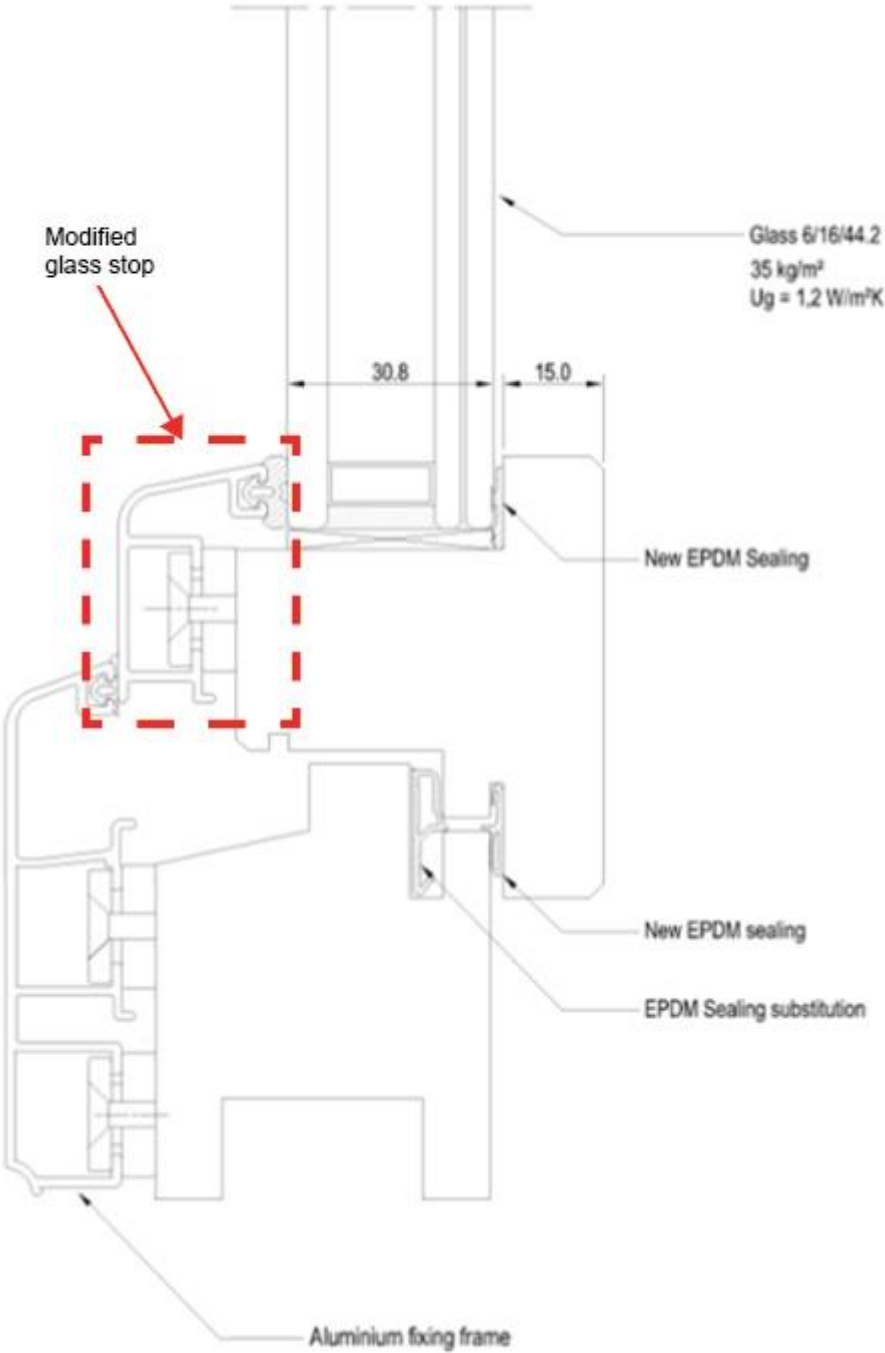


Figure 6. CASE 2 - Glazing substitution on an aluminium frame

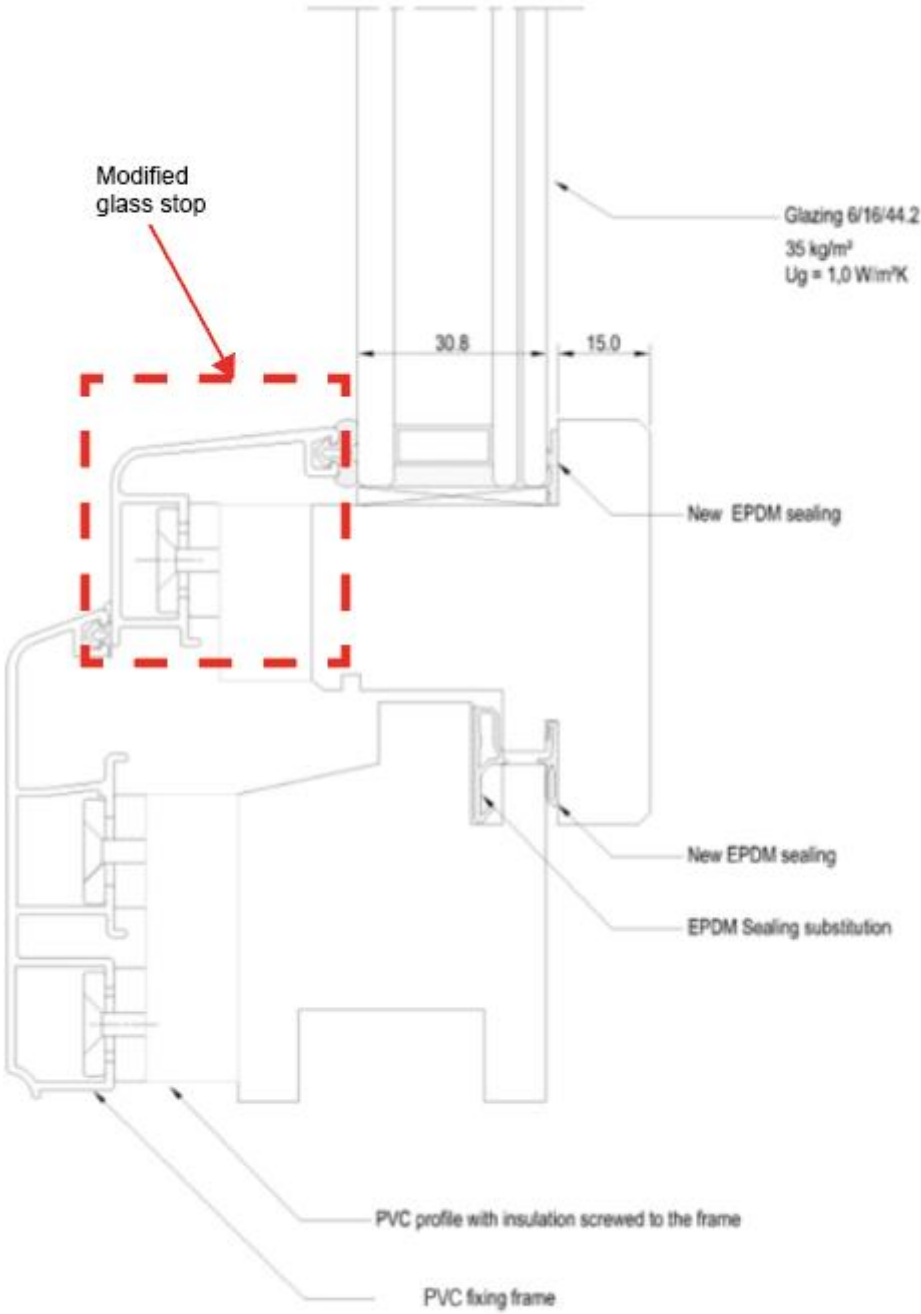


Figure 7. CASE 3 - Glazing substitution on a PVC frame

## 2.5. Improvements on weatherstrips

Draught-proofing is a low-cost option to improve the thermal performance of existing windows. Since existing windows are often a source of air infiltration, the improvements of weatherstrips is one of the possible solution to reduce energy consumption and improve thermal comfort without changes in the building appearance and at minimal cost. Among the draught-proofing solutions, compression strips are usually cheap and easy to install. Compression strips are available in a range of different materials, such as EDPM rubber, silicone, etc.

In order to choose the proper draught-proofing product, the following aspects should be taken into considerations:

- the dimensions of the gaps to be sealed;
- weatherstrips could be seen or not when window is closed and opened;
- the colour of the weatherstrips matching to the window frame;
- consider seasonal expansion and contraction of the window.

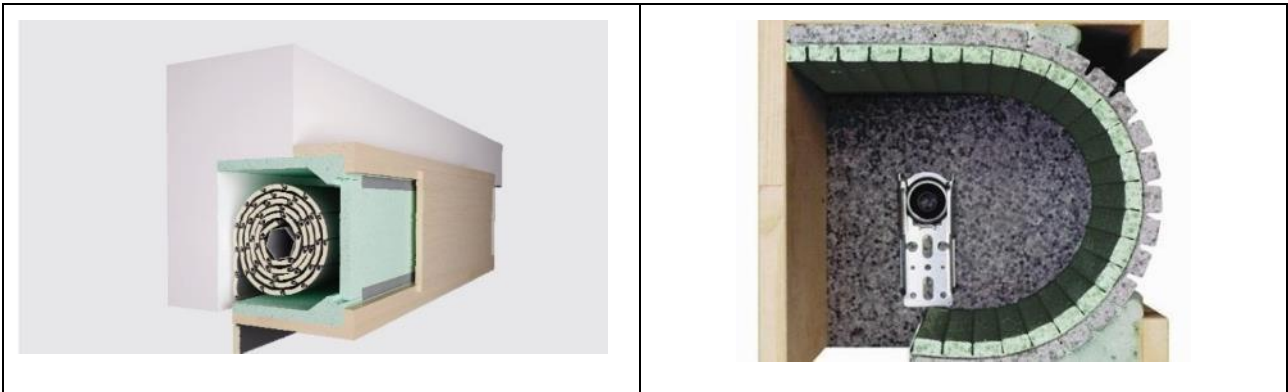
This solution doesn't present relevant circularity issues and maintenance issues.



## 2.6. Roller shutter box insulation

If a roller shutter is present in the window system, its box may represent a node which causes a reduction in thermal performance.

Based on the box and the closing panel geometry and dimensions, different solutions may be adopted to enhance its thermal resistance. The insulation system, in fact, must be suited for mounting without completely disassemble the box and the roller; also, it has to adapt to the box section. The best solutions, identified according to a survey among commercial options, are shown in Fig. 8.



**Figure 8.** Solutions for roller shutter box insulation<sup>1, 2</sup>.

Typically, the one on the left is suitable when the masonry interface is regular, while the second one can be applied even on curved surfaces. Insulation thickness must be checked according to the available space around the roll.

*Circularity issues:* The procurement of the new shutter box or the insulating material should include, in the technical specification, requirements concerning the use of recycled materials or remanufactured elements; the easiness to disassemble in recyclable parts the new shutter box at the end of its service life.

This solution doesn't present relevant maintenance issues.

<sup>1</sup> Courtesy of Würth Group

<sup>2</sup> Courtesy of Milesi Plast srl