HeriTACE

Envelope improvement concepts for heritage buildings

Deliverable D2.2

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Executive Summary

The deliverable "D2.2: Envelope improvement concepts for heritage buildings" is a report that documents the renovation concept creation in Task 2.2 concerning building envelope components: walls, roofs, ceiling and basement floors, windows and shading devices.

The methodology is based on EN 16883 "Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings". The assortment of case study buildings (as described in deliverable D5.1 of the project) along with assessment of their condition and properties (as established in tasks T2.1, T3.1 and T4.1) form the basis for it.

The first part of the report gives a longlist of the measures (46 items) and characterizes them in terms of applicability, effect on the heritage values, effect on inhabitants of the building, environmental impact and technical properties. The second part describes further narrowing of the selection to shortlists, specifically for the archetypical buildings and discusses different scenarios where a combination of them could be applied.

This deliverable should be considered in combination with HVAC (deliverable D3.1) and R2ES (deliverable D4.2) concepts to achieve a holistic overview of the retrofit solutions and scenarios for the heritage building archetypes targeted in HeriTACE. The concepts will be applied to the building and neighbourhood level energy modelling to assess their performance (T3.2, T3.5 and T4.5).

Abbreviations and acronyms

Acronym	Description
EU	European Union
HeriTACE	Future-proofing HERItage Buildings by Optimising Comfort and Energy in Time and SpACE
IAQ	Indoor air quality
HVAC	Heating, ventilation, air conditioning
R^2ES	Renewable and Residual Energy Sources
WP	Work package

Introduction

The ambitions of the European Union (EU) are substantial: to achieve climate neutrality by 2050. The European Green Deal and the New European Bauhaus aim to achieve a sustainable and inclusive society through transdisciplinary collaboration and innovation. The necessity and value of sustainable use and transformation of existing built environment has been emphasized in research for a long time (Fufa et al., 2021). However, one of the most significant challenges in this transition will be the renovation wave of our housing stock, which accounts for 27% of the final energy use of the EU (Eurostat, 2022). Historic cities in Europe present an additional challenge. It is evident that the historically valuable buildings in these cities must be preserved while respecting and considering the inherent heritage and societal values. However, it is unclear how we can balance the aspirations on heritage conservation on individual units with the overarching ambition for climate neutrality at the building stock level. More specifically, there is a need for a framework to assess these different aspects at building or neighbourhood level, and offer insights and solutions to address this challenge.

The HeriTACE project investigates how we can future-proof our heritage buildings in a manner that bridges the gap between heritage restrictions and environmental ambitions. The project focuses specifically on small to medium-sized heritage townhouses pre-dating 1945. Achieving the ambitious goal of climate-neutrality requires a transdisciplinary team to consider all aspects of renovation: heritage value, energy use, user comfort, functionality, cost-effectiveness, and waste management. Heritage restrictions often preclude generic solutions, necessitating innovative approaches to insulation, heating, ventilation, and heat/cold generation.

This report presents the list of envelope retrofit measures that have been selected by local groups of experts as possible solutions to be applied to the archetypical buildings that are studied within the project. The measures deal with exterior walls, roofs, windows and air tightness and are categorized as such.

The first part of the report gives the wider list of the measures and characterizes them in terms of applicability, effect on the heritage values, effect on inhabitants of the building, environmental impact and technical properties.

The second part describes further narrowing of the selection specifically for the archetypical buildings and discusses different scenarios where a combination of measures could be applied.

1. Longlist of envelope improvement solutions

1.1 General

This chapter provides the longlist of measures that can help improve the energy efficiency of the archetypes selected in Task 5.0 (D5.1) and serves as a starting point for further narrowing down to specific combinations of retrofit solutions (see chapter 2).

The methodology is based on EN 16883 "Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings", which suggests a holistic approach to selecting the energy retrofit measures. The assortment of case study buildings (as described in deliverable D5.1 of the project) along with assessment of their condition and properties (as established in tasks T2.1, T3.1 and T4.1) form the basis for it.

Next step is the selection of the longlist of plausible solutions that will be further narrowed down to a shortlist in chapter 2 of this report. The groups from different case study regions included experts with background in building physics, construction site management, heritage and architecture. The expert groups selected feasible solutions based on the needs, possibilities and restrictions of their archetypes. The aspects that were weighed included: technical properties & compatibility with the building, compatibility with heritage values, economic viability, energy performance & sustainability, indoor environmental quality and user experience. Sources of this list include Interreg project HiBERatlas, IEA SHC Task 59, Horizon EU project RIBuild, Prio-Climat-project, IEA EBC Annex 76, Interreg project BIPV meets history, WTA recommendations, FP7 EFFESUS project, FP7 3ENCULT project and expert knowledge and experience of the researchers and practitioners working on task T2.2.

The measures are categorized based on the part of envelope they are applied to and described based on parameters and scales given in Table 1. It should be kept in mind that the solutions on the list are not automatically and universally approved for use and their suitability has to be assessed on archetype and, if necessary, also on case-by-case level.

Table 1 Description of parameters given in longlist of solutions.

List of information	Description
General information	
Product name	An example of the product on the market.
Brand name	Name to identify a company or product.
Source website	Source URL where information or content on the product is published.
Description	A brief description of the product.
Illustration	Generic images of the product.
Relevant climate zone	Applicability of the current measure to different climatic zones relevant to HeriTACE while targeting the archetypes studied in the project.

Common parameters	
Relevant building structure	The building structure type to which the measure can be applied
Integration impact	Description of the impact of incorporating the product or system on the building's structure.
Visibility	Description of the level of visibility of the product after the installation, in terms of dimension, shape, colour, texture, visual perception of 'strangeness'. "Low" indicates that the visual impact is small, meaning that the retrofit product creates a slightly different visual perception of the historic element it is applied on; "Medium" indicates that the visual impact is intermediate, meaning that the retrofit product creates a huge different visual perception of the historic element it is applied on, leaving, however, recognizable its relationship with the other building parts; "High" indicates that the visual impact is considerable, meaning that the retrofit product changes the aesthetics of the building element and its relationship with the other building parts.
Reversibility	Description of the ability to undo or remove a change or installation of a product without causing permanent damage or alteration to the current state of conservation. "Low" indicates that the solutions are hardly reversible, meaning that the retrofit product highly affects the building in case of installation and /or dismantling; "Medium" indicates that the removal of the product may cause minor damage to the building parts; "High" indicates that the retrofit product would not affect the historic building in the installation and /or dismission activities.
Conservation compatibility	Description of how well a product or system aligns with preserving the historical or cultural integrity of the building.
Decrease of operational carbon emissions	Reduction of emissions in the operational phase. It is classified according to a comparative rating by experts, ranging from the lowest value "+" to the highest reduction "+++".
Amount of embedded carbon needed for renovation	Embedded carbon emissions over the entire lifecycle of the product. It is classified according to a rating ranging from the lowest environmental impact "-" to the highest impact "---". It is a comparative assessment given by experts for the different products evaluated.
Technology Readiness Level	Classified according to the following list: TRL 1 basic principles observed TRL 2 technology concept formulated TRL 3 experimental proof of concept TRL 4 technology validated in lab TRL 5 technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) TRL 6 technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) TRL 7 system prototype demonstration in operational environment TRL 8 system is complete and qualified

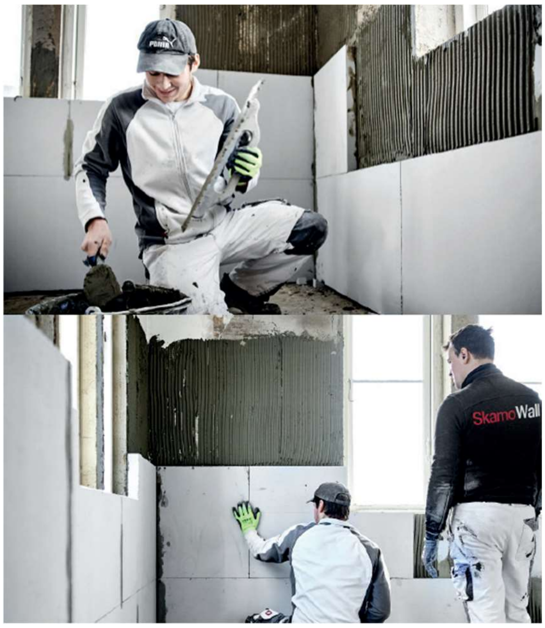
	TRL 9 actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space) n.a. not applicable
Operational costs	Operational cost rating of the product based on a scale that ranges from the cheapest "€" to the most expensive "€€€". It is evaluated by means of expert rating and comparative assessment.
Capital costs (investment)	Investment cost rating of the product based on a scale that ranges from the cheapest "€" to the most expensive "€€€". It is evaluated by experts comparing the different products analysed.
Impact on user	
User discomfort during retrofit	An assessment of user discomfort and interruption duration caused by the installation works of the current solution. It is evaluated by comparing the different products analysed, considering the corresponding installation procedure.
Street & traffic disturbances during retrofit	An assessment of interruptions to the street traffic caused by the installation works of the current solution. It is evaluated by comparing the different products analysed.
Long term impact	A descriptive assessment of the (mainly technical) impact of the finished solution on the user.
Overall parameters	
Impact on acoustic performance	Relative impact on sound insulation caused by application of the current solution. It is evaluated by comparing the declared properties of different products analysed.
Impact on façade detailing	Description of the impact on décor and details on the façade caused by application of the current solution.
Frost damage risk for the structure	Relative impact on frost damage risk caused by application of the current solution ranging from "Reduced risk" to "High risk". It is evaluated by comparing the different products analysed.
Mould growth risk	Relative mould risk caused by application of the current solution, it is not only restricted to the interior surface, but also inside the structure. Categories are: "No risk", "Mould risk in severe cases" (e.g. rain penetration, historic materials with extraordinary properties, if building is left unused and unheated for extended periods, etc.) and "Mould risk in casual use" (e.g. penetrations in vapour tight interior insulation caused by user, high indoor humidity load due disabled ventilation system, etc). It is evaluated based on experience and knowledge of the experts and may be supplemented by relevant information.
Corrosion risk	Relative impact on corrosion risk caused by application of the current solution ranging from "Reduced risk" to "High risk". It is evaluated by comparing the different products analysed.
Salt damage risk	Relative impact on corrosion risk caused by application of the current solution ranging from "Reduced risk" to "High risk". It is evaluated by comparing the different products analysed.
Effect on indoor air quality	Relative impact on indoor air quality caused by application of the current solution ranging from "Reduced risk" to "High risk". It is evaluated by comparing the different products based on information given by producers and experience and knowledge of the experts.

Risk of cracking on façade	Relative impact on risk of cracking of the facade caused by application of the current solution. It is evaluated by comparing the different products based on experience and knowledge of the experts.
Insulation & air tightness solution parameters	
Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	An approximate range of sensibly and safely applicable thermal resistances of the current solution.
Range of typical thickness of insulation layer, mm	An approximate range of sensibly and safely applicable thicknesses of the insulation layer, based on experience and knowledge of the experts.
Thermal conductivity of insulation material λ_D, W/(m*K)	An approximate value of thermal conductivity of the insulation material declared by the producer.
Thermal impact on thermal bridges compared to baseline	Shows if the energy losses through thermal bridges are affected by the current measure. "-" = increased losses; "+" = reduced losses. Assessed based on experience/calculations of the experts.
Impact on interior thermal mass	A relative change of the thermal buffering capacity of the interior surfaces. It is evaluated by comparing the different products analysed based on information declared by the producer and expert knowledge.
Improvement of overall air tightness	Relative improvement of airtightness due to application of the measure. "+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice.
Window solution parameters	
Thermal transmittance of glazing U_g, $W/(m^2 \cdot K)$	An approximate thermal transmittance of the insulated glazing unit (IGU) of the window as declared by the producer or calculated by the experts.
Thermal transmittance of frame U_f, $W/(m^2 \cdot K)$	An approximate thermal transmittance of the window frame as declared by the producer or calculated by the experts.
Solar factor (g-value), -	An approximate solar heat gain coefficient of the glazing as declared by the producer.
Improvement of overall air tightness	Relative improvement of airtightness due to application of the measure based on knowledge of experts. "+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice

1.2 Insulation and airtightness solutions

1.2.1 Interior insulation with calcium silicate (CaSi)

General information

Part of envelope:	walls
Brand name:	Skamol SkamoCovering board
Source name:	Skamol
Source website:	https://skamowall.com/products/skamowall-board
Description: Vapour open "capillary active" interior insulation system for masonry walls.	Illustration:  *https://skamowall.com/media/h14nlljs/skamowall-mounting-instruction-uk.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
	X	X	X

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Outside: none; inside: high
Reversibility	Low
Conservation compatibility	Facades remain the same, interior details would be lost.
Decrease of operational carbon emissions ("+++" = significant decrease)	++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller. Thermal comfort would increase in winter, but may contribute to overheating in summer. New interior finish (plaster).

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in severe cases
Corrosion risk	Low risk
Salt damage risk	Low risk
Effect on indoor air quality	Low risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0.29–0.74
Range of typical thickness of insulation layer, mm	20–50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.068
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	–
Impact on interior thermal mass	Significant decrease of thermal mass, summer comfort needs to be assessed in warm climate.
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.2 Interior insulation with PIR, covered with aluminium

General information

Part of envelope:	walls
Brand name:	Kingspan Therma TW50
Source name:	Kingspan
Source website:	https://www.kingspan.com/gb/en/products/insulation-boards/wall-insulation-boards/thermawall-tw50/
Description: Vapour tight insulation system	Illustration:  *https://www.kingspan.com/gb/en/products/insulation-boards/wall-insulation-boards/thermawall-tw50/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Outside: none; inside: high
Reversibility	Medium
Conservation compatibility	Heritage value of facades is preserved, interior details would be covered.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, long period

Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller but more comfortable. Exposed masonry interior would dissapear

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in casual use
Corrosion risk	Moderate risk
Salt damage risk	Low risk
Effect on indoor air quality	Moderate risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0.9 - 2.3
Range of typical thickness of insulation layer, mm	20 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.022
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	–
Impact on interior thermal mass	Significant decrease of thermal mass
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.3 Interior insulation with PIR, internal surface covered with gypsum board

General information

Part of envelope:	walls
Brand name:	Kingspan Therma TW56
Source name:	Kingspan
Source website:	https://www.kingspan.com/ee/et/tooted/soojustusplaadid/seina-soojustusplaadid/therma-tw56/
Description: Vapour tight insulation system, semi-finished interior surface. Should be attached to the wall using composite fixings and kept air- and vapourtight.	Illustration:  *https://www.kingspan.com/ee/et/tooted/soojustusplaadid/seina-soojustusplaadid/therma-tw56/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Outside: none; inside: high
Reversibility	Medium
Conservation compatibility	Heritage value of facades is preserved, interior details would be covered.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller but more comfortable. Exposed masonry interior would dissapear

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in casual use (if air- & vapourtightness is not ensured)
Corrosion risk	Moderate risk
Salt damage risk	Low risk
Effect on indoor air quality	Moderate risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	0.7 – 1.7
Range of typical thickness of insulation layer, mm	20 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.029
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	–
Impact on interior thermal mass	Significant decrease of thermal mass
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.4 Interior insulation with insulating plaster (plaster with EPS granules)

General information

Part of envelope:	walls
Brand name:	Weber Weber.therm 505 Dämmputz
Source name:	Weber
Source website:	https://www.de.weber/baustoffe-fuer-waermedaemmung-wdvs/daemmputz/webertherm-505-hdp
Description: Interior insulation mortar with added EPS granules to reduce thermal conductivity.	Illustration:  *https://www.de.weber/en/insulating-external-thermal-insulation-composite-system-etic/high-performance-insulating-plastersrenders/webertherm-505-hdp*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
	X	X	X

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Outside: none; inside: high
Reversibility	Low
Conservation compatibility	Heritage value of facades is preserved, interior details would be covered.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller but more comfortable. Exposed masonry interior would be covered.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in severe cases
Corrosion risk	Low risk
Salt damage risk	Low risk
Effect on indoor air quality	Low risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0.3 - 1.0
Range of typical thickness of insulation layer, mm	20 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.05 - 0.07
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	–
Impact on interior thermal mass	Significant decrease of thermal mass, summer comfort needs to be assessed in warm climate.
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.5 Interior insulation with insulating plaster (using hemp fibers)

General information

Part of envelope:	walls
Brand name:	GraHemp Bio Beton®500 Venezia
Source name:	GraHemp
Source website:	https://grahemp.ie/products/insulating-hemp-lime-plaster-single-bucket?variant=44207505375420
Description: Vapour open interior insulation plaster with hemp fibers to reduce the thermal conductivity.	Illustration:  *https://grahemp.ie/products/insulating-hemp-lime-plaster-single-bucket?variant=44207505375420*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
		X	X

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Outside: none; inside: high.
Reversibility	Low
Conservation compatibility	Heritage value of facades is conserved, interior details would be lost
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller but more comfortable. Exposed masonry interior would be covered.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in severe cases
Corrosion risk	Low risk
Salt damage risk	Low risk
Effect on indoor air quality	Low risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0.13 - 0.42
Range of typical thickness of insulation layer, mm	15 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.07-0.12
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	–
Impact on interior thermal mass	Slight increase of thermal mass, summer comfort needs to be assessed in warm climate.
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.6 Interior insulation with AAC (autoclaved aerated concrete)

General information

Part of envelope:	Walls
Brand name:	Xella Ytong Multipor
Source name:	Xella
Source website:	https://technik.xella.de/media/ressources/multipor/broschueren-innendaemmung/multipor-innendaemmsystem-innendaemmung.pdf
Description: Capillary active autoclaved aerated concrete blocks for interior insulation	Illustration:  *https://technik.xella.de/media/ressources/multipor/broschueren-innendaemmung/multipor-innendaemmsystem-innendaemmung.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Outside: none; inside: high
Reversibility	Low
Conservation compatibility	Heritage value of facades is preserved, interior details would be lost
Decrease of operational carbon emissions ("+++" = significant decrease)	++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller but more thermally comfortable comfortable during heating season. Exposed masonry interior would be covered.

Overall parameters

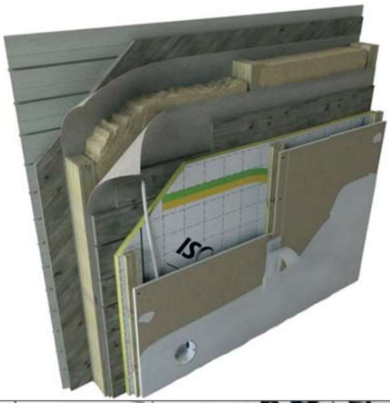
Impact on acoustic performance	Positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in severe cases
Corrosion risk	Low risk
Salt damage risk	Low risk
Effect on indoor air quality	Low risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1 - 2
Range of typical thickness of insulation layer, mm	50 - 100
Thermal conductivity of insulation material λ_D, W/(m*K)	0.045
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	-
Impact on interior thermal mass	Significant decrease of thermal mass
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.7 Interior insulation of wooden log with mineral wool

General information

Part of envelope:	Walls
Brand name:	Isover Vario® InLiner
Source name:	ISOVER
Source website:	https://www.isover.ee/lahendus/palkseina-soojustamine-seestpoolt#description
Description: 25mm insulation + air and variable vapour barrier in one product, simplifying the construction process	Illustration:   *https://www.isover.ee/documents/paigaldusjuhis/vario-inliner-paigaldus.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
	X	X	

Common parameters

Relevant building structure	Wood
Integration impact	Medium
Visibility	No
Reversibility	High
Conservation compatibility	Heritage value of facades is conserved, interior details would be lost
Decrease of operational carbon emissions ("+++" = significant decrease)	+

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Rooms would become smaller but more comfortable. Exposed masonry interior would dissapear

Overall parameters

Impact on acoustic performance	No influence
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	No change
Mould growth risk	Mould risk in severe cases
Corrosion risk	No change
Salt damage risk	No change
Effect on indoor air quality	No change
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0.8
Range of typical thickness of insulation layer, mm	25
Thermal conductivity of insulation material λ_D, W/(m*K)	0.031
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	-
Impact on interior thermal mass	Slight decrease of thermal mass
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.8 Interior insulation of walls with wood-fibre board

General information

Part of envelope:	Walls
Brand name:	Hunton Thermal insulation
Source name:	Hunton
Source website:	https://www.hunton.no/
Description: Interior insulation makes it possible to preserve the existing cladding/facade if it is listed. Insulation material with low carbon footprint.	Illustration:  *https://huntonfiber.co.uk/products/wall/hunton-nativo-wood-fiber-insulation-boards/* *https://multimetall.ee/et/3-hunton-puitkiudvill-tooted*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Wood
Integration impact	High
Visibility	Medium to low
Reversibility	Medium
Conservation compatibility	Not visible from outside. Conserves the exterior cladding
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€€€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	Occupants must be moved out during the retrofit
Street & traffic disturbances during retrofit	No interruption
Long term impact	Should be done before interior finishing. Airtight building needs sufficient ventilation

Overall parameters

Impact on acoustic performance	Improved
Impact on façade detailing	All the exterior facade details would stay the same, but not that of the interior
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Mould risk in casual use (e.g. high indoor humidity load; risk is also dependent on the historic structure and specific product that is used)
Corrosion risk	No change
Salt damage risk	No change
Effect on indoor air quality	Moderate risk
Risk of cracking on façade	The façade becomes colder and more moist

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1.3–2.6
Range of typical thickness of insulation layer, mm	50–100
Thermal conductivity of insulation material λ_D, W/(m*K)	0.038
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.9 Aerosol sealant for air leakage control

General information

Part of envelope:	air leakage locations
Brand name:	AeroSeal
Source name:	AeroBarrier
Source website:	https://aeroseal.com/aerobarrier/
Description: Whole building or part of a building would be overpressurized. Aerosol would be sprayed into the air and the substance would try to escape the room through cracks and cavities, sticking to walls of the cracks and filling these eventually. After solidifying air leakage would be reduced.	Illustration:  *https://aeroseal.com/how/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Low
Reversibility	Low. Small particles would penetrate the masonry.
Conservation compatibility	Heritage value is preserved, but interior surfaces could become more shiny. If the cracks are caused by (seasonal) deformations of the building components, they would probably reappear in some time
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€€€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	Occupants must be moved out during the retrofit
Street & traffic disturbances during retrofit	No interruption
Long term impact	Should be done before interior finishing. Airtight building needs sufficient ventilation.

Overall parameters

Impact on acoustic performance	Very small, positive impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	No change
Mould growth risk	Mould risk in case of insufficient ventilation
Corrosion risk	Low risk
Salt damage risk	No change
Effect on indoor air quality	Moderate risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0 (only air leakage control)
Range of typical thickness of insulation layer, mm	Not relevant
Thermal conductivity of insulation material λ_D, W/(m*K)	Not relevant
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	–
Impact on interior thermal mass	No impact
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.10 Exterior insulation with aerogel plaster

General information

Part of envelope:	walls
Brand name:	Fixit
Source name:	Aerogel insulating plaster
Source website:	https://www.fixit-aerogel.com/en/
Description: A plaster with reduced thermal conductivity because of the aerogel content inside the plaster. Might allow to recreate original details with plaster or on top of it.	Illustration:  *https://www.youtube.com/watch?v=tCFNx7WyyKI*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
		X	X

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Low
Reversibility	Low. Removing the plaster without affecting the façade here under would be challenging.
Conservation compatibility	This solution may be compatible if the restrictions on the facade are not very strict or the historic layer needs to be removed and cannot be preserved. Simpler façade details can be imitated on top of new plaster.

Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("– – –" = significant increase)	–
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	In cases where the plaster is damaged, this solution may be an alternative to replace a traditional material for reducing also the thermal losses from walls

Overall parameters

Impact on acoustic performance	Small, positive impact
Impact on façade detailing	More advanced geometry is possible to be imitated, patina would be lost.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Moderate risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	1.07 - 1.79
Range of typical thickness of insulation layer, mm	30 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.028
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.11 Exterior insulation with insulation plaster (plaster with EPS granules)

General information

Part of envelope:	walls
Brand name:	Weber
Source name:	Weber.therm 505 Dämmputz
Source website:	https://www.de.weber/baustoffe-fuer-waermedaemmung-wdvs/daemmputz/webertherm-505-hdp
Description: Reduced thermal conductivity because of the EPS granule content inside the plaster. The original details could be recreated with or on top of the plaster.	Illustration:  *https://www.de.weber/en/insulating-external-thermal-insulation-composite-system-etic/high-performance-insulating-plastersrenders/webertherm-505-hdp*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
		X	X

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Low
Reversibility	Low. Removing the plaster without affecting the façade here under would be challenging.
Conservation compatibility	This solution could be compatible if heritage restrictions are not very strict and/or historic plaster is damaged, not recoverable and it should be removed and replaced.
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-

Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	In cases where the plaster is damaged, this solution may be an alternative to replace a traditional material for reducing also the thermal losses from walls.

Overall parameters

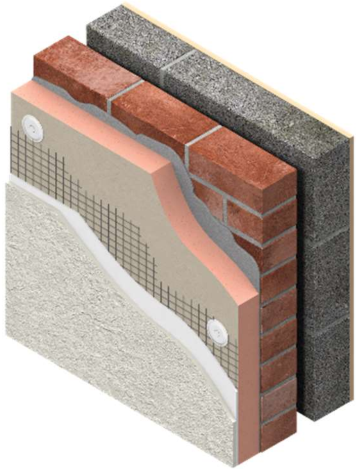
Impact on acoustic performance	Better airborne noise insulation.
Impact on façade detailing	More advanced geometry is possible to be imitate
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Moderate risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	0.3 - 1.0
Range of typical thickness of insulation layer, mm	20 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.05 - 0.07
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.12 Exterior insulation with phenolic foam (ETICS)

General information

Part of envelope:	walls
Brand name:	Kingspan
Source name:	Kingspan website
Source website:	https://www.kingspan.com/gb/en/products/insulation-boards/wall-insulation-boards/kooltherm-k5-external-wall-board/
Description: Highly efficient insulation material to use as exterior insulation – lower insulation layer thicknesses are required to achieve the thermal resistance. Plastered with thin plaster. Insulation is glued and fixed mechanically to the wall structure and plastered with a thin plaster system. According to local fire regulations, fire breaks could be required, escpecially for taller buildings - although it is more fire resistant than e.g. EPS.	Illustration:  *https://www.kingspan.com/gb/en/products/insulation-boards/wall-insulation-boards/kooltherm-k5-external-wall-board/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	Low. Removing the insulation layer without affecting the façade here under would be challenging.
Conservation compatibility	Restoring the historic facade of the building would be hard because the insulation is glued on the facade.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9

Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort and lower thermal losses than before.

Overall parameters

Impact on acoustic performance	Better airborne noise insulation.
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Moderate risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Cracks could appear, if applied incorrectly

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.9 - 9.5
Range of typical thickness of insulation layer, mm	60 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.021
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.13 Exterior insulation with PIR-EPS composite (ETICS)

General information

Part of envelope:	walls
Brand name:	Caparol
Source name:	Capatect DalmatinerFassadendämmplatte S 024
Source website:	https://www.caparol.de/caparol_pim_import/caparol_de/products/ti/113351/TI_024_CT_EN.pdf
Description: More efficient insulation material than EPS. Makes it possible to attach plaster systems because of EPS surface layer. Insulation is glued and fixed mechanically to the wall structure and plastered with a thin plaster system. According to local fire regulations, fire breaks could be required, escpecially for taller buildings.	Illustration:  *https://www.caparol.de/caparol_pim_import/caparol_de/products/ti/113351/TI_024_CT_EN.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	Low
Conservation compatibility	Restoring the historic facade of the building would be hard because the insulation is glued on the facade.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort and lower thermal losses than before.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Moderate risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Cracks could appear, if applied incorrectly

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	2.5 - 8.3
Range of typical thickness of insulation layer, mm	60 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.024
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.14 Exterior insulation with PIR (ETICS)

General information

Part of envelope:	walls
Brand name:	Finnfoam
Source name:	PIR FF GTI
Source website:	https://finnfoam.ee/wp-content/uploads/2024/02/FF-PIR-GT_2017_ee_-FF-FR_201-FF-2017-07-04.pdf
Description: More efficient insulation material than EPS. Plaster attaches to outer textile layer of PIR. Insulation is glued and fixed mechanically to the wall structure and plastered with a thin plaster system. According to local fire regulations, fire breaks could be required, escpecially for taller buildings.	Illustration:  *https://www.linkedin.com/posts/estplasttootmine_siidisaba3-estplast-finnfoam-activity-7178269452696735744-Sr-p*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	Low
Conservation compatibility	Restoring the historic facade of the building would be hard because the insulation is glued on the facade.

Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort and lower thermal losses than before.

Overall parameters

Impact on acoustic performance	Better airborne noise insulation
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Cracks could appear, if applied incorrectly

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.31 - 7.69
Range of typical thickness of insulation layer, mm	60 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.0260
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.15 Exterior insulation with EPS Silver (ETICS)

General information

Part of envelope:	walls
Brand name:	Reiden
Source name:	EPS60 Silver
Source website:	https://reideniplaat.ee/en/products/eps-60-silver/
Description: Wide-spread and cost-effective rigid insulation solution. Insulation is glued and fixed mechanically to the wall structure and plastered with a thin plaster system. According to local fire regulations, fire breaks could be required, escpecially for taller buildings.	Illustration:  *https://reideniplaat.ee/en/products/eps-60-silver/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	Low
Conservation compatibility	Restoring the historic facade of the building would be hard because the insulation is glued on the facade.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort and lower thermal losses than before.

Overall parameters

Impact on acoustic performance	Better airborne noise insulation.
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Cracks could appear if applied incorrectly

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1.56 - 6.25
Range of typical thickness of insulation layer, mm	50 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.0320
Thermal impact on thermal bridges compared to baseline (“-” = increased losses; “+” = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness (“+” = slight improvement, “++” = moderate improvement, “+++” = modern best practice)	+

1.2.16 Exterior insulation with rigid mineral wool (ETICS)

General information

Part of envelope:	walls
Brand name:	Paroc
Source name:	Paroc Linio 10
Source website:	https://www.paroc.com/sv-se/products/paroc-linio-10#specifikationer-litteratur
Description: Wide-spread rigid insulation solution. Insulation is glued and fixed mechanically to the wall structure and plastered with a thin plaster system. Fire resistant.	Illustration:  *https://www.paroc.com/et-ee/products/paroc-linio-10*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	Low
Conservation compatibility	Restoring the historic facade of the building would be hard because the insulation is glued on the facade.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort and lower thermal losses than before.

Overall parameters

Impact on acoustic performance	Better airborne noise insulation.
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Cracks could appear if applied incorrectly

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	1.39 - 5.56
Range of typical thickness of insulation layer, mm	50 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.036
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.17 Dismantlable ETICS system with mineral wool, attached ONLY with mechanical fixings

General information

Part of envelope:	walls
Brand name:	Weber
Source name:	ETICS weber.therm circle
Source website:	https://www.de.weber/en/insulating-external-thermal-insulation-composite-system-etics/etic-system-solutions/etics-webertherm-circle
Description: Insulation solution without glue mortar between old wall and insulation. It would be removable afterwards and only small drill holes would needed to be filled afterwards	Illustration:  *https://www.de.weber/en/insulating-external-thermal-insulation-composite-system-etics/etic-system-solutions/etics-webertherm-circle#*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	Medium
Conservation compatibility	Heritage value is preserved, only small fixing element holes would remain after insulation removal.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€

Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort and lower thermal losses than before.

Overall parameters

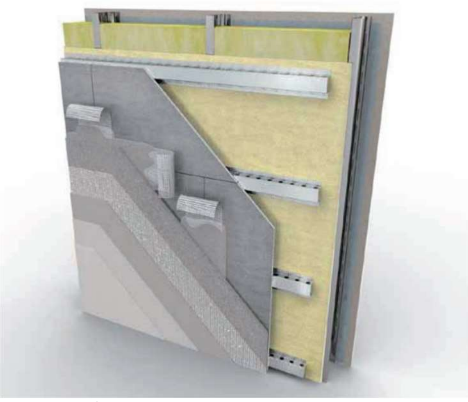
Impact on acoustic performance	Positive impact
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1.4 - 5.6
Range of typical thickness of insulation layer, mm	50 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.036
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.18 Exterior insulation with ventilation cavity, hanging support for plaster. Built on site

General information

Part of envelope:	walls
Brand name:	Saint-gobain
Source name:	AquarocTM system
Source website:	https://prod-gyproc-ie.mac3.content.saint-gobain.io/sites/mac3.gyproc.ie/files/assets/MAM/assets/1/5DAF8FCD673C4EB2912961FFD641B009/doc/BD156DD883944C8B8751B84F8DE67887/PDS-Gyproc-Ireland-Aquaroc.pdf
Description: Insulation system with ventilated facade. Plastered finish, but with reduced risk of hygrothermal deterioration. Quite high space requirements due to ventilation cavity.	Illustration:  *https://puumarket.ee/wp-content/uploads/aquaroctm_tuulduv_fassaadide_krohvimise_susteem.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X		

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	High
Reversibility	Medium
Conservation compatibility	Small fixing element holes would remain after insulation removal.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- - -

Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks

Overall parameters

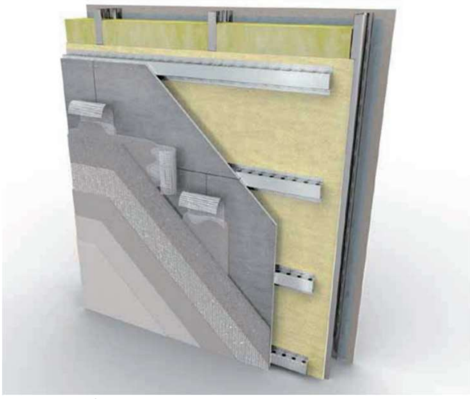
Impact on acoustic performance	Positive impact
Impact on façade detailing	All the details would be covered.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.9 - 5.9
Range of typical thickness of insulation layer, mm	100 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.034
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.19 Exterior insulation with ventilation cavity, hanging support for plaster. Prefabricated exterior insulation panels.

General information

Part of envelope:	walls
Brand name:	Saint-gobain
Source name:	AquarocTM system
Source website:	https://prod-gyproc-ie.mac3.content.saint-gobain.io/sites/mac3.gyproc.ie/files/assets/MAM/assets/1/5DAF8FCD673C4EB2912961FFD641B009/doc/BD156DD883944C8B8751B84F8DE67887/PDS-Gyproc-Ireland-Aquaroc.pdf
Description: Insulation system with ventilated facade. Timber based additional insulation elements are pre-fabricated, but plaster would be applied on site afterwards for no visible joinery.	Illustration:  *https://puumarket.ee/wp-content/uploads/aquaroctm_tuulduv_fassaadide_krohvimise_susteem.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X		

Common parameters

Relevant building structure	Brick & wood
Integration impact	High
Visibility	High
Reversibility	Medium
Conservation compatibility	Historic structure is protected from rain and thermal fluctuations, only small fixing element holes would remain after insulation removal. Compared to on site construction, prefabricated element fixings have less holes, but they are larger.

Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- - -
Technology Readiness Level	TRL 8
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Heavy machinery for short period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks. Higher thermal comfort, lower thermal losses.

Overall parameters

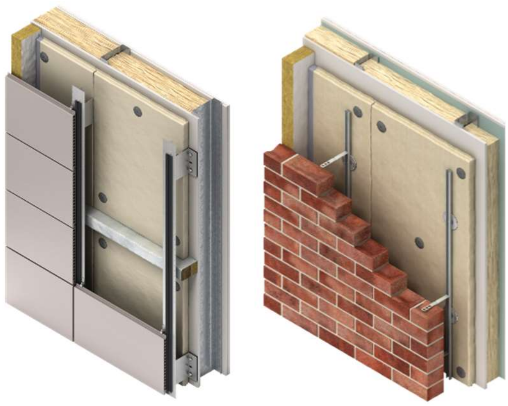
Impact on acoustic performance	Positive impact
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.9 - 5.8
Range of typical thickness of insulation layer, mm	100 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.034
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.20 Exterior insulation from microporous silica-based insulation board. Prefabricated element with ventilation cavity

General information

Part of envelope:	walls
Brand name:	Kingspan
Source name:	AlphaCore Pad insulation
Source website:	https://www.kingspan.com/gb/en/products/insulation-boards/wall-insulation-boards/alphacore-pad/
Description: A microporous silica-based insulation board for premium performance, could be used with ventilated facades. Compared to highly efficient insulation materials which are sensitive to fire (eg PIR), AlphaCore has Euroclass A2 s1,d0 (limited contribution to fire, may produce some smoke) and can therefore be used in applications with higher fire safety requirements.	Illustration:  *https://www.kingspan.com/gb/en/products/insulation-boards/wall-insulation-boards/alphacore-pad/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X		

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	High
Reversibility	High
Conservation compatibility	Small fixing element holes would remain after insulation removal. Historic structure is protected from rain and thermal fluctuations.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- - -
Technology Readiness Level	TRL 7
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Heavy machinery for short period
Long term impact	Higher thermal comfort, lower thermal losses.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1 - 2.5
Range of typical thickness of insulation layer, mm	20 - 50
Thermal conductivity of insulation material λ_D, W/(m*K)	0.02
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.21 Exterior insulation with brick imitation tiles as finishing. Prefabricated element with ventilation cavity

General information

Part of envelope:	walls
Brand name:	Caparol Meldorfer
Source name:	Original Meldorfer®
Source website:	https://www.caparol.de/fileadmin/data/pdf/English/Meldorfer/CAP130350_BRO_Meldorfer_flat_facing_bricks_EN.pdf
Description: Lightweight option for brick imitation – prefabricated insulation elements wit ventilation cavity. Hanging support with ventilation cavity.	Illustration:  *https://www.caparol.de/fileadmin/data/pdf/English/Meldorfer/CAP130350_BRO_Meldorfer_flat_facing_bricks_EN.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X		

Common parameters

Relevant building structure	Brick & wood
Integration impact	High
Visibility	High
Reversibility	Medium
Conservation compatibility	Small fixing element holes would remain after insulation element removal. Historic structure is protected from rain and thermal fluctuations.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- - -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Heavy machinery for short period
Long term impact	Higher thermal comfort, lower thermal losses.

Overall parameters

Impact on acoustic performance	Better airborne noise insulation.
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	2.94 - 5.88
Range of typical thickness of insulation layer, mm	100 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.0340
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.22 Exterior insulation of walls with wood fibreboard

General information

Part of envelope:	walls
Brand name:	Steico Protect dry
Source name:	Steico
Source website:	https://www.steico.com/en/products/etics/steico-etics-timber/steicoprotect-dry
Description: Wood fibre insulation boards that can be rendered directly. This specific product is treated during the manufacturing process making it more mould proof than usual wood products. Glued on the exterior surface of the façade.	Illustration:  https://www.steico.com/fileadmin/user_upload/importer/downloads/4028b6097384810e0174971a1e7421e2/STEICOprotect_dry_en_i.pdf

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick & wood
Integration impact	High
Visibility	Medium
Reversibility	Low
Conservation compatibility	Restoring the facade of the historic building would be hard because the insulation is glued on.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	Regular maintenance of the facade plaster is necessary to avoid biological growth and cracks

Overall parameters

Impact on acoustic performance	Airborne noise insulation is improved.
Impact on façade detailing	Existing historic details would be covered, simpler details could be imitated on top of insulation.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	Mould risk in severe cases (water leakages; long-term mould resistance should be researched)
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Cracks could appear, if applied incorrectly

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, $m^2 \cdot K/W$	1.5-5.4
Range of typical thickness of insulation layer, mm	60-200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.037
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.23 Thin lime-cement plaster applied on insulation

General information

Part of envelope:	walls
Brand name:	Sakret KAM R Lime-cement plaster and KS Exterior silicate paint
Source name:	Sakret
Source website:	https://en.sakret.lv/
Description: 10mm plaster system that could be applied on different insulation materials (EPS, phenolic foam, mineral wool and wood fibre insulation). Smooth surface, finished with silicate paint. Could be hydrophobized.	Illustration:  *Photo: TalTech*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Low
Reversibility	Low
Conservation compatibility	As this solution involves installing both exterior insulation and plaster, it can be compatible if the restrictions on the facade are not very strict or the historic layer needs to be removed and cannot be preserved. Simpler façade details can be imitated on top of new plaster.
Decrease of operational carbon emissions ("+++" = significant decrease)	++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--
Technology Readiness Level	TRL 3
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	This intervention would reduce thermal losses from walls and mould risk on thermal bridges. The thermal comfort will increase too.

Overall parameters

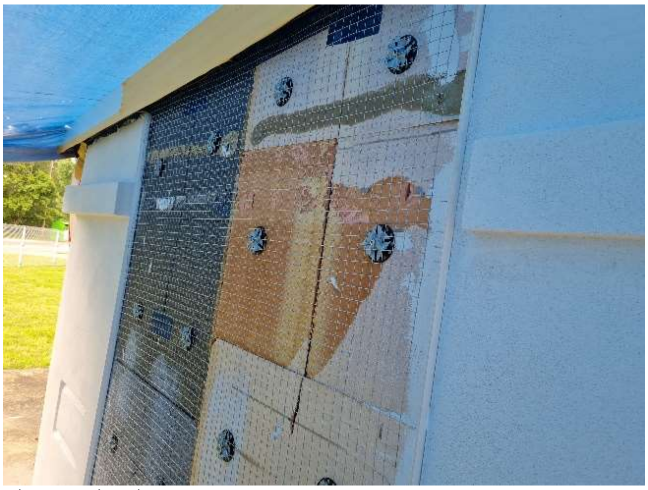
Impact on acoustic performance	Airborne noise insulation is improved.
Impact on façade detailing	Existing historic details would be covered, but simpler details could be imitated on top of insulation.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Moderate risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1.3-9.5
Range of typical thickness of insulation layer, mm	50-200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.021-0.037
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.24 Thick hydraulic lime-cement plaster applied on insulation

General information

Part of envelope:	walls
Brand name:	Sakret KAM-R, NHL-1, NHL-2 and KFF Lime paint
Source name:	Sakret
Source website:	https://en.sakret.lv/
Description: 30mm thick plaster system that could be applied on different insulation materials (EPS, phenolic foam, mineral wool and wood fibre insulation). Thick plaster layer would result with more authentic finish and moisture behaviour, similar to the historical thick plaster that is applied straight on stone and masonry walls. Smooth surface, finished with lime paint. Could be hydrophobized.	Illustration:  *Photo: TalTech*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick
Integration impact	Medium
Visibility	Low
Reversibility	Low
Conservation compatibility	As this solution involves installing both exterior insulation and plaster, it can be compatible if the restrictions on the facade are not very strict or the historic layer needs to be removed and cannot be preserved. Simpler façade details can be imitated on top of new plaster.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--
Technology Readiness Level	TRL 3

Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No interruption
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	This intervention would reduce thermal losses from walls and mould risk on thermal bridges. The thermal comfort will increase too.

Overall parameters

Impact on acoustic performance	Airborne noise insulation is improved.
Impact on façade detailing	Existing historic details would be covered, but simpler details could be imitated on top of insulation.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Moderate risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1.3 - 9.5
Range of typical thickness of insulation layer, mm	50 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.021 - 0.037
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.25 Roof insulation with wood fibre insulation

General information

Part of envelope:	roof
Brand name:	Steico flex
Source name:	Steico
Source website:	https://www.steico.com/en/flex
Description: This solution can be used when converting an attic to living space. Wiid fibre insulation has low carbon footprint and is placed between rafters and if necessary below as well. Roof underlay membrane is usually required on top of insulation, which generally makes it necessary to remove the roofing material too.	Illustration:  *https://www.steico.com/en/flex*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	High
Visibility	Low
Reversibility	High
Conservation compatibility	This solution may be compatible when both roof and ceiling finish have been already changed in recent period or they may be removed due to bad technical condition.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	Limited interruption, long period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Mainly positive consequences: higher thermal comfort, more living space (compared to unheated attic), lower thermal losses, less noise. However, roofing failures are more difficult to detect and repair.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	n.a.
Frost damage risk for historic structure	No risk
Mould growth risk	Mould risk in severe cases (e.g. water & air leakages, if left unheated for prolonged periods)
Corrosion risk	No risk
Salt damage risk	No risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	4.4 - 11.1
Range of typical thickness of insulation layer, mm	160 - 400
Thermal conductivity of insulation material λ_D, W/(m*K)	0.036
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	Slight decrease of thermal mass
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.26 Rigid insulation under concrete floor (e.g. EPS, XPS, PU etc)

General information

Part of envelope:	floors
Brand name:	ESTplast EPS 100
Source name:	ESTplast
Source website:	https://estplast.ee/est/eps-100/
Description: Rigid floor insulation. Existing floor structure (if it exists) is removed, insulation is applied on top of the soil. On top of insulation, PE film is applied and concrete floor poured. It is recommended to install underfloor heating pipes inside the concrete floor.	Illustration:  *https://universalconstructionfoam.com/projects/concrete-slab-insulation-for-hydronic-heat/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	All types
Integration impact	Low
Visibility	Medium. The thickness of the existing floor would be altered.
Reversibility	Low
Conservation compatibility	Existing floor structures could be in bad conservation conditions, nevertheless, concrete floor makes it possible to add more insulation and stability to the existing situation.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- - -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Occupants must be moved out during the retrofit
Street & traffic disturbances during retrofit	No interruption
Long term impact	Reduced thermal losses and improved comfort, hygrothermally safer solution than e.g. ventilated wooden floor above soil.

Overall parameters

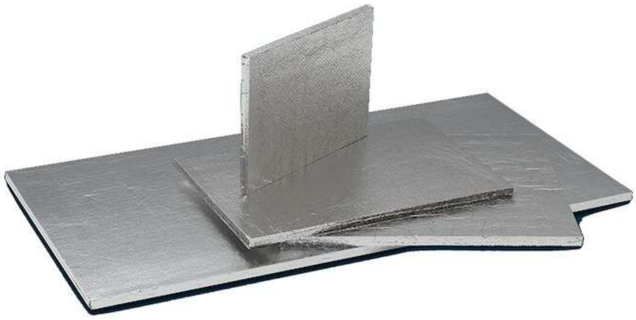
Impact on acoustic performance	No impact
Impact on façade detailing	n.a.
Frost damage risk for historic structure	No risk
Mould growth risk	No risk
Corrosion risk	No risk
Salt damage risk	No risk
Effect on indoor air quality	Possible improvement (if previous solution had issues with moisture).
Risk of cracking on façade	n.a.

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.7 - 8.1
Range of typical thickness of insulation layer, mm	100 - 300
Thermal conductivity of insulation material λ_D, W/(m*K)	0.037
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	Significant increase of thermal mass
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.27 Floor insulation with vacuum insulation panels

General information

Part of envelope:	floors
Brand name:	Promat Ultima VIP
Source name:	Promat
Source website:	https://www.promat.com/en/industry/products-solutions/high-temperature-insulation/rigid-panels/ultima-vip/
Description: Vacuum insulated panels for building applications - Promat	Illustration:  *jushttps://www.promat.com/en-us/construction/products/range/thermal-and-combined-fire-and-thermal-upgrade-boards/promat-ultima-vip/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Medium
Reversibility	Medium
Conservation compatibility	Low
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	---
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Occupants must be moved out during the retrofit
Street & traffic disturbances during retrofit	No
Long term impact	Concerns on durability of these products(?)

Overall parameters

Impact on acoustic performance	Low
Impact on façade detailing	No impact
Frost damage risk for historic structure	No impact
Mould growth risk	No impact
Corrosion risk	No impact
Salt damage risk	No impact
Effect on indoor air quality	No impact
Risk of cracking on façade	No impact

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.0 - 5.7
Range of typical thickness of insulation layer, mm	20 - 40
Thermal conductivity of insulation material λ_D, W/(m*K)	0.007-0.01
Thermal impact on thermal bridges compared to baseline ("–" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.28 Floor insulation of ventilated floor spaces

General information

Part of envelope:	Floors
Brand name:	multiple
Source name:	Thermofloc
Source website:	https://www.thermofloc.com/en/cellulose-based-insulation/applications/floor-ceiling-insulation
Description: Hollow, ventilated floor spaces (e.g. in the case of wooden flooring with a wooden structure) give the opportunity to fill up this cavity with insulation material by blowing in loose-fill insulation materials such as cellulose or place more flexible insulation materials such as mineral wool mats.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium, an intrusion should be made (e.g. by removing some wooden flooring) to blow in the insulation material. When placing mats, more flooring should be removed.
Visibility	Low
Reversibility	Medium. When using insulation mats, they could be removed rather easily.
Conservation compatibility	Good technique to insulate the existing flooring without any visible consequences. Removing (part of) the flooring should happen carefully.
Decrease of operational carbon emissions ("+++" = significant decrease)	++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL9
Operational costs	€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	During the blowing-in of the insulation, the residents should protect themselves.
Street & traffic disturbances during retrofit	No impact.
Long term impact	Better acoustic and thermal performance.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	n.a.
Frost damage risk for historic structure	Low risk
Mould growth risk	Insulation material is treated to be more resistant to mould growth
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	n.a.
Risk of cracking on façade	n.a.

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	variable
Range of typical thickness of insulation layer, mm	Variable, depended on dimensions floor.
Thermal conductivity of insulation material λ_D, W/(m*K)	0.03-0.05
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	0
Impact on interior thermal mass	0
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	0

1.2.29 Dismantling the old brick or limestone wall and building new well insulated wall with the same masonry, using historic cement-lime mortars

General information

Part of envelope:	walls
Brand name:	Paroc Cortex One
Source name:	Paroc
Source website:	https://www.paroc.com/et-ee/products/paroc-cortex-one
Description: Old wall would be carefully taken apart and masonry would be cleaned from the mortar. New wall would be created from modern masonry, then 200mm mineral wool with integrated wind barrier / rain screen would be attached. There would be an air cavity between the new facade, made from original masonry and the wind barrier / rain screen. Masonry would be attached to interior wall with (stainless) steel anchours.	Illustration:  Photo: Martin Talvik

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X		

Common parameters

Relevant building structure	Brick
Integration impact	High
Visibility	Medium
Reversibility	Low
Conservation compatibility	Old structure would be taken apart, but original material is used on the same site in a same wall. Final result is highly dependent of the workmanship quality. As this solution is a drastic intervention, it can be compatible if the restrictions on the facade are not very strict and/or the historic layer is in bad condition.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- - -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	Occupants must be moved out during the retrofit
Street & traffic disturbances during retrofit	Street finishing and soil must be removed temporarily
Long term impact	Lower thermal losses, higher thermal comfort.

Overall parameters

Impact on acoustic performance	Better airborne noise insulation
Impact on façade detailing	Only simple geometry is possible to be imitated.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Low risk
Salt damage risk	Low risk
Effect on indoor air quality	No risk
Risk of cracking on façade	Low risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	2.8 - 5.6
Range of typical thickness of insulation layer, mm	100 - 200
Thermal conductivity of insulation material λ_D, W/(m*K)	0.036
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	Slightly reduced, but still significant
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.30 Repointing/refilling the joints between old masonry with new historical mortar

General information

Part of envelope:	walls
Brand name:	Sakret KZM-2
Source name:	Sakret
Source website:	https://sakret.ee/product/kzm-2-valge-pae-ja-looduskivi-ladumissegu/
Description: Cracks in the historic wall can cause significant water and air leakage. Repointing the joints would reduce the leakages and moisture-related issues (e.g. frost, mould) while slightly increasing thermal comfort. The composition of the mortar should be selected so that it is compatible with the historic materials and structure.	Illustration:  *https://www.self-build.co.uk/repointing-brick-stone-walls/*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick
Integration impact	Low
Visibility	Low
Reversibility	High
Conservation compatibility	The correctly selected repointing mortar will increase the durability of
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€€€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	Limited interruption, short period
Street & traffic disturbances during retrofit	Scaffolding installation for long period
Long term impact	If the mortar has similar components to the historic one, the solution would be more compatible and durable. Reduction of water infiltration and air leackage would reduce negative effects in the long term on the indoor microclimate and on the building conservation.

Overall parameters

Impact on acoustic performance	No impact
Impact on façade detailing	All the facade details would stay the same
Frost damage risk for historic structure	Reduced risk
Mould growth risk	Reduced risk
Corrosion risk	Reduced risk
Salt damage risk	Reduced risk
Effect on indoor air quality	Reduced risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	n.a.
Range of typical thickness of insulation layer, mm	n.a.
Thermal conductivity of insulation material λ_D, W/(m*K)	n.a.
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	No change
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.31 XPS plinth insulation board with 15mm lightweight concrete board cover

General information

Part of envelope:	cellar
Brand name:	Styrock HR
Source name:	Styrock
Source website:	https://www.styrock.eu/wp-content/uploads/2020/08/Styrock-brochure-ENG.pdf
Description: Plinth area could be insulated with moisture safe XPS boards. Preinstalled lightweight concrete board makes the plinth stucco to last longer than if applied straight on the insulation.	Illustration:  *https://www.styrock.eu/wp-content/uploads/2020/08/Styrock-brochure-ENG.pdf*

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X		

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Medium
Reversibility	Low
Conservation compatibility	This solution affects only the plinth of the façade.
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Temporary bridges to access the building
Street & traffic disturbances during retrofit	Street finishing and soil must be removed temporarily
Long term impact	Higher thermal comfort, lower thermal losses, possibly lower risk of moisture related issues.

Overall parameters

Impact on acoustic performance	No impact
Impact on façade detailing	All the details would be covered.
Frost damage risk for historic structure	Reduced risk
Mould growth risk	No risk
Corrosion risk	Reduced risk
Salt damage risk	Moderate risk
Effect on indoor air quality	No risk
Risk of cracking on façade	No additional risk

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	1.5 - 3.6
Range of typical thickness of insulation layer, mm	50 - 120
Thermal conductivity of insulation material λ_D, W/(m*K)	0.033
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+

1.2.32 Airtightness of window wall interfaces

General information

Part of envelope:	Walls
Brand name:	Isola Wiflex Tape
Source name:	Isola
Source website:	https://www.isola.no/produkter/vegg/vindsperretape/vindsperre-tape-wiflex
Description: Used around windows to improve the airtightness of the transition. Also used for sealing joints, penetrations, details, transitions and connections between air barriers and other building materials.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Low
Visibility	Low
Reversibility	High
Conservation compatibility	Heritage building components would be preserved
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	Limited interruption, short period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Decreasing the heat loss by air leakages around windows

Overall parameters

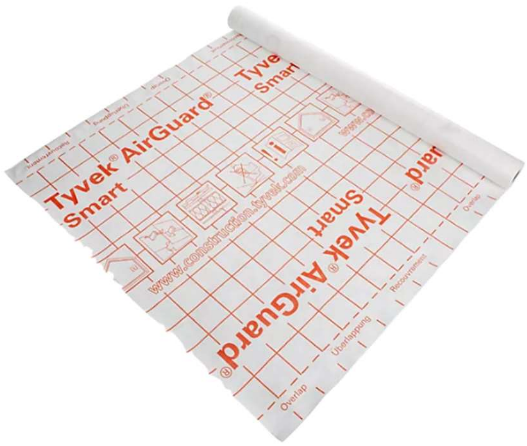
Impact on acoustic performance	Positive impact
Impact on façade detailing	No impact
Frost damage risk for historic structure	Same
Mould growth risk	Reduced
Corrosion risk	Same
Salt damage risk	Same
Effect on indoor air quality	Air infiltration through the envelope is decreased. Enough ventilation of indoor air should be controlled
Risk of cracking on façade	Same

Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	Not relevant
Range of typical thickness of insulation layer, mm	Not relevant
Thermal conductivity of insulation material λ_D, W/(m*K)	Not relevant
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	Only if combined with insulation of gap between window and wall.
Impact on interior thermal mass	No change
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.2.33 Moisture adaptive vapour barrier

General information

Part of envelope:	Walls, roofs
Brand name:	Tyvek® AirGuard Smart2
Source name:	Tyvek
Source website:	https://www.isola.no/produkter/vegg/dampsperre/dampsp-airguard-smart2-1-5x50m
Description: Vapour barrier with varying water vapour resistance (sd-value) to allow drying of moisture. Used for air and vapour sealing in ceiling and walls in normal dry buildings. Compact/Closed structures are assumed where all cavities are fully insulated and the interior cladding has low water vapor resistance. Can be used separately, but is typically installed in combination with interior thermal insulation and positioned behind the interior (vapour open) cladding.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	The product is positioned behind the interior cladding and not visible, however, its typically used in combination with interior insulation which affects the interior appearance.
Reversibility	High
Conservation compatibility	Used in combination with interior insulation. Exterior façade can be conserved.
Decrease of operational carbon emissions ("+++" = significant decrease)	++

Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	Occupants will be interrupted and must be moved out during the retrofit if internal retrofit, for external retrofit they can stay
Street & traffic disturbances during retrofit	No interruption
Long term impact	Might lead to smaller living areas if interior retrofit

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	Low
Frost damage risk for historic structure	Low
Mould growth risk	Dependent on whether combined with interior (increased) of exterior insulation (decreased)
Corrosion risk	-
Salt damage risk	-
Effect on indoor air quality	Air infiltration through the envelope is decreased. Enough ventilation of indoor air should be controlled
Risk of cracking on façade	-

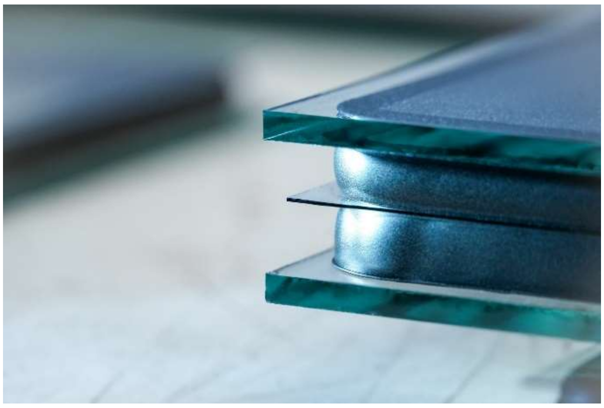
Insulation & air tightness solution parameters

Achievable thermal resistance of new layers for typical thickness range, m²·K/W	Not relevant
Range of typical thickness of insulation layer, mm	Not relevant
Thermal conductivity of insulation material λ_D, W/(m*K)	Not relevant
Thermal impact on thermal bridges compared to baseline ("-" = increased losses; "+" = reduced losses)	+
Impact on interior thermal mass	No
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+++

1.3 Window solutions

1.3.1 Thin-glass triple-pane glazing for windows

General information

Brand name:	In various research facilities
Source name:	Pacific Northwest National Laboratory (PNNL)
Source website:	https://www.osti.gov/biblio/2202444 https://link.springer.com/article/10.1007/s12273-018-0491-3 https://www.osti.gov/biblio/2202438
Description: Very efficient thin glazed window, that has very thin middle layer for reduced weight and carbon footprint. Thin triple pane glazing could fit into existing frame as well as traditional double-glazing.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Medium
Reversibility	Medium.
Conservation compatibility	Compared to traditional triple pane windows, they are much thinner and less visible. To host the new this glass in the window it is necessary to widen or adjust the historic frame seat.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 8
Operational costs	€

Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	Limited interruption, short period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Higher thermal comfort, lower thermal losses.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	n.a.
Frost damage risk for historic structure	n.a.
Mould growth risk	n.a.
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	n.a.
Risk of cracking on façade	n.a.

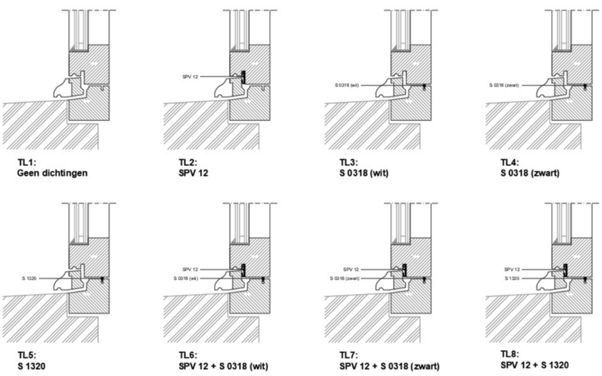
Window solution parameters

Thermal transmittance of glazing U_g, W/(m²·K)	0.5
Thermal transmittance of frame U_f, W/(m²·K)	n.a.
Solar factor (g-value), -	0.7
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	n.a.

1.3.2 Install gaskets/selants to improve airtightness of window frames

General information

Brand name:	Deventer
Source name:	Deventer
Source website:	https://www.deventer-profielen.nl/
Description: By milling the space for new gaskets or sealants, the airtightness of existing (wooden) window frames can be improved a lot. The view of the window is not altered.	Illustration:



Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
x	x	x	x

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium. The original window frames need to be adjusted.
Visibility	Low.
Reversibility	Medium. The sealants can be removed, but the holes remain present.
Conservation compatibility	When the original windows are in a good condition and are not replaced/fitted with new glazing, this is a good option to improve the performance of the windows.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	The manipulation of the window frames is most of the time done on site, so limited interruption.
Street & traffic disturbances during retrofit	No interruption
Long term impact	Better airtightness so less risk of draught.

Overall parameters

Impact on acoustic performance	Large
Impact on façade detailing	n.a.
Frost damage risk for historic structure	n.a.
Mould growth risk	n.a.
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	When no ventilation system is employed, the improved airtightness might have a negative effect on the IAQ.
Risk of cracking on façade	n.a.

Window solution parameters

Thermal transmittance of glazing U_g, W/(m²·K)	n.a.
Thermal transmittance of frame U_f, W/(m²·K)	n.a.
Solar factor (g-value), -	n.a.
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	+++

1.3.3 Single pane glazing with low e-glass

General information

Brand name:	Tatra glass Heritage Drawn 4.5 ECO laminated– Tatraglass
Source name:	Tatra glass
Source website:	https://tatraglass.co.uk/heritage-drawn-4-5/
Description: A single glass pane of drawn or mouth blown glass (respectively 4.5 mm and 2 mm) is laminated to a high-performance glazing type. The result is a single glass pane with a thickness between 6.8 and 8.8 mm with a thermal performance that is better than classic single glass panes and with a historic exterior look. The high performance glass pane is provided with a low e-coating.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Low
Reversibility	Low
Conservation compatibility	The very thin single glass pane can be a good replacement for the original glass pane (when possible). The glass view can be adjusted to resemble the original look.
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--
Technology Readiness Level	TRL 9
Operational costs	€€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	Limited interruption, short period

Street & traffic disturbances during retrofit	No interruption
Long term impact	Look from the inside may be not the original glass look. Better thermal performance, less risk of condensation.

Overall parameters

Impact on acoustic performance	Low
Impact on façade detailing	Low
Frost damage risk for historic structure	n.a.
Mould growth risk	n.a.
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	n.a.
Risk of cracking on façade	n.a.

Window solution parameters

Thermal transmittance of glazing U_g, $W/(m^2{\cdot}K)$	3.6
Thermal transmittance of frame U_f, $W/(m^2{\cdot}K)$	n.a.
Solar factor (g-value), -	0.8
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	n.a.

1.3.4 Vacuum glazing

General information

Brand name:	Fineo Heritage
Source name:	Fineo
Source website:	www.fineoglass.eu
Description: The air cavity of this double glazed system is a vacuum, resulting in very low thermal losses through the glass and a very thin (11.3) and lightweight (27.5 kg/m²) glass system. Different monumental glasses are possible, resembling the original look as much as possible. The process of making the air cavity vacuum necessitates a grid of micro-pillars, which could be visually disturbing.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Medium (micro-pillars are visible)
Reversibility	Low
Conservation compatibility	The vacuum glazing is a good replacement for the original glass pane (when possible). The glass view can be adjusted to resemble the original look.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	Limited interruption, short period

Street & traffic disturbances during retrofit	No interruption
Long term impact	Better thermal performance, the original loos might be disturbed by the micro-pillars.

Overall parameters

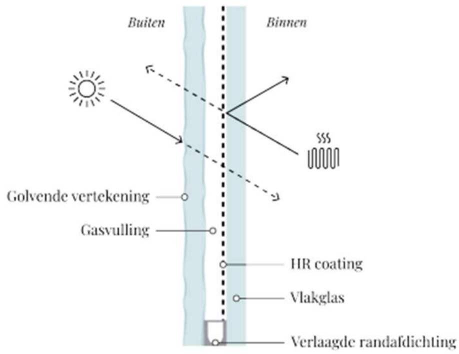
Impact on acoustic performance	Medium (Rw = 39 dB)
Impact on façade detailing	Small
Frost damage risk for historic structure	n.a.
Mould growth risk	n.a.
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	n.a.
Risk of cracking on façade	n.a.

Window solution parameters

Thermal transmittance of glazing U_g, W/(m²·K)	0.7
Thermal transmittance of frame U_f, W/(m²·K)	n.a.
Solar factor (g-value), -	0.6
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	n.a.

1.3.5 Thin double glazing

General information

Brand name:	Monuglas® Historic 9
Source name:	Monuglas
Source website:	https://monuglas.nl/oplossingen/
Description: Thin double glazing consists of two glass panes. The exterior glass pane is a replica of historical glass panes and has a thickness of 3 mm. The interior glass pane is typical glass pane of 3 mm thickness. The air cavity of 3 mm is filled with inert gas (e.g. Krypton) which ensures a low thermal transmittance. The total glass system is 9 mm and has a historical look and therefore can be integrated in existing frames.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Low
Reversibility	Low
Conservation compatibility	The thin double glazing can be a good replacement for the original glass pane (when possible). The glass view can be adjusted to resemble the original look.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, short period

Street & traffic disturbances during retrofit	No interruption
Long term impact	Better thermal performance,

Overall parameters

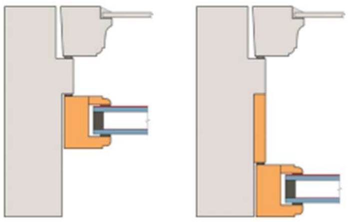
Impact on acoustic performance	Low
Impact on façade detailing	Low
Frost damage risk for historic structure	n.a.
Mould growth risk	n.a.
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	n.a.
Risk of cracking on façade	n.a.

Window solution parameters

Thermal transmittance of glazing U_g, W/(m²·K)	2
Thermal transmittance of frame U_f, W/(m²·K)	n.a.
Solar factor (g-value), -	0.64
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	n.a.

1.3.6 Secondary window

General information

Brand name:	Casement window
Source name:	Tingvoll (but also other suppliers exist)
Source website:	Varevindu | Tingvoll Dør og Vindu https://tingvollint.no/produkter/varevindu/ Energy efficient heritage windows (SINTEF research report about energy efficient casement windows in Norwegian)
Description: A new, high performance casement window ("varevindu" in Norwegian) is installed on the inside of an existing window. This way, the house's exterior architecture and historical style are preserved, without compromising energy and comfort. The frames are supplied with insulating glass, which significantly reduces heat loss. The transition between old and new window must be air tight to prevent condensation between new and old window. Condensation between windows may be an issue in cold climates and sufficient air tightness must be addressed.	Illustration:   cross section of window

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	

Common parameters

Relevant building structure	Brick & wood
Integration impact	Low
Visibility	Medium (from the inside) to low (outside)
Reversibility	High
Conservation compatibility	Low visibility from the outside. Preserves the existing window.

Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	- -
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€…€€

Impact on user

User discomfort during retrofit	Limited interruption, short period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Increased thermal comfort and reduced losses during winter period.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	Low
Frost damage risk for historic structure	Moderate risk
Mould growth risk	Increase
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	When no ventilation system is employed, the improved airtightness might have a negative effect on the IAQ.
Risk of cracking on façade	n.a.

Window solution parameters

Thermal transmittance of glazing U_g, W/(m²·K)	0.75-0.80 (estimates from[1])
Thermal transmittance of frame, U_f, W/(m²·K)	-
Thermal transmittance of window, Uw, W/(m²·K)	0.9 – 1.3 (estimates)
Solar factor (g-value), -	0.60-0.70 (estimates)
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

[1] Energy efficient heritage windows (SINTEF research report about energy efficient casement windows in Norwegian)

1.3.7 Antiquarian window

General information

Brand name:	Antikvarvinduet
Source name:	Antikvarvinduet (Røros dør og vindu)
Source website:	https://antikvarvinduet.no/
Description: Antiquarian windows are modern window designs that replicate the aesthetic shape and geometry of traditional or historic windows while incorporating advanced materials and technologies to try to meet contemporary performance standards. Constraints regarding thickness of the frame (from historical viewpoint) can limit the thermal performances. Double and triple glazing is possible when thickness is adequate. They meet the requirements of the Directorate of cultural heritage (Riksantikvaren) in Norway	Illustration:  

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
X	X	X	X

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	High, even if the appearance of the new antiquarian window is the same as for the existing (old) window
Reversibility	Low. the existing window is replaced by a new window. The existing window can be stored and put back if needed.
Conservation compatibility	The historic window is removed, losing historical material. This solution can be considered compatible in cases where historical windows are no longer recoverable.
Decrease of operational carbon emissions ("+++" = significant decrease)	+++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	--

Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Limited interruption, short period
Street & traffic disturbances during retrofit	No interruption
Long term impact	Increased thermal comfort and reduced losses during winter period.

Overall parameters

Impact on acoustic performance	Positive impact
Impact on façade detailing	Low
Frost damage risk for historic structure	n.a.
Mould growth risk	Decrease
Corrosion risk	n.a.
Salt damage risk	n.a.
Effect on indoor air quality	When no ventilation system is employed, the improved airtightness might have a negative effect on the IAQ.
Risk of cracking on façade	n.a.

Window solution parameters

Thermal transmittance of window U, W/(m²·K)	1.0
Solar factor (g-value),	0.5 - 0.75 dependent of type of coating
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	++

1.3.8 Thin secondary window

General information

Brand name:	Duplo Doppelfenster
Source name:	Duplo Fenster
Source website:	https://www.duplo-fenster.com/
Description: Thin secondary window that is mounted (with screws) on the existing window frame and not on the interior structure of the walls. The extra layer of thin glass reduces the heat losses and improves the acoustic insulation without changing the view of the original window and without removing the existing historic window. The heat losses can be reduced up to 50%. The new thin secondary window can be opened so that it can be cleaned easily.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
x	x	x	x

Common parameters

Relevant building structure	Brick & wood
Integration impact	Medium
Visibility	Low
Reversibility	Medium. When removing this product, the historic window will present small holes on the frame that can be closed easily.
Conservation compatibility	High. The historic window will be preserved.
Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€

Impact on user

User discomfort during retrofit	No impact

Street & traffic disturbances during retrofit	No impact
Long term impact	Positive impact on thermal comfort, same lighting levels

Overall parameters

Impact on acoustic performance	High (up to +31 dB in airborne noise insulation)
Impact on façade detailing	n.a.
Frost damage risk for historic structure	n.a.
Mould growth risk	n.a.
Corrosion risk	n.a.
Salt damage risk	n.a
Effect on indoor air quality	Low
Risk of cracking on façade	n.a.

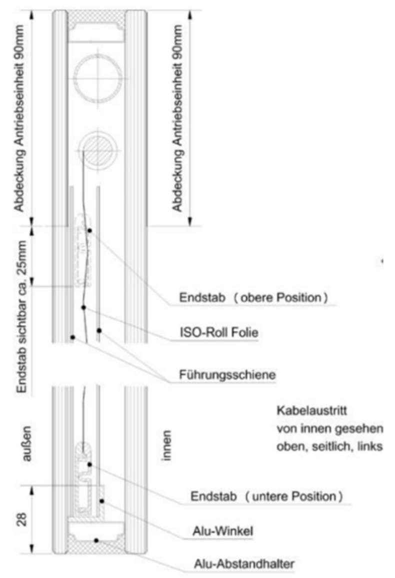
Window solution parameters

Thermal transmittance of glazing U_g, W/(m²·K)	3.7 (on a single-glazed window)
Thermal transmittance of frame U_f, W/(m²·K)	n.a.
Solar factor (g-value), -	n.a.
Improvement of overall air tightness ("+" = slight improvement, "++" = moderate improvement, "+++" = modern best practice)	0

1.4 Solar shading

1.4.1 Glass integrated solar shading

General information

Brand name:	Glastec ISO-rol
Source name:	ISO-Roll insulating glass roller blind
Source website:	https://www.glastec.com/de/produkte/sonnenschutz-sichtschutz-im-isolierglas/fenster-fassade/iso-roll-isolierglasrollo
Description: Very-thin solar shading solution that integrates solar shading between glass panes. The result is a glass and shading system of only 3.5cm thickness.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
x	x	x	x

Common parameters

Relevant building structure	All types
Integration impact	Medium: new glass pane should be installed, but the integration of the solar shading itself has no impact
Visibility	LOW: when the solar shading is open, nothing is visible.
Reversibility	LOW: the whole glass pane should be replaced.
Conservation compatibility	Solution for integrating solar shading without any impact on the facade itself. The view of the facade is also not changed.

Decrease of operational carbon emissions ("+++" = significant decrease)	++
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	---
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€€

Impact on user

User discomfort during retrofit	Existing glass panes need to be removed, so impact during installation
Street & traffic disturbances during retrofit	Short impact during finishing
Long term impact	Overheating is prevented.

Solar shading solution parameters

Solar factor (g-value), -	0.06-0.12 (solar shading closed)

1.4.2 Actuator for swing-shutters

General information

Brand name:	Ehret
Source name:	EHRET window shutters
Source website:	https://www.ehret.com
Description: Actuator to automatically open/close swing existing shutters with low visible impact.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
x	x	x	x

Common parameters

Relevant building structure	Brick & wood
Integration impact	LOW: only a hole of Ø70mm and 140 mm depth is needed.
Visibility	LOW: only the torque mechanism is visible when the shutters are closed (40x50mm). When the shutters are open, barely something is visible.
Reversibility	Medium: holes remain.
Conservation compatibility	Good low impact solution for automating the solar shading, while keeping the existing materials. However, this solution may be applied in cases where the existing solar shading system presents an opening hardware system that is easy to handle and in good condition.
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-

Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	No impact
Street & traffic disturbances during retrofit	Only during short installation period
Long term impact	No manual control over shutters anymore

Solar shading solution parameters

Solar factor (g-value), -	0.02 (solar shading closed)

1.4.3 Automated (existing) roller blinds

General information

Brand name:	eWickler Comfort eW320-M
Source name:	Reichelt elektronik
Source website:	https://www.reichelt.com/de/nl/elektronische-accu-riemwikkelaar-opbouw-12-15-mm-display-wir-1001-000069-p364769.html?&nbc=1
Description: The existing roller blinds can be preserved and can be automated, retaining its original function. Adding a motor to the original manual mechanism can make this solar shading work automatically, on condition that the original shading is still in good condition.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
x	x	x	x

Common parameters

Relevant building structure	Brick & wood
Integration impact	Low
Visibility	Low
Reversibility	High
Conservation compatibility	The existing roller blinds can be reused and integrated in the HVAC strategy without causing a high impact.
Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€

Impact on user

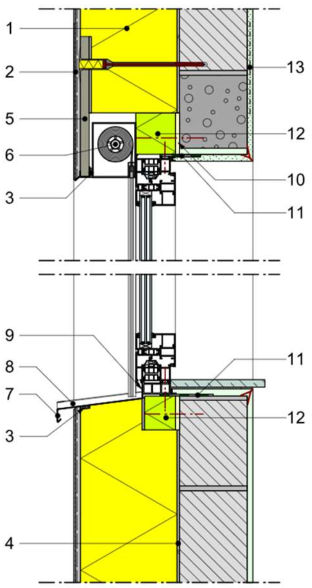
User discomfort during retrofit	No impact
Street & traffic disturbances during retrofit	No impact
Long term impact	Less manual control over roller blind.

Solar shading solution parameters

Solar factor (g-value), -	0.02 (solar shading closed)

1.4.5 Exterior solar screen shading

General information

Brand name:	Renson
Source name:	Fabric sun protection
Source website:	https://cdn.renson.eu/Public_Publications/8130/Fixscreen-Minimal-Medium-M7A
Description: A solar screen can be added to the exterior side of the window. In combination with an ETICS insulation system, the solar shading components are barely visible.	Illustration: 

Relevant climate zones:

Tundra (Köppen E, eg. hills of Norway & Italy)	Cold & moist climate (Köppen Df, eg. Tallinn, Trondheim)	Mild & moist climate (Köppen Cf, eg. Brussels, Northern Italy)	Warm climate (Köppen Cs, eg. Southern Italy)
x	x	x	x

Common parameters

Relevant building structure	All types
Integration impact	HIGH: Mounted on windows or integrated in insulation layer.
Visibility	HIGH: when mounted on window it is always visible, when integrated in insulation layer it is less visible.
Reversibility	LOW: when integrated in insulation layer it is difficult to erase, when mounted on windows it can be removed more easily.
Conservation compatibility	Because of the high impact and high visibility it can only be applied in places where there are no valuable elements. Difficult to apply in combination with rounded windows.

Decrease of operational carbon emissions ("+++" = significant decrease)	+
Amount of embedded carbon needed for renovation ("- - -" = significant increase)	-
Technology Readiness Level	TRL 9
Operational costs	€
Capital costs (investment)	€€

Impact on user

User discomfort during retrofit	Short and localized disturbance.
Street & traffic disturbances during retrofit	Scaffolding or motorized work platform needed
Long term impact	Higher thermal comfort

Overall parameters

Impact on acoustic performance	High
Impact on façade detailing	High
Frost damage risk for historic structure	n.a.
Mould growth risk	Mould risk in severe cases (thermal bridge at lintel would largely remain)
Corrosion risk	Low
Salt damage risk	n.a.
Effect on indoor air quality	Medium
Risk of cracking on façade	Low

Solar shading solution parameters

Solar factor (g-value), -	0.3-0.6 (solar shading closed in combination with double glazing)

2. Shortlists and scenarios of envelope solutions

2.1 General

The longlist of envelope retrofit solutions compiled in previous chapter is further narrowed down here. Expert groups assessed the longlists based on their specific archetypes and excluded inappropriate solutions, assessed the remaining measures based on risks and benefits and finally selected the packages of measures to be further evaluated in next stages of the project. Similarly to the longlist curation, the aspects that were weighed included: technical properties & compatibility with the building, compatibility with heritage values, economic viability, energy performance & sustainability, indoor environmental quality and user experience. The methodology and scenarios considered by different expert groups were specific to the archetypes and are documented in next sections of this chapter.

2.2 Italy

2.2.1 Introduction

For the Italian demo the Gothic Lot and the Courtyard Building have been identified as the archtetypes for which to develop the shortlists at this stage of the project and in preparation of the simulation studies.

Three different insulation levels are referred to in the description below: minimum level refers to hygienic aspects (avoid mould), standard level is what today is typically implemented (taking as an indicator the U-value which has to be reached for the subsidy "bonus ristrutturazione" in the so-called Italian climate zone "E", to which Mantova with its ~2300 Kd refers to), while the advanced level goes one step further in terms of energy performance (taking the U-values of "EcoBonus/SuperBonus" as references).

2.2.2 Gothic Lot

As described in detail in Deliverable D5.1 "Case study selection at building and neighbourhood level" the Gothic lot is a Medieval typology recurrent in Italy as a townhouse typology with several variants, which have in common (i) a relatively narrow front to road, which is often protected due to its heritage value, (ii) consistent depth (they are usually considerably longer than wide) with these walls however not facing outdoor climate but being in common with the neighbouring building, and (iii) a back façade towards an courtyard; (iv) the stairs are usually in the centre leading up to a chimney or ventilation tower providing with a glazed area also light to the interior part of this narrow building type; (v) in most cases the cellar is unused resp. used for storage of robust goods, has earthen or stone floor and vaults or wooden ceiling; (vi) the attic is usually unused and often too low in hight to be transformed to living space without change of the roof itself; (vii) between storeys there are wooden floors, the ceilings of which might be decorated and (viii) also the interior walls are not seldomly decorated; (ix) original windows have wooden frame and single glazing – but have very often already been replaced.

For the retrofit concepts this means that it is usually quite easy …

1. to insulate the **ground floor from the cellar below** (a second thought has to be given to the thermal bridge towards the street, where it might be difficult to continue the potential exterior insulation below grade to overlap, while it should be feasible to avoid the thermal bridge on the courtyard side)
2. and to insulate the **unused attic** with an insulation layer laid **on the attic floor** which keeps the roof itself untouched. The chimney/ventilation tower has to be considered separately.

With top and bottom well insulated, between one third and half of the thermal envelope has already been improved.

3. On the **back façade** in most cases **exterior insulation** can be allowed from conservation point of view. For standard insulation, approximately 10 cm of an insulation material with thermal conductivity λ of 0.04 W/(m·K) are needed, with λ=0.06 W/(m·K) 16 cm, with λ=0.03 W/(m·K) 8 cm are enough. For advanced insulation levels this results in 14 cm, resp. 20 cm or 10 cm.
→ exterior insulation will also allow to easily avoid thermal bridges at the bottom towards the ground.
→ if the windows are changed (or completely removed for restoration and afterwards replaced), they can be installed at the right position to keep the original depth of the window reveal (exterior view)
4. On the **front façade** an intervention from outside will in most of the cases be avoided.
    a. If **interior insulation** is possible (i.e. if the internal walls and ceilings are not decorated) this is a good solution. To reach the target U-values for subsidies will not be easy: standard insulation levels can be reached with 7-8 cm of an insulation material with λ=0.04 W/(m·K), or 5 cm with λ=0.03 W/ W/(m·K) (e.g. aerogel plaster). For the 10 cm needed for a material with λ = 0.06 W/(m·K) (e.g. perlite insulating plaster) the availability of space has to be evaluated.
    With interior insulation the thermal inertia of the respective wall is not any more available for mitigating overheating in summer. However, historic buildings do also have considerable mass in partition walls and ceilings. Whether these are enough should be investigated in the simulation studies following the selection of short list measures.
    b. If due to internal decoration no interior insulation is possible, a (even thin) layer of **insulation plaster on the outside** should be considered: in order to avoid interior surface temperatures below critical values with regard to mould growth, about 3 cm of a typical insulation plaster and 1-2 cm of aerogel plaster should be applied.
    c. If **neither interior nor exterior insulation** are possible in order to preserve heritage values, the humidity of the air in the adjacent rooms should be kept low enough to avoid mould problems: this can be done with **mechanical ventilation** (which at the same time allows for heat recovery and respective energy saving), with a **well thought natural ventilation** and/or with the limitation of the **use of these rooms** to **reduce moisture production**.

5. Where original **windows** are still preserved, they can be restored/repaired and their thermal performance can improved
    a. either **adding a secondary window**, especially when the original window is in good condition and would need only minor repair.
    In case of interior insulation the added secondary window should be placed in the insulation level to minimize thermal bridges;
    b. **changing the glazing** within the existing frame: the new glazing can be a standard double glazing, if the existing frame allows for the weight and thickness, or could alternatively be thin double glazing (saving both space and weight) or vacuum (saving space and allowing for high thermal improvement with a limited weight).
    c. or **adding a low impact secondary glazing**, especially when the original windows do have a filigrane structure;
    both a) and c) allow to keep the glazing visible from the outside and thus both the original material and the aesthetics of a single, slightly uneven glass;
    both b) and c) will be combined with improving the airtightness when the frame is repaired.
    d. If windows have already been changed, from a conservation point of view they might be replaced with **new, conservation compatible and thermally efficient windows** which at the same time fit the historic building better (filigrane wooden frame etc.).
    From a resource efficiency point of view, and especially if the existing windows do aesthetically fit the historic building, a balance can be made to understand whether the savings (and comfort benefits) of a new window outweigh the material and economic investment.
    e. The **skylight** can usually be improved without visible impact – and at the same time adapted to be openable for natural ventilation/ventilative cooling in summer.
6. The **shutters** and existing **shading system** have to be repaired and included in the proposed (and simulated) use cases, especially in order to limit overheating during summer.
7. The **courtyard**, especially if **green**, can be a source for **fresh air** for **(night) ventilation**. The potential for ventilative cooling should be investigated (todays air pollution in Mantova might however be a limiting factor).

2.2.3 Courtyard building

For the courtyard building the above considerations are still valid. The ratio of the front façade for the overall thermal envelope is higher, which means that improving it, will be even more important – and sometimes also more difficult, as the courtyard building might more have interior decoration on walls and ceilings. On the other hand side, ventilation concepts for summer comfort might be easier to implement due to the varied orientations. Improving windows will play an important role, as they are bigger in size compared to the Gothic Lot.

2.2.4 Overview

The above listed measures are combined to different scenarios in Table 2 and clustered to "Business as usual", Minimal intervention, Maximum energy efficiency and Novelty. All scenarios have in common the insulation of the top and bottom boundary.

Table 2 Categorized renovation scenarios for the Italian archetypes.

Part of envelope	Solution	Scenario			
		Business as usual	Minimal intervention	Maximum energy efficiency	Novelty
Bottom boundary (basement ceiling)	Insulation materials are placed against the ceiling of the basement.	all	all	all	all
	Insulation above portici		where applicable	where applicable	where applicable
Top boundary (roof or attic floor)	Insulation layer laid on the floor of the unused attic	all	all	all	all
	Insulation of the ventilation tower		where applicable	where applicable	where applicable
Front Facade	Exterior insulation plaster		M3	E2	N3
	Interior insulation	B3	M2	E1	N1 N2
	No insulation	B1 B2	M1		
Back Facade	Exterior insulation	B2	M3	E1	
	Exterior insulation - advanced			E2	N1 N3
	Interior insulation	B3	M2		N2
	No insulation	B1	M1		
Windows	Window seals to increase air-tightness		M1 M3		N2 N3
	Add secondary window		M2	E1 E2	N1
	Change single to double, insulating glazing		M3		
	Change single to thin double, insulating or vacuum glazing				N1 N3
	Add low impact secondary glazing				N2
	Replace window	B1 B2 B3		E1 E2	
Shading	Repair shutters		M1 M2 M3	E1 E2	N1 N2 N3
	Automate shutters				N1 N2 N3
Notes		B1 needs moisture control!	M1 needs moisture control!		Use of ventilation tower

Business as usual

B.1 Neither front nor back façade are insulated

All Business as usual scenarios have in common, that windows are replaced with (more or less conservation compatible) new windows. It is however still quite common not to intervene at all on the walls. Attention in this case on moisture control! New windows will be airtight and mould risk on not insulated walls will increase, if moisture is not control via (natural or mechanical) ventilation or adequate use

B.2 Front façade not insulated, exterior insulation on back façade

In this Business as usual scenario windows are again replaced, the protected front façade is not insulated (especially, if the interior is decorated, and the exterior also protected), but the back façade is insulated from the outside. The new windows of the back façade can in this case be positioned in the insulation layer level, but this step is often not done.

B.3 Front and back façade with interior insulation

In this Business as usual scenario windows are again replaced, the same interior insulation system is applied to both front and back façade. The kind of interior insulation system varies in business as usual: both mineral wool with vapour barrier and capillary active system with e.g. calcium silicate are found.

Minimal intervention

M.1 No window retrofit, no wall insulation

This is an envelope concept where minimal retrofit measures are implemented, and thought for cases where both the exterior and the interior surfaces are of historic value and decorated. The existing (single glazed) windows in the front and back facade are preserved, their air-tightness is however increased with window seals. Shutters are repaired for an effective control of summer overheating. Neither front nor back walls are insulated – however as mentioned above the top and bottom boundaries are.

This scenario has to make sure the a proper moisture control concept is in place and relies on local comfort providing approaches, if the overall energy demand should be limited.

M.2 Minimum exterior intervention: secondary window, front & back interior insulation

This is an envelope concept where the exterior interventions are minimised: the windows are improved adding a secondary window on the inside, both the front and back façade are insulated internally (and the secondary window is placed in the insulation level), in order not to lose too much thermal inertia, suspended ceilings and floors are avoided and priority is given to insulation systems with a higher thermal capacity. Shutters are repaired for an effective control of summer overheating.

M.3 Minimum interior intervention: glazing changed, front insulation plaster, back exterior insulation

This is an envelope concept where the interior interventions are minimised in buildings with valuable decoration: the windows are improved by changing the glazing to double glazing and adding new seals. The front façade is provided with insulating plaster to avoid mould risk and back façade is insulated from the exterior. Shutters are repaired for an effective control of summer overheating.

Maximum energy efficiency

E.1 Front interior insulation and secondary window, back exterior insulation and new window

From an energy saving point of view, on the front façade interior insulation leads to better results than a (thin) insulation plaster and is combined with a secondary window, which can be positioned in the new insulation layer level (avoiding the thermal bridge). At the back façade, where the original windows anyway might already have been replaced, exterior insulation is combined with conservation compatible new windows positioned in the insulation layer level (avoiding thermal bridge and negative aesthetic impact). Shutters are repaired for an effective control of summer overheating.

E.2 Front insulation plaster and secondary window, back advanced exterior insulation and improved existing window

This scenarios differs from E.1 in the fact that for cases with decorated interiors, instead of interior insulation on the front façade an insulation plaster is provided at the exterior. The lower energy saving is counter-balanced with advanced exterior insulation approaches at the back façade.

Novelty

N.1 Front interior insulation and secondary window, back advanced exterior insulation and improved existing window with vacuum glazing, ventilative cooling.

Considering novel solutions the E.1 scenario can be improved by applying instead of a standard interior insulation system, one with aerogel insulation plaster. The preferred window improved remains the addition of a secondary window in the insulation layer level. On the back façade advanced exterior insulation is proposed to be combined with the retrofit of the existing window with vacuum glazing.

Shutters are repaired for an effective control of summer overheating, and potentially automated, the chimney or ventilation tower is used for natural ventilation and ventilative cooling

N.2 Similar to M.2 with low impact secondary glazing, ventilative cooling

N.2 is the scenario using novel approaches for a minimum exterior intervention scenario: internal insulation with aerogel plaster and instead of the secondary window a low impact secondary glazing is added.

Shutters are repaired for an effective control of summer overheating, and potentially automated, the chimney or ventilation tower is used for natural ventilation and ventilative cooling

N.3 Similar to M.3 with thin double/vacuum glazing, ventilative cooling

N.3 is the scenario using novel approaches for a minimum interior intervention scenario: exterior insulation plaster on the front façade uses aerogel plaster, and glazing of windows is changed to thin double glazing or vacuum galzing.

Shutters are repaired for an effective control of summer overheating, and potentially automated, the chimney or ventilation tower is used for natural ventilation and ventilative cooling

2.3 Belgium

2.3.1 Defining renovation scenarios

The Belgian historic townhouses which are the subject of this research all have a similar construction method. The solid masonry walls, gable roofs with purlins and rafters, the wooden floors and the stone finishing in the hallway are recurrent components in all the different archetypes, which are the middle-class townhouse, the private mansion, the modest house and the multi-family townhouse. The differences between these archetypes are mainly situated on the scale of the building and the internal organization. Because of that, the shortlist of technical interventions for the Belgian cases is the same for the different archetypes. However, the heritage context in Belgium is complex, which requires tailored combinations of technical interventions to match the need to preserve varying combinations of built heritage elements.

A series of envelope renovation scenarios have been defined based on workshops with heritage experts as shown in Table 3. The renovation scenarios are divided in four categories of renovations:

- Business as usual
- Minimal intervention
- Maximum energy efficiency
- Novelty

Business as usual describes typical renovation solutions applied with relatively reasonable budget and without too stringent heritage constraints. *Minimal exterior intervention* reflects solutions which may be used in case of strict heritage requirements. The solutions must be carefully considered and implemented according to each buildings conditions and prerequisites. *Maximum energy efficiency* cost more than the *business as usual* option but is more energy efficient. *Novelty* includes some more advanced technical solutions which are eighter still in development, are technically available, but not used because of lack of knowledge owing to high purchase price.

Within these categories, a lot of different combinations are still possible on the techniques used. These different scenarios are elaborated extensively in section 2.3.2. They include retrofit strategies for walls, floors, roofs and windows. Additionally, attention is given to solar shading devices, although not included in the overview or in the description of scenarios. The type of solar shading is depended on too many variables, including orientation, type of windows, heritage context, etc. so that the scenario combination should only be made when a more concrete research object is available.

Table 3 Categorized renovation scenarios for the Belgian archetypes.

Part of envelope	Solution	Scenario			
		Business as usual	Minimal intervention	Maximum energy efficiency	Novelty
Front windows	Integrating gaskets in the existing window frames to improve the airtightness		M.2 M.4		N2
	Installing secondary windows behind the existing windows.	B.1		E.1 E.2	
	Replacing the existing single glazing with thin double glazing to reduce the thermal losses.		M.4	E.3 E.4	
	Replacing the existing single glazing with vacuum glazing to reduce the thermal losses.				N.2 N.3
	Replacing the existing windows with new high-performance historicizing windows.	B.2		E.5 E.6	
	Mounting a thin secondary windows on the existing window frame, reducing the thermal losses.				N.1
Back windows	Integrating gaskets in the existing window frames to improve the airtightness		M.2 M.4		N2
	Replacing the existing single glazing with thin double glazing to reduce the thermal losses.		M.4		
	Replacing the existing single glazing with vacuum glazing to reduce the thermal losses.				N2
	Replacing the existing windows with new high-performance windows. Any material and design is possible (without altering the window openings)	B.1 B.2	M.3	All	
Front Facade	Insulating from the interior side with calcium silicate, Autoclaved Aerated Concrete, wood-fibre board, mineral wool or wood-fibre boards to the necessary thickness (EPB-legislation)			E.1 E.3	
	Applying interior insulation only in the rooms where no valuable interior elements are present. Insulation layer with the necessary thickness (EPB-legislation).	B.2	M.3		
	Minimal insulation is integrated in valuable rooms mainly to prevent thermal discomfort (not to achieve a certain U-value). This can be achieved by applying an insulating plaster (EPS granules, hemp fibres) or a more typical interior insulation material with a limited thickness. In less valuable			E.2 E.4 E.5	N.2

Part of envelope	Solution	Scenario			
		Business as usual	Minimal intervention	Maximum energy efficiency	Novelty
	rooms, typical interior insulation is applied.				
	Insulating from the exterior side by applying insulating plaster on the facade. This plaster can be an aerogel plaster or insulating mortar (mortar with EPS granulates).			E.6	
Back facade	Insulating from the exterior side using an ETICS system with EPS (or EPS silver) or mineral wool insulation. Exterior insulation with a prefabricated ventilated cavity is also possible.	All	M.2 M.3	All	N.3
Top boundary (roof or attic floor)	The pitched roof is insulated between the rafters with typical insulation materials.	All	All	All	All
	The flat roof is insulated from the exterior side, using typical insulation materials.	All	All	All	All
Bottom boundary (basement ceiling)	Insulation materials are placed against the ceiling of the basement.	B.1	M.1 M.2 M.4	E.1 E.3 E.5	
	Rigid insulation materials (EPS, XPS, PU) are placed under a new concrete floor or screed.	B.2	M.3	E.4	
	Vacuum insulating panels are place on top of the existing floor structure.				N.1 N.2
	The ventilated floor space of the wooden flooring is filled up with insulation materials.			E.2 E.6	N.3

2.3.2 Building envelope concepts

In this section the different renovation scenarios are described elaborately, following the same subdivision as in Table 3.

Business as usual

B.1 Secondary glazing, exterior back facade insulation

The existing (single glazed) windows in the front façade are preserved. By adding a secondary window at the interior side, the airtightness is improved, and the thermal losses are limited to state-of-the-art levels. The windows in the back are replaced with new high-performance windows.

The front facade is not insulated. The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

B.2 New historicizing windows, local interior insulation

The windows in the front facade are replaced by historicizing new wooden windows, with better thermal and airtightness properties than the existing wooden single-glazed windows. This can only be done when the existing windows are in a condition that is not salvageable or when the existing windows have been already replaced in recent periods (e.g. PVC windows from the 80's). The windows in the back are replaced with new high-performance windows.

The front facade is not insulated from the exterior side, and only from the interior side on the levels where no valuable interior is present. Typical interior insulation materials can be applied here with the necessary thickness to achieve the maximum U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K)). The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The slab on ground (of the basement or the ground floor) is insulated by providing rigid insulation boards under a (new) concrete floor.

Minimal intervention

M.1 No window retrofit, no wall insulation

This is an envelope concept where minimal retrofit measures are implemented. The existing (single glazed) windows in the front and back facade are preserved. The valuable front facade is not insulated, not from the exterior side, nor from the interior side. The back façade is also not insulated. The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

This is a very simple, but minimal, retrofit strategy. Insulating the floor and roof is a well-known measure and therefore cheap to apply. The heat loss reduction will be rather small compared to the uninsulated state.

M.2 Airtightness gaskets, no front facade insulation

The existing (single glazed) window in the front and back facade are preserved. Integrating new gaskets and seals in the existing wooden frame improves the airtightness. The valuable front facade is not insulated, not from the exterior side, nor from the interior side. The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

This retrofit strategy can be applicable to historically valuable dwellings because minimal impact on the valuable windows, front facade and interior Is ensured. Nonetheless, the few opportunities that are present to improve the airtightness and the thermal performance are seized.

M.3 New windows in back facade, local interior insulation

The existing (single glazed) window in the front façade are preserved. The windows in the back are replaced with new high-performance windows. The front facade is not insulated from the exterior side, and only from the interior side on the floors where no valuable interior is present. Typical interior insulation materials can be applied here with the required thickness to achieve the maximum U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K)). The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The slab on ground (of the basement or the ground floor) is insulated by providing rigid insulation boards under a (new) concrete floor.

M.4 Thin double glazing, no wall insulation

The existing window frames in the front facade and back façade are preserved but the single glazed pane is replaced by thin double glazing specifically manufactured for heritage building application. Integrating new gaskets and seals in the existing wooden frame improves the airtightness.

The valuable front facade is not insulated, not from the exterior side, nor from the interior side. The back façade is also not insulated. The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

Maximum energy efficiency

E.1 Secondary window, interior insulation

The existing (single glazed) window in the front façade are preserved. By adding a secondary window at the interior side, the airtightness is improved, and the thermal losses are limited to state-of-the-art levels. The windows in the back are replaced with new high-performance windows. The front facade is insulated from the interior side with typical interior insulation materials to the necessary thickness to achieve the maximum U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K)). This way of insulating is only possible when no valuable interior elements are present on this facade and the edges of ceilings and walls connecting to this facade.

The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

E.2 Secondary glazing, limited interior insulation

The existing (single glazed) window in the front façade are preserved. By adding a secondary window at the interior side, the airtightness is improved, and the thermal losses are limited to state-of-the-art levels. The windows in the back are replaced with new high-performance windows. The front facade is not insulated from the exterior side, only from the interior side. In the spaces where a valuable interior is expected, minimal insulation is integrated mainly to prevent thermal discomfort (not to achieve a certain U-value). This can be achieved by applying an insulating plaster or a more typical interior insulation material with a limited thickness. On the other levels the front facade is insulated from the interior side with typical insulation materials with the necessary thickness to achieve the maximum

U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K)). The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. All the intermediate floors are insulated by filling the floor cavity space with (granular) insulation material, resulting in better thermal zoning and better acoustics within the building.

E.3 Thin double glazing, interior insulation

The existing window frames in the front façade are preserved but the single glazed pane is replaced by thin double glazing specifically manufactured for heritage building application. The windows in the back are replaced with new high-performance windows.

The front facade is insulated from the interior side with typical interior insulation materials to the necessary thickness to achieve the minimal U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K)). This way of insulating is only possible when no valuable interior elements are present on this façade and the edges of ceilings and walls connecting to this facade. The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

E.4 Thin double glazing, limited interior insulation

The existing window frames in the front façade are preserved but the single glazed pane is replaced by thin double glazing specifically manufactured for heritage building application. The windows in the back are replaced with new high-performance windows. The front facade is not insulated from the exterior side, only from the interior side. In the spaces where a valuable interior is expected, minimal insulation is integrated mainly to prevent thermal discomfort (not to achieve a certain U-value). This can be achieved by applying an insulating plaster or a more typical interior insulation material with a limited thickness. On the other levels the front facade is insulated from the interior side with typical insulation materials with the necessary thickness to achieve the maximum U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K))

The back facade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The slab on ground (of the basement or the ground floor) is insulated by providing rigid insulation boards under a (new) concrete floor.

E.5 New historicizing windows, limited interior insulation

The windows in the front facade are replaced by historicizing new wooden windows, with better thermal and airtightness properties than the existing wooden single-glazed windows. This can only be done when the existing windows are in a condition that is not salvageable or when the existing windows have been already replaced in recent periods (e.g. PVC windows from the 80's). The windows in the back are replaced with new high-performance windows. The front facade is not insulated from the exterior side, only from the interior side. In the spaces where a valuable interior is present, minimal insulation is integrated mainly to prevent thermal discomfort (not to achieve a certain U-value). This can be achieved by applying insulation plaster or a more typical interior insulation material with a limited. On the other floors, the front facade is insulated from the interior side with typical insulation materials with the necessary thickness to achieve the maximum U-value requirement for newly built dwellings in Belgium (0.24 W/(m²·K)).

The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor between the ground floor level and the basement is insulated by mounting insulation on the ceiling of the basement.

E.6 New historicizing windows, exterior front facade insulation

The windows in the front facade are replaced by historicizing new wooden windows, with better thermal and airtightness properties than the existing wooden single-glazed windows. This can only be done when the existing windows are in a condition that is not salvageable or when the existing windows have been already replaced in recent periods (e.g. PVC windows from the 80's). The windows in the back are replaced with new high-performance windows. The front facade is insulated at the exterior side using insulation plaster. This can only be done when the facade is less valuable because it is not the original plaster, the dwelling is not in CHE-area or when there are few ornaments. By using an insulating plaster, the ornaments and detailing that is present, can be preserved as much as possible. The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with mineral wool insulation. All the intermediate floors are insulated by filling the floor cavity space with (granular) insulation material, resulting in better thermal zoning and better acoustics within the building.

Novelty

N.1 Thin secondary window, no wall insulation

The existing (single glazed) window in the front façade are preserved. By adding a thin secondary window at the interior side, the thermal losses are limited without any big alterations to the existing windows. The windows in the back are replaced with new high-performance windows. Neither the front facade nor the back facade is insulated. The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor of the ground floor (or basement) is insulated using vacuum insulating panels.

N.2 Vacuum glazing, no wall insulation

The existing window frames in the front and back facade are preserved but the single glazed pane is replaced by high performance vacuum glazing. Integrating new gaskets and seals in the existing wooden frame improves the airtightness.

The valuable front facade is not insulated, not from the exterior side, nor from the interior side. The back façade is also not insulated. The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. The floor of the ground floor (or basement) is insulated using vacuum insulating panels.

N.3 Vacuum glazing, limited interior insulation

The existing window frames in the front façade are preserved but the single glazed pane is replaced by high performance vacuum glazing. The windows in the back are replaced with new high-performance windows. The front facade is not insulated from the exterior side, only from the interior side. In the spaces where a valuable interior is present, minimal insulation is integrated mainly to prevent thermal discomfort (not to achieve a certain U-value). This can be achieved by applying an insulating plaster or a more typical interior insulation material with a limited thickness . On the other levels, the front facade is insulated from the interior side with typical insulation materials with the necessary thickness to achieve the maximum U-value requirement for newly built dwellings in Belgium (0.24 $W/(m^2 \cdot K)$).

The back façade is insulated at the exterior side (making use of an improved ETICS system or other finishing materials using ventilated cavity). The pitched roof is insulated between the rafters (using e.g. mineral wool) and the flat roof (if present) is insulated from the exterior side with typical insulation materials. All the intermediate floors are insulated by filling the floor cavity space with (granular) insulation material, resulting in better thermal zoning and possibly better acoustics within the building.

2.4 Norway

2.4.1 Retrofitting of wooden log town house

Retrofitting the Norwegian archetype, heritage wooden log townhouses, with thermal insulation is a delicate process that requires balancing improved energy efficiency and indoor comfort with the preservation of architectural and cultural integrity and avoid building damages. The archetype showcases distinct characteristics rooted in local craftsmanship, traditional materials, and architectural styles. Key characteristics: constructed primarily with locally sourced timber, often pine or spruce, use of traditional joinery techniques, with minimal use of nails or modern fasteners. For the Norwegian wooden log town houses, most restrictions apply to the exterior façades. Restrictions on the interior are very rare for town houses used for habitation and other permanent commercial activities.

In 2.4.2 - 2.4.4 is an outline of the two main scenarios of energy retrofit – external insulation and internal insulation and window retrofit with adding a casement window or new window retrofit – along with some considerations for achieving optimal results.

For 2.4.2 and 2.4.3. see report "Modelling input" for detailed description of characteristics and technical input representing the building/architype.

2.4.2 Exterior retrofitting

Adding insulation to the exterior is a more energy-efficient solution where thermal bridges can be more efficiently handled and moisture problems dealt with but may not always be permitted in heritage buildings due to its impact on appearance. For façades the recommended solution involves removing the old exterior cladding and any membranes before applying a layer of thermal insulation (e.g., mineral wool or wood fibre) to the wall. Cover the insulation with a weatherproof and breathable wind barrier and a cladding that matches the original facade as closely as possible. The new cladding should have a ventilated air gap behind for drainage and drying of rainwater. Ensure continuity of insulation and airtightness (see 1.2.30 and 1.2.31) around windows, doors, roof edges and similar. Reinsulating also the joists/floor towards the roof and ground. Cold attics and basements are common for wooden log town houses. The attic floors and basement ceilings are typically insulated on the cold side of the structure. In some cases, additional insulation is use in combination with blown-in insulation in the structure. Sufficient ventilation of the attic/basement space must be ensured. Ventilation of indoor space must be considered/improved and sufficient air tightness of the structures must be ensured to avoid moisture problems.

2.4.3 Interior retrofitting

Adding insulation to the interior of a façade is a solution applied when external heritage values set restrictions to changes and/or the owners want to upgrade the building partly/in steps. Large thermal bridges will be apparent and are difficult to handle. The solution might also be vulnerable to moisture problems and need well-thought-out solutions. Most common are removing old internal linings and any membranes behind before applying a layer of thermal insulation (e.g., mineral wool or wood fibre) on the wall. A traditional vapour barrier (e.g. PE-foil) is normally applied on the interior side of the thermal insulation. Alternatively, a moisture adaptive vapour barrier may be applied (see 1.2.33). Ensure continuity of insulation and airtightness (1.2.30 and 1.2.31) around windows, doors, roof edges and similar. The joists towards the roof and ground must also be reinsulated.

2.4.4 Window retrofitting

For windows a casement (1.3.6), a thin secondary window (1.3.10) can be added or they can be replaced with an antiquarian window (see 1.3.7). The transition between window and wall may be sealed with barrier tape to increase the air tightness (see 1.2.30 and 1.2.31).

2.4.5 Defining renovation scenarios

The options listed in the longlist were considered and reasonable solutions applicable for the wooden log town house were chosen. The solutions are defined according to four renovation scenarios:

- Business as usual
- Minimal exterior intervention
- Maximum energy efficiency
- Novelty

Business as usual describes typical renovation solutions applied with relatively reasonable budget, but without emphasizing the conservation value. *Minimal exterior intervention* reflects solutions which may be used in case of strict heritage requirements. The solutions must be carefully considered and implemented according to each buildings conditions and prerequisites, without emphasizing costs. *Maximum energy efficiency* cost more than the *business as usual* option but is more energy efficient. *Novelty* includes some more advanced technical solutions which are either still in development, are technically available, but not used because of lack of knowledge or due to high purchase price.

Table 4 Shortlisted solutions and scenarios for the Norwegian wooden log town house archetype.

Part of envelope	Solution	Scenario			
		Business as usual	**Minimal exterior intervention**	**Maximum energy efficiency**	**Novelty**
Walls	The interior cladding and barrier layer is removed. Thermal insulation is added on the interior side. A traditional vapour barrier (sd>10m) is applied on the inside along with the interior cladding. Thickness of insulation must be carefully considered.		X		
	The old cladding and exterior barrier layer are removed. Exterior insulation (5–15 cm) is then added on the exterior side along with an air barrier layer and a ventilated cladding.	X		X	
	Exterior cladding is preserved owing to heritage values. The interior cladding and barrier layer is removed. Thermal insulation is added on the interior side. A moisture adaptive vapour barrier (sd>0.2-35m) is applied on the				X

Part of envelope	Solution	Scenario: Business as usual	Scenario: Minimal exterior intervention	Scenario: Maximum energy efficiency	Scenario: Novelty
	inside along with the interior cladding.				
Windows	Existing windows are replaced with new antiquarian windows (double glazing) (if existing windows are non-original or beyond repair)	X			
	Existing windows are replaced with new antiquarian windows (triple glazing) (if existing windows are non-original or beyond repair)			X	
	A casement window ("varevindu" in Norwegian) is installed on the inside of an existing window. This way, the façade is preserved, without compromising energy and comfort.		X		
	A casement window ("varevindu" in Norwegian) is installed on the exterior side of an existing window. This way, the windows interior architecture and historical style are preserved, without compromising energy and comfort.			X	
	Replace existing glass pane with vacuum glazing (if original window frames are in good condition).				X
Window-wall transition	The transition between window and wall may be sealed with barrier tape and insulated to increase the air tightness and avoid drafts.	X	X	X	
Top boundary (roof or attic floor)	Mineral wool or wood fibre insulation (boards or blown-in) can be added on the attic floor. Sufficient ventilation of the attic must be ensured. The air tightness of attic floor and ventilation of indoor space must be considered and improved if needed.	X	X	X	X
	Mineral wool or wood fibre insulation (boards or blown-in) can be added on the interior side of the attic floor. Can be combined with blown-in insulation within the floor structure. Sufficient ventilation of the attic must be ensured. The air tightness of attic floor and ventilation of indoor space must be considered/improved.	X			
Bottom boundary	Mineral wool or wood fibre insulation can be added on the basement ceiling. Sufficient	X	X	X	X

Part of envelope	Solution	Scenario			
		Business as usual	Minimal exterior intervention	Maximum energy efficiency	Novelty
(basement ceiling)	ventilation of the basement must be ensured. May be combined with blown in insulation within the floor structure.				
	Mineral wool or wood fibre insulation can be added on the interior side of the floor. Sufficient ventilation of the basement must be ensured. May be combined with blown in insulation within the floor structure. Risk of moisture damage must be considered.	X			

2.5 Estonia

2.5.1 Defining the renovation scenarios

Five examples of different typical Estonian townhouses were selected in the project. On site inspections, interviews with inhabitants and measurement of indoor air quality were conducted before developing the renovation strategies. Original construction documents were studied in the archives. Based on the information gathered, committee of experts was summoned to develop renovation strategies for two historic building archetypes from Uus Maailm case study area in Tallinn.

Members of the committee of experts had wide experience and knowledge in fields of heritage protection, building design, structural design, HVAC design, construction site supervision and management experience on heritace protected sites. There were two four-hour-meetings organized at which data collected from the case study buildings was presented and consensus decisions were made after fruitful discussions for each building. All of the options listed in the longlist were considered for each case study building and reasonable solutions were chosen for each particular building.

For each case study, four renovation scenarios were proposed:

- Business as usual
- Minimal exterior intervention
- Maximum energy efficiency
- Novelty

"Business as usual" describes typical renovation solutions applied in 2024 in Estonia, if similar buildings are renovated with relatively reasonable budget and generally following heritage restrictions. "Minimal exterior intervention" is a scenario where changes to the historic exterior are kept to the minimum and energy saving measures are applied to the interior (as the interior surfaces are not protected and have usually been modified already) or left out altogether. "Maximum energy efficiency" would be recommended renovation solution, being very energy efficient and durable. In many cases, heritage characteristics would be better preserved than with "business as usual" solutions. "Maximum energy efficiency" solution would cost more than "business as usual" option, but it would be achievable on current market with additional financial subsidies. "Novelty" solution includes also some more advanced technical solutions that are either still in development phase and not yet available on the market or are technically available, but not used because of lack of knowledge about the solutions or significance price premium.

Target for selecting the solutions listed in "maximum energy efficiency" and "novelty" was that at least 60% energy savings must be reached together with corresponding HVAC & R2ES solutions. In many cases, "business as usual" options could also reach 60% savings, if efficient heating and ventilation systems are introduced, but it should be further studied, how excessive must be the improvement of the systems to compensate for the boundary solutions. In case of "minimal exterior intervention" it would be very challenging to reach 60% energy savings and it was not the aim for this renovation scenario.

2.5.2 Wooden apartment building

As described in D5.1, the valuable characteristics of this archetype are the shape and look of the exterior. Depending on the current state of the historic materials their replacement can be possible (in many cases the service life of components has been depleted by now or they have been replaced with unsuitable ones in the past). Single solutions are difficult to implement to the Wooden apartment building archetype while keeping true to the heritage characteristics, however, usually a good compromise can be reached by balancing different specific retrofit solutions in combination. For example, only insulating the walls from the exterior side would leave the windows recessed compared to the façade plane. However, if the façade, windows, roof and plinth are retrofitted together, the high impact combination could be acceptable as the original configuration of the façade is preserved (although not yet in patinated form).

The **façades** of these Estonian archetype buildings are usually covered with wooden boarding with ventilation gap – the envelope can be thermally upgraded using vapour open fibrous insulation, but it requires replacement of the boarding. Adding an airtight and vapour open housewrap between the original log wall and exterior insulation will provide airtightness without excessive interior modifications. Aerogel-based vapour open insulation board such Kingspan Alphacore has 1.5x lower thermal conductivity than mineral wool and can help reduce the necessary insulation thickness or achieve higher thermal resistance.

There are also some buildings that are plastered – then the plastered ventilated exterior insulation systems should be preferred. ETICS systems are at risk of moisture and frost damage due to moisture convection through the leaky log walls and hence should be avoided.

If exterior insulation is not possible, interior insulation can be considered to some degree, however, caution should be taken as log walls are sensitive to moisture and mould and rot damage are possible. Solutions such as Isover Inliner combining 3 cm of insulation and smart vapour barrier can add a certain extent of safety in case there are accidental moisture leaks from the outside compared to traditional vapour barriers.

In case of most of the buildings in this archetype, the **roof** could be excessively insulated with relatively ease. One possible option is to renovate attic space in a way that it could be converted into living space. This additional living space could be used by the house association to fund the renovation of the building. Otherwise, insulation can be applied to the attic floor.

Same principle could be applied with **basements** – they can be converted to living or commercial spaces and in that case, the plinth and basement floor can be insulated. If the original plastered plinths are not in good condition, it would be acceptable to insulate them externally. However, the buildings of this archetype can also have plinth as exposed limestone masonry, which is characteristic look and considered worth preserving. Interior insulation with "capillary active" mineral insulation could then be considered along with insulation of the basement floor. If the basements would be kept as storage spaces, the basement ceiling can be insulated. If exterior insulation of the walls is not possible, then both façade and plinth area should not be insulated from the exterior side. If it is possible to insulate externally, both plinth and façade could be insulated together, then also the windows could be moved outside to mimic the original geometry.

The original **windows** are double frame wooden windows (single pane in each frame) – in many cases they have been replaced with wide-ranging types from copies of the originals to ones with no heritage value (e.g. single frame double glazed PVC windows). If the historic windows are in good shape, they can be upgraded by replacing interior glazing with 2 or 3-pane insulated glass unit or the interior frame with a modern window (as studied in T2.5 of the project) while preserving the historic frame. Necessary solar shading can be achieved through optimizing the solar heat gain coefficient (g-value) of the glazing.

Table 5 Shortlisted solutions and scenarios for Estonian wooden apartment building archetype.

Part of envelope	Solution	Scenario			
		Business as usual	Minimal exterior intervention	Maximum energy efficiency	Novelty
Walls	Ext. ventilated insulation (fibrous insulation, 7–10 cm); air barrier between log & ext. insulation; interior insulation (5-10 cm mineral wool) + smart vapour barrier			X	
	Ext. ventilated insulation (fibrous insulation, ca 7–10 cm); air barrier between log & ext. insulation	X			
	Exterior vented (or plastered) aerogel board insulation (Kingspan Alphacore)				X
	Interior insulation (3 cm min. wool) + smart vapour barrier (Isover Inliner)		X		X
Plinth	Interior insulation (50 mm "capillary active" vapour open mineral insulation) + waterproofing		X		X
	Exterior insulation (XPS, PUR spray foam) + waterproofing	X		X	
Bottom boundary (basement ceiling or floor)	Horizontal insulation (concrete slab + EPS 100 mm) if basement is heated and used	X	X	X	X
	Cellar ceiling insulation (min. wool 100 mm) if basement is unheated	X	X	X	X
Top boundary (roof or attic floor)	Insulation between rafters + air & vapour barrier (if attic is converted to living space): 200 mm mineral wool insulation	X			X
	Insulation between rafters & crossframing + air & vapour barrier (if attic is converted to living space): 200+100 mm insulation			X	
	Blown insulation on attic floor (if attic not inhabited)		X		
Windows	New windows with historic appearance (triple glazing) (if existing windows are non-original or beyond repair)			X	
	New windows with historic appearance (double glazing) (if existing windows are non-original or beyond repair)	X			
	Replace interior glass pane with vacuum glazing (if historic windows are in good condition)		X		X

Part of envelope	Solution	Scenario			
		Business as usual	Minimal exterior intervention	Maximum energy efficiency	Novelty
	Replace interior frame with modern window (if historic windows are in good condition)				X

2.5.3 Stalinist brick apartment building

Similarly to the wooden apartment building archetype, the energy saving measures of the Stalinist brick apartment buildings are more likely to be acceptable from the heritage point of view if combined and applied together to preserve the exterior look of the building.

The **façades** of the archetypical buildings were originally finished with lime or lime-cement facade plaster that has smooth finish and painted often with two different colours. In case of facades with not very complicated detailing, the exterior walls could be insulated and then plastered to preserve the original look. However, the aim should be to reach the durability at least as long as the original finish had. Thicker layers and lime or cement-lime based materials are preferred from the heritage point of view but could also mitigate some of the issues current ETICS solutions have (i.e. frost damage due to too high vapour resistance, "ungraceful" aging, etc) – this will be further determined in task T2.3 of the HeriTACE project.

If the exterior insulation cannot be applied (e.g. lot of fine décor), injecting PUR foam to the air cavities of the existing walls could be used – however, as shown in Tuulemäe case, the thermal bridges at tie stones remain and the foam might fail to completely fill the cavity leaving the results underwhelming. To overcome that, the measure could furthermore be combined with "capillary active" mineral interior insulation to mitigate the thermal losses and low interior surface temperature at tie stones. However, interior insulation is costly and causes severe disturbance of the users during installation while also having inherent moisture risks – it is therefore not considered as a separate option here.

As the courtyard side of the facades are usually simpler, exterior insulation can be possible there while combining with the previous measure on the street side.

Same concepts of **attic and basement** conversions and insulation solutions as were considered for wooden apartment buildings apply here as well.

Compared to the wooden apartment building archetype, almost all **windows** have been replaced and typically have no heritage value (e.g. single frame double glazed PVC windows). However, in this case it is simple to improve the energy efficiency through upgrading the windows to triple glazed modern windows with historic look. If the historic windows are in good shape, they can be upgraded by replacing interior glazing with 2 or 3-pane insulated glass unit or the interior frame with a modern window (as studied in T2.5 of the project) while preserving the exterior look. Necessary solar shading can be achieved through optimizing the solar heat gain coefficient (g-value) of the glazing.

Table 6 Shortlisted solutions and scenarios for Estonian Stalinist brick apartment building archetype.

Part of envelope	**Solution**	**Scenario**			
		Business as usual	**Minimal exterior intervention**	**Maximum energy efficiency**	**Novelty**
Walls	Plastered exterior insulation (ETICS), PF insulation 100 mm, thick plaster			X	X
	Plastered exterior insulation (ETICS), thin polymer plaster, min. wool insulation (100 mm)	X			
	Cavity insulation (injected PUR foam) + capillary active interior insulation (50 mm)		X		
	Exterior insulation w. aerogel plaster (30 mm) + Cavity insulation (injected PUR foam)				X
Plinth	Interior insulation (50 mm "capillary active" vapour open mineral insulation) + waterproofing		X		X
	Exterior insulation (XPS below ground, min. wool above ground or PUR spray foam) + waterproofing	X		X	
Bottom boundary (basement ceiling or floor)	Horizontal insulation (concrete slab + EPS 100 mm) if basement is heated and used	X	X	X	X
	Cellar ceiling insulation (min. wool 100 mm) if basement is unheated	X	X	X	X
Top boundary (roof or attic floor)	Insulation between rafters + air & vapour barrier (if attic is converted to living space): 200 mm mineral wool insulation	X			X
	Insulation between rafters & crossframing + air & vapour barrier (if attic is converted to living space): 200+100 mm insulation			X	
	Blown insulation on attic floor (if attic not inhabited)		X		
Windows	New windows with historic appearance (triple glazing) (if existing windows are non-original or beyond repair)			X	
	New windows with historic appearance (double glazing) (if existing windows are non-original or beyond repair)	X			
	Replace interior glass pane with vacuum glazing (if historic windows are in good condition)		X		X
	Replace interior frame with modern window (if historic windows are in good condition)				X

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