European Commission

European Construction Sector Observatory

Renovating the building envelope – Quo vadis?

Trend Paper Series

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Table of Contents

Table of Figures

Table of Tables

1. Background

1.1 Context and objectives

In the context of a green and digital transition as Europe recovers from the COVID-19 pandemic, several industrial ecosystems including construction have been identified as playing a key role. The Renovation Wave Strategy[1] sets out how construction will help decarbonise the EU building stock, given that buildings represent about 40% of energy consumption and 36% of energy-related CO_2 emissions in the EU[2]. Construction is also highlighted in the EU Member States' Recovery and Resilience Plans, which dedicate part of their planned investments and reforms to renovation work.

The renovation or retrofitting of the building envelope is one of the most important ways to reduce thermal losses and operational CO_2 emissions[3]. While the construction of highly energy efficient building envelopes is hardly new, the uptake of intensive and deep renovation to existing building envelopes has been slow thus far. In reaction, a number of countries[4] have implemented policy and market incentives to support building envelope renovation at cost effective prices.

The deployment of innovative and digital technologies that facilitate the renovation of the building envelope is of prime importance. Such technologies improve the efficiency of the renovation process by reducing the amount of material, labour and financial resources. In turn, a highly energy efficient building envelope will significantly contribute to a decarbonisation of the building stock.

This Trend Paper looks at recent policies and practical initiatives to foster the implementation of innovative solutions to renovate building envelopes. These include fixing and installing **prefabricated elements**, integrating **renewable energy** systems and services, and **green envelopes**. The Paper examines the drivers, opportunities, and challenges around their adoption. Finally, a set of conclusions are drawn for EU policy makers and other relevant actors on how to support and foster the adoption of technologies to renovate building envelopes.

In the following chapter (Chapter 2), the building envelope is explained in more detail, describing its main components and features, and the different technologies that were developed to renovate it. It also highlights some of the key market trends – emphasising the main benefits and challenges behind renovating the building envelope. Chapter 3 provides three examples of how some of the most innovative, yet commercialised, technologies are used to renovate the building envelope, highlighting key activities, results and challenges/opportunities. Lastly, Chapter 4 focuses on the main insights and conclusions, as well as their implications for policy makers.

1.2 Methodology

This Trend Paper uses case studies that were based on interviews and desk research. The case studies focus on fixing and installing prefabricated elements and integrating renewable energy systems and services, and green envelopes. The case studies were selected based on i) the level of information available in the public domain; ii) their innovative character and potential benefits; and iii) the level of alignment with the European Commission priorities.

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[1] European Commission (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[2] ECSO (2021). Digitalisation in the construction sector. Analytical Report. https://ec.europa.eu/growth/document/download/3ae8a41e-4b82-4150-968c-1fc73d1e2f61_en

[3] Luo (2019). Active building envelope systems towards renewable and sustainable energy. https://www.sciencedirect.com/science/article/abs/pii/S1364032119300061

[4] These for instance include Denmark, Germany and the Netherlands through the implementation of the energiesprong programme. See more information at: https://cordis.europa.eu/article/id/123617-building-retrofits-critical-to-europes-lowcarbon-pathway/fr

The scope of the analysis of this report is limited to a selection from the entire landscape of technologies, materials and innovations. The information in this report should therefore be complemented by other work in order to gain a comprehensive overview of the subject.

2. Innovative techniques for the renovation of the building envelope

2.1 Renovating the building envelope

The EU residential building stock[5] tends to be old and therefore energy inefficient. For policy-makers to address climate change, the renovation of EU residential buildings must be a key priority. A high-quality building envelope can significantly lower energy consumption[6]. As such, it has the potential to deliver sustainable and long-term impact.

2.1.1 The concept of the building envelope

The building envelope is commonly referred to as the physical separation between the conditioned (the interior) and unconditioned environment (the exterior) of a building from elements such as air, heat, noise, light, and water[7]. It serves three primary functions: support (structure); control (energy and climate through insulation and ventilation) and aesthetics (the architectural look).

Figure 1: The building envelope illustrated

Source: EU Smart Cities information system (2020)[8]

The main components of the building envelope are the roof, floor, walls, windows and doors. Nonetheless, it helps to think about each component as part of a whole system of the building envelope. If there is a change to one of the components, it may impact the quality of the entire building envelope, such as performance requirements of thermal, acoustic, light transmission, or moisture protection[9]. For instance, both thermal, and to a lesser extent, acoustic performance is affected by the presence, number, and insulation characteristics of windows and doors[10] (more information in Annex 1).

Recent research focuses on adaptive or responsive building envelopes – i.e. one that would be able to adapt to the external environment and to its users' needs and interests. Depending on the season, working conditions, and user preferences, the building envelope could adapt to let in/out more heat or airflow[11]. Another solution, the green building envelope, has been highlighted as a means of developing efficient energy-neutral solutions, while adding greenery to the urban environment, thus contributing to both climate change

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[5] ECSO (2018). Improving energy and resource efficiency. https://ec.europa.eu/growth/sectors/construction/observatory/analytical-reports_en

[6] JRC (2017). Best Environmental Management Practice in the tourism sector. https://ec.europa.eu/environment/emas/takeagreenstep/pdf/BEMP-7.2-FINAL.pdf

[7] Aslani et al.: (2019). Energy-Efficiency Technologies in the Building Envelope: Life Cycle and Adaptation Assessment. https://www.sciencedirect.com/science/article/abs/pii/S235271021830319X

[8] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

[9] Lovell (2011). Building envelope: an integrated approach. https://issuu.com/papress/docs/building-envelopes

[10] Arnold (2016). Building Envelope Design Guide. https://www.wbdg.org/guides-specifications/building-envelope-design-guide/building-envelope-design-guide-introduction

[11] Perino et al. (2015). Switching from static to adaptable and dynamic building envelopes: A paradigm shift for the energy efficiency in buildings. https://content.iospress.com/articles/journal-of-facade-design-and-engineering/fde0039

mitigation and adaptation (see figure below). With further technological progress, the stream of adaptive or responsive building envelope research is expected to gain even more momentum over the next decade.

Figure 2: The Maersk Tower (Denmark)

Source: Cfmoller.com[12].

The Maersk Tower's façade is divided into a grid structure of storey-high copper-covered shutters. The shutters adjust as required to protect from direct sunlight and over-heating, and also give the façade a deep relief effect and reduce the tower's large-scale appearance.

Figure 3: Green building envelope

Source: Arup, 2021[13].

The green building envelope not only contributes to human health (e.g. plants provide stress relief), but also has a significant influence on the micro-climate in the built environment. Green building envelopes can be used to mitigate climate change and particularly heatwaves.

Actors from the public and private sectors are increasingly aware that renovating the building envelope is fundamental to achieving a green transition. There are a wide range of potential economic, environmental and social benefits as illustrated in the table below. Anecdotal evidence shows that building envelope renovations focusing on the insulation and the substitution of single-glazed windows with double-glazed ones are expected to lead to a 50% and 90% reduction in heating demand and CO_2 emissions respectively. They have already contributed to energy savings of up to 60%, as demonstrated in Spain in the city of Vitoria-Gasteiz. This project was financed with the support of the European Union, the Regional Government and the Municipality[14].

Table 1: Overview of the main benefits linked to renovating the building envelope

Type of benefits	Benefits
Economic benefits	• Building envelope renovations **reduce the resources needed to heat/cool** buildings, which brings down operational costs; • Energy-efficient buildings allow its residents to have better **access to energy** as less energy is needed to perform the same functions. In essence, energy-efficient buildings support energy affordability (vs energy poverty) and reduce overall energy dependency; • Energy-efficient buildings benefit from **higher valuations** on the real estate market.

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[12] Cfmoller.com. The Maersk Tower awarded for its innovative façade. https://www.cfmoller.com/g/The-Maersk-Tower-awarded-for-its-innovative-facade-i17770.html#

[13] See more information at : https://www.euronews.com/green/2021/05/13/what-are-green-envelopes-and-why-would-they-transform-the-future-of-cities

[14] IEA (2020). Cost-effective Building Renovation at District Level Combining Energy Efficiency & Renewables. https://annex75.iea-ebc.org/Data/publications/Annex75_STC_WPC1_VitoriaGasteiz_Spain_202003233.pdf

Environmental benefits	• Building envelope renovations result in lower energy consumption and CO2 emissions (and other pollutants resulting from combustion processes such as fine particles).
Social benefits	• Building envelope renovations **increase thermal and acoustic comfort** without excessively relying on thermal and electrical systems; • Indoor air quality: proper design and installation of thermal insulation (in combination with the necessary ventilation systems) can help **prevent indoor air quality problems**, for example resulting from condensation, humidity or mould, or from draughts throughout the building.
Macro-level benefits	• Building envelope renovations help to improve indoor quality and the health of occupants, and their **comfort and well-being**. This leads to noticeable productivity improvement (for enterprises) and of social and health expenditures (for public authorities); • The reduced environmental impact also leads to societal benefits, in particular through **climate change mitigation** and preventing related climate damage costs; • Broad societal benefits (e.g. **local job creation and business stimulus**, supporting the local green economy) are tangible for various stakeholders involved in renovating projects.

Source: Adapted from EU Smart Cities information system (2020)[15]

In order to achieve and maximise these benefits, it is essential to use innovative techniques and processes (including materials) that will make the building envelope renovating process more efficient and effective. There are currently some key innovative techniques and processes that could play a significant role in the renovation strategies and plans to be implemented by EU Member States as part of their Recovery and Resilience Plans and the overall Renovation Wave Strategy[16].

2.1.2 Overview of technologies behind the renovation of the building envelope

In most residential and service buildings **heat can be lost through every element of the building envelope, especially roofs**. Proper insulation and sealing reduce heat loss in cold environments, keeps out excess heat in hot weather, and helps maintain a comfortable, quality indoor environment for the tenants.

The amount of insulation required varies according to the building type and climate. For instance, offices and commercial buildings have a higher internal thermal load. That means heat is generated from people's bodies and the use of electronic equipment. There are also many different types of insulating material, and some are better suited to specific applications and less suited to others. Various technologies can be integrated into the building envelope.

Windows and glazing

Windows have several functions. Principally, they provide a view of the outdoors and let in daylight, but they also offer protection from external elements (bad weather). Ideally, windows should let in as much daylight as possible, while minimising the consequent heat influx in summer and maximising it in winter. Appropriate sizing, orientation and type of glazing and framing elements are essential to balance the flow of heat and light.

Well-insulated window systems are especially important for cold climates. High-performance windows such as **double-glazed** or **triple-glazed windows, as well as low-e coated windows** have become extremely common in northern European countries, where heating systems are more used and the insulation

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[15] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

[16] European Commission (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

performance of windows can have a significant impact on energy consumption (and, therefore, on energy bills). Austria, Germany and Switzerland have the highest market share for triple glazing, at 54% of total window sales[17].

Higher-performance windows with lower U-values reduce occupant discomfort near windows. However, solar control also needs to be addressed, because excessive solar heat and glare can cause discomfort[18]. **Advanced solar control glazing** systems are designed to reflect near-infrared light while transmitting high levels of visible light, hence reducing the need for tinted glass. Some types of windows can reflect over 70% of the solar heat and over 80% of the sun's UV rays without changes in the glass colour[19], thus significantly reducing the need for air conditioning and making them applicable to most contexts (higher protection levels are possible with tinted glass). Combining these advanced solar control glazing and exterior shading solutions could offer an improved solution that is relevant across the EU.

Dynamic glazing offers the potential to modulate solar heat through glazing while maintaining a view of the outdoors. For example, **electrochromic windows** change opacity in response to voltage, thus giving the building's occupants control over the amount of light and heat passing through. Another example is **thermochromic windows,** in which the reflectivity of the glass and transmittance properties change at specific temperatures[20].

Figure 4: Electrochromic glazing in an office in Germany

Source: SageGlass.com

The use of electrochromic windows reduces overall energy loads by an average of 20% and peak energy demand by up to 26% over a building's lifecycle[21]. Greater market uptake and economies of scale are needed to improve dynamic solar control so that it can become cost-effective for mainstream markets.

According to some estimates, there could be **up to a 37.4% reduction in CO_2 emissions and energy consumption** by 2050 from buildings alone, by using high-performance windows in all buildings in the EU[22]. By 2030, simply by doubling the replacement rate of single-glazed windows for more performant windows in the EU, it would be possible to achieve around 20% of the EU's 2030 energy efficiency targets[23]. These savings would mainly benefit European countries with colder climates, where heating is most used (for example, replacing old windows with high performing ones could lead to a reduction of energy consumption by 2050 compared to 2020 of up to 45% in Latvia, Estonia, and Lithuania, 42% in Denmark and Belgium, and 40% in Hungary)[24]. Nonetheless, important savings would also take place in warmer countries such as Spain, Italy or Portugal (all three are estimated to reduce energy consumption by 26% in 2050 compared to 2020). In line with the Energy Performance of Building Directive (EPBD), EU Member States are required to develop long-term renovation strategies. The European market of high-performance windows and glazing are expected to grow[25] over the next few years as a consequence of the rising renovation rates across the EU.

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[17] IEA: Technology Roadmap – energy Efficient Building Envelopes. Available at: https://www.iea.org/reports/technology-roadmap-energy-efficient-building-envelopes

[18] Ibidem.

[19] Morleyglass. More information on: https://www.morleyglass.co.uk/tinted-glass-roof/

[20] See for instance, the Switch2Save project. https://switch2save.eu/

[21] SageGlass. Sustainability. https://www.sageglass.com/en/benefits/sustainability

[22] Glass for Europe. Glazing potential: energy savings and CO_2 emission reduction. Available at:https://glassforeurope.com/glazing-saving-potential-2030-2050/#1554817237395-6c002fcd-0c9c

[23] Simon, F. (2020). Glass industry boss: Replacing old windows can bring huge energy savings. Available at: https://www.euractiv.com/section/energy/interview/glass-industry-boss-replacing-old-windows-can-bring-huge-energy-savings/

[24] Glass for Europe. Glazing potential: energy savings and CO_2 emission reduction.

[25] Pilkington (2019). Revised EU energy efficiency rules have opened a window of opportunity for the glass and glazing industry. Available at: https://www.pilkington.com/en-gb/uk/news-insights/featured-articles/eu-energy-efficiency-rules-have-opened-a-window-of-opportunity-for-the-glass-and-glazing-industry-np

The European Commission has developed common standards on window performance and has fostered research and renovations through, for instance, the Renovation Wave[26], numerous projects funded under Horizon 2020 (three of them presented in Chapter 3), and the revised Energy Performance of Buildings[27] and proposed Energy Efficiency Directives[28]. A variety of products, including roller shades, awnings, and exterior or interior blinds, made of various materials, fabrics and configurations, can now also be tested and compared in whole-building simulation software against EN 14500 to estimate energy savings.

Exterior walls

In hot climates, walls characterised by a **reflective surface** are part of an innovative technique that consists of installing external walls with the capacity to reflect heat. This is to prevent heat from accumulating in the envelope and, consequently, entering conditioned spaces, hence why they are also known as “cool walls”. Reflective walls can simply be white coloured walls that reflect visible and near-infrared light, thereby reducing the amount of solar radiation that the building is exposed to. Light-coloured external walls can reflect up to 90% of sunlight when new, but tend to lose reflectance as they age and become darker due to pollution, dirt, and atmospheric events[29]. Darker walls typically reflect less than 50% of sunlight. Reflective walls can reduce whole-building annual heating, ventilation, and air conditioning energy use by 3% to 25% for single-family homes, and up to 9% for retail stores[30].

Overheating can also be addressed by equipping external surfaces with vegetation (e.g. **green walls**, garden walls, or green buildings). The plants are usually planted in a mix of soil and aggregates and the external walls are equipped with a built-in irrigation system. These walls can be further equipped with sensors to regulate the irrigation of the plants. Green walls can offer additional insulation, and they can also play a role in minimising the effects of air pollution[31]. North America and Europe are assessed to be the biggest markets for green walls, but significant market opportunities are expected to emerge in Asia due to its high air pollution rates. Green walls provide air purification, absorb excess heat that would otherwise flow into the building, and, thereby contribute to the overall energy performance of the building. A more detailed analysis of green envelopes is provided in section 3.3 Green building envelopes.

Figure 5: Types of green walls

Source : EBF-greenroof.eu

Research and prototyping also focuses on the development of **adaptive walls**, understood as prefabricated multi-functional lightweight panels that can reduce the need for heating and cooling by more than 50% in comparison with renovations that use conventional materials. Adaptive walls allow for a controlled heat and air exchange with the outdoors. A project named ADAPTIWALL integrated a glass covered solar collector and

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[26] European Commission. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[27] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG

[28] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on energy efficiency (recast). COM/2021/558 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0558

[29] Levinson, A. et al. (2019). Solar-Reflective “Cool” Walls: Benefits, Technologies, and Implementation. Available at: https://www.osti.gov/servlets/purl/1615340

[30] Ibidem.

[31] Transparency Market Research. Green Wall Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2017 – 2025. https://www.transparencymarketresearch.com/green-wall-market.html

an indoor radiator into their pre-fabricated façade walls offering improved: i) heating—outdoor heat is harvested, stored in the concrete buffer and released to the inside of the building when needed for (additional) heating; ii) cooling—indoor heat is harvested, stored in the concrete buffer and released to the outdoor environment when needed for cooling; iii) breathing—indoor air is refreshed with outdoor air with minimal energy loss. ADAPTIWALL uses nanomaterials in the concrete walls that can store three times more energy than normal concrete. The inclusion of a glass covered solar collector allows for 20% higher energy savings compared to other non-transparent adaptive concepts[32].

Roofs

Similarly to reflective surfaces in walls, **cool roofs** are able to reflect solar radiation to reduce the amount of heat transmitted to the rest of the building. Reflective roofs can reduce indoor temperatures in hot climates, thus cutting down the need for air conditioning[33].

The global market for green roofs is expected to grow by more than 17% by 2027 compared to 2020 levels[34], which is partly attributable to the growing public awareness of climate change and bad air quality, and Europe is the leading market[35]. Green roofs provide numerous benefits, ranging from purification of the air, reduction of ambient temperature (plants can absorb up to 50% of the sunlight and reflect up to 30% of it[36], leading to a reduction of up to 75% of the need to use air condition[37]), driver for biodiversity, and noise reduction. Another important feature of green roofs is their capacity to function as rainwater buffer, thus reducing the pressure on the public sewage infrastructure. Although difficult to measure, some studies have proved that green roofs can retain on average 50-75% of the total rainwater volume and provide a significant reduction in pollutants dissolved in the water[38]. Cities and communities can benefit from green roofs as they positively affect climate adaptation while providing additional insulation. Green roofs can be combined with other solutions, for instance blue roofs[39] or photovoltaic panels, to exploit the full potential of the building envelope.

Another potential innovative renovation is the **integration of renewable energy solutions** directly into the external façade of the building, that is the so-called building-integrated photovoltaics (BIPV). With the promotion of buildings that consume little or no energy, roofs are becoming a typical location for the installation of photovoltaic (PV) cells. PV panels are alternative cladding and can help improve the thermal performance of the roof by offering shading, while also producing electricity. Most are installed well above the roof surface, with natural ventilation below the solar panel to provide heat rejection of the absorbed energy and maintain PV efficiency[40].

Figure 6: A building with integrated PV panels

Source: PVEurope.eu

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[32] Multi-functional light-weight WALL panel based on ADAPTive Insulation and nanomaterials for energy efficient buildings. Available at: https://cordis.europa.eu/project/id/608808

[33] Sahoo, S.; S. Sudhir; and B. Shah (2013). "Study of cool roof on rural and low-income house group", presented at the Centre for Environmental Planning and Technology University (CEPT).

[34] Clevercities.eu. Deliverable 5.1 Market analysis.

[35] Ibidem.

[36] Sempergreen. Benefits of a green roof. Available at: https://www.sempergreen.com/en/solutions/green-roofs/green-roof-benefits

[37] New York Times. The Green Roof Revolution. Available at: https://www.nytimes.com/2019/10/09/realestate/the-green-roof-revolution.html

[38] Johnson, P. A. (2008). Green Roof Performance Measures - A Review of Stormwater Management Data and Research.

[39] Blue roofs are roof designed to provide temporary water storage that is gradually released over a certain period of time. They are usually used to prevent floods due in risk areas. The Wimbledon Grounds' roofs, a residential project in the UK, include one of the largest blue roofs in Europe, with a surface of 14,000 m^2. The old sewers in the city are not able to cope with the unchecked run-off from roofs and are regularly overwhelmed, causing flooding and overflows. The blue roof helps reducing flooding by holding back rainwater and then gradually releasing it when the storm has passed. More information at: https://green-roofs.co.uk/14000sqm-blue-roofs-wimbledon-grounds/

[40] IEA. Technology Roadmap for Energy Efficient Building Envelopes.

EU rooftops could potentially produce 680 TWh of solar electricity annually (representing 24.4% of current electricity consumption), two thirds of which would be available at a cost lower than current residential tariffs[41]. The installation of PV panels can present several challenges. Countries with currently low electricity prices and high real estate investment interest rates tend to have lower installation rates, because the benefits of installation are outweighed by current costs[42]. Another challenge is ensuring that roof penetration does not cause water leaks. Furthermore, PV cells do not reflect heat as well as other materials for roofs and may underperform due to higher cell temperatures. Roofs with PV cells are not necessarily well-insulated and the absorbed energy could flow into the building and increase temperatures.

Innovative solutions to renovate building envelopes are continuously being developed. Most **technologies and solutions are rapidly advancing**, partly thanks to the growing demand in the market linked to the availability of public incentives and the efforts made to achieve national and European climate and energy goals.

2.2 Market development

2.2.1 State of play of building renovating in the EU

Approximately 75% of the current EU building stock is energy inefficient, and it accounts for almost 40% of the EU total energy consumption and 36% of greenhouse gas emissions[43].

The EU building stock is relatively old – 45.4% and 75.4% of it was built before 1969 and 1990 respectively[44]. However, the state of play is not homogenous across EU Member States: the share of occupied buildings built before 1990 (including historical buildings) is higher in the north-east regions (i.e. in Sweden, Estonia, Latvia, Lithuania, Hungary, Romania, and Bulgaria), while the share of historical buildings, built before 1920, is greater in central Europe (i.e. in Belgium, France and Germany)[45]. Moving forward, it is assumed that 80% of the existing building stock will still be in existence by 2050[46].

The current annual renovation rate in the EU is low in comparison to the set objectives (relating to both renovations and climate). In fact, the rate for residential buildings is estimated at 1%, dropping to 0.2% when focusing on deep renovations only[47]. Rates are estimated to be equivalent for non-residential buildings[48]. Recent studies[49] demonstrate that the annual renovation rate for EU-27 + the United Kingdom should grow to well above 2% in the next ten years in order to achieve the renovation of almost 80% of existing buildings by 2050. Currently, the rates vary between 0.4 to 1.2% among individual EU Member States.

Renovations of the EU building stock between 2012 and 2016 translated into an annual primary energy savings of 8.8% in residential building renovations and 17% in non-residential building renovations (the performance of the building was measured before and after the renovation). Deep renovations generate energy savings of up to 70%, while lighter renovations generate an average of 13%[50].

The amount of investment earmarked for renovation in the EU is growing, supporting the development of the construction sector and the creation of more and better jobs. This trend is expected to continue following

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[41] Bodis, K.; Kougias, I.; Jager-Waldau, A.; Taylor, N.; Szabo, S. (2019). A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. *Renewable and Sustainable Energy reviews* 114.

[42] Ibidem.

[43] Zangheri P. et al., (2020), Building energy renovation for decarbonisation and Covid-19 recovery, EUR 30433 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-24766-1, doi:10.2760/08629, JRC122143.

[44] ECSO (2018). Improving resource and energy efficiency.

[45] JRC (2021). Building energy renovation for decarbonisation and Covid-19 recovery. https://joinup.ec.europa.eu/sites/default/files/document/2020-12/KJNA30433ENN.en_.pdf

[46] Jovanovic (2019). Energy-efficient building design in Southeast Europe.

[47] Below threshold (x < 3% savings); Light renovations (3% ≤ x ≤ 30% savings); Medium renovations (30% < x ≤ 60% savings); Deep renovations (x > 60% savings).

[48] EC (2019). European Commission: Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU. https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf

[49] Zangheri P. et al., (2020), Building energy renovation for decarbonisation and Covid-19 recovery, EUR 30433 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-24766-1, doi:10.2760/08629, JRC122143.

[50] EC (2019). European Commission: Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU. https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf

the recent EU policy development, such as the Renovation Wave Strategy[51]. Building renovation not only increases energy efficiency of buildings, but also improves living conditions of citizens and supports both the economic sector and the EU climate ambitions in the short and long term.

2.2.2 Drivers of building renovation

Policy drivers

In recent years, the EU has developed several strategies, policies and financing schemes to advance its climate objectives. Among them is the EU Green Deal, its Clean Energy Package including the updates of Energy Performance of Buildings and Energy Efficiency Directives, and the Renovation Wave[52] which have a direct impact on the construction sector and its activities. In particular, these initiatives support renovation of buildings, with the ultimate goal of achieving Europe's climate objectives.

At the national level, EU Member States have also been active in developing policy initiatives, translating the EU climate objectives into their national contexts. Notably, they all developed i) long-term renovation strategies; ii) recovery and resilience plans; and iii) national energy and climate plans (NECP). The table below provides examples of the two first initiatives.

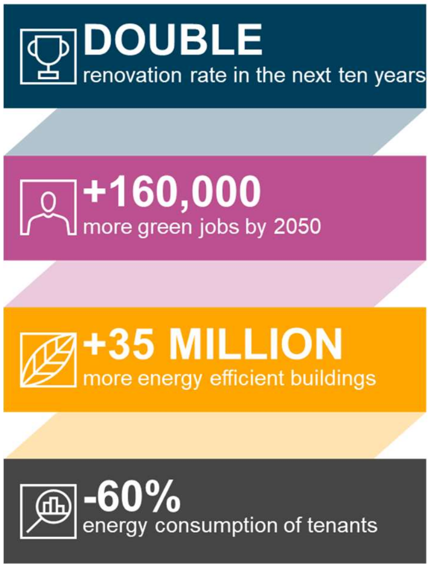

Table 2: Illustrative examples of renovation related measures at national level

Country	Recovery and Resilience Plan renovation measures	Long-term renovation strategy measures
France	A total of EUR 6.7bn has been allocated to building renovation within the "France Relance" package (7.2%), of which EUR 5.8 bn is financed through the National Recovery and Resilience Plan (14% of the Recovery and Resilience Plan funding).	• From 1 January 2023, dwellings whose final energy consumption will exceed a certain threshold may no longer be rented out; • From 1 January 2028, all dwellings with excessive energy consumption will have to be renovated; • 49% decrease in building sector GHG emissions by 2030 compared to 2015; • Residential: 22% reduction in energy consumption in the building sector by 2030, 29% by 2040, and 41% by 2050, compared to base year 2015.
Italy	In Italy, approximately EUR 18.5 bn is allocated to renovation, of which EUR 15bn is funded through the National Recovery and Resilience Plan. The majority (EUR 4.7bn) is directed towards energy efficiency and seismic engineering of private and public housing. In addition, the government created the 'Superbonus' scheme, which offers a 110% tax rebate for the purchase cost of	• Italy aims to ensure 209 ktoe per year of final energy savings (equivalent to 0.6% of the residential sector's final energy demand in 2018); • For 2022 and 2023, it is expected to achieve around one third of annual energy savings set in the NECP, and one third of annual renovation efforts in terms of area;

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[51] European Commission (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[52] European Commission (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

	technologies such as insulation of the building envelope, heat pumps and new boilers, solar PV and co-generation, and home automation. Before the ‘Superbonus’, only 1.5% of residential sector renovations in Italy were medium depth, and 0.3% deep renovations, based on floor area. In the non-residential buildings sector only 4.9% were medium depth, and 0.6% deep renovations.	• In terms of emissions, a reduction of emissions by 718 ktCO_2 per year, covering 50,000 residential buildings per year; • Italy also set the goal to accelerate the deep renovation rate to 0.7% per year in the residential sector by 2030, and 2.9% in the non-residential sector (excluding hospitals); • To be eligible, renovation in residential buildings needs to be classified as “deep renovation”, achieving an improvement of at least two energy classes.
Germany	Germany plans to spend approximately EUR 2.6bn (10% of its total funds for the National Recovery and Resilience Plan) for building renovation goals. The Plan’s residential programme aims to achieve deep renovation of 40,000 dwellings by 2026, corresponding to a renovated area of 3,676,000 m2. Germany’s LTRS sets the target of increasing the renovation rate from 1.3% to 2% for single and two-family houses and from around 1.5% to over 2% for apartment blocks by 2030.	• From 2030 onwards, the renovation rate is expected to increase from around 1.3% to over 2% for single and two-family houses and from around 1.5% to over 2% for apartment blocks.
Spain	Spain’s Recovery and Resilience Plan comprises measures worth EUR 69.5bn. EUR 7.8bn (11%) is allocated to buildings, the majority of which is for renovation across residential and public buildings (EUR 6.8bn). The residential sector attracts the highest share of investment, which aims at renovating 1.2 million out of 18.7 million primary residences by 2030. It is estimated that the Recovery and Resilience Plan will deliver 71,000 home renovations on average per year, which would exceed Spain’s NECP target of 50,000 homes per year for the 2021-2026 period.	• 1.2 million homes (out of 18.7 million primary residence homes) to be renovated by 2030; • Energy savings of 64 154 GWh (cumulative for 2020- 2050); • For residential buildings, a 37% reduction in energy use and 99% reduction in CO_2 emissions by 2050 compared to 2020; • For residential buildings, consumption from heating to be less than 55% by 2050 against 2020 levels; • 7.1 million houses are expected to undergo deep renovation by 2050, lowering their individual consumption by 12 kWh/m^2; • The stock of new buildings between 2020 and 2050 is projected to stand at 3.9 million houses, all of them being nearly zero-energy buildings.

One of the programmes developed and implemented in EU member States targeting the renovation of buildings is the Energiesprong programme, which is further detailed below.

Box 1: The Energiesprong programme

The aim of Energiesprong program[53], originated in the Netherlands but now spreading throughout Europe and the US, is to bring viable net-zero energy refurbishment solutions – through deep renovations - to the mass market. The Energiesprong brokered a deal to bring 110 000 buildings to a nearly Zero-Energy Building (nZEB) standard. A net-zero energy house as defined under Energiesprong generates enough energy to heat a house, provide hot water and power its household appliances. This can be achieved by adopting technologies such as prefabricated facades, insulated rooftops with solar panels, smart heating, and ventilation and cooling systems. Through the use of prefabricated elements, the building envelope can be renovated in less than 10 days, thus addressing one of the main concerns about building renovation, that is the length of it.

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[53] More information available at this link: https://energiesprong.org/

In general, an Energiesprong renovation is financed by future energy cost savings plus the budget for planned maintenance and repairs over the coming 30 years. Energiesprong was supported by several EU grants[54].

One of the projects renovated with the Energiesprong approach was a 1930s Hameln apartment block (Germany). It was a great success and brought the building up to climate net-zero standards. A photovoltaic system on the roof generates enough energy annually to cover the building's heating, hot water and electricity needs. A company from Brandenburg prefabricated the façade elements. Windows, ventilation, power cables, fiberglass insulation and coatings were already integrated into the elements. They were installed on site as a new shell on the house with remarkable speed.

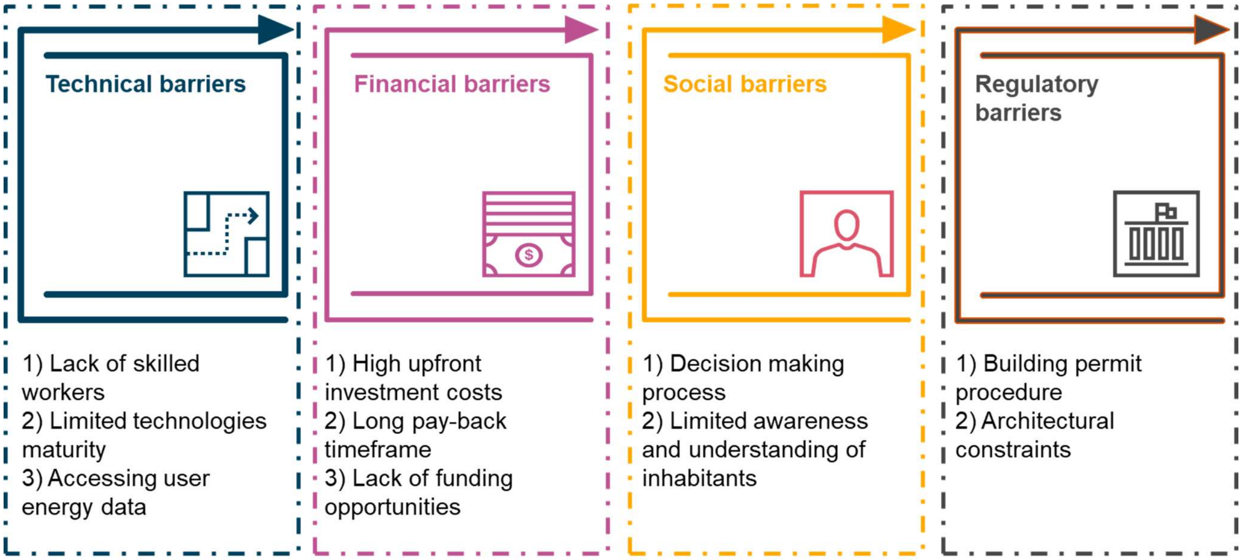
Over the last few years, there have also been several successful pilots in other countries and many more houses are planned in the UK (225), the Netherlands (14400), France (6550) and Germany (480).

Source: Energiesprong official website.

2.2.3 Main barriers to building envelope renovation

While renovating the building envelope can generate significant positive impact, the market trend reveals that it is not a widespread practice. There are several contributing factors for this trend, which are often categorised in one of the four following dimensions: i) technical barriers; ii) financial barriers; iii) social barriers; and iv) regulatory barriers.

Figure 7: Overview of the main barriers affecting building envelope renovations



The biggest technical barriers are linked to the fact that building envelope renovations involve relatively new technologies and processes, which leads to several other issues, namely:

1. the lack of skilled workers who are trained and can deal with the new technologies and the complexity of renovating from a technical and logistic perspective[55];
2. The lack of sufficiently mature, feasible and viable technologies that are at the stage of commercialisation, where economy of scale and market awareness are sufficiently developed;
3. The limited information and data on energy consumption and use, which makes it challenging to design integrated solutions and assess their potential benefits. This is due to a lack of effective integration of players in the value chain, and a lack of process control and standardised due diligence.

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[54] Transition Zero (three-year Horizon 2020 grant), E=0 (InterregNWE) and Mustbe0 (InterregNWE)

[55] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

Financial barriers are a recurrent challenge and are mainly due to difficulties in having a comprehensive life cycle cost perspective for investors and financers. They are often categorised as follows:

1. High upfront costs: due to the relatively new technologies involved and the nature of the work, renovating the building envelope requires a significant investment, which for homeowners, may be the second most significant expense after the purchase of the home itself. Homeowners may prefer more affordable energy efficiency solutions[56];
2. Long pay-back timeframe (which can reach 30 to 50 years)[57]: While the investment required is significant, the pay-back timeframe is relatively long, disincentivising homeowners to engage in renovating the building envelope;
3. Lack of funding opportunities: While this may change with the upcoming implementation of the Recovery and Resilience Plan in each Member State, current funding opportunities to renovate the building envelope are often limited. Financing schemes from commercial banks are often risk averse and tend not to consider energy savings and the related financial returns in their assessments[58], while public support schemes may not be available or attractive for low to medium income homeowners with limited access to traditional finance[59].

Social barriers refer to informal practices that shape and influence the needs and interests of end users and owners. These barriers can be summarised as follows:

1. 48.6% of the existing EU building stock is comprised of multi-apartment buildings, often with multiple owners[60]. This makes the decision-making process rather complex, especially as each owner may benefit to different extents from the building envelope renovation[61];
2. There is a lack of knowledge and awareness of the environmental impact quotient (EIQ) and energy issues and solutions. Users and owners are not necessarily aware of the financial and sustainable benefits of a building envelope renovation, as well as how it affects (i) building quality perception and building functionality, (ii) real estate value, and (iii) overall community health, as these may be intangible or long-term. Instead, users and owners tend to have little trust towards new energy solutions and technologies, and fear the potential risks, uncertainties and burdens associated with renovation activities[62].

Regulatory barriers are linked to the difficulties (timeframe, costs and/or effort) of obtaining the necessary building permits to renovate building envelopes. Moreover, some architectural-related regulations (e.g. where adding external wall insulation or replacing historic window frames and glazing is not permitted) greatly limits the possible building envelope renovation solutions.

3. Case studies

This Chapter will look at three case studies focusing on i) fixing and installation of prefabricated elements; ii) the integration of renewable energy systems and services; and iii) green envelopes. They highlight some of the practical challenges and opportunities of renovating the building envelope, which could in turn help inform policymakers who wish to support the renovation of the national building stock. These case studies were

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[56] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

[57] D'Oca et al. (2018). Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. https://www.mdpi.com/2075-5309/8/12/174

[58] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

[59] D'Oca et al. (2018). Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. https://www.mdpi.com/2075-5309/8/12/174

[60] See more information at: https://ec.europa.eu/energy/eu-buildings-factsheets_en

[61] D'Oca et al. (2018). Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. https://www.mdpi.com/2075-5309/8/12/174

[62] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

selected based on the quality and comprehensiveness of information available, using both primary (interviews) and secondary (desk research) sources.

3.1 Fixing and installation

In the context of fixing and installation, several solutions and techniques were developed, the most common i) use insulation materials to the exterior walls, roof and floor, and ii) replace existing windows with double or triple glazed types. Other techniques, at various levels of market stages, include the adoption of Active Solar Thermal Facades (ASTFs), which can function as building envelope and solar collector components.

The following case study focuses on Plug and Play modular façade renovation. This type of façade is installed on top of the existing one and has the potential to integrate a significant range of insulation materials. It is also capable of coupling with and connecting to different heating, ventilation and air conditioning (HVAC) technologies and energy distribution systems, as well as with solar renewable energy sources (RES). The Plug and Play concept provides two main benefits: i) it optimises the installation process by correcting and absorbing irregularities; and ii) it integrates the energy system and the use of renewables within the building envelope.

The RenoZEB project[63] is unlocking the underlying potential of building envelope renovation through the fixing and installation of innovative Plug and Play solutions and processes[64]. The project's objective is to exploit the potential of nearly Zero-Energy Buildings (nZEB). These low energy buildings are central to achieving EU's climate objectives.

3.1.1 The RenoZEB project: installation of Plug and Play facades

The RenoZEB project has been developed to respond to the complex issue of sustainable deep renovation of buildings. RenoZEB promotes building renovations and nZEB buildings, as well as provides users with: i) cost-effective multifunctional modular Plug and Play solutions for large-scale deep nZEB rehabilitation schemes; ii) innovative methodologies and ICT tools; iii) training; iv) guidelines; and v) demonstration cases. RenoZEB's systemic approach to renovating is a modern, technological transition towards a decarbonised economy and a more sustainable society.

Through their RD&I efforts, the RenoZEB partners (made of SMEs, large companies, non-profit organisations, public bodies and academia) developed two streams of building envelope renovation solutions: hardware and software. The hardware solution (OPAC1) includes modular Plug and Play panels and materials (e.g. wood and ceramic) for renovation. Each option comes with specific thermal information and improves the building to varying degrees. The software solution is a collaborative platform for stakeholders, which includes tools to design, plan and compare the building before and after the renovation, to i) verify its potential improvements (e.g. in energy efficiency, logistics); and ii) assess whether the benefits outweigh the costs for the renovation.

The RenoZEB team adopts a human-centric behaviour software, which collects information about heating consumption and electricity use (specifically for lighting), measured by sensors in the building and its facades. The software then delivers data on temperature, humidity and power consumption in order to predict tenants' behaviours and consequently reduce energy consumption.

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[63] Grant agreement ID: 768718; Funded under: H2020-EU.2.1.5.2. More information available at: https://cordis.europa.eu/project/id/768718

[64] More information available at: https://renozeb.eu/

The RenoZEB project developed three virtual pilots[65]: i) a residential building in Bulgaria; ii) an office building in Greece; and iii) a shopping centre in Italy, and two demo cases[66] in Estonia and in Spain.

We focus on the demo case conducted in Estonia[67]: the renovation of a residential building in Võru built in the late 1980s with an overall surface area of 1,307 m^2.

Figure 8: RenoZEB demo case in Võru, Estonia

Source: RenoZEB.eu

Prefabricated, multifunctional façades were installed on top of the existing structure. The façades are externally insulated and have the thickness necessary to provide a U value (thermal transmittance) of 0,18 [W/m^{2}K], which reduces the energy loss associated with infiltration. Additionally, all the windows of the building were substituted with high-performance triple-glazing windows.

In order to further guarantee energy savings and cost reduction, the ventilation, heating and domestic hot water (DHW) production facilities, control systems and energy meters were substituted with more efficient and sustainable solutions. For instance, a low invasive ventilation system was installed, guaranteeing minimum energy efficiency of 80%, while the heating and DHW facilities balance temperature inside and outside the apartments.

3.1.2 Results

The project ends in January 2022.

A preliminary analysis of the results shows a reduction of energy consumption by 60% and a 53% increase in the overall energy efficiency of the building. As such, the energy label changed from previous label "E" (231 kWh/m^2 a) to label "B" (124 kWh/m^2 a). This pilot project is expected to contribute to a reduction in construction waste and time (-65% in comparison to traditional methods); growth of economic benefits from a reduction in energy demand, and the satisfaction of the tenants.

Estonia plans to renovate 141,000 buildings (54 million m^2 in total) within 30 years. The Võru project could serve as a good example of an efficient and effective renovation that addresses the needs of the market as well as the climate policy objectives of the country. This project contributed to the renovation wave in the nZEB market. Moreover, it can encourage owners to deeply renovate their properties by offering affordable and practical solutions.

3.1.3 Key insights

Based on the market assessment[68] conducted by the RenoZEB team, the main barriers to the wider deployment of innovative fixing and installation solutions (e.g. Plug and Play) are explained in table below.

The demo cases of RenoZEB had to overcome these challenges throughout the project's life cycle. Policy changes at the local level contributed to regulatory issues (e.g. changes in requirements), and the

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[65] More information available at this link: https://renozeb.eu/results/virtual-demo-cases.html

[66] More information available at this link: https://renozeb.eu/results/real-demo-cases.html

[67] More information available at this link: https://renozeb.eu/results/real-demo-cases/rannaliiva.html

[68] 1st RenoZEB Market Assessment. Available at: https://renozeb.eu/fileadmin/Media/Reports/RenoZEB_Market_Assessment.pdf

administrative process (e.g. building permit) led to delays in the work and consequently impacted the budget. There have also been some technological issues (problems with highly specific tools needed to install the facades but rarely used before), which reflect the innovative, new nature of the techniques used as part of the project. Despite slowing the overall installation, however, these issues were not among the most complex ones, as they can be easily solved by upskilling workers. It also became clear that the flow of information about the use of innovative and sustainable products between developers, architects, users and other actors needs to be improved.

Another key insight of the RenoZEB projects was the lack of awareness about innovative solutions among investors. In order to attract significant financial support, that would add to public resources, raising awareness among investors is crucial. Setting up SMART targets and KPIs, and conducting impact evaluations would provide further fact-based evidence of the benefits of renovating the building envelope.

3.2 Integration of renewables and services

The transformation of existing buildings into energy-autonomous and energy-efficient buildings can be achieved through the installation of a series of renewable energy technologies, high-efficiency conversion devices and energy storage solutions. The design of an appropriate set of technologies tailored to the specificities of each individual building (i.e. building thermal demand, position, geographical area, etc.) and the correct system operations are mandatory for cost-effective solutions.

3.2.1 The RE-COGNITION project: integration of renewable energy technologies

The RE-COGNITION[69] project aims to foster large-scale deployment of building-level renewable energy and safely connect it to the grid. It is developing an integrated solution to maximise the use of the energy that is locally produced by building-level renewable energy technologies. This would reduce costs and advance the transition towards nZEBs.

The project is structured around two main pillars:

- First, to develop a non-intrusive and scalable cross-cutting Renewable Energy Sources (RES) integration platform. Through this platform, the Automated Cognitive Energy Management Engine (ACEME) along with an intelligent Gateway (iGateway) is deployed, to optimally harness the energy generated from each of the available energy sources, taking into account real-time consumption, operation of storage units, and grid conditions.
- Second, RE-COGNITION wants to contribute to the development to the field of less mature renewable technologies to be integrated in the building envelope (such as Building Integrated Photovoltaic and Vertical-Axis Variable Geometry Wind Turbine) and more established constant-source technologies (like micro-CHP based on biogas) for the building environment, along with optimally designed envelope system peripherals (i.e. latent-heat thermal storage and hybrid systems, driven by solar-thermal power for cooling purposes).

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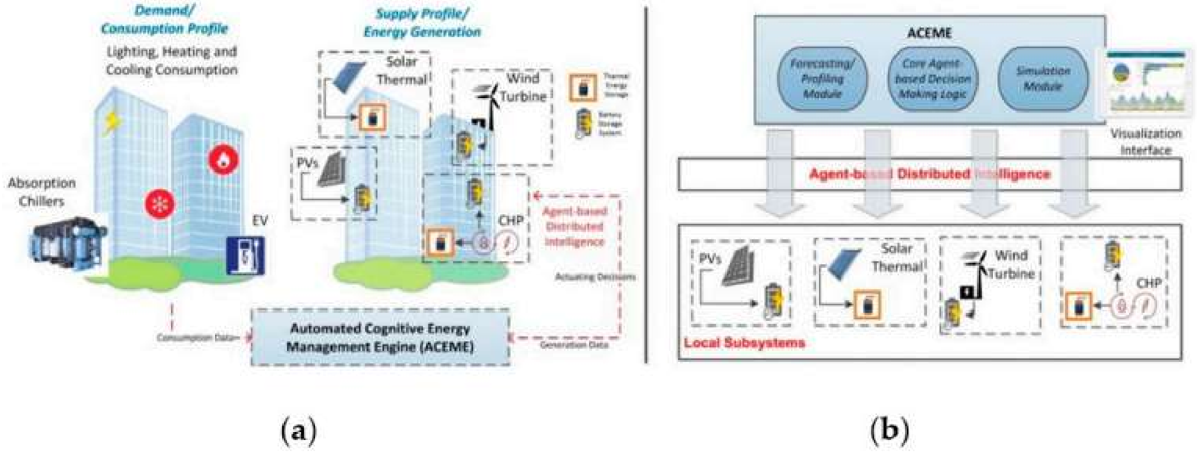
[69] ReCognition. This project has received funding from the European Union's Horizon 2020 research & innovation programme under grant agreement n° 815301. More information at: https://re-cognition-project.eu/

Figure 8: RE-COGNITION project main pillars



(a) (b)

Source: Guelpa, E.; Manco’, G.; Verda, V. (2020).

The multi-energy system supplies the electricity–heating–cooling demands of residential buildings through the optimal allocation of energy production by four different power generation sources, which are intended as integrated within the building envelope. The types of RES that the RE-COGNITION project uses[70] are:

- **Micro combined heat and power unit** – an innovative high-efficiency energy solution that uses natural gas or biogas to generate both heat and electricity for the home by capturing excess thermal energy that would normally be lost during power generation. This solution can be integrated in the building envelope and represents a strategic approach to compensate for the intermittency of renewables. The units used in the RE-COGNITION projects are developed by EnerTwin Heat&Power[71] and allow for small-scale cogeneration using a microturbine that can operate with biogas.
- **Lightweight photovoltaic** – these panels are designed to be suitable for older buildings, where the installation of solar PV is limited by the load-bearing capacity of the building. Therefore, they can be easily integrated without completely renovate the building envelope. Lightweight PV is made from composite materials and polymer films, replacing standard glass for the back sheet and glass configuration for the front sheet.
- **Vertical axis wind turbines** – these passive variable wind turbines are classified as small-scale, making them more suitable for highly populated areas. The geometry of the wind turbine is designed to capture and maximise urban wind. Each blade is able to self-adapt to different wind conditions. These turbines meet the needs of urban boundary layer flows and building-specific applications, characterised by high turbulence and variable wind speeds in space and time and where traditional turbines have performed poorly[72].
- **Latent heat thermal storage** –energy is stored and released by the melting and solidification of a material, also known as the phase transition of a medium. This technique allows for higher storage density compared to conventional water storage. As an added value, it has two to three times smaller storage volumes, allowing for easier integration in building applications.

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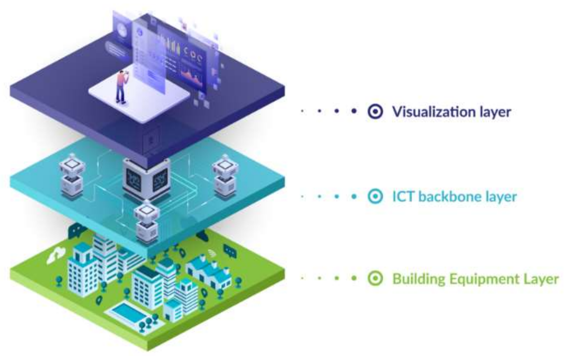
[70] Mancò, G.; Guelpa, E.; Colangelo, A.; Virtuani, A.; Morbiato, T.; Verda, V. Innovative Renewable Technology Integration for Nearly Zero-Energy Buildings within the Re-COGNITION Project. *Sustainability* 2021, 13, 1938.

[71] EnerTwin. Available at: https://enertwin.com/

[72] Windcity. Available at: http://www.windcity.it/en/

3.2.2 Results

Figure 9: The RE-COGNITION project system to link building envelope equipment with stakeholders



Source: re-cognition-project.eu

The RE-COGNITION project developed a three-layer system architecture that connects new **building equipment within the building envelope** (RES and storage components, as well as peripheral electrical and thermal equipment) **to the ICT backbone** (the smart infrastructure which includes an automated cognitive energy management engine, an intelligent gateway, and a building energy flow simulator). Together they make up the visual dashboard (see Figure below). It is the **interface** through which the stakeholders communicate with the RE-COGNITION system[73].

The visual dashboard gives the project's stakeholders a complete overview of the building system (i.e. equipment included in the building envelope and ICT backbone). Before the end of the project, planned for March 2022, the project team plans to finalise the user interfaces for all pilot sites and enhance communication services among different system components to strengthen user-oriented functionalities[74].

Figure 11: RE-COGNITION's Visual Analytics Dashboard

Source: re-cognition-project.eu

The RE-COGNITION project assessed the possibility and feasibility of integrating innovative renewable energy solutions into existing building envelopes, thus optimising building's energy consumption and overall emissions. It had six pilot implementations in four European countries (Italy, Greece, Romania, and the United Kingdom). The development and optimal exploitation of RES technologies through the RE-COGNITION

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[73] RE-COGNITION project. https://re-cognition-project.eu/

[74] Ibidem.

integration framework resulted in significant **benefits in cost** (reduction of 11% to 42%) **and emissions** (reduction of 10% to 25%)[75] for the building.

3.2.3 Key insights

Although the RE-COGNITION project had certain successes, several challenges remain, namely, social acceptance, a trained workforce, and the affordability of components (which, since they are used in unique installations, tend to be more expensive).

The European market for building-tailored RES solutions needs to grow and become more integrated. This would not only increase awareness among consumers and professionals, but also increase the availability of components. Financial support (e.g. public incentives, tax exemptions, preferential loans, etc.), legislative and regulatory homogenisation and integration (i.e. strengthening of the European Single Market in these sectors to create European value chains), as well as upskilling and training the workforce would all benefit the market.

3.3 Green building envelopes

Green building envelopes can alleviate the heat island effect, reduce energy demand and CO_2 emissions and support biodiversity[76].

The green building envelope offers additional plant-based "*areas in the form of building envelopes and provide the dense inner city with surfaces for effective and applied green infrastructure*"[77]. In practice, the green envelope components are roofs and walls (sometimes referred to as roof and vertical greenery systems).

Figure 10: Illustrative example of benefits from the green building envelope

Source: Arup (2016), Cities alive: green building envelope.

Green walls can either be ground based, also called climbing walls, (i.e. where the greenery is grown upwards from ground level, either from the soil, pots or planter boxes) or wall based, a.k.a. modular walls (i.e. where the greenery grows from containers on the surface of the wall). Modular walls tend to be more expensive as the installation requires more material, whereas climbing walls are cheaper but require more time for the plants to grow. Green roofs can be classified as extensive (lightweight and low-maintenance) or intensive solutions[78].

3.3.1 The ProGIreg project: Green infrastructure for urban regeneration

The ProGIreg project – which stands for "Green productive infrastructure for post-industrial urban regeneration" was launched in 2018 with the financial support of the EU through the Horizon 2020 Programme (EUR 10.4 million grant). An additional EUR 1.2 million was raised by ProGIreg's 34 partners. They are comprised of cities, NGOs, research institutions, and businesses, allowing the project to leverage different types of expertise and knowledge.

The project created living labs in four cities that advanced nature-based solutions, i.e. '*solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and*

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[75] Mancò, G.; *et al.* Innovative Renewable Technology. *Sustainability*.

[76] Radic (2019). Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits. https://d-nb.info/1200466454/34

[77] Arup (2016). Cities alive : green building envelope. http://www.arup.com/cities_alive/green_building_envelope

[78] Rosasco (2019). Selection of (Green) Roof Systems: A Sustainability-Based Multi-Criteria Analysis. https://www.mdpi.com/2075-5309/9/5/134/pdf-vor

economic benefits and help build resilience'[79]. As part of the nature-based solutions, green building envelopes reduce storm water runoff, capture CO_2 emissions, filter pollutants, and increase biodiversity.

The table below illustrates various projects in the area of green walls and roofs.

Table 3: Overview of Green walls and roof project in the context of the ProGIreg

Location	**Name of the project**
Turin, Italy	• Green roof at Casa nel Parco; • Green wall indoor at school; • Green wall outdoor on a homeless dormitory; • Green roof at WOW.
Zagreb, Croatia	• Green Roof and Wall at Sljeme meat-processing factory; • Green Roof and Wall on other factory buildings at the same site.
Zenica, Bosnia	• Green roofs and green walls.
Cluj-Napoca, Romania	• (Upcoming) Green roofs and walls on public buildings in the city, making them more pleasant and energy efficient.

We will use the example of the Sljeme meat-processing factory in Zagreb, Croatia to highlight the activities, results and lessons learnt. The objective of this project was to revitalise an urban (and former industrial) area by renovating local buildings and developing productive, green infrastructure that supports socioeconomic development in the city of Zagreb. The factory is being revamped for public facilities with a 700m^2 green roof (150m^2 of solar panels) and 300m^2 of green walls in the future, and thus make the buildings more energy efficient and aesthetically pleasing.

Figure 11: Current vs. envisaged green walls and roof

Source: From Spajić (2020)[80].

Part of this effort focuses on the creation of a mini-urban farm, which is designed as a new complete solution that integrates a green roof, green walls and aquaponics technologies. This farm will be used for education, a mini market, workshops, plant transplanting and more.

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[79] See more information at : https://progireg.eu/nature-based-solutions/background/

[80] Spajić (2020). ProGIreg Nature for renewal. http://foris.fao.org/meetings/download/_2020/xi_workshop_of_the_silva_mediterranea_working_grou/presentations/_05_spajic.pdf

Box 2: Description of the mini urban farm

The implemented farm is a green technology centre in the Sljeme factory area and has both commercial and educational functions. The basic components of such a stand-alone system are one unit measuring 6 x 6 m, an example of green wall and roof, an aquaponic system inside, a microclimate automation and control and irrigation systems.

The farm contains the aquaponic system with water quality management equipment for a fish processing area, storage area, packaging area, and growing plants. A green wall structure has been erected on two sides of the unit, to protect the area from the sun and to collect excess rainfall for later use[81].

Source: From ProGIreg, 2021:93[82].

A significant amount of time was invested in the preparatory phase in order to get buy-in from citizens and to ensure that project fits within the local economic and social context of Zagreb as well as the strategic objectives of the city. The actors carried out a spatial analysis to better understand the local context, i.e. socio and cultural inclusiveness, human health and wellbeing, ecological and environmental issues, and the economic and labour market[83]. This exercise also provided them with a baseline against which they could monitor and benchmark the progress made in the project. Notably, the project invited citizens to three co-designing workshops. Once tested and validated, the approach was implemented into practice.

3.3.2 Results

The green wall of the mini urban farm was finalised in September 2021, together with the installation of sensors (measuring temperature and relative humidity) to monitor the air conditions. Leaf samplings have been tested in September 2021 to measure biomonitoring activities.

A monitoring and assessment framework has been put in place to assess the short, mid and long-term benefits of the measures implemented. The indicators used include inter alia social and economic impact indicators, carbon storage, saved carbon dioxide emissions, ozone (O_3) and nitrogen dioxide (NO_2) concentrations, air temperature, amount of soil saved, water quality[84].

Figure 12: Green Wall of the mini urban farm

Source: From ProGIreg, 2021[85].

3.3.3 Key insights

ProGIreg proved to be relatively successful since its inception. The project managed to address several challenges, and highlight key success factors – notably the importance of stakeholder consultation and buy-in.

These insights are summed up in the table below.

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[81] ProGireg (2021). Report on benefits produced by implemented NBS.

[82] Ibidem.

[83] See more information at : https://progireg.eu/resources/planning-implementing-nbs/

[84] ProGireg (2021). Report on benefits produced by implemented NBS.

[85] Ibid.

Table 4: Overview of challenges specifically for green walls and lessons learnt

Type of challenge	Description
Technical barriers	• Choice of the plants: climate adaptation, adequate characteristics (e.g. CO_2 absorption), pace of growth, propensity to spontaneous development, etc.; • Surface deterioration and plans detachments; • Lack of skills: specific training for the staff in charge of maintaining green walls.
Financial barriers	• High installation and maintenance costs: while no number was provided, the installation costs are perceived as relatively high.
Social, environmental, and regulatory barriers	• Reduce the potential environmental burden by maximising the use of recycled or natural materials; and integrating water recovery systems and sensors for water and nutrient minimisation; • Engage with citizens and stakeholders to get sufficient ownership and buy-in, and to maximise the social impact of the project.

Source: Adapted from ProGIreg (2021)[86]*.*

4. Conclusions

4.1 Main insights

The literature and case studies on building envelope renovations presented in this report highlight some of the challenges and opportunities that public and private sector actors face in fostering the renovation of the EU building stock. Overall, there is an increasing market interest in renovating the building envelope to reduce energy consumption, improve the quality of life of owners and tenants, and increase the commercial value of proprieties. Similarly, the public sector sees renovating as a chance to meet ambitious climate objectives. Governments at the European and national levels have introduced policy measures, schemes and projects in several EU Member States. Discussions no longer speculate whether the EU and its Member States should support renovating the envelopes of their building stock, but rather how to do so efficiently (in terms of cost and results ratio) and effectively (in terms of sustainability goals and quality standards). To do so, it is important to understand (i) what constraints exist that should be addressed to foster renovating building envelopes and, more generally, increase the renovation rate of the EU building stock, and (ii) what drivers exist and what opportunities are available that the public sector could and should leverage.

The literature and the case studies demonstrate that there are still significant barriers that limit a wider uptake of renovation measures. These are financial, technical, and social barriers, and involve different actors, from policymakers, to companies and consumers – including both building users and owners.

The first type of barrier that innovative renovation solutions face is financial. Despite innovative solutions outperforming their traditional counterparts in many cases (i.e. cost/benefit or energy savings), their widespread uptake continues to be a challenge. New solutions often struggle to move from the prototype and pilot phases to market adoption.

The second type of barrier is technical. Some of the more innovative techniques, although very promising based on their first applications, are still facing challenges in their implementation. As shown in the case studies, technical issues were encountered in specific applications (e.g. building-integrated photovoltaic panels on older buildings require additional assessments on whether the building structure can support the additional weight). In addition, construction companies struggle to find skilled labour to conduct renovation activities using innovative techniques and solutions, especially when coupled with digital technologies.

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[86] ProGireg (2021). Report on technological barriers. https://progireg.eu/fileadmin/user_upload/Deliverables/D5.2_Report_on_technological_barriers_proGIreg_28_02_2021.pdf

The third barrier is behavioural and regulatory. Building owners, users and companies are sometimes not aware of, and hence not interested in, new renovation techniques and all their benefits. For instance, as explained by a representative of the European Federation of Green Roofs and Wall Associations[87], the benefits provided by green envelopes in cooling and shading are not necessarily better than some traditional insulation techniques that perform the same function, and might have a higher investment cost. However, green envelopes also contribute to improved air quality in the area, they absorb stormwater and thus help communal pipes deal with unexpected weather events, and support biodiversity by providing shelter and food to native species and insects. Individuals looking into renovation usually focus on direct benefits to themselves and often overlook the benefits that go beyond the single building or apartment. Building owners and users may have different interests and needs – what is often referred to as split incentives. In terms of the regulatory framework, the building permit process adds to the challenges because it may be slow or does not sufficiently consider the benefits of modern solutions, such as green envelopes. Regulations regarding the architectural value of buildings, such as historical buildings, do not permit significant renovation or limit the use of certain solutions.

All three barriers limit the development of the market, whose maturity remains under-optimal. This then translates into challenges for construction companies not only in terms of developing technologies, but also in terms of purchasing new machinery and hiring a sufficiently skilled workforce. New renovation solutions usually require the purchase of machines and software, and is often seen as an immediate cost rather than an investment with long-term benefits (e.g. shorter installation time, fewer workers in the construction site, fewer opportunities for mistakes). As there are not enough pilot projects that study the mid to long-term impact, the benefits are often unclear.

These shortcomings and barriers can be addressed using a combination of different solutions and actions. The following section provides a summary of the main recommendations for policymakers.

4.2 Lessons for policymakers

Policymakers play a key role in helping develop the market for building envelope renovations. They can support a wide range of activities, including:

1. **Co-financing the development of sustainable innovations allowing them to reach the commercialisation stage.** Public investments play a key role in supporting the development of innovative solutions that are often considered too risky and not profitable enough for private sector actors. By financing pilot projects related to building envelope renovations, the public sector will be able to demonstrate their benefits, replicability and upscaling. To do so, the public sector should firstly support the scale up and commercialisation of innovations and solutions that have already been piloted. This can be achieved by, for instance, proposing dedicated risk sharing mechanism such as guarantees, and more generally the development of financial instruments based on e.g. debt (through concessional loans). These types of financial instruments are particularly effective in attracting private sector investments – thus leveraging to a great extent limited public resources. Secondly, the public sector can also support further innovations and new generations of solutions and pilots through public support to research and development. This type of support should mainly be in the form of grants to companies and financial support to universities and innovation centres.
   It is important to highlight that the EU has developed, as part of the 2021-2027 Multiannual Financial Framework, several programmes and instruments that can support both existing innovations and future innovations, such as Horizon Europe, InvestEU, and the Recovery and Resilience Facility.
2. **Innovative solutions should unburden owners and users to the largest extent possible from some of the annoyances of renovations** (in terms of noise, waste communication and monitoring efforts), so as to incentivise their use and adoption and address some of the barriers that limit building envelope renovations. Beyond the technical aspects per se, it will be important for governments to incentivise

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[87] EFB. https://efb-greenroof.eu/

and leverage on digital platforms and technologies to coordinate with stakeholders and informing all parties of the renovation process (which is often perceived as a considerable effort for all parties).

3. **Financially incentivising construction enterprises and building owners to engage in building envelope renovation activities.** This type of support will have a two-fold positive effect on the construction market. On the one hand, it will increase demand for building envelope renovations by supporting owners and users to understand and be aware of the benefits of renovations, and afford them. On the other hand, it will foster the supply of renovation solutions by targeting companies and supporting them in the development and adoption of innovative solutions. Public authorities can support building owners and users (e.g. through grants, tax incentives, subsidised loans). The amount and type of funding would depend on the depth of the renovation of the building envelope. For construction enterprises, adopting innovative techniques and processes can be perceived as risky (cost of adopting new machinery/equipment/software, as well as adapting the business processes and having the right set of skills). Therefore, governments should provide financial support to companies and especially SMEs engaging in building envelope renovations.

4. **Providing technical assistance for companies as well as buildings owners and users**. Governments should support the reskilling and upskilling of construction workers in order to address the shortage of skills (including digital skills), which often impede the uptake of innovative techniques. Public authorities could also fund technical support in the form of expert-led workshops or advice for SMEs on e.g. how to integrate innovative building envelope renovations techniques. Such experts, also financed by governments, could also provide so-called ‘one-stop shop’ support for building owners and users, clarifying the different benefits that can be expected as well as the underlying costs. Under the Horizon 2020 programme, several projects in this field have been funded, such as ProRetro[88], HIROSS4all[89], and SHEERenov[90]. Public authorities could also take steps to better communicate the benefits of envelope renovation and the opportunities to do this at a local level.

5. **Public authorities can unburden administrative procedures by simplifying and modernising building permit processes.** In particular, digitalising the building permit and including the possibility of making it interoperable with data from BIM models and other sources such as cadastre, could make the process easier, faster, more transparent, and more straightforward for all stakeholders. Public authorities could also make allowances for changes to the building envelope, including innovative solutions (e.g. green envelopes, photovoltaics, etc.) in their urban development plans.

6. **Support for cross-border mobility of companies and workers should be incentivised**. The implementation of EU-wide policies (e.g. via the Energy Performance of Buildings Directive) has partially addressed the heterogeneity of the European market, which, however, still remains fragmented. Specifically, construction companies largely operate in their own country or region of origin and rarely scale up and expand in other EU countries. In turn, this limits the diffusion of innovative technologies for the renovation of the building envelope, as potential customers are not aware of it and economies of scale are more difficult to establish. In this context, public authorities should support cross-border mobility of companies and workers through, for instance, match-making platforms to connect companies, building owners, and project managers across the EU, and technical assistance for companies and workers to deal with legislation, social security, and other regulatory aspects of expanding in other EU countries.

7. **Facilitating collaboration and partnership between construction companies, associations, academia, and civil society to foster credibility and engagement.** Such a collaboration could contribute to the development of i) large-scale projects demonstrating the benefits of renovating the building envelope; ii) policy action to address challenges experiences by actors on a local level; iii)

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[88] European Commission. Promoting building retrofits in the private residential sector through One-Stop-Shops in Germany. https://cordis.europa.eu/project/id/894189

[89] European Commission. Home Integrated Renovation one-stop-shop for vulnerable districts. https://cordis.europa.eu/project/id/846707

[90] European Commission. Seamless services for Housing Energy Efficiency Renovation. https://cordis.europa.eu/project/id/890473

promotion and marketing materials raising the awareness of stakeholders. At the EU level, the Built4People partnership for a sustainable built environment, under the Horizon Europe programme, is planning to work with innovation clusters in every Member State. Its overall aim is to support innovation across the value chain.

8. **Engage with end users, throughout the process of renovating the building envelope.** Promoting renovations should not only focus on energy efficiency, but should also highlight benefits to human health and wellbeing. A good idea is preparing a pamphlet for the people who will live in the newly renovated building, that includes instructions and advice on how to seize the advantages and benefits of the building[91]. This will help raise awareness and address behavioural barriers, while supporting tenants in getting the most out of the new solutions. Involving many different actors will contribute to the credibility and legitimacy of deciding to renovate the building envelope, and foster knowledge sharing among the various actors.

In conclusion, all construction stakeholders have a role to play in supporting innovative and efficient solutions for the renovation of the building envelope. Renovation of the envelopes, and more generally the renovation of buildings, should be approached in a comprehensive manner and take into consideration various factors: cost, climate benefits, quality of life, health and wellbeing, and more. Renovation is not only a way to decarbonise the European building stock, but also to reach the EU climate objectives, and importantly, to improve citizens' quality of life.

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[91] EU Smart Cities information system (2020). Building envelope retrofit solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_building_envelope_retrofit.pdf

5. Annex 1: Building envelope component and their impacts

The table below provides a high-level indicative visualisation of the impact of some of the building envelope features on their performance, safety requirements and aesthetic considerations.

FUNCTION AND PERFORMANCE RELATIONSHIPS OF THE BUILDING ENVELOPE

	Systems	Walls	Glazing	Roof	Below ground level
Basic performance requirements	**Thermal**	■	■	■	□
	Moisture Protection	■	■	■	■
	Acoustics	■	🟦	□	□
	Light Transmission	□	■	🟦	□
	IAQ	🟦	🟦	□	□
	Mould Protection	🟦	🟦	□	□
	HVAC Integration	■	■	🟦	□
	Natural Ventilation	□	■	□	□
	Durability	■	■	■	■
	Sustainability	■	■	■	🟦
Safety requirements	**Fire Protection**	■	■	■	□
	Floods	■	🟦	□	■
	High Winds	■	■	■	□
	Seismic	■	■	🟦	■
	Blast, CBR	■	■	■	■

■	Major influence	🟦	Average influence	□	Limited influence

Source: From Arnold (2016).