

Case Study for Environment Friendly Thermal Envelope Renovation

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Abstract. As carbon dioxide emissions are still growing, and the building sector is highly responsible for. Because the existing building stock dominates against the newly built and the operational energy consumption is double that of the embodied energy of building materials, renovation is the key area that can reduce the CO₂ emissions effectively. This study presents the implementation and results of the REHOUSE project, focusing on a Hungarian demonstration site—a late 19th-century dormitory in Budapest. There were developed eight renovation packages from which three was implemented in the Hungarian demo building. The Adaptable Dynamic Building Envelope provides a framework for the outer surface of renovated buildings, allowing for the integration of Intelligent Window Systems and activated cellulose insulation. The original wall and window thermal transmittance were reduced from 1.32 W/m²K and 1.4 W/m²K to the values of 0.24 W/m²K and 0.5 W/m²K respectively. As a result of the renovation, the Intelligent Window System saves 3.6 MWh annually, while the Adaptable Dynamic Building Envelope and its integrated insulation contribute an additional 16.62 MWh in annual energy savings. Besides these the installed PV systems on the façade and on the roof produce 36.57 MWh energy every year. The annual energy balance of the building was reduced to half of the original. The project demonstrated the importance of renovation and the significant potential in environment protection in this way.

1 Introduction

Evidence for the current climate crisis is clearly visible in the escalating global temperatures and the surging density of atmospheric carbon dioxide. As of late November 2024, CO₂ levels reached 426 ppm, marking a staggering rise from 369 ppm at the turn of the millennium and a mere 304 ppm a hundred years ago. While these concentrations are alarming, the trajectory of yearly discharge rates is perhaps more critical. Recent data indicates that fossil fuel use and industrial cement manufacturing pushed 2024 emissions up by nearly 1%, hitting a historic high of 37.4 billion tons [1]. When factoring in land-use shifts like forest clearing, the total output for the year is projected at 41.6 billion tons [2]. This resulted in an atmospheric CO₂ jump of 3.75 ppm in 2024 alone the most rapid increase recorded since the

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late 1950s [3]. Projections suggest that maintaining this pace gives us only a six-year window before a 50% probability of breaching the 1.5°C warming threshold becomes permanent [4, 5]. The building sector is highly responsible for these atmospheric changes in concentration of carbon dioxide, by producing about 40 percent of carbon emission year by year [6, 7]. The fallout from this trend threatens the stability of both human civilization and the natural world. Mitigating these risks requires a unified, aggressive international response, by reduction of the carbon emission generated by the buildings including the embodied energy and the operational energy. However, the operational energy is almost double that of the emission due to the manufacturing of building materials. Because market-driven competition among global corporations often discourages self-imposed production limits, state-level regulation remains the most effective tool for curbing emissions. Consequently, the success of climate mitigation hinges on political will and building codes and intensity of renovating energy consuming buildings. Currently, the global landscape of building renovation is fragmented; while certain jurisdictions have enacted rigorous, mandatory legal structures, others remain hesitant or lag in their commitments. In this study, we would like to show an example of how effective the envelope renovation of a more than a hundred-year-old building. The reduction of energy consumption could be the most effective way to protect the environment, and the second one is to change the energy of fossil origin to a renewable one.

1.1 The strategies for renovation

Among the most pressing challenges facing the construction sector today is the management of operational carbon dioxide, which is inherently tied to the day-to-day energy consumption of the built environment. Forecasts indicate that operational emissions will decrease from roughly 75% to around 50% of the industry's total carbon output over the coming decades [8]. Although this trajectory reflects measurable progress, it simultaneously underscores the growing significance of embodied carbon as a share of the sector's overall climate impact.

Regarding overall emission abatement, well-designed renovation programmes demonstrate considerable potential: an optimally configured refurbishment scheme can yield total energy savings of 33.63 kWh/(m²·yr) and prevent approximately 86.01 tonnes of CO₂ from being released annually [7].

Data from documented renovation initiatives further illustrate the scale of achievable reductions. Across a portfolio of refurbishment projects, annual avoided CO₂ emissions amount to 947.55 tonnes in aggregate. Of this total, improvements to the building envelope account for a reduction of 247.65 tonnes per year, while upgrades to air-conditioning and lighting systems contribute 220.88 and 479.09 tonnes per year, respectively [9].

The concurrent optimisation of energy consumption and carbon emissions should be treated as a central objective in any energy-related building refurbishment. A structured methodology developed under the IEA EBC Annex 56 framework provides a cost-effective basis for identifying, evaluating, and benchmarking renovation measures, targeting reductions in both energy use and carbon output. Although primarily oriented towards residential stock, the approach also extends to non-residential buildings that do not incorporate complex HVAC systems [10].

Enhancing building envelope performance offers the greatest lever for CO₂ reduction, particularly in climatic zones subject to extreme cold or heat. Addressing the inefficiency of older buildings that were constructed without energy performance requirements represents an urgent priority. As a foundational step, passive envelope interventions should be prioritised to raise thermal performance to at least the threshold levels prescribed by applicable energy codes — and ideally beyond — thereby curtailing heating and cooling energy demand at the source.

1.2 Economic aspects of renovation

Economic evaluation of renovations is critical for decision-making. Using an integrated AI framework, an average of 56.62% energy savings, 51.60% carbon emissions reduction, and 24.27% life cycle cost reduction can be achieved [11]. The final recommended passive renovation combination results in 51.8% primary energy reduction, with a specific initial investment of 144.71 lb/m² and a discounted payback period of 18 years [12].

A national study by Lawrence Berkeley National Laboratory found that office buildings typically achieved 22% energy savings through commissioning, with an average simple payback period of 1.1 years. Cost-effectiveness is achieved when annual energy cost savings equal or exceed annual credit costs.

Every time we extend the life of a building instead of tearing it down and replacing it with a new one, we avoid releasing thousands of tons of carbon into the atmosphere. By reusing the existing structure of a building, we typically avoid more than half the embodied carbon impact of new construction. The key factors are the cost of renovation and the time of return of investment (ROI). This time is very difficult to calculate because it depends on the energy prices which is not possible to forecast even for more than two-three years. In case of high energy prices, the ROI will be much shorter time than in case of low energy prices. The predictable local energy prices determine the official regulations of the region, such as in the EU the energy prices are much higher than that of Russia or Belarus that is why the building codes and the building renovation is stricter in the EU and not focusing to the energy efficiency of countries having fossil fuel abundantly.

2 Materials and methods

REHOUSE project is being implemented in cooperation with 25 partners, led by Fundacion CARTIF, with a total of 8 countries participating. The project will run for 48 months, with completion scheduled for September 2026. The main goal of the project is to develop renovation solutions for making building more energy efficient from the side of renewable energy productions and for saving energy supplied into the building.

The renovation packages will be deployed across 4 locations serving as demonstrators located in Greece, Italy, France and Hungary. These buildings renovations include detailed design, pilot set-up, demonstration and evaluation to validate in operational conditions (social) the prototypes of the 8 renovation packages.

The main objective of REHOUSE is to develop fully functional prototypes and demonstrate in operational environments so called TRL7 (Technology Readiness Level). Eight Renovation Packages (RPs) of promising technology innovations designed for a wide range of building renovation actions, including deep renovations. They will overcome those main barriers that currently slow down the EU building renovation rates, following circularity principles, including multi-functionality through integration of active & passive elements, prefabrication and off-site construction and assembly of components, while respecting aesthetics, as well as the architectural and historic value of buildings. REHOUSE project will develop eight renovation packages (main features are shown in Table 1) to serve to a variety of renovation processes, ranging from simple renovations to large-scale deep renovations.

Table 1. Renovation Packages (RPs) in REHOUSE project

Renovation packages		Main targets covered
#1	Multi-source heat pump — integrating thermal energy storage, thermal panels, and HFO refrigerant	Renovation Package #1 introduces an innovative multi-source heat pump designed for the simultaneous utilization of diverse local renewable energy sources (e.g. ambient air, solar,

		geothermal) alongside advanced thermal energy storage systems.
#2	Adaptable/dynamic building envelope — integration of solar panels, battery systems, insulation materials, ventilation units	The ADBE prototype establishes a structural ecosystem in which an aluminium-glass façade, developed according to contemporary construction standards and adaptable specifications, serves as the central element.
#3	SmartWall	SmartWall is an integrated multi-technology wall solution combining: 1) fully factory-assembled panels with environmentally friendly insulation, 2) a compact fan coil unit for both heating and cooling, 3) a mechanical ventilation system, 4) battery storage, 5) off-the-shelf PV panels, and 6) high-efficiency glazing with automated shading control.
#4	Centralised holistic heating & cooling renovation kit	A centralised energy supply solution for heating and cooling purposes. The system is built around a commercial reversible air-to-water heat pump powered by on-site BIPV generation and coupled with a stratified bio-based PCM Thermal Energy Storage unit.
#5	Multipurpose façade system with bio-based insulation and BIPV	A prefabricated façade-integrated system conceived for deep building renovations aimed at achieving meaningful improvements in overall energy performance. It incorporates hemp-based insulation materials together with readily installable, visually appealing BIPV panels.
#6	PanoRen — robotic fastening systems, second-life PV facing slab, ventilation duct	PanoRen presents a novel multi-functional envelope concept developed on the basis of an existing insulation panel product (Panobloc®), enhanced with second-life PV facing slabs to support on-site renewable energy generation.
#7	Activated cellulose thermal insulation produced from wood waste	Renovation Package #7 comprises a rigid insulation board manufactured from wood processing residues such as sawdust, without the addition of adhesives or binding agents. Rather than incinerating this wood waste, the material is repurposed into thermal insulation panels exhibiting notable compressive strength and low thermal conductivity.
#8	Intelligent window system — smart sensors and microcontrollers; the system assesses solar gain availability	REHOUSE RP#8 comprises a modular, cost-effective Intelligent Window System (IWS) that can be readily mounted onto the exterior skin of either new or existing buildings, enabling smart regulation of solar gains through integrated sensor technology. The system is applicable to both existing and newly fitted windows across all building typologies. IWS limits thermal losses during winter operation and mitigates overheating risks during summer.

REHOUSE will also deliver guidelines, technical specifications and other relevant information about the renovation packages to contribute to their full digitalization, the reduction of production and installation time, to facilitate the seamless integration of these solutions in complex renovation interventions making use of advanced and highly coordinated processes that incorporate Digital Building Logbooks, Building Renovation Passports and Smart Readiness Indicator (SRI), to support the preparation of ambitious renovation projects matched with the best available financing sources and to recycle and reuse the components of the renovation packages after their service life to close the loop of a fully circular process. REHOUSE will lay on a strong social basis placing people in the core of the renovation process with the aim that renovation packages contribute to a real economic affordability of the interventions, less-disturbance during the renovation works and better quality of living indoor environment, users' comfort and reduced energy and maintenance costs after the interventions. REHOUSE will foster during the demonstrations

enhanced civic engagement and active participation via social innovation activities. All components of each renovation package will start from a medium maturity-level, ranging from a functional validation at laboratory scale (TRL4) or a technology validated in relevant environment (TRL5) and will deliver, through some research and development activities a system prototype demonstrated in an operational environment (TRL7), prepared to start the last stages of their pathway-to-the-market after REHOUSE's end, thus enabling their way towards achievement of a full-system proven in operational environment (TRL9).

2.1 Hungarian demo building

The demo building in Hungary is a dormitory built in the late 1800s and located in Budapest, with a Semi-continental climate, see Figure 1.

The Faith Church is responsible for the demo site. RP2, RP7, and RP8 upgrades were implemented at the demonstration site, and these were integrated with each other.

This is a fairly large building, with 70 rooms and a floor area of 1,027 square meters.

The building has a C energy rating, its annual energy consumption is 25.8 MWh/year for electricity and 91.0 MWh/year for gas. The baseline CO₂-eq emissions is 126.6 kgCO₂/m²/year.



Fig. 1. The Hungarian demo building in original form.

The building originally served as an industrial manufacturing facility before being repurposed as a student residence. During earlier refurbishment works, attic rooms were constructed and double-glazed windows with a U-value of 1.4 W/m²K were installed. The external walls had never undergone renovation, with estimated U-values of 1.32 W/m²K. Space heating and domestic hot water (DHW) are currently provided by two 45 kW natural gas boilers; mechanical cooling is absent, and no on-site renewable energy systems are in operation.

This Budapest demonstration site is a student dormitory affiliated with the nearby Saint Paul Academy. The facility accommodates approximately 65 students from rural regions and abroad. The building owner aims to deliver high-quality living conditions for students while advancing sustainability objectives and reducing operational expenditure. Both the university and the ownership group have committed to achieving Nearly Zero Energy Building (NZEB) status.

The renovation initiative will prioritise substantial improvements to the building's energy classification, targeting NZEB compliance through the deployment of RP#2 (Adaptable Dynamic Building Envelope, ADBE) as the principal component, complemented by RP#7 (Activated Cellulose Insulation) and RP#8 (Intelligent Window System, IWS).

The IWS will be mounted directly onto the exterior face of the existing windows, cutting renovation costs to approximately one third of a full window replacement and minimising disruption for building occupants.

Altogether 41 windows (altogether 98 m²) will be renovated. Preliminary simulations estimate 50% of heat loss reduction leading to yearly energy savings of 3.6 MWh.

Wall renovation with 100% environment-friendly cellulose panel insulation will be applied in two layers altogether 15 cm thickness in the part of the façade surface. The renovated walls will reach the current building code value which is locally 0.24 W/m²K and reduce heat losses towards estimated yearly energy savings of 16.62 MWh.

Onsite renewable energy production: 20 BIPV panels with about 20 m² will be integrated into the ADBE system (RP#2) on the building walls accounting for 5.9 kWp. In addition, external funds to the project will enable us to add 80 PV panels 120 m² on the sloped, south-west oriented roof. Total onsite PV production is estimated at 36.57 MWh/yr and will be used for self-consumption and/or grid injection according to the Hungarian legislation when surplus energy is available. An Energy Storage unit 55.2 kWh Lean Acid battery, 1150 Ah-48 V was also installed as part of the overall renovation project.

2.2 Design of Adaptable Dynamic Building Envelope

The key benefits of this multi-functional façade approach are: 1) Modular design using fully prefabricated units available in a range of dimensions, enabling bespoke fabrication tailored to each building's façade geometry; 2) simplified installation requiring no extensive or costly preparatory works; 3) integration of multiple commercially available technologies including contemporary (e.g. bio-based) insulation, PV panels, electrical battery storage, and HVAC equipment; 4) embedded monitoring and actuation sensors enabling comprehensive remote control and real-time performance tracking.

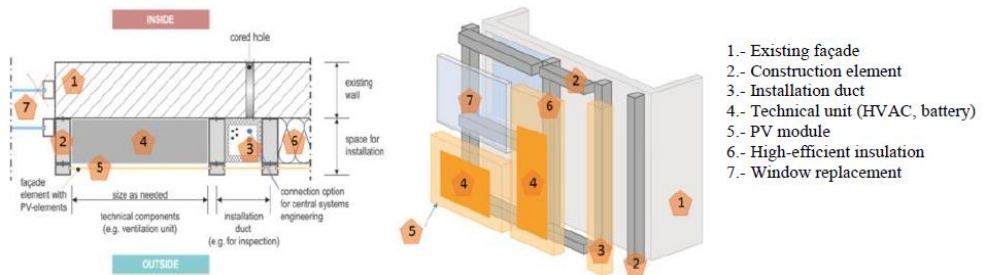


Fig. 2. Indicative ADBE components and technical drawing (source CERTH and RENEL).

The advantage of the ADBE system is the ability to host different active and passive building envelope elements (Fig. 2.) such as the Intelligent Windows System; Photo Voltaic panels or Solar panels as active elements and Activated Cellulose and any other type of thermal insulation materials as passive elements. The frame system of ADBE provides the fixing opportunity to the different embedded systems while the ADBE is fixed to the original wall of the building to be renovated.

2.3 Development of Activated Cellulose Insulation Material

Activated Cellulose is a thermal insulation material derived entirely from natural, renewable feedstocks. The core objective is to valorise wood and agricultural residues generated as by-products during various phases of timber processing. Beyond wood, any lignocellulosic material with a cellulose content of at least 20–25% — including crop

residues and fast-growing biomass — may serve as a raw material. Preliminary trials evaluated forestry by-products such as wood sawdust and tree bark. From a thermal insulation standpoint, tree bark exhibited the most favourable properties, while wood sawdust demonstrated superior compressive strength.

As these materials are entirely of natural origin, the resulting mixture constitutes a sustainable, bio-based insulation referred to as the “ground mix.” During the activation stage, cellulose chains cross-link with one another, imparting mechanical rigidity to the material through hydrogen bonding between the hydroxyl groups of the cellulose and lignin polymer chains. (Fig. 3.) However, this bonding alone does not provide adequate moisture resistance for external applications. To improve resistance to water and water vapour, a minor quantity of natural wax (approximately 1% by weight) is incorporated into the mixture, enhancing its durability in humid conditions.

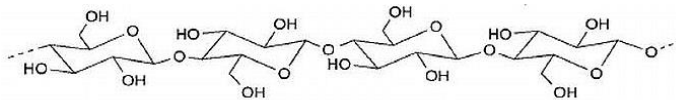


Fig. 3. Structure of cellulose chain.

2.4 Development of Intelligent Windows System

A significant proportion of building heat loss in winter and unwanted heat gain in summer occurs through glazed surfaces. Increasing the thermal resistance of windows therefore offers considerable energy savings potential. The IWS is a multi-component assembly integrated into the building envelope, consisting of a mounting frame attached to the wall via multiple bracket elements. Its central component is a horizontally sliding window driven by a chain mechanism powered by an electric motor. (Fig. 4.)

The opening and closing behaviour of the IWS is governed by a sophisticated electronic control circuit that continuously monitors indoor and outdoor environmental parameters to determine the optimal window position. Through intelligent sensors and microcontrollers, the system evaluates the availability of solar gain during winter periods: when solar radiation is available, thermal resistance is reduced to allow passive solar gains; when radiation is absent, the system automatically reverts to maximum insulation mode to minimise transmission heat losses. During summer, the IWS shields the primary windows from direct solar radiation, reducing HVAC energy demand without interfering with normal window operation.

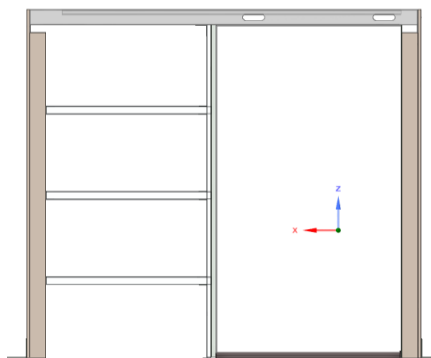


Fig. 4. The structure of the Intelligent Windows System, on the right side is the moving glass.

For effective thermal management, the sliding window unit consists of a double-glazed panel filled with argon gas and equipped with low-emissivity coatings on the glass surfaces. The window panel is suspended from two trolleys running along a horizontal rail integrated into the frame. The trolleys are connected to the upper edge of the panel via custom-extruded aluminium profiles bonded to the glass. The exposed vertical edge of the sliding panel is fitted with a plastic edge protector to prevent injury and incorporates a brush seal to reduce air infiltration in the closed position.

Horizontal translation of the sliding panel is provided by a DC motor acting through a chain drive assembly. (Fig.5.). The drive components are fabricated from aluminium, copper, and steel, while the static structural elements are produced from engineering-grade plastic.

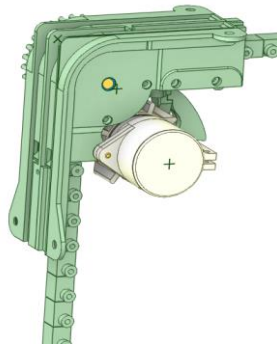


Fig. 5. 3D drawing of the driving unit.

3 Implementation and results

3.1 Implementation of Adoptable Dynamic Building Envelope

The required period for the construction of ADBE will be significantly reduced due to the high level of prefabrication of the particular components and off-site construction. Particularly the IWS design was performed to take into consideration of ADBE sizes and connection points. The PV panels size was fit for the gap of ADBE frame. The Activated Cellulose modules were able to connect to the anchor part of ADBE.

The ADBE components was designed by Platanplan Ltd (Hungary) and fixed to the wall (Fig. 6.), while the IWS designed and prefabricated by Woodspring company (Hungary).



Fig. 6. ADBE structure fixed to the wall.

3.2 Activated Cellulose Insulation

Production consists of four sequential stages: 1) Fibre Preparation: raw fibres are produced using appropriate fiberisation techniques. 2) Panel Forming: the fibres are shaped into insulation boards using a dedicated mould that accounts for the swelling behaviour of cellulose; because panel dimensions decrease during curing, the initial mould must be approximately 8–10% oversized relative to the target final dimensions. Experimental data confirm that the insulation retains wood's anisotropic character, though unlike natural wood (which has three-directional properties), the panels display distinct mechanical and thermodynamic behaviour in only two principal directions. 3) Curing: the formed panel undergoes curing in a controlled environment at temperatures between 35°C and 60°C to consolidate bonding and achieve final dimensional stability. 4) Surface Finishing: following curing, panels may exhibit surface irregularities or edge imperfections; sanding or precision cutting is applied to obtain uniform thickness and smooth, perpendicular surfaces, regardless of whether the final panel shape is rectangular or hexagonal.



Fig. 7. Experimental fixing of Activated Cellulose to the wall of the demo site.

The Activated Cellulose insulation material was prefabricated into ready-to-install units, allowing direct installation upon arrival at the demonstration sites. The fabrication process required several formatting and cutting steps to achieve precise dimensions and uniform shapes. Initially, the laboratory-scale product was produced in panels measuring 410 mm × 410 mm, with thicknesses of 50 mm and 60 mm. However, for semi-industrial production, the panel size was increased to 520 mm × 520 mm, with adjusted thicknesses. This larger format allowed for faster installation, although it required greater care during transportation and handling due to the increased weight and fragility of the units.

Unlike other insulation materials, Activated Cellulose requires no additional assembly steps on-site. The chosen packaging format also offers practical advantages, as each unit can be lifted directly onto the scaffold and opened only at the point of installation, ensuring both efficiency and protection of the material.

3.3 Intelligent Windows System

Initially, a wood-frame prototype of IWS was constructed and tested. Several design modifications were required to achieve a durable and reliable final solution. After the necessary improvements, the components and technical specifications of the IWS were finalized. In total, 41 windows were equipped with the IWS in the Hungarian demonstration building, which required the production of an equivalent number of component sets. The prefabrication process was divided into distinct stages, covering the manufacturing of

mechanical and moving parts, including the chain and suspension system, as well as the assembly of the motor unit with clutch and the electronic control box containing sensors and switches Figure 8.



Fig. 8. IWS frame and electric engine on the corner and the moving mechanism on the top.

The IWS installation started on the frame structure and this frame was strongly connected to the ADBE system (Fig. 9.). After that, the actuator mechanism including the moving chain and hanging parts were installed. Every part had to be tested because, after the covering of the surface, the accessibility to the parts is restricted. When the mechanics were ready, the glass had to be hung in the frame. This work was really challenging, taking into consideration the large window size and weight (~50 kg) and the limited space in and behind the scaffold.

With the glass on the frame, it became possible to fix the sensors for moving and also for controlling the system. The control sensors are responsible for providing data to the control unit which decides if opening or closing the IWS according to the needs. The last electronic unit to be installed was the control box. This box contains the central programmed unit and the battery. The battery was built in for the case when no electricity is present in the building, and it is needed to open or close the window. The last step was to seal the moving glass. The sealing around the moving glass has more function. It is highly important to prohibit water ingress behind the building envelope. The most crucial part for this is the edge of the IWS where the glass moves behind the façade. The second most important function is to seal the air filtration. The filtration can cool down the inside part in winter mode and reduce the insulation effect of IWS. The third one, which is in close connection with the former one, is noise insulation. If the edge is well sealed, then noise vibration cannot reach the original window. This function is especially important on the roadside of the building. The last steps of installation were to place and install the control box, behind the door on the window side frame, and to test the operation.



Fig. 9. Installed IWS in front of the existing window.

4 Conclusions

Renovation progress was started with the design of the mentioned three renovation packages such as the Adaptable Dynamic Building Envelop, Activated Cellulose and the Intelligent Windows System which contains significant development processes. After these two years of development and prefabrication progress the local renovation progress took about twelve months taking into consideration the extended size of the building and the sophisticated and professional solutions. The work was finished at the very end of 2025.

The second good experience is the successful integration of ADBE and IWS systems. Both systems were designed separately.

The methodology for fixing to the wall was gluing with low expanding polyurethan foam. This technology does not result unexpected and disadvantageous heat bridges over the fixing clamps of ADBE systems see Figure 7.

To determine the improvement in the building's energy characteristics, a longer period is required to measure energy consumption and gather feedback from occupants. However, the calculation and short time measurement help to estimate the increment of thermal resistance of the wall and the windows surfaces. The original U value of the wall was $1.32 \text{ W/m}^2\text{K}$ and with the 13-15 cm additional insulation layer the U value reduced to $0.24 \text{ W/m}^2\text{K}$. The results become comparable to the newly built buildings and make it possible to decrease the heat loss to the one third or one fourths parts of the original value depending on the wall geometry and the heat bridges.

In case of windows the original value was $1.4 \text{ W/m}^2\text{K}$ and the additional double insulation glass layer the expected value is about $0.5 \text{ W/m}^2\text{K}$. This shows also a significant change minimizing the heat loss in winter and heat gaining in summer.

The quintessence of the case renovation study are the followings:

- Older buildings could contain unexpected features which make more difficult the renovation process, and needs ad hoc solutions for reaching the expected results in aesthetic and thermal properties, however these problems can be solved, and it is worth doing so.
- Improving the thermal resistance of building envelopes can dramatically reduce expected energy consumption, potentially to as little as one-third of the original

value. Therefore, renovation is an indispensable condition for achieving a carbon-neutral building sector.

- To improve thermal performance of old building the walls and the windows play an important role but they are to be renovated easily compared to the ground floor or the roof.
- There are needed developed solutions for effective renovation of old buildings taking into consideration the reused and recycled materials for keeping the sustainability principle during renovation.
- The emission rates of energy consuming buildings can be significantly improved by applying innovative solutions instead of demolishing the original structures, including windows.
- The cost of industrialized manufacturing in a workshop with controlled conditions and high-tech machines can be much lower than that of local production, that is why the prefabrication is more competitive.
- Preliminary design and prefabrication of renovation parts make the site work more effective and minimize the disturbance the local waste production and also the noise load during the renovation progress.
- Thanks to advanced solutions, cost-effective renovations can be carried out while improving environmental impacts, considering the interests of property owners, operators, and users too.

Based on these results, the renovation packages developed and tested in the Hungarian demo building can be replicated in other buildings with significantly less time and energy consumption. The renovated building is shown in Figure 10.



Fig. 10. The Hungarian demo building after renovation.

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