architektur + raumplanung

DIPLOMA THESIS

ENERGY RETROFITTING STRATEGIES FOR PROTECTED BUILDINGS: CASE STUDY ANALYSIS

Submitted in satisfaction of the requirements for the degree of
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by

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Abstract

This study, evaluates energy retrofitting strategies for a protected bourgeois apartment- and office building built in 1904, located in Vienna's 1st district designated as conservation area and UNESCO World Heritage site, balancing energy efficiency with heritage conservation. Through expert interviews and a thorough literature review, the research assesses regulatory constraints and potential retrofit measures. Employing Building Information Modeling (BIM), the study calculates the energy performance for the base case (no measures taken) and three retrofit scenarios ranging from passive measures (thermal envelope upgrades) to active measures (improving energy systems), to the integration of renewable technologies.

Findings reveal that by cumulatively implementing passive, active and renewable energy measures, energy consumption and corresponding CO2 emissions can be reduced by 31-64% and 33-70% respectively, compared to the base case. Through a comprehensive analysis of Vienna's building stock, depending on the combination of measures, the number of historic residential buildings to be renovated in Austria to meet the European Performance of Buildings Directive targets by 2035 was estimated. The number ranges between around 17,000 to 34,000 thousand buildings comparable to the case study in size and use. This research thereby highlights the significant potential for energy savings in historical buildings, advocating for retrofit solutions that comply with conservation standards and contribute to sustainable urban development.

Kurzfassung

Diese Studie bewertet Strategien zur energetischen Sanierung eines geschützten bürgerlichen Wohn- und Bürogebäudes aus dem Jahr 1904. Das Gebäude befindet sich im 1. Wiener Gemeindebezirk, in einer ausgewiesenen Schutzzone und UNESCO-Weltkulturerbestätte. Ziel ist es, die Energieeffizienz mit Ensembleschutz in Einklang zu bringen. Anhand von Expert:inneninterviews und einer ausführlichen Literaturrecherche werden regulatorische Rahmenbedingungen und mögliche Sanierungsmaßnahmen untersucht. Mithilfe von Building Information Modeling (BIM) wird die Energieperformance für den Ausgangszustand (ohne Maßnahmen) und drei Sanierungsszenarien berechnet, die von passiven Maßnahmen (Optimierung der Gebäudehülle) über aktive Maßnahmen (Verbesserung der Energiesysteme) bis hin zur Integration erneuerbarer Technologien reichen.

Die Ergebnisse zeigen, dass durch die kumulative Umsetzung passiver, aktiver und erneuerbarer Maßnahmen der Energieverbrauch und die damit verbundenen CO_2-Emissionen um 31-64 % bzw. 33-70 % im Vergleich zum Ausgangszustand reduziert werden können. Durch eine umfassende Analyse des Wiener Gebäudebestands wurde die Anzahl an historischen Wohngebäuden geschätzt, die in Österreich saniert werden müssten, um die Ziele der Europäischen Gebäuderichtlinie bis 2035 zu erfüllen. Je nach Maßnahmenkombination bewegt sich die Zahl zwischen rund 17.000 und 34.000 Tausend Gebäuden, die in Größe und Nutzung mit der Fallstudie vergleichbar sind. Die Forschung hebt somit das erhebliche Potenzial für Energieeinsparungen in historischen Gebäuden durch Sanierungslösungen hervor, die den Ensembleschutzstandards entsprechen und zur nachhaltigen Stadtentwicklung beitragen.

Contents

1. Introduction

1.1 Motivation and context

In an era where urban landscapes dominate and environmental concerns escalate, the importance of renovating cities for better energy performance cannot be overstated. This thesis is grounded in the context of the Energy Performance of Buildings Directive ("EPBD") (EU Commission 2024), which envisions zero-emission buildings as the new standard for new constructions and sets ambitious targets for deep renovation of the buildings across the whole EU by 2050.

The EPBD is an integral part of the broader "Renovation Wave" legislation aimed at reducing Europe's carbon footprint. Given that buildings account for 40% of the energy consumption in the EU and about three-quarters of the building stock is energy inefficient (EU Commission 2024), the reform of this sector is critical for achieving climate neutrality by 2050. The revised EPBD entered into force on the 28th of May 2024. Member states are required to transpose most of its provisions into national law by the 29th of May 2026 (Cross 2024). Austria, like all EU member states, faces the significant challenge of implementing the EPBD within the context of its own unique building standards, climate, and national regulations.

Each country's unique historical context adds complexity. Officially protected buildings, those with special architectural or historical merit often face stricter restrictions when it comes to renovation or modification, since standard renovation practices might compromise the building's character. Due to this difficulty, the EPBD exempts "buildings officially protected as part of a designated environment or because of their special architectural or historical merit". Therefore, while EU member states are not legally obliged to retrofit these buildings, they are encouraged to do so wherever feasible, as even small improvements in this category can significantly contribute to achieving broader energy efficiency goals and climate targets.

The potential impact of renovating protected buildings is considerable, given the sheer volume of older structures across Europe and their often suboptimal energy performance. However, achieving energy efficiency in these buildings is far more complex than standard renovation projects. The limitations and requirements imposed by heritage protection laws demand careful planning and innovative solutions. Specifically, retrofitting measures must often be invisible or minimally invasive to preserve the original character of the building, while still delivering meaningful reductions in energy consumption and emissions. These challenges create a tension between the preservation of architectural integrity and the adoption of modern energy-saving technologies. Conventional retrofitting methods, such as cladding or solar panel installations, may be unsuitable due to visual or structural constraints. As a result, creative approaches tailored to the unique needs of historical buildings are essential. These might include advanced internal insulation techniques, custom-designed energy-efficient windows, or the integration of renewable energy systems in ways that blend seamlessly with the building's appearance.

1.2 Research question

A comprehensive review of the development trends in energy conservation and emission reduction for existing buildings was conducted by Huang *et al.* (2022). This review, based on an analyses of 1494 publications from 2008 to 2022, incorporates global research efforts that have made significant progress in developing models and frameworks to identify factors influencing energy consumption, addressing obstacles to energy-saving retrofits, and proposing optimization and evaluation schemes for energy efficiency, among other advancements (Huang *et al.* 2022). Researchers emphasize, that a focused scientific effort should be made when addressing energy conservation in historical architecture, as these buildings must preserve their cultural and societal testimonial value (F.Cabeza *et al.* 2018).

The need to achieve energy efficiency standards has become a central goal across the European Union. Within this framework, this research aims to explore viable energy-saving solutions specifically tailored to protected buildings in Vienna. By aligning with the energy performance targets outlined in Article 9 of the EPBD (Official Journal of the European Union 2024), this study seeks to identify and propose strategies that achieve meaningful reductions in energy consumption and C02 emissions, without compromising the historical essence of these structures.

The following specific questions will guide this investigation:

1.) How can renovations be carried out for buildings officially designated as part of a protected environment or recognised for their special architectural or historical significance, where adherence to standard renovation practices might compromise their character or appearance, or where technical constraints pose challenges to renovation efforts?

2.) What are the potential C02 and energy demand savings that can be achieved following renovation, taking into account both feasible energy efficiency improvements and the constraints imposed by the building's protected status?

However, this research does not focus on the financial feasibility or cost-benefit analysis of implementing energy-saving measures. Nevertheless, it is important to recognize that the economic viability of retrofitting efforts can significantly impact the success and widespread adoption of energy efficiency measures, making it an area for future research.

1.1 Research design

This thesis studies an existing bourgeois apartment- and office building in Vienna's historical 1st district, built in 1904 during the late "Gründerzeit" and early "Moderne" period. Once the case study building is identified, as illustrated in Fig 1., a detailed 3D model is developed using the Building Information Modeling (BIM) software ArchiCAD. The building geometry is then recreated in ArchiPYSIK software, with a focus on the building's envelope, including external walls, roofs and ground floor areas, windows, doors and other openings. The model is further refined by adding insights into the building's thermal properties, HVAC (heating, ventilating, air-conditioning, cooling) systems and energy sources, enabling the calculation of its current energy performance.

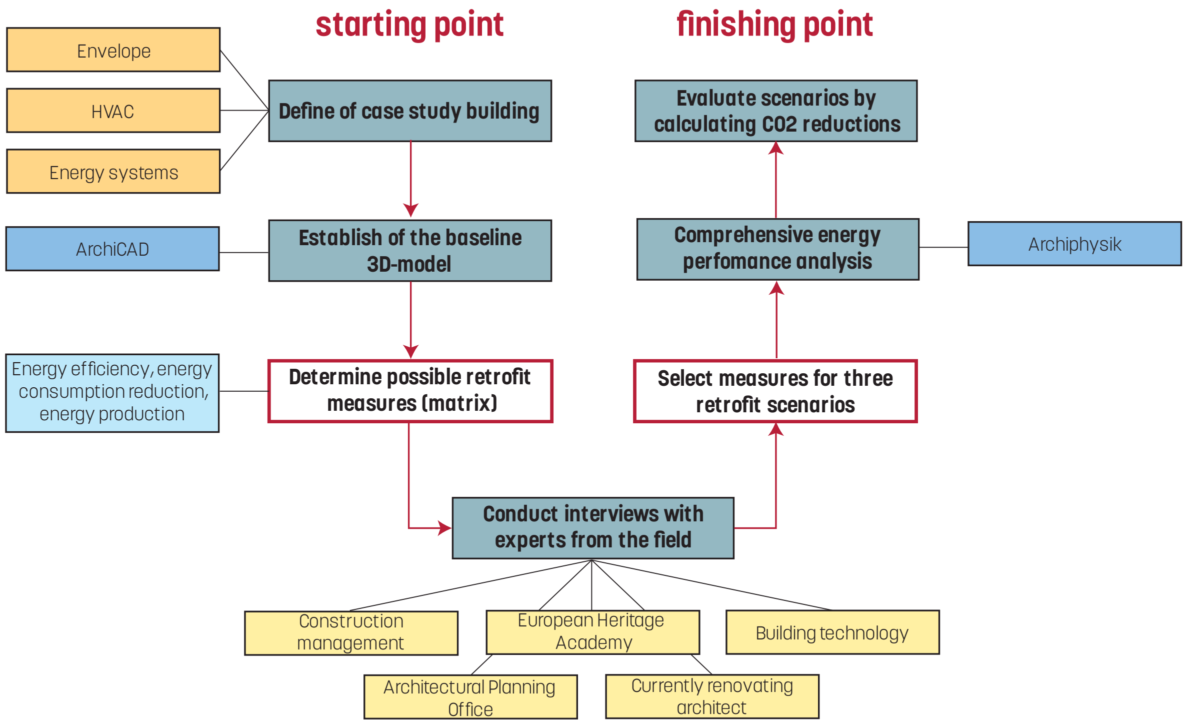

Fig 1. Workflow

In parallel, interviews are conducted with experts in fields related to historical building renovation, urban planning, and building technology. These interviews aim to collect insights into the practical challenges and opportunities of retrofitting protected and historical buildings. Drawing on the evaluation of retrofit measures within the literature review and expert consultations, three distinct retrofit scenarios are created. Each scenario represents a different combination of measures created to improve energy efficiency: from the conventional approach to one that appears more cost-intensive in the short term. Using comprehensive energy performance analysis, the potential CO2 and energy demand reductions for the three retrofit scenarios are calculated. This analysis provides a basis for identifying the most effective retrofit strategies for the case study building, offering insights into sustainable renovation practices for other protected buildings.

1.2 Collaborative research

In collaboration with researcher Marija Nakeva, whose study examines the same building from the perspective of the circular economy and life cycle extension through eco-balancing, various research tasks were conducted. Fig 2. outlines these collaborative efforts. The collaborative research involved collecting all available information on the building from the state archive MA37 (MA37- Baupolizei, n.d.), documentation survey, 3D modeling of the existing structure using BIM software ArchiCAD and conducting interviews with experts from relevant fields. The two studies build on a shared research foundation and contribute to retrofitting the case study building. More specific descriptions of shared tasks can be found in the Annex.

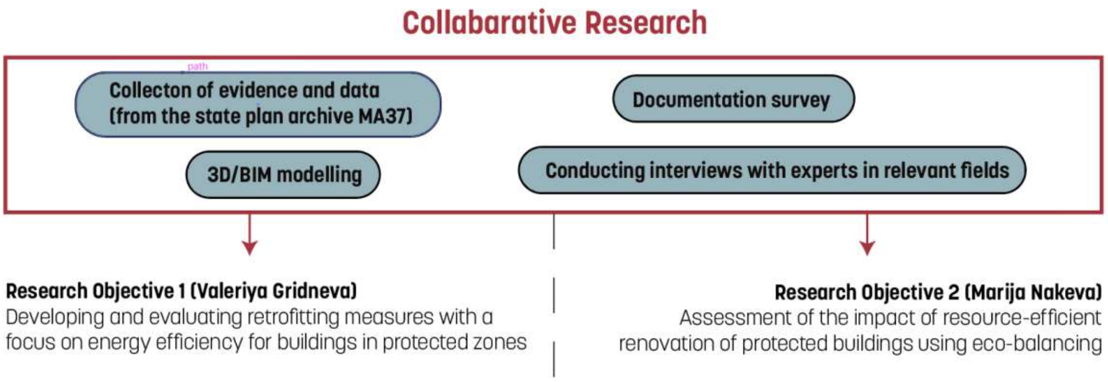

Fig 2. Diagram of collaborative research efforts: overview of two research objectives, shared data collection, and intended outcomes

2. Legislative Framework

2.1 EU Green Deal

The European Green Deal represents a bold initiative by the European Union to spearhead a global transition to a sustainable economy. Launched with the ambition of making Europe the first climate-neutral continent by 2050, the Green Deal outlines an integrated set of policy initiatives aimed at promoting green energy, reducing greenhouse gas emissions, and fostering economic growth through sustainable means. While the Green Deal addresses a wide range of sectors, like transportation, agriculture, and industry, the building sector plays one of the critical roles. Buildings are one of the largest energy consumers in the EU, and improving their energy performance is essential to achieving the overarching goals of the Green Deal.

The overall goal of the framework is to reduce EU emissions by 55% by 2030. To support this transformation, the "Fit for 55" package was developed, comprising a series of measures that include the EU Emission Trading System, the Social Climate Fund, the EU member states' emissions reduction targets, the Energy Efficiency Directive, as well as the EPBD. These policies collectively aim to reduce the environmental impact of the building sector, enhance the energy efficiency of the building stock, and ensure that new and existing buildings can contribute positively to the EU's climate neutrality goal.

2.2 *Introduction to EPBD*

The EPBD aims to reduce energy consumption in buildings and enhance their overall energy performance. Originally introduced in 2002, the directive has been revised multiple times and was ultimately entered into force in May 2024. It sets out ambitious goals to achieve a highly energy-efficient and decarbonised building stock by 2050, aligning with the broader objectives of the European Green Deal. To achieve these goals, the EPBD outlines two key targets for improving energy efficiency in the building sector: 1) renovating existing buildings to enhance their energy performance and 2) establishing zero-emission building standards for all new constructions. Article 2(4) requires each member state to develop Minimum Energy Performance Standards (MEPS) which dictate certain energy performance requirements that existing buildings must meet during major renovations or at market trigger points such as sale, rent, or change of use. These standards are to be quantified by a numeric indicator of primary or final energy use measured in kWh/(m²y) and to be achieved by specific deadlines.

By 2030, at least 16% of the worst-performing non-residential buildings should be renovated, increasing to 26% by 2033. For residential buildings, the directive aims for a 16% reduction in primary energy consumption by 2030, and between 20-22% by 2035. To verify compliance with these standards, the EPBD mandates the use of Energy Performance Certificates (EPCs) (Article 19). These certificates, which must be issued when buildings are constructed, sold, or rented, provide detailed information about a building's energy use and potential avenues for energy consumption reduction. Additionally, the EPBD requires that all member states issue a Renovation Passport (Article 12), serving as a detailed plan for staged deep renovation, assisting property owners and investors in planning the optimal timing and scope for necessary interventions. These passports are to be used jointly with energy performance certificates to streamline processes. Lastly, to facilitate these initiatives, each member state is tasked with establishing a national Database for the Energy Performance of Buildings (Article 22). This database is to be publicly accessible, will collect and analyse data on individual buildings and the overall national building stock, supporting the strategic implementation of the directive's goals.

2.3 Protected Buildings in EPBD

Protected buildings, often referred to as historical or heritage buildings, are addressed with special considerations. More specifically, the EPBD allows exemptions or tailored requirements for these buildings to ensure that energy performance improvements do not compromise their integrity or cultural value. Renovating protected buildings to meet modern energy efficiency standards presents unique challenges. The EPBD recognises these challenges and provides EU member states with the flexibility to adapt the application of energy performance requirements to these types of buildings. For example, while the directive encourages the improvement of energy performance in all buildings, it allows for derogations when compliance would unacceptably alter the character or appearance of protected buildings.

Many historical buildings cannot accommodate conventional insulation methods or modern HVAC systems without significant alterations to their structure or appearance. The EPBD mandates that member states must consider the feasibility of applying energy performance requirements to protected buildings and may exempt them from certain standards if necessary. To illustrate the practical application of the EPBD in protected buildings, several EU countries have developed case studies. A research group of *University IUAV of Venice* for example, has developed a set of technologies implemented in the frame of the refurbishment of an historical building in the very centre of Venice, in order to lower energy consumption and increase occupants' comfort. Technologies such as Surface Water Heat Pump, Demand Controlled Ventilation and trigeneration were employed to minimise visual impact while enhancing energy performance. Global primary energy savings equal to 36% have been calculated, if compared with a traditional baseline HVAC system (Schibuola *et al.* 2018)

The EPBD provides a framework that recognises the unique status of protected buildings while still promoting the broader goal of improved energy efficiency across the EU's building stock. By allowing adaptations and exemptions, the directive ensures that energy performance enhancements are feasible and appropriate for buildings of historical value, ensuring that heritage conservation and energy efficiency goals are both met.

2.4 Protected Buildings in Vienna

Cultural heritage management in Austria includes two primary categories of building protection – *monument protection (Denkmalschutz)* and *protected zones (Schutzzonen).* While these categories differ in origin and specific focus, they share the common goal of preserving historical structures.

Buildings under *monument protection* represent roughly 2% of Vienna's building stock (BDA 2024), and are recognised for their national cultural, historical, or architectural significance. *The Federal Monuments Office (Bundesdenkmalamt)* is responsible for the preservation, safety, and maintenance of listed buildings (BDA n.d.). Any form of destruction or alteration–including maintenance and repair measures–that would impact the substance, historical appearance, or artistic effect of the building is strictly regulated. Such changes require formal authorisation from *the Federal Monuments Office*, except in cases of imminent danger or when the building's preservation is no longer deemed to be in the public interest (e.g., if the building is beyond repair or its significance has been lost) (Denkmalschutzgesetz - DMSG 2024). This authorisation process includes a detailed review where the applicant must provide clear plans and justifications for the proposed changes. The Federal Monuments Office carefully evaluates whether the changes are in line with conservation principles, ensuring that any intervention does not undermine the building's historical and cultural value. Retrofitting approaches in these cases must prioritise preservation over modernisation, limiting the scope of energy-efficient upgrades.

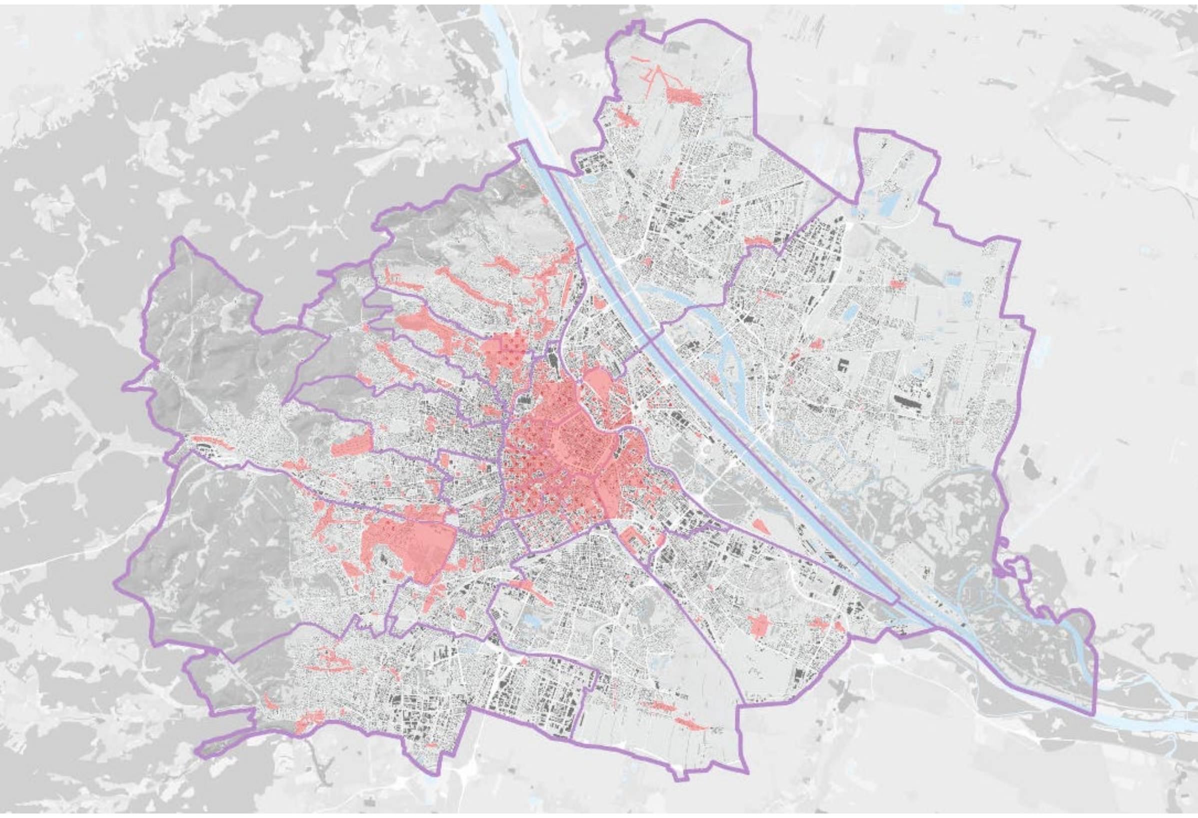

Fig 3. Land use and zoning plan, protected zones, Vienna Austria (Stadt Wien n.d.)

Buildings in protected zones make up over 16,000 buildings, representing roughly 9 percent of the city's total building stock (Landström 2024), (Wien Kulturgut: Schutzzonen Wien n.d.). The term *protected zones (Schutzzonen)* is defined by the city and used to describe urban areas with architectural ensembles or districts of historical significance. In these areas specified in the land use and zoning plan (Stadt Wien n.d.), the preservation of the characteristic cityscape needs to be ensured. This concerns its natural conditions, its historical structures, its characterising fabric, and the variety of functions. Permits for renovations, demolitions, and other alterations of the building in protected zones are managed by MA37 (the Building Inspection Authority, Baupolizei) and MA19 (the

Architectural Planning Office, Stadtgestaltung). MA37 is responsible for building safety and regulatory compliance, while MA19 oversees architectural planning, ensuring that modifications align with the protected zone's aesthetic and historical character. Demolition permits for buildings in protected zones and for buildings outside protected zones that were built before 1 January 1945, are rarely granted and are only issued when preservation conflicts with public interest or when substantial economic justifications exist due to a building's condition (Stadt Wien n.d.).

The number of registered cultural properties in Vienna (see Fig 3.) are highlighted in red, equating 9% of the building stock (Wien Kulturgut: Schutzzonen Wien n.d.).

The initiative called *Offensive Altbauschutz* promotes the conservation and careful modernisation of older structures that contribute to Vienna's historical context, even if they are not designated monuments or located within protected zones (Votava n.d.). This primarily includes buildings from the *Gründerzeit period (founders' period)*, encompassing 23,500 buildings, or 13% of Vienna's building stock (Lundström 2024). The objective of the initiative is to protect these structures from demolition by examining if their public value and impact on the cityscape.

Given the limitations and requirements imposed by these various types of protection, achieving energy efficiency in such historically significant buildings poses unique challenges. The need to preserve architectural integrity often conflicts with conventional retrofitting methods, demanding innovative approaches that respect the constraints of cultural heritage while pursuing environmental goals. Industrial buildings fall outside the scope as they are not typically subject to the same preservation regulations or architectural considerations and, therefore, do not face the same constraints in achieving energy efficiency.

3. Literature review/Energy efficiency approaches

3.1 Energy saving passive measures

Huang *et al.* (2022), as mentioned earlier, conducted a literature mining analysis of 1,494 studies in energy conservation and emission reduction for existing buildings published between 2008 and 2022 to assess the research status and future trends. Among the highly cited literature, the highest number of the total citations were made on energy-saving measures, highlighting scholars' strong focus on this research area. Additionally, the study noted that energy conservation in existing buildings has evolved, with energy-saving technologies gradually shifting from solely passive measures to an integrated approach combining passive, active, and renewable energy measures (Huang *et al.* 2022).

Historical buildings are usually considered as low energy-performing buildings, at the same time they provide a fundamental testimonial role in the society (F.Cabeza *et al.* 2018). Renovating historic buildings requires balancing efficiency and heritage. Conventional measures like external insulation can be challenging, as they may compromise architectural authenticity. Enhancing energy efficiency through internal envelope insulation, cool coatings, and window retrofitting is the first approach that can be considered (F.Cabeza *et al.* 2018).

Feng and Janssen (2021) highlight the issues with internally insulated facades for their tendency to easily absorb moisture, leading to moisture related challenges such mold, frost damage, and structural or health risks. A potential solution proposed in this study is a hydrophobisation treatment, which prevents walls from absorbing liquids while maintaining its drying capability through vapor diffusion, thereby resolving–or at least mitigating–moisture-related issues (Feng and Janssen 2021).

The Technical University of Denmark, in collaboration with Aalborg University, conducted real-life tests over 20 months on eight different internal insulation types in a historic masonry building. The vapor-tight system demonstrated the best performance in respect to moisture safety (Pagoni *et al.* 2025).

In fact, external walls are not always the primary focus of preservation for protected buildings, nor is internal insulation always feasible. A research project in Rome used *Vila Mondragone*, an extended building of great artistic and historical value, as a case study to evaluate its energy performance before and after refurbishment (Cornaro *et al.* 2016). In this case, external insulation was chosen because parts of the existing mortar were already damaged and required restoration. Additionally, many interior surfaces were covered with frescoes of great historical value, making internal insulation impossible. The chosen insulating material for the renovation and simulations was insulating plaster and screed with a thickness of 4 to 6 cm and thermal conductivities of 0.045 W/mK and 0.06

W/mK, respectively. The application of high-performance insulating plaster significantly improved energy efficiency, reducing energy demand by up to 38%.

Franco *et al.* (2015) discusses other possible measures to improve the thermal performance, which include insulation of the floor on ground, insulation of roofing systems, and upgrading the energy efficiency of the windows. The latter one, in particular, requires careful consideration (Franco *et al.* 2015).

The Budapest University of Technology and Economics conducted a dynamic energy simulation based on several window refurbishment scenarios for the *Palace of the Hungarian Academy of Sciences (Magyar Tudományos Akadémica)*. The results demonstrated that even in the realm of historic buildings and monument preservation integrating interpane shading devices with simple automated control systems - a non-intrusive refurbishment measure - has a very beneficial effect on the energy balance of traditional windows (Bakonyi and Dobszay 2016). In *Sun protection and city scape (Sonnenschutz und Stadtbild)* the City of Vienna explores sun-shading solutions that are both effective and harmonious with the historic cityscape (Ursula Schneider 2021). To mitigate solar gain while preserving architectural aesthetics, Vienna offers subsidies of up to €1,500 per flat for the installation of external sun protection, if it aligns with heritage guidelines and integrates well with the historic urban landscape.

Beyond facades, roofs also play a crucial role in regulating a building's thermal performance. Most of the older buildings have traditional clay tile roofs that absorb solar radiation, affecting buildings energy efficiency and contributing to urban climate issues. A study in Italy examined the thermal-energy performance of a 16th-century historic residential building with innovative cool clay tiles (Pisello 2015). Results showed a cooling energy savings of up to 51% compared to the base model, with a heating penalty of less than 2%. If applied at larger scale, they could serve as an effective strategy for urban heat island mitigation.

3.1 Energy saving active measures

The study by Ardente *et al.* (2011) analyses case-study actions for retrofitting public buildings across Europe, highlighting key energy-saving benefits. The most significant improvements were found in the envelope's thermal insulation, including high-efficiency windows and insulating frames. Substituting insulation, lighting, and glazing components also proved effective. Renovating HVAC systems and lighting led to substantial energy savings. However, the study found that energy production from solar and wind plants was often overestimated during design, resulting in lower energy savings and higher payback periods than initially predicted (Ardente *et al.* 2011).

A study conducted by *the Technical University of Denmark* on energy savings in Danish residential buildings highlighted the potential for substantial energy savings through mechanical ventilation with heat recovery (HRV). Ventilation losses typically range from 35-40 kWh/m², of which 80-90% could be recovered (Tommerup and Svendsen 2006). Heat recovery systems coupled with heat pumps make a good combination for buildings ventilation due to their high-efficiency, low-cost, good integrability into façade, and compatibility with other units (Liu *et al.* 2024).

A pivotal study conducted in 2014 by *DEIM, Università di Palermo*, focused on the impact of Building Automation Control (BAC) and Technical Building Management (TBM) systems on residential buildings. The findings indicate that the installation of BAC and TBM systems proves increasingly advantageous with higher energy consumption levels of the building and lower initial energy classifications. These systems directly enhance the energy performance of buildings, subsequently elevating their energy class in accordance with EN 15217 standards, thereby potentially influencing both the energy certification process and the market value of the properties (M.G. Ippolito 2014). The study highlights that several factors, including the type of energy appliances and the heating/cooling systems installed, modulate the extent of impact. However, the presence of BAC and TBM systems is conclusively beneficial for improving a building's energy efficiency and operational dynamics (M.G. Ippolito 2014).

3.2 Energy saving renewable energy measures

A study by *the University of Naples Parthenope* and *the University of Cassino and Southern Lazio* presents a renewable district heating and cooling system using solar, geothermal, and biomass energy. A 1-year simulation on a case study of the district area of Monterusciello in Southern Italy is conducted. The system demonstrates satisfactory yearly performance, with a solar collector field efficiency exceeding 40% and an adsorption chiller Coefficient of Performance (COP) of 0.5. While the system is not economically viable without public funding (with a Simple Payback of 20.9 years), it achieves a significant primary energy savings ratio of over 75% (Carotenuto *et al.* 2017).

Wang *et al.* (2021) explore the use of geothermal energy as a renewable source to meet heating demands in utility systems within Locally Integrated Energy Sector (LIES). The comparison between geothermal and natural gas utility systems shows that by using geothermal energy, over 70% of the load can be saved compared to relying solely on natural gas. The study also highlights, when geothermal energy load is insufficient, the model can determine the optimal storage temperature for heat recovery (Wang *et al.* 2021).

Solar photovoltaic (PV) systems and solar thermal collectors are common renewable energy solutions for reducing reliance on grid electricity and conventional heating systems. However, integrating solar panels on heritage buildings can be challenging due to aesthetic considerations and structural limitations. Studies on similar retrofitting projects have shown that lightweight PV panels can be installed with minimal visual impact, especially on less visible roof sections (F.Cabeza *et al.* 2018).

A study conducted by Franco *et al.* (2015) focuses on improving energy efficiency in existing heating and lighting systems. For lighting, introducing an LED system could reduce electricity needs by 50%. The study also considers the use of micro-turbine systems fuelled by natural gas for cogeneration or tri-generation, which would provide thermal power, lighting, and possibly localized cooling. These micro-turbines, with an electrical output of 100 kW and thermal output of 167 kW, would help reduce CO2 and NOx emissions, lower resource consumption by using renewable fuels like biogas, and improve energy efficiency (Franco *et al.* 2015).

The literature highlights that retrofitting historic buildings requires a delicate balance between preserving architectural heritage and improving energy performance. Passive measures like internal insulation, cool coatings, and innovative roofing materials show potential, but their feasibility depends on the building's specific features and preservation constraints. Active systems such as mechanical ventilation with heat recovery and building automation significantly enhance energy efficiency, being especially viable in high-energy-consuming structures. Renewable energy solutions, like solar PV and geothermal heating, offer promising results but are often limited by structural or aesthetic challenges, with economic viability frequently reliant on subsidies. Case studies demonstrate substantial energy savings while also emphasizing the importance of realistic expectations and tailored solutions to optimize energy efficiency without compromising cultural and historical value.

4 Case study

4.1 Case study building description

This thesis studies an existing bourgeois apartment- and office building, built in 1904 during the late *Gründerzeit* and early "Moderne" period, and represents a typical Viennese rental building, widely known as *Zinshaus*. It was selected based on several criteria: its architectural significance, its typicality in terms of construction, and its location in a conservation area, which adds layers of regulatory complexity to retrofitting efforts. Built in the era of industrial development and general urbanisation, these buildings still characterise the cityscape today and give the city its special flair. The building is located at Seilergasse 16 in Vienna's historical 1st district. Fig 4. illustrates the map of the 1st district with the case study location marked in red. This entire district is designated as a protected area and is also listed as a UNESCO World Heritage site.

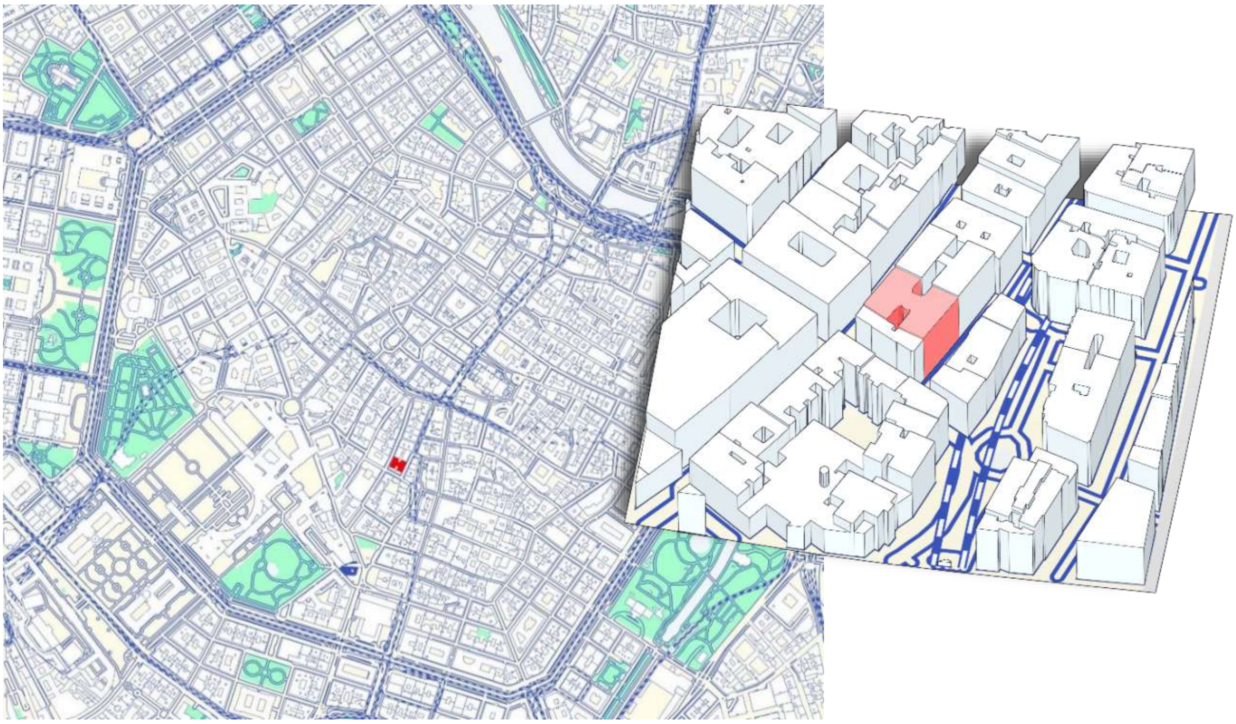

Fig 4. Vienna city centre - 1ST district

The building has a floor area of 850 m2 with seven upper- and two underground floors, totalling 6317.6 m² GFA. The construction primarily features brick masonry for the walls and reinforced concrete for the ceilings. The historical box-type windows, which reflect typical building practices from the transition from *Gründerzeit-era* to *Moderne*, have been preserved until today. There are two enclosed yards within the building with total 70 m².

Table 1.
Building model parameters

Total gross floor area (GFA)	6317.6 m^2
Floors	7 + 2 underground floors
Total height	31.16 m
Building envelope surface	5654.7 m²
Window areas	22.56%
Thermal zones	3 - retail, offices, apartments

Originally built as an apartment house, the building has undergone several indoor reconstructions and is now used primarily as an office building. Historical architectural plans indicate that the initial layout comprised two large residential flats per floor. In the early 1920s and 1930s, one or two apartments were changed into offices. By 1970 the majority of residential units had been transformed into office areas. Since then, the office spaces have been leased to a long-term single tenant, who has influenced the building's interior design. This is particularly evident in the stories 1 to 4 – the plans look identical –

the floor layout was made to be the same. The tenant was expanding over time, which required additional workspace. Therefore, as seen in the references of the building storey plans – in the first, second and fourth floors the building is connected with the neighbouring building, effectively merging them into a single functional unit. It is important to note, for these interconnected floors, the geometry of the neighbouring building must be included in calculations for total energy performance.

Fig 5. Studied building 3D model

In the 1990s, a significant renovation was undertaken, adding a new top floor to the structure. It resulted in a big change of the layout of the floor below, as well as the demolition of the east mansard roof. The facades of these two new floors are made of steel and glass, allowing a lot of natural light to flood the interiors. The interior of these floors reflects the influence of the deconstructivism architectural style, which was popular during the 90s. Layout is characterised by non-linear spatial arrangements, asymmetrical walls, sharp angles, and irregular forms - these spaces showcase a bold contrast in materials and colours. While most of the upper floors are dedicated to office spaces, the western section of the top floor retains four residential apartments, with an additional apartment located on the fourth floor. The vertical connection within the building happens by a single elevator, designed in an elegant modern style. The ground floor, or mezzanine level, is fully leased to retail stores. It features a ceiling height of 4.2 meters, while the average height for the other stories is 3.45 meters. Storage and technical rooms are located in the cellar.

Heating of the building is currently supplied by a gas-powered system. Cooling is achieved through conventional air conditioning systems. These systems use outside air to lower room temperatures, which requires substantial electricity and energy consumption. Additionally, air conditioning systems demand considerable space for recoolers, which were placed on the roof and balconies at the yard. Electricity for the building is sourced from central plant relying on fossil fuels, primarily gas. The roof surface is partially designed as an extensive green roof, contributing to sustainability. The potable and sanitary water supply uses the same water pipes sourced from the high-spring water supply system, that provides water across the entire city.

Seilergasse 16, view of the building's eastern facade

Spiegelgasse 15, view of the building's western facade

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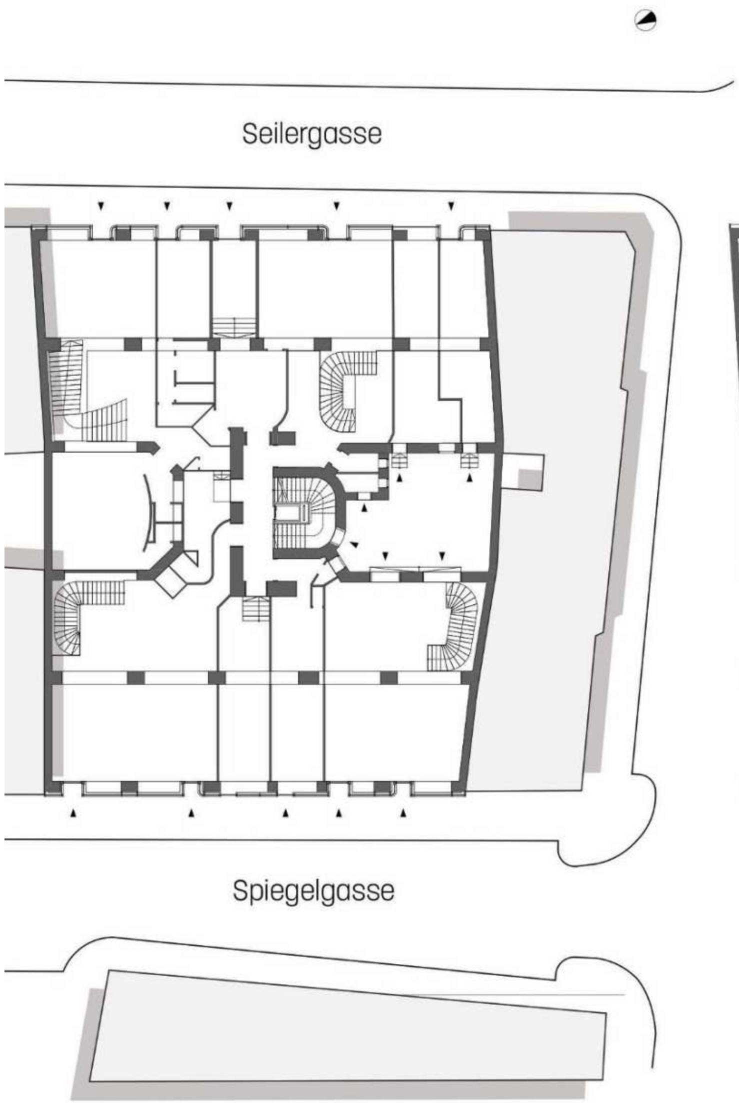
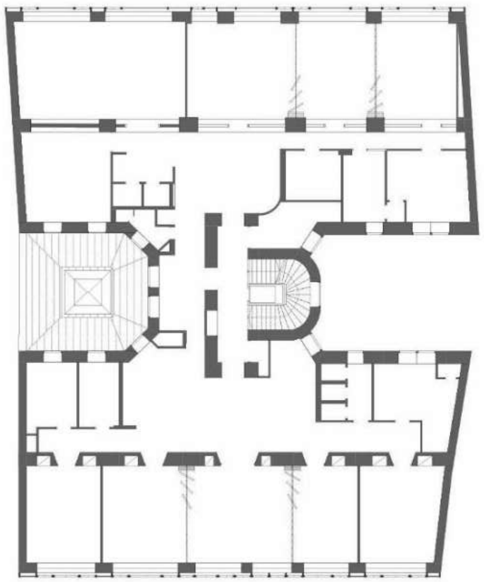


MEZZANINE 1.



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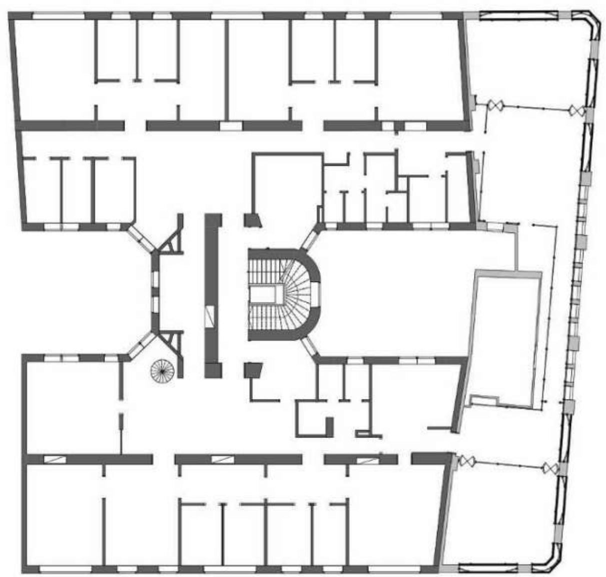

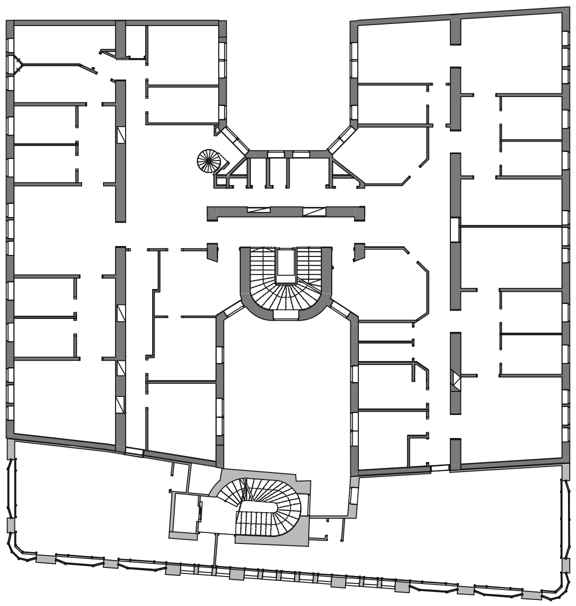

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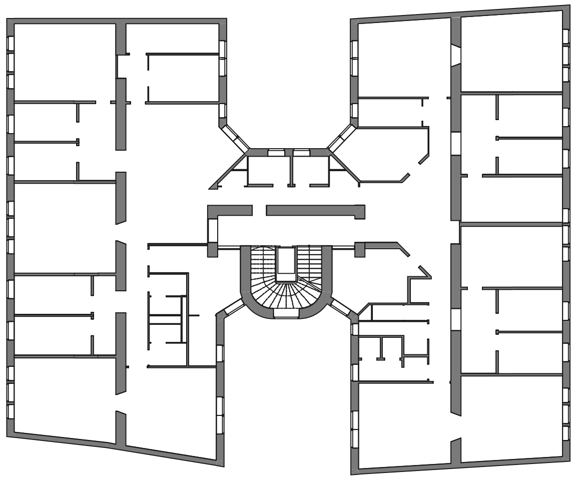

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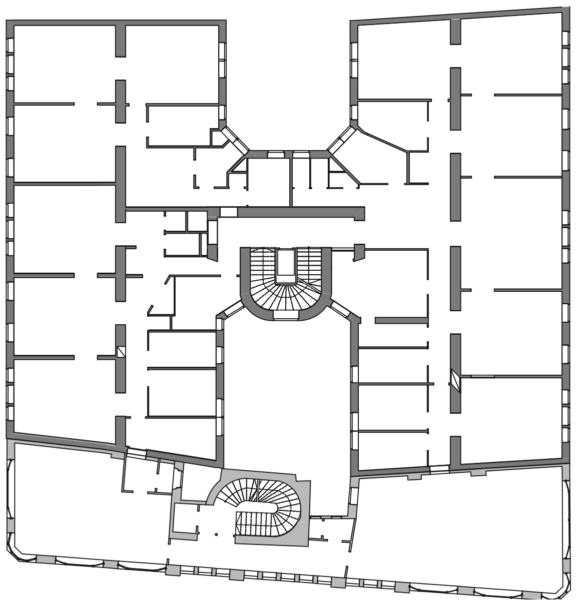

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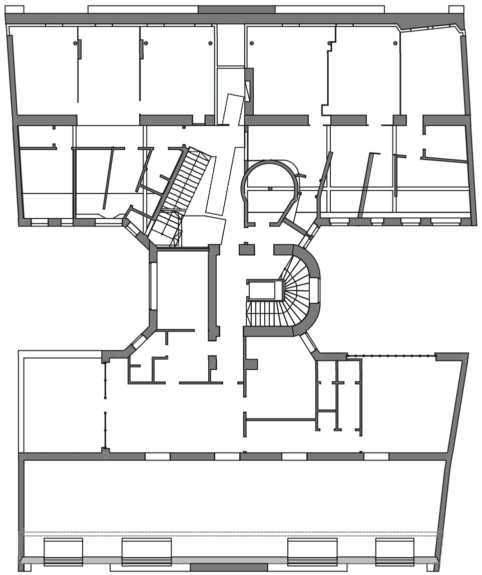

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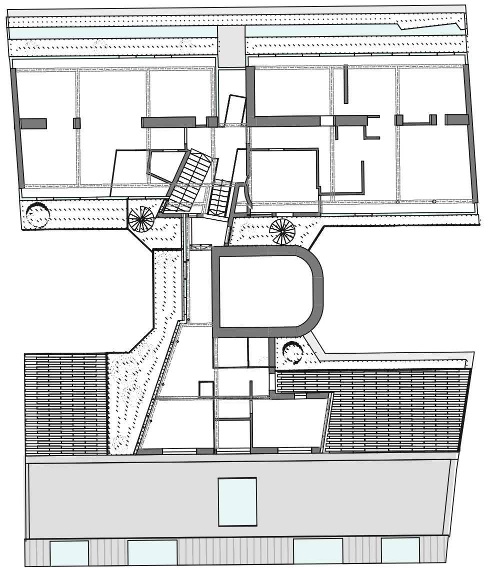

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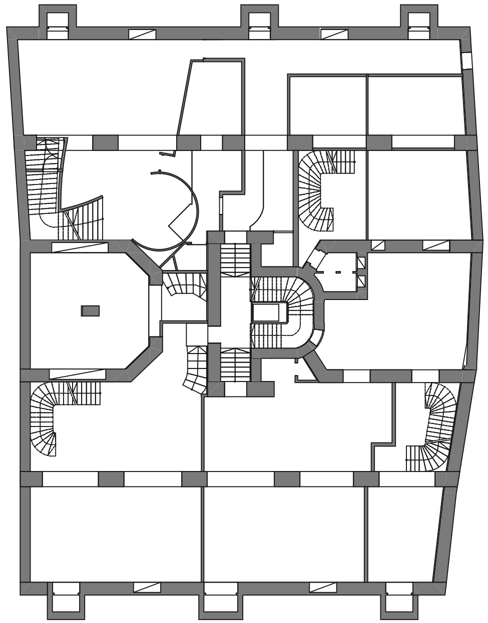

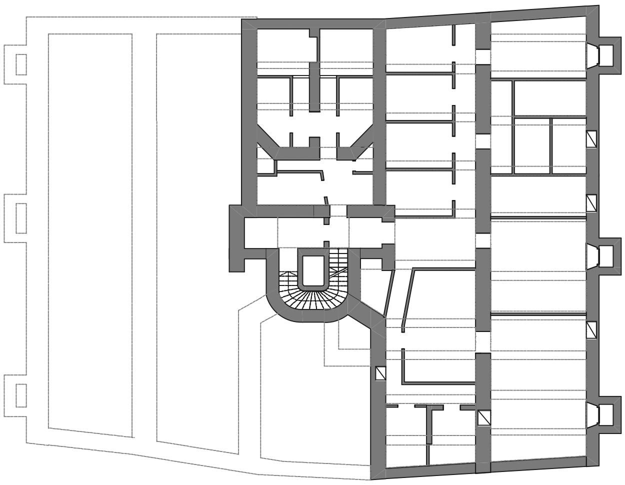

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4.1 Vienna building stock

As of January 1st 2024, Vienna's building stock comprised approximately 185,000 buildings (Statistics Austria 2024). These structures span across different construction periods, each marked by its specific architectural characteristics. Buildings from before 1945 represent two different epochs of architectural significance, that reflect the city's historical and social developments. Buildings constructed during the two world wars from 1919 to 1944 make up 12.5%, the smallest share of the stock. This period often referred as "Red Vienna" represents a time of economic difficulties and political changes, which influenced Vienna's urban development.

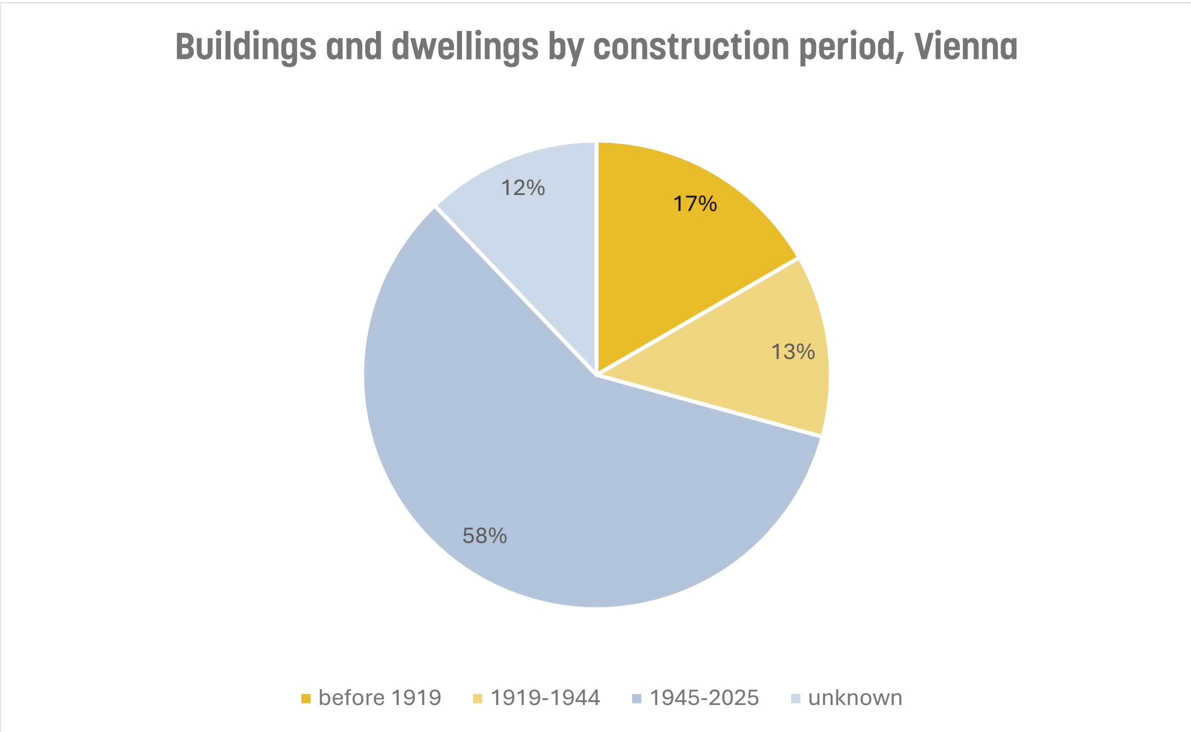

Fig 6. Buildings and dwellings by construction period in Vienna (Statistics Austria 2024).

During this time, the city focused on social housing projects to combat the dire living conditions prevalent in the city. These Gemeindebauten (municipal buildings) are characterised by their functional design and communal facilities. Notable examples include the Karl-Marx-Hof and the Rabenhof.

The case study building, built in 1904, classified as a part of the older epoch – before 1919 – which makes up around 17% of the building stock. This period is characterised by the grandeur of the Austro-Hungarian Empire, especially notable in the Ringstraße buildings constructed from the mid-19th century. This era brought about opulent palaces, grand public buildings, and expansive boulevards. Architectural styles such as Historicism, which included Neo-Gothic, Neo-Renaissance, and Neo-Baroque, were predominant (wien.info n.d.) (Friehs n.d.). Notable examples include the Vienna State Opera and the Natural History as well as Art History Twin-Museums.

As illustrated in Fig 6., approximately 29% of the total building stock consists of the buildings constructed before 1945. However, it is important to note that this percentage encompasses all types of constructions, including residential buildings, buildings for institutional households, hotels, office buildings, wholesale and retail trade buildings, industrial buildings, and others. The development of retrofitting strategies in this study primarily targets residential buildings, making up 84% of Vienna's building stock, as shown in Table 2 below.

Table 2.
Buildings and dwellings categorised by building use. (Statistics Austria 2024)

Residential buildings with one conventional dwelling	**90,800**	**49.1%**
Residential buildings with two conventional dwellings	**5,100**	**2.8%**
Residential buildings with three or more conventional dwellings	**60,205**	**32.5%**
Buildings for institutional households	766	0.4%
Hotels and similar buildings	1,442	0.8%
Office buildings	5,065	2.7%
Wholesale and retail trade buildings	2,853	1.5%
Traffic and communication buildings	459	0.3%
Industrial buildings and warehouses	3,608	2.0%
Buildings for public entertainment, education and health care	2,571	1.4%
Other buildings	7,709	4.2%
Unknown	4,541	2.5%
Total:	185,119	**100%**
Residential buildings:	156,105	84.3%

Residential buildings constructed before 1945 therefore make up anywhere between 13% and 29%[1]. Around 24%, assuming the distribution of building types is equal across all construction periods. The case study building is located in a protected zone 157 protected zones, covering a total of 16,000 buildings (Landström 2024)or 9 percent of the city's total building stock (Wien Kulturgut: Schutzzonen Wien n.d.). These are by enlarge buildings constructed before 1945 and are subject to strict heritage protection rules during renovations. The target buildings for the development of retrofitting strategies in this study therefore make up 8.6%. The largest difference in terms of renovation strategies between buildings in protected zones and other residential buildings constructed before 1945 are the protection rules on the outer appearance, which typically limits renovations on outer insulation of the building for instance. Therefore, the retrofitting strategies in this study could be applied to all residential buildings constructed before 1945 or around 24% of total building stock, considering this difference.

5 Methodology

5.1 Theoretical framework and qualitative assessment

The qualitative part of this study aims to understand both the practical and theoretical aspects of retrofitting historically protected buildings. To achieve this, semi-structured interviews are conducted with a selected group of experts who specialise in the fields related to the renovation of historical buildings, urban planning, and building technologies. Interviews are made to be semi-structured, allowing guided questions to keep the discussions consistent with the freedom for open-ended responses. This approach allows to thoroughly explore each expert's knowledge while giving them the flexibility to discuss the issues that matter most in their field. The goal was to effectively gather experience-based opinions, understand how Austria approaches retrofitting of buildings in conservation areas or historically protected buildings, and observe how theoretical strategies are applied in practice. By talking with various experts, the study was able to collect diverse perspectives representing different stakeholders involved in historical building renovations.

Experts are chosen for their professional backgrounds and their involvement in projects related to historical buildings. The selection process aims to include a diverse range of experts – from architects who are currently working directly with the case study building, to building technology experts, to local government officials and academic researchers – to ensure a broad perspective on the challenges and opportunities in building retrofit

[1] Lower bound estimate equal to all building constructed before 1945, excluding all non-residential buildings: $53{,}685 - 29{,}014 = 24{,}671\ (13.3\%)$; Upper bound estimate equal to all building constructed before 1945, including all non-residential buildings: $53{,}685 = (29.0\%)$. Average estimate equal to all building constructed before 1945, multiplied by the population residential building ratio: $53{,}685 * 84.3\% = 45{,}256\ (24.4\%)$.

projects. Selection criteria focused on professional experience, specific knowledge related to the study's case building, and previous involvement in sustainable renovation practices.

Interviewed people:

- **Markus Wimmer**
  Burghauptmannschaft, deputy head of stuff, building management
- **Gerald Wagenhofer**
  European Academy of Heritage, maintenance manager & trainer for cultural heritage
- **Georg Kolmayr**
  Municipal department MA19, responsible expert of the inspections section
- **Michael Haugeneder**
  ATP sustain, executive management, expert in building technology
- **Martin Mittermair**
  Mittermair Architects, currently case study building planning/renovating architect

Interviews are conducted in most cases face-to-face but also via video conferencing, depending on the availability of the experts. Each interview lasts approximately 60-90 minutes, allowing sufficient time to cover all relevant topics in depth. The interviews are recorded with the consent of the participants to ensure accuracy in data collection and analysis.

Questions asked in the interviews include:

Q1. *How will the Austrian government implement the new EU directive on the overall energy efficiency of buildings (EPBD, effective from May 28th, 2024)? The regulation exempts historically protected buildings, but national governments have the option to encourage renovations to increase energy efficiency even for these buildings. Is it already apparent whether Austria will take action in this area? If yes, in what form might this happen?*

Q2. *Who is the responsible and decision-making department in renovation cases? Is there room for negotiation in these decisions?*

Q3. *To what extent can windows, doors, or façade designs be altered?*

Q4. *To what extent can the substance of a protected building be altered during renovation? To what extent can changes be made to the interior of the buildings in protected zones?*

Q5. *What are the best or most effective renovation strategies for the buildings in protected zones or/and buildings under monument protection, especially to improve energy efficiency?*

Q6. *How well can the materials used in renovations be combined with the original materials from the early 20th century?*

Q7. *The first district of Vienna is set to be equipped with central heating by 2040, as described in the "Get off Gas" program by Wien Energie. In this context, is there still a need to consider alternative heating systems? If yes, which* *alternatives would be particularly suitable from a heritage conservation perspective?*

After conducting all the interviews, the responses from the experts are analysed systematically to identify important themes and insights about retrofitting historically protected buildings. Prior to the thematic analysis, the interview questions are grouped into categories reflecting the key aspects of the study. This categorisation is essential for organising the data into coherent themes, facilitating a structured and focused analysis. Grouping questions helps to highlight the relationships and distinctions between different areas of expert knowledge, ensuring that the analysis covers all relevant dimensions of the research topic comprehensively.

Table 3.
Identifying themes based on questions

N	Theme	Relevant Questions	Comments
Tb	**Regulatory: Energy efficiency and sustainability in historical buildings**	Q1, Q2	Questions that explore how Austria and Vienna are addressing energy efficiency in heritage buildings, and who are the decision-making parties.
Ub	**Material compatibility and renovation techniques**	Q6, Q5	A question that examines what renovation strategies are common for the city of Vienna and how modern materials are integrated into historical buildings, ensuring that renovations are both sustainable and aesthetically appropriate.
Vb	**Permitted structural and aesthetic changes in protected buildings**	Q3, Q4, Q7	Questions that focus on what structural and aesthetic changes are allowed, both externally (facades, windows) and internally, and whether alternative heating systems are viable.

All recorded interviews were transcribed using an AI tool called Clipto.AI. This transcription captured full conversations for thorough review. The transcriptions were then manually coded to align responses with common themes and questions. These responses were subsequently integrated into the structured framework outlined earlier, and a summary of the interviews was compiled.

Table 4.
Aligning the interview responses with common theme, summarizing interviews

Theme 1: Regulatory: Energy efficiency and sustainability in historical buildings	
Q1: AUSTRIAN GOVERNMENT AND EPBD	
Interviewee A	- ***Example synthesis:*** *"Preserving buildings instead of demolishing and rebuilding is becoming a stronger priority in Austria, especially in city centres. Some countries manage land use and preservation better than Austria, but the approach is shifting toward greater emphasis on maintaining existing structures."*

Interviewee B	
Interviewee C	
Interviewee D	
Interviewee E	
Q2: INVOLVED PARTIES	
Theme 2: Material compatibility and renovation techniques	
Q5: RENOVATION RECHNIQUES	
Q6: MODERN VS. ORIGINAL MATERIALS	
Theme 3: Permitted Structural and Aesthetic Changes in Protected Buildings	
Q3: ALTERATIONS TO WINDOWS, DOORS OR FAÇADE DESIGNES	
Q4: CHANGES TO INTERIORS, EXTERIORS AND THE ROOF	
Q7: ALTERNATIVE ENERGY SYSTEMS AND OTHER HVAC	

Simultaneously, a comprehensive Matrix of retrofitting measures was developed, drawing on various reference projects analysed during the literature review. This Matrix details retrofitting strategies for existing and protected buildings, specifying focus areas, spatial requirements, and key operational parameters.

To qualitatively evaluate the proposed Matrix, a thematic analysis was conducted. This process involved extracting responses that referenced specific retrofitting measures. The analysis highlighted commonalities and differences in expert perspectives, offering valuable insights into key challenges, opportunities, and best practices for retrofitting protected buildings. Information collected from the interviews was crucial for identifying potential areas for sustainable retrofitting. By integrating expert insights with findings from the literature review, the Matrix was refined and finalized to ensure its practical applicability and relevance.

Table 5.
Analysing proposed retrofitting measures based on interviews summary

Analysis for Matrix Approach 1: Passive measures in the building construction	
Interviewee A	*Example synthesis:* emphasises the effectiveness of insulating the top floor ceiling and notes the substantial thermal mass of thick walls, which reduce the need for additional external insulation...
Interviewee B	
Interviewee C	
Interviewee D	
Interviewee E	
Analysis for Matrix Approach 2: Active measures in the building services	
Analysis for Matrix Approach 3: Renewable energy	

Based on this analysis, three distinct retrofit scenarios – combinations of measures - were formulated for the case study building. The scenarios were made following a stepwise approach: beginning with thermal renovations (passive measures), advancing to combinations of passive and active measures, and lastly integrating passive, active, and renewable energy solutions together. Each scenario is designed to improve the building's energy performance, specifically focusing on preserving the external appearance.

The qualitative findings are not only valuable on their own but also play a crucial role in informing the quantitative component of the study. Since the analysis of the expert interviews serve as the input for the quantitative impact study, the approach ensures that the quantitative analysis is firmly grounded in practical, real-world considerations.

5.2 Quantitative impact – BIM modeling and energy assessment

The quantitative phase of the study uses Building Information Modeling (BIM) software ArchiCAD, to develop a detailed 3D model of the case study building. The process started with the collection of photographic documentation of all plans from the state plan archive (MA37). Following this, during a site viewing, the case study building was found to be undergoing renovation, exposing numerous openings in the floors and walls. These openings were carefully recorded, revealing the structural compositions of various constructional elements, allowing for the creation of an exceptionally accurate and detailed 3D model.

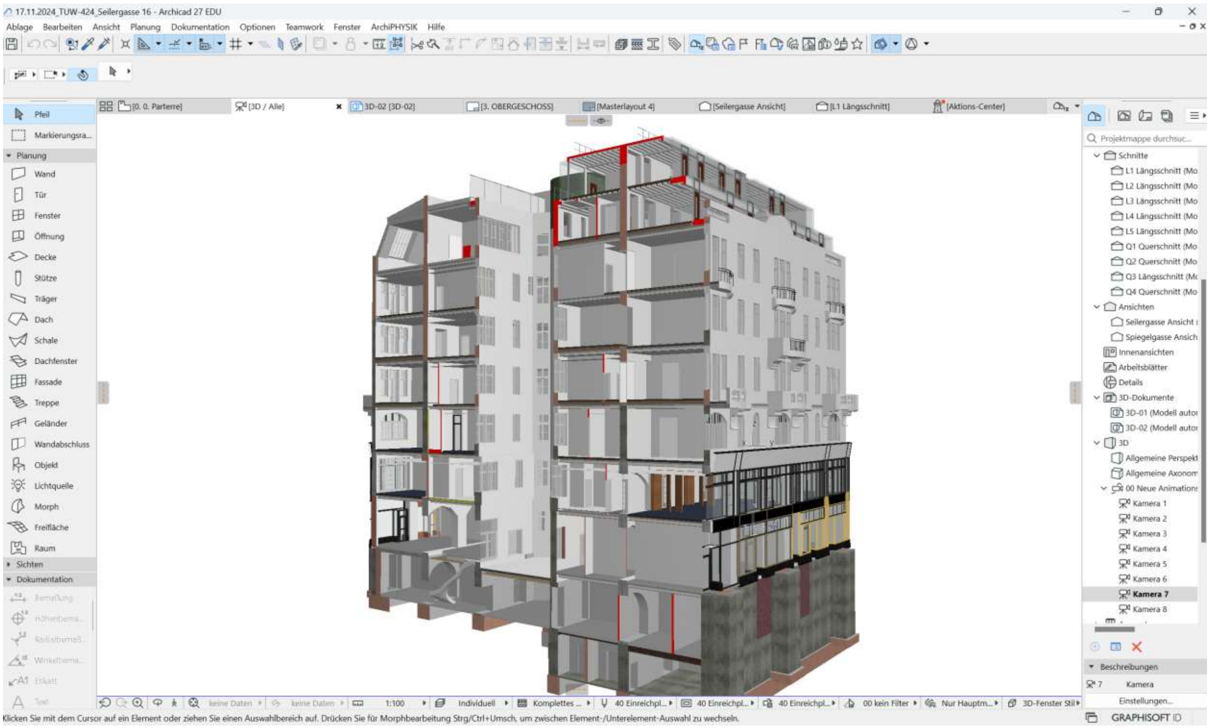

Fig 7. Case study BIM-model, ArchiCAD

Following the development of the 3D model in ArchiCAD, plans were extracted to ArchiPHYSIK software. This software is instrumental for analysing the building's thermal behaviour. Detailed data on the material properties of external walls, roofs, floors, and openings such as windows and doors were added, alongside information about the building's HVAC systems and energy sources. The heat transfer coefficient - U-values - for the building structural elements were applied according to the OIB Guidelines 6 (OIB 2023).

This comprehensive process enabled precise calculations of the building's current energy performance, based on which an energy certificate of the building was established. The energy certificate of the studied building reveals various aspects of the building's current energy performance under the assumptions of a standardised user behaviour and the local climate conditions.

As a next step, a comprehensive energy performance analysis for each retrofit scenario was conducted. This involved calibrating the measures of each scenario into ArchiPHYSIK as if they were implemented in a real-world context. The analysis gave an overview how would the building perform in case these measures are applied. Energy certification was established for each scenario, offering a clear comparative framework. The assessment quantified the potential energy demand and CO2 reductions, emphasising the environmental benefits of the proposed interventions.

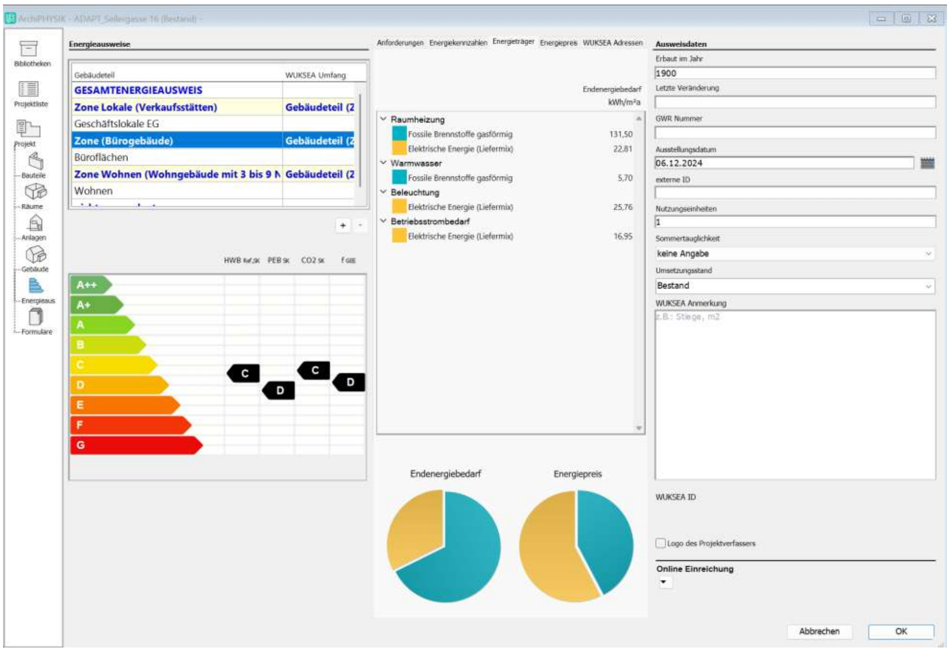

Fig 8. Case study thermal performance evaluation, ArchiPHYSIK

The final analytical step involves comparing the energy demands and potential CO2 reductions across the three scenarios, providing a practical evaluation of which strategy offered the most significant improvements in terms of energy efficiency and sustainability.

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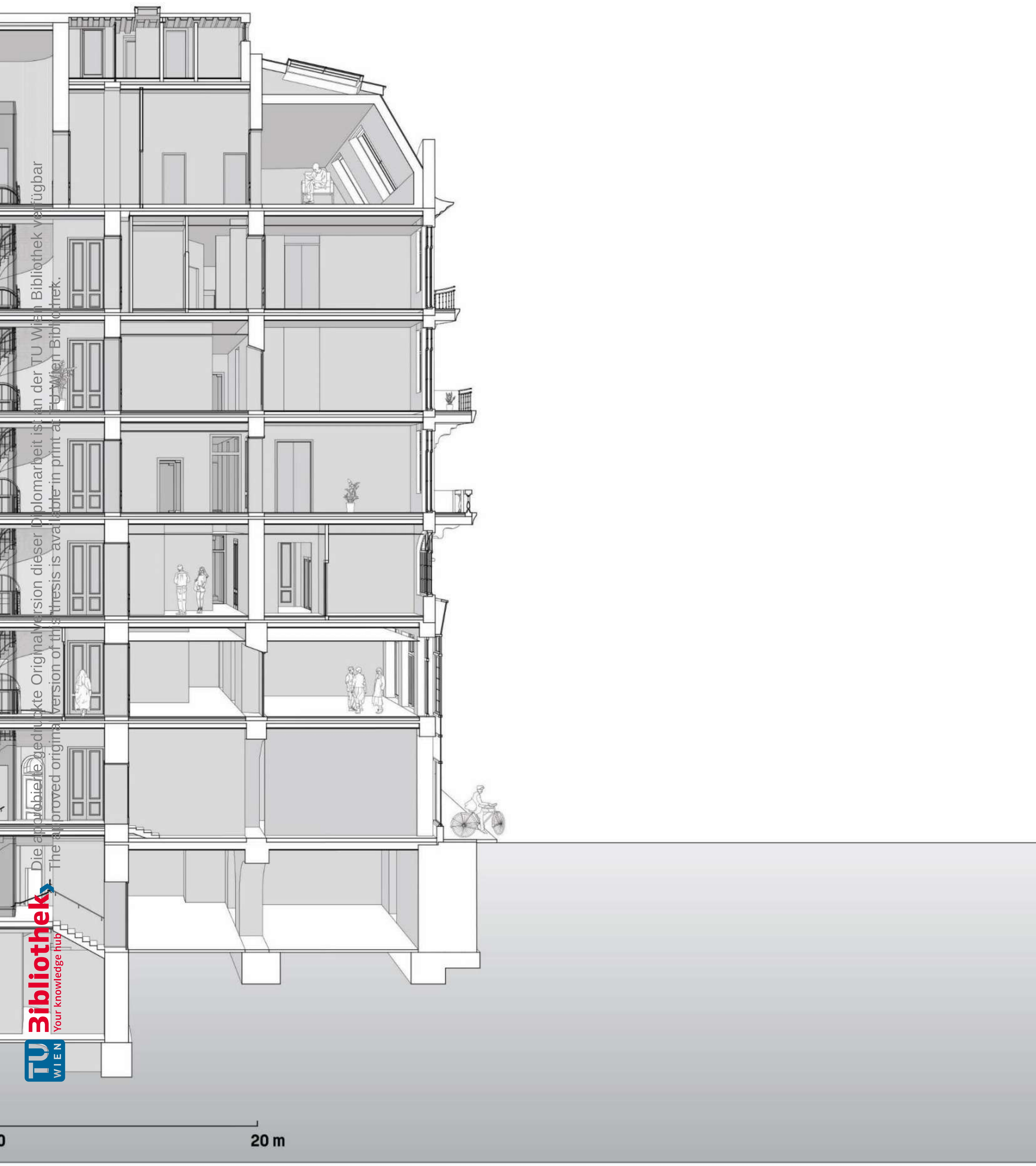
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6 Results

6.1 Matrix - retrofitting measures

In this section a comprehensive set of retrofitting measures is introduced (Table 6), designed to enhance the energy efficiency and sustainability of urban buildings. The measures are categorised into three approaches: passive measures to enhance the thermal quality of the building envelope, active measures to improve the energy efficiency of technical building systems, and renewable energy measures aimed at increasing the use of renewable energy sources and reducing CO2 emissions. Various retrofit measures are presented, categorised by approach, along with their technical specifications and space requirements, to provide a comprehensive guide for practical application. The unique challenges posed by protected buildings, such as maintaining their visual integrity, complying with conservation regulations, and addressing structural limitations are also outlined.

Approach	Retrofit description	Focus Area and space requirements	Specifications[2]
Passive measures in the building construction (to reduce energy demand)	External envelope insulation *Front walls*	Front walls, 20-30 cm layer	The heat transfer coefficient (U-value) for the external walls in conditioned rooms must not exceed 0.35 W/(m²K). Insulating materials are to be selected based on the existing walls. They could include mineral wool, EPS, XPS, polyurethane foam (PU) and polyisocyanurate (PIR), cellulose, wood fibre, aerogel, vacuum insulation panels VIPs.
	External envelope insulation *Courtyard walls*	Courtyard walls, 20-30 cm layer	
	Internal envelope insulation *Walls*	Walls, 20-80 mm layer	The target U-value is the same to that of external insulation, with a minimum 0.35 W/(m²K). It's crucial to include a vapor barrier to prevent condensation.
	Internal envelope insulation *Roof*	Roof, 15-30 cm layer	U-value of 0.20 W/(m²K) or lower for the ceilings and roof slopes against outdoor air or attic spaces. Materials: mineral wool, EPS, XPS, polyurethane foam (PU), cellulose.
	Internal envelope insulation *Basement ceiling*	Basement ceiling, 10-20 cm	The minimum U-value for the ceilings against unheated building spaces (cellar) as well as the floors above the ground is 0.40 W/(m²K). Materials to be considered: mineral wool, EPS, XPS, polyurethane foam (PU). A vapor barrier is recommended to prevent mould growth and structural damage.
	Glazing upgrade	Glass	Low-e glazing, triple glazing, vacuum glazing and double vacuum glazing with low-e coating to be considered.
	Windows upgrade	Windows	The target heat transfer coefficient is 1.40 W/(m²K) for residential and 1.70 W/(m²K) for non-residential buildings.

[2] Specifications are derived from various recommendations collected during the expert interviews, with the largest contribution made by building technology expert Michael Haugeneder. The U-values presented are based on Austrian standards, as of the latest update in May 2023 (OIB Richtlinien 2023).

			Improving the inner panes with insulation or even upgrading the inner pane with new glass (specifically for Vienna box type windows) is possible in building located in protected zones.
	Shading	Glass area	Traditional awnings with fabric blinds, classic vertical shutters, persiennes systems and others (Ursula Schneider 2021).
	Façade extension*	The actual dimensions of the extension will depend on the local zoning laws and the building's proximity to property boundaries.	This may involve reinforcement of the current structure to handle the additional load of the extension.
	Double skin façade / glass envelope*	Approx. 35 cm gap between the building façade and glass envelope	Wrapping up a building with a glass envelope that is ventilated in the summer and closed in the winter, functioning as a buffer zone. This envelope includes openings at windows and doors. Steel structure should ideally rest on the ground rather than being mounted onto the existing facade.
	Soil de-sealing	Backyard surface (+waterproofing the basement)	Backyard soil de-sealing allows natural processes, such as water infiltration or plant growth, to return and is generally good for the microclimate. It must be ensured that the basement is properly sealed to prevent water pooling around the walls. De-sealing can be combined with rainwater collecting measurement (e.g. "Sponge City").
	Waterproofing the ground floor with metal flashing	Socle (plinth)	Due to capillary action, moisture from the ground is drawn up into the base zone, causing the plaster to crack and peel, and the area to stay damp. This can be easily prevented by inserting a metal sheet. This involves cutting through the base zone and inserting a metal sheet to create a moisture barrier.
	Extensive greenery	Roof top, open terraces	Planting on roofs can improve building insulation and reduce heat absorption. Requires structural assessment for load-bearing capacity and waterproofing. Adequate access for maintenance should be planned in advance.

	Natural ventilation through chimneys	The cellars, which raised about a meter above ground level and vertical shafts for air distribution.	Sometimes for a better air quality maintenance this measure could be combined with mechanical systems, which helps to control the air circulation.
	Sun-reflecting roof cool clay tiles	Roof, around 20-mm layer of the surface	Regular cleaning is required to remove debris, moss, and algae.
Active measures in the building services (to increase consumer efficiency)	LED lighting	Bulbs replacement	A typical LED light bulb uses about 10 watts, according to EnergySage, compared to about 60 watts for most incandescent bulbs. Could be combined with PV solar panels.
	Integration of controlled mechanical ventilation	Indoor spaces	Mechanical ventilation systems can generate noise. Sound insulation materials around the ventilation unit to be considered and ductwork to minimise noise transmission into occupied spaces.
	Central cooling system	Roof or terrace: for air-cooled systems Inside spaces, often suspended ceilings: for fan coil units	As noise can be a concern, especially in densely populated urban areas, soundproofing measures should be incorporated around the cooling units and ducts.
	Floor heating (hydronic – water-based or electric systems)	Floors	It is ideal if there is already a need of updating the floor structure, as it integrates easily into the renovation process finishing it with screed. Since floor heating operates at lower temperatures than radiators, it pairs well with energy-efficient systems like heat pumps or condensing boilers. Unlike radiators, floor heating also offers the advantage of using it for floor cooling.
	Water heat pump	Mechanical room (basement) for the main unit, access to a continuous water source (e.g. Danube)	Noise of all HVAC equipment must be addressed. Using vibration pads can help reduce noise transmission. Heat pumps and chillers are visually not attractive, consequently, they must be hidden or masked Problems of the equipment weight, structure of the building must be verified (OIB Richtlinien 2023).
	Electric heat pump based on compression cycle	Outdoor space for condenser or heat pump unit	

	Air water heat pump	Basement: heat pump unit Roof or terrace: heat pump and chiller	Air-water heat pump make a good combination with geothermal energy source.
Renewable Energy (to cover residual energy requirements with renewables)	Rainwater collector	Roof surface - collection area Basement / backyard: for a storage tank, a pump and control and monitoring system Ground level: filtration and first-flush system	Though challenging in older buildings with limited space, it's feasible and affordable if planned well. Alternatively, the Sponge City approach channels rainwater into the ground, temporarily storing it in a de-sealed area (e.g in the courtyard), where excess water naturally infiltrates the soil.
	District heating	Basement for the heat exchanger Control room	Especially great solution if there is a nearby access for the building to the district heating supply pipe.
	District cooling	Mechanical room typically in the upper floors	District cooling is being expanded in Vienna. Currently, as of February 2025, district cooling services are available in several streets within the first district of Vienna, and there are plans to significantly increase this coverage.
	Integration of solar (PV) panels	Roof top, terrace for the panels	Orientation, tilt angle, sun path must be considered The roof must be strong enough to support the weight of the collectors and any mounting hardware. This might require reinforcing the roof structure.
	Solar thermal collectors*	Roof top, terrace for the panels Mechanical room for the storage tank	
	Hybrid solar & air collector	Roof top, terrace for the panels Mechanical room for the storage tank	A hybrid collector generates both heat and electricity on the same surface, saving space and boosting efficiency. It provides power even in winter when regular solar collectors don't produce heat, and in summer, it cools PV modules to improve performance and extend lifespan.

	Pellet based heating system	Basement or ground-level for dedicated boiler Pellet storage close to the boiler	Wood pellets are generally less expensive than oil or gas, especially in regions where biomass is plentiful. Ash collection and vent cleaning are necessary to keep the system operating efficiently. Can also be used for domestic hot water. The installation cost can be higher than some traditional heating systems, although Viennese government incentives are often available.
	Geothermal Energy	Basement for the heat pump unit and control systems Ground outside: ground loop installation	Geothermal energy systems require space for drilling wells. This can be a challenge in areas with limited available land. The type of soil or rock beneath the ground affects the efficiency and design of the geothermal system. Geothermal energy paired with a heat pump offers the highest efficiency.
	Wastewater heat recovery*	Mechanical room, typically close to the main drainage pipe or water heater.	This system captures the heat from warm wastewater, such as water from showers, sinks, or washing machines, and recycles that heat to warm incoming cold water or air.

Table 6 Matrix – retrofitting measures

6.2 Expert interviews

In addressing the question concerning façade alterations in renovation projects for the buildings in protected zones, experts identified backyard walls, cellar ceilings, and roofs as common target surfaces for external insulation. Installing insulation on backyard walls is considered a practical solution, as it preserves the historical façade while still addressing energy demands. However, attention must be given to the existing thermal mass of the walls, which, if sufficiently thick, may eliminate the need for additional external insulation. The challenges of internal insulation were also discussed, particularly its requirement to be vapor-tight, necessitating a complex construction system with a vapor barrier and protective layer. Internal insulation is noted as being more suitable for owner-occupied properties, as it requires careful maintenance; tenants in rental or commercial properties may unintentionally damage the moisture protection.

Regarding windows, experts pointed out that insulated glass often loses effectiveness over time (typically 5-7 years) as the gas within the panes escapes. Upgrading old glazing or replacing entire windows is an effective measure for reducing heat loss. In the case of wooden box windows, restoring the outer frames and upgrading the inner panes can deliver excellent thermal performance. When well-maintained, these windows can achieve energy efficiency levels comparable to modern ones.

Authorities are seen to be open to innovative solutions for sun protection and shading for historical buildings, if they maintain aesthetic uniformity and compatibility with the building's original design. Overall, while modern improvements are essential for enhancing energy efficiency and indoor comfort, any alterations to protected buildings must be thoughtfully designed to respect their architectural heritage and historical significance.

On the most effective renovation strategies, the experts agreed that the standardised solutions are not suitable for historic or protected buildings and often require customised strategies to balance energy efficiency with preservation. All experts supported the integration of modern systems like heating, cooling, and ventilation, along with renewable energy sources, as effective measures that can be implemented without compromising the historical integrity of buildings. However, differences in approach emerged in the use of technology and regulatory considerations. One expert discussed the application of smart technology to adjust energy use based on occupancy and weather data, optimising efficiency particularly on days with variable usage. Another expert brought up potential future regulatory shifts, suggesting that environmental sustainability might become more integral to preservation efforts under initiatives like the EU Green Deal.

Experts acknowledged district heating as a good rising alternative in Vienna to natural gas. In 2020, 43% of heating system sales in Austria relied on natural gas. By 2022, this figure had dropped to 22%. This shift aligns with Vienna's "Away from Gas" initiative, aimed at reducing dependence on natural gas (Querol Cumbrera 2024). Other alternatives were discussed, including geothermal heating, which, despite high installation costs, offers a sustainable solution in a longer-term perspective. An expert in building technology highlighted, if a property has potential for on-site energy solutions, the priority is always to utilise that potential. Hybrid systems combining geothermal energy with air-to-water heat pumps were suggested to balance efficiency with practical concerns. Overall, while district heating is progressing, integrating a mix of alternative systems is good for environmental sustainability.

By addressing overheating during warmer seasons and the problem of high energy demands of ventilation systems, district cooling was highlighted as a potential solution and growing network in Vienna. This system, primarily powered by the Danube, is designed to replace individual cooling machines in buildings. This approach reduces on-site electricity consumption and alleviates pressure on the local grid, enabling energy capacity to support other systems like mobility and ventilation. The system delivers cold water at approximately 15°C, similar to district heating, which supplies hot water already preheated up to 80°C. Both systems require on-site equipment for temperature adjustments but do not consume additional electricity to heat or cool the water. They are powered by a mix of energy sources, including wind, thermal power plants, and others.

A building technology expert highlights that modern mechanical ventilation systems enable air treatment and heat recovery, providing indoor comfort, temperature control, and moisture protection while consuming minimal energy.

There was a discussion on the varying requirements between ensemble and monument protections, highlighting that ensemble protection might allow for the use of modern materials to maintain visual appearance, whereas monument protection often prefers rather the use of original materials to ensure authenticity and longevity. Another important factor for choosing the renovating material is a need to match the physical properties of new materials with original ones, particularly in terms of breathability and moisture control. In addressing the extent to which the substance of protected buildings can be altered during renovations, expert interviews highlighted a strategic balance between preservation and modernisation.

Photovoltaic (PV) systems can be considered for the integration on a building based on several factors such as visibility, structural suitability, and optimal orientation for energy production. One expert highlights modern alternatives like PV tiles designed to replicate historical roofing materials being favoured for their aesthetic compatibility. In Vienna's 1st district, a UNESCO World Heritage site, roof modifications are particularly sensitive, as any modifications must preserve the skyline. When renovating roof elements in this area, photos are sometimes taken from the top of St. Stephen's Cathedral to assess the visual impact on the roofscape and ensure the skyline remains unaltered.

Comparing and analysing measures based on interview responses is outlined in Table 7. Analysis is organised in a table with key opinions regarding different retrofitting measures coded with the interviewee. The full interviews summary has been included to Annex.

Table 7.
Comparing and analysing Matrix based on interview responses

Analysis for Matrix Approach 1: Passive measures in the building construction	
Insulation	
A. Markus Wimmer	emphasises the effectiveness of insulating the top floor ceiling and notes the substantial thermal mass of thick walls, which reduce the need for additional external insulation. He highlights windows, particularly Vienna box windows, as key areas for improvement by enhancing inner pane insulation. Additionally, he cautions against over-insulating, to preserve the building's necessary breathability and prevent suffocation issues.
C. Georg Kolmayr	discusses the lessened public interest in preserving the original appearance of small courtyards, which primarily serve for ventilation or lighting, suggesting flexibility in implementing insulation and other modern interventions in such areas.
D. Michael Haugeneder	notes that internal insulation often only works in theory due to the need for it to be vapor-tight, requiring a complex construction that includes a vapor barrier and a protective layer. He points out that in commercial and rental properties, internal insulation is hard to maintain as tenants could damage the moisture protection. Thus, it is more suitable for owner-occupied apartments where the owner can be informed about the necessary protection measures.
E. Martin Mittermair	discusses upgrading roof insulation, noting that even though the roof of the case study building was insulated in the 1990s with a standard 6 to 8 cm layer of insulation, modern standards now require a thicker layer, around 30 cm, suggesting a significant enhancement in thermal protection for energy efficiency.
Glazing upgrade	
A. Markus Wimmer	states that upgrading to thermal glazing is possible only if the existing window frames are robust enough to support the additional weight. If windows are too damaged, they are rebuilt to historical models but are reinforced to accommodate new glazing.
B. Gerald Wagenhofer	highlights that modern insulated glass often loses effectiveness over 5-7 years as the gas within them escapes, indicating that traditional box windows can achieve insulation values close to those of modern windows if well-maintained.
D. Michael Haugeneder	confirms the effectiveness of glazing upgrades for retrofitting, noting the availability of various types of glass for box windows, including thinner versions with excellent U-values. He highlights not only the energy benefits but also improvements in sound insulation and airtightness that enhance indoor quality. However, he points out that such upgrades typically necessitate a ventilation system to manage moisture.
E. Martin Mittermair	details plans to replace old glass surfaces that do not meet current standards with modern triple-glazed insulating glass, enhancing insulation significantly. He explains that this involves updating to glass that includes two gas-filled chambers between three panes.
Windows upgrade	
B. Gerald Wagenhofer	highlights that traditionally well-maintained windows can last over 100 years. However, the modern window industry pushes for replacements every 30 years, driven by sales motives.
C. Georg Kolmayr	discusses the good thermal performance achievable by well-maintained wooden box windows. By restoring the outer frames and upgrading the inner panes, these windows can reach energy efficiencies comparable to modern triple-glazed windows.
D. Michael Haugeneder	discusses retrofitting options for Viennese box windows designed for the renovation of Gründerzeit buildings. These retrofits include modern insulating panes on the inside while maintaining a traditional appearance on the outside. This method addresses heat loss and improves energy efficiency.

E. Martin Mittermair	talks about replacing old, inefficient glazing at the roof top with new triple-glazed insulating glass. This upgrade involves three panes with two gas-filled chambers, enhancing the window's insulation capabilities.
Shading & sun-reflective roofing materials	
A. Markus Wimmer	discusses a research study which found that sun-reflective roof coatings provided a negligible temperature yield of only 0.1% without additional measures, suggesting that such coatings alone do not offer significant energy efficiency improvements.
B. Gerald Wagenhofer	points out that when choosing sun-reflective roofing materials, such as tiles, the decision should consider not just their utility but also whether they align with the values of the historic building, emphasising the importance of appearance alongside functionality.
C. Georg Kolmayr	discusses the need for sun protection solutions in protected zones, especially for decorated buildings, where standard solutions like industrial roller shutters are incompatible with the historic cityscape. He advocates for historical or period-appropriate shading solutions such as utilising gaps in wooden box windows, employing folding wings, or opting for textile alternatives, which were common during the Gründerzeit era. He also highlights the challenge of achieving uniformity in shading, particularly in residential buildings where renovations may occur individually, but asserts that solutions can be found.
D. Michael Haugeneder	notes that roofing with highly reflective shingles should be openly discussed from a heritage conservation perspective. He mentions that while highly reflective shingles can reduce solar heat gain and lower the cooling load of the top floor, their overall impact varies significantly depending on the roof size relative to the total building footprint.
Natural ventilation	
A. Markus Wimmer	describes a natural ventilation system used in buildings built before World War I, which draws air from the cellar, maintaining a consistent temperature year-round. He details how this system employs special channels and fans to facilitate efficient temperature management.
B. Gerald Wagenhofer	emphasises that historical buildings often have intelligently designed natural ventilation systems. He advises assessing the functionality of these existing systems before considering the installation of mechanical ventilation.
D. Michael Haugeneder	highlights how chimneys and cellars in older buildings can be repurposed to support modern HVAC systems. Specifically mentions that raised cellars allow for natural ventilation, which supports technologies requiring external air, like ventilation or cooling systems. This integration can maintain air quality and energy efficiency without extensive mechanical installations.
Analysis for Matrix Approach 2: Active measures in the building services	
LED	
D. Michael Haugeneder	Highlights the importance of LED lighting as an essential measure for reducing energy consumption in sustainable retrofits, its integration is particularly effective when combined with solar panels.
Modern HVAC	
A. Markus Wimmer	discusses the complexities of integrating mechanical ventilation systems in historic buildings, which involve large ducts and machinery that consume space, increase operational costs, and may lead to energy inefficiencies.
C. Georg Kolmayr	highlights the recent amendments in building codes, specifically Paragraphs 85 and 86, aimed at regulating the installation of air conditioning units and other cooling systems on rooftops in the first district and protected zones, ensuring these installations do not compromise the historical aesthetics of the area.
D. Michael Haugeneder	stresses the importance of installing mechanical ventilation systems to protect buildings, particularly against moisture issues. He notes that purely natural ventilation is ineffective in structures with significant cold mass, which leads to

	insufficient pressure differences for effective air movement. Additionally, modern mechanical ventilation facilitates air treatment and heat recovery, ensuring indoor comfort, temperature control, and efficient moisture protection with minimal energy use.
E. Martin Mittermair	outlines plans for a new centralised cooling system on the rooftop, hidden from street view, with a technical shaft for air distribution across all floors, ensuring efficient air quality and temperature control throughout the building. All small current ventilation devices in the building will be removed.
Air-to-water heat pumps	
D. Michael Haugeneder	notes that while air-to-water heat pumps are gaining popularity, their major drawback is noise, especially for larger systems needed in big buildings due to the significant airflow required. He suggests a hybrid approach as a solution, combining geothermal energy to cover 30-40% of the load, with an air-to-water heat pump supplementing the reduced demand to balance performance and mitigate noise issues.
Analysis for Matrix Approach 3: Renewable energy	
Grey water recovery	
A. Markus Wimmer	highlights, the importance of efficient water usage, especially in urban areas; notes, that reactivating cisterns and greywater systems can provide significant benefits.
D. Michael Haugeneder	mentions that greywater systems contribute to CO_2 emissions reductions by decreasing the energy demand associated with water treatment and supply; these systems recycle water for non-potable uses, reducing the overall environmental footprint and supporting sustainable urban infrastructure.
PV systems	
A. Markus Wimmer	emphasises assessing visibility from outside the building, structural suitability of the roof, and optimal orientation for sunlight exposure before installing photovoltaic systems on historic buildings.
B. Gerald Wagenhofer	suggests prioritising green roofs (like one existing on the case study building) over PV panels for their ecological benefits.
C. Georg Kolmayr	discusses options for integrating PV systems on roofs, focusing on making color adjustments and placing systems where they are not visible from public spaces to balance heritage preservation with ecological measures.
D. Michael Haugeneder	mentions companies producing PV systems designed to replicate historical roofing materials. These systems, while 12-20% less efficient than standard black panels, offer a visually acceptable solution for integrating solar technology into protected architectures.
Solar thermal collectors	
D. Michael Haugeneder	mentions that solar thermal collectors are not practical in buildings primarily used for office space unless there is a significant consumer like a restaurant that could benefit from the system. Discusses the importance of covering a portion of electricity needs through battery systems to relieve the network, especially in office buildings where nighttime energy demand is lower. Notes that solar thermal collectors are effective in buildings with high hot water demand but perform poorly in transitional seasons due to high humidity.
District heating	
A. Markus Wimmer	notes that while urban district heating provides reliable supply and manageable maintenance, there are concerns about its economic viability and environmental impact since it largely depends on gas.
B. Gerald Wagenhofer	expresses skepticism about the sustainability of gas-based district heating planned for Vienna's first district, highlighting potential conflicts with long-term environmental goals. Advises caution when combining gas heating systems with air-based systems like air conditioning. He highlights that the gas boiler could affect

	the air pressure within the system, potentially leading to dangerous situations if not reviewed and managed carefully.
C. Georg Kolmayr	mentions that Vienna's existing district heating network should cover densely populated areas well, but also highlights the potential for alternative energy systems to locally meet heat demands and foster synergies among buildings.
D. Michael Haugeneder	discusses Vienna's strategy to expand district heating by moving away from gas, particularly in the first district. He notes that achieving this requires buildings to reduce energy consumption by 70%. Due to preservation restrictions, historic buildings cannot meet near-zero energy standards and should prioritise on-site renewable energy solutions like geothermal to supplement district heating and enhance CO2 neutrality.
E. Martin Mittermair	discusses the current connection of the building in Plankengasse to district heating, which will be extended to provide hot water to merged buildings, emphasising a practical application of district heating in urban renovation.
District cooling	
D. Michael Haugeneder	discusses the expansion of Vienna's district cooling network, primarily powered by the Danube. This system aims to eliminate the need for individual cooling machines in buildings, thereby reducing on-site electricity consumption and freeing up energy capacity in the local grid, which supports other systems like mobility and ventilation.
E. Martin Mittermair	describes district cooling as supplying cold water around 15°C, similar to district heating which delivers hot water up to 80°C. Both systems require additional on-site equipment to adjust temperatures and are powered by various energy sources including wind, thermal power plants, and natural gas.
Geothermal energy	
A. Markus Wimmer	discusses geothermal energy as an effective heating source, particularly in older buildings, but highlights the complexity and high investment required. He notes that geothermal heating often relies on electricity, adding to its operational considerations
D. Michael Haugeneder	emphasises the importance of utilising on-site geothermal potential before considering external green energy sources. He describes geothermal systems using flush drilling techniques, which are suitable for urban areas like Vienna due to the prevalence of loose materials, although this method produces significant mud. He mentions newer slant drilling techniques that can access larger areas even in restricted spaces, although they offer slightly reduced performance from 55 W/lfm to 45 W/lfm.

Following the analysis of the expert interviews, the case study building was analysed from both regulatory and technical perspectives to determine which measures are most suitable for a sustainable retrofit. Based on the proposed measures outlined int the matrix and expert opinions, the following retrofit measures were excluded for the studied building, with the reasons outlined below:

- *Front façade insulation:* not viable for front façades of buildings in protected zones, as the architectural integrity of the façade must be preserved.
- *Façade extension:* not viable for the same reasons as mentioned above.
- *Double-skin façade / Glass envelope:* this option was excluded due to the lack of sufficient space to accommodate the approximately 35 cm gap required between the building façade and the glass envelope.
- *Natural ventilation through chimneys:* geometrically unfeasible.

- *Solar thermal collectors:* more suitable for buildings with higher water demand, like residential, making it less efficient for the studied building's needs.
- *Pellet-based heating system:* this solution is better suits for areas lacking access to district heating, which is not the case for the studied building.
- *Wastewater heat recovery:* similar to solar thermal collectors, this option is more effective for buildings with significant water demand, which does not align with the building's characteristics.

Other retrofitting measures may be considered as viable options, as long as external appearance of the building is preserved.

6.3 *Three scenarios of retrofitting*

Drawing on the above analysis of expert interviews as well as relevant literature (see Chapter 3.) on the effectiveness and suitability of retrofitting measures (Huang *et al.* 2022), (F.Cabeza *et al.* 2018), (Feng and Janssen 2021), (Pagoni *et al.* 2025), (Cornaro *et al.* 2016), (Franco *et al.* 2015), (Bakonyi and Dobszay 2016), (Ursula Schneider 2021), (Pisello 2015), (Ardente *et al.* 2011), (Tommerup and Svendsen 2006), (Liu *et al.* 2024), (M.G. Ippolito 2014), (Carotenuto *et al.* 2017), (Wang *et al.* 2021), (F.Cabeza *et al.* 2018), (Franco *et al.* 2015), three retrofit scenarios are proposed for the case study building and presented in this chapter. The first scenario focuses solely on passive measures. The second scenario combines active with passive measures, and the third incorporates both approaches alongside renewable energy solutions.

The first retrofitting scenario concentrates on improving the building envelope's thermal performance by reducing internal heat loss. A conventual approach suggests adding thermal insulation to the building's outer envelope and upgrading old windows. However, as the case study building is located in a protected zone, thermal insulation of the front façade is not permissible, nor is replacing the windows on the front façade. Instead, possible solutions include upgrading the glazing of the inner pane of the street-facing windows and adding thermal insulation where there is no public interest in the preservation, such as the backyard walls, the cellar ceiling, or the roof. Old windows on the backyard-side are to be fully upgraded to modern windows with triple glazing. Additional measures such as the integration of shadings will be applied to enhance energy efficiency by reducing solar heat gain during the summer, minimising cooling demands, and improving indoor comfort throughout the year. The proposed retrofit measures for Scenario 1 are shown in Fig 10.

The semantic material properties of the building are defined according to the latest standards outlined in OIB RL 6 (OIB 2023). The average U-values of the building elements for both the base case model and the retrofitting Scenario 1 are listed in the Table 8. Each following Scenario integrates the thermal measures from Scenario 1 outlined above.

Scenario 2 builds on these passive measures by incorporating the following active measures: ventilation with heat recovery, LED lighting, district heating, and district cooling.

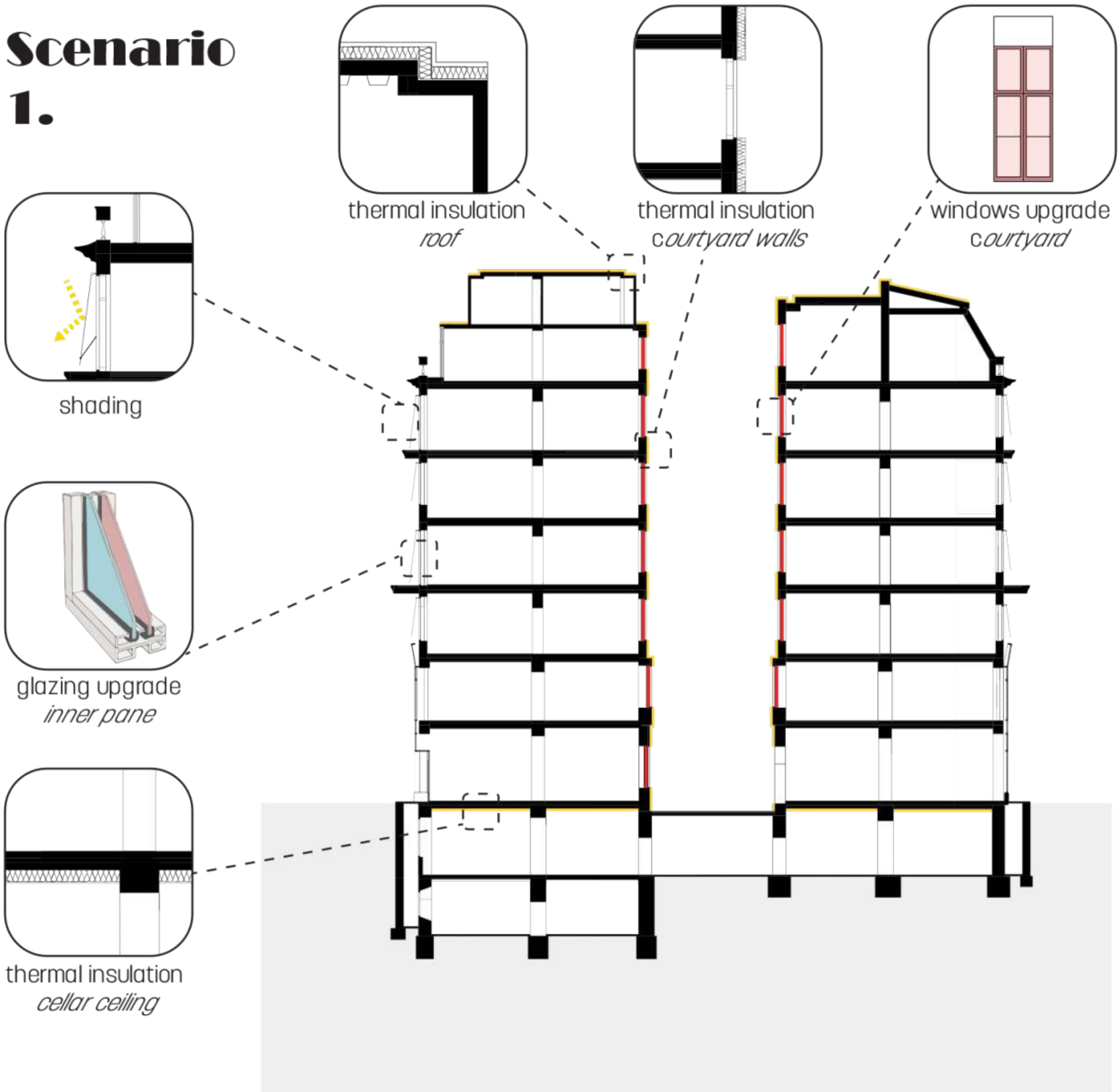

Fig.10 Scenario 1: thermal insulation of the roof, backyard walls, cellar ceiling, glazing upgrade front façade, windows upgrade backyard, shading.

Table 8

Scenario 1 - Building envelope: U-values before and after the considered interventions.

Measure	Action	Base case av. U-value (W/m²K)	Retrofit av. U-value (W/m²K)
Insulation roof slab	+ EPS 20cm	0.75	0.185
Insulation roof top walls	+ Stone-wool 18cm	1.18	0.185
Insulation backyard walls	+ Stone-wool 18cm	0.95	0.165
Insulation cellar ceiling	+ Glass-wool 28cm	1.20	0.285
Windows upgrade backyard	Triple glazing	3.00	0.95
Glazing upgrade inner pane street	Double glazing inner pane	2.55	1.20
Glazing upgrade roof top	Triple glazing	1.90	1.10

Mechanical ventilation with heat recovery (MVHR) is facilitated by a heat exchanger, which absorbs heat from outgoing air and transfers it to incoming fresh air without mixing the two airflows. This reduces the need for additional heating to maintain indoor temperatures. Unlike an air conditioning system, the heat exchanger does not actively heat or cool but instead utilises available heat. A single centralised unit with a duct system can serve the entire house, positioned in a technical room at the upper floors or outside. Air supply and extraction vents are typically placed in each room (Mechanical ventilation with heat recovery n.d.).

District heating is generated in state-of-the-art plants directly in Vienna. The city's ultimate goal is to make district heating climate-neutral and completely natural gas-free (Wien Energie n.d.). A neighbouring building to the case study building is already powered by district heating, providing direct access for connection. The system operates by transporting hot water from a central plant to consumer buildings through insulated pipes (WTS - Expert in Water, Wastewater, Air & Energy n.d.).

District cooling is combined with the ventilation system, using fan coils installed in the ceilings of rooms with highest overheating potential to distribute cool air (21 degrees 2021).

LED lighting is included as an energy-efficient solution for artificial lighting throughout the building. LED lights consume significantly less energy than traditional incandescent or fluorescent lighting while providing the same or better illumination quality. They also have a longer lifespan, reducing maintenance and replacement costs over time (Energy Star n.d.). Fig 11. illustrates the proposed retrofit measures.

Scenario 2.

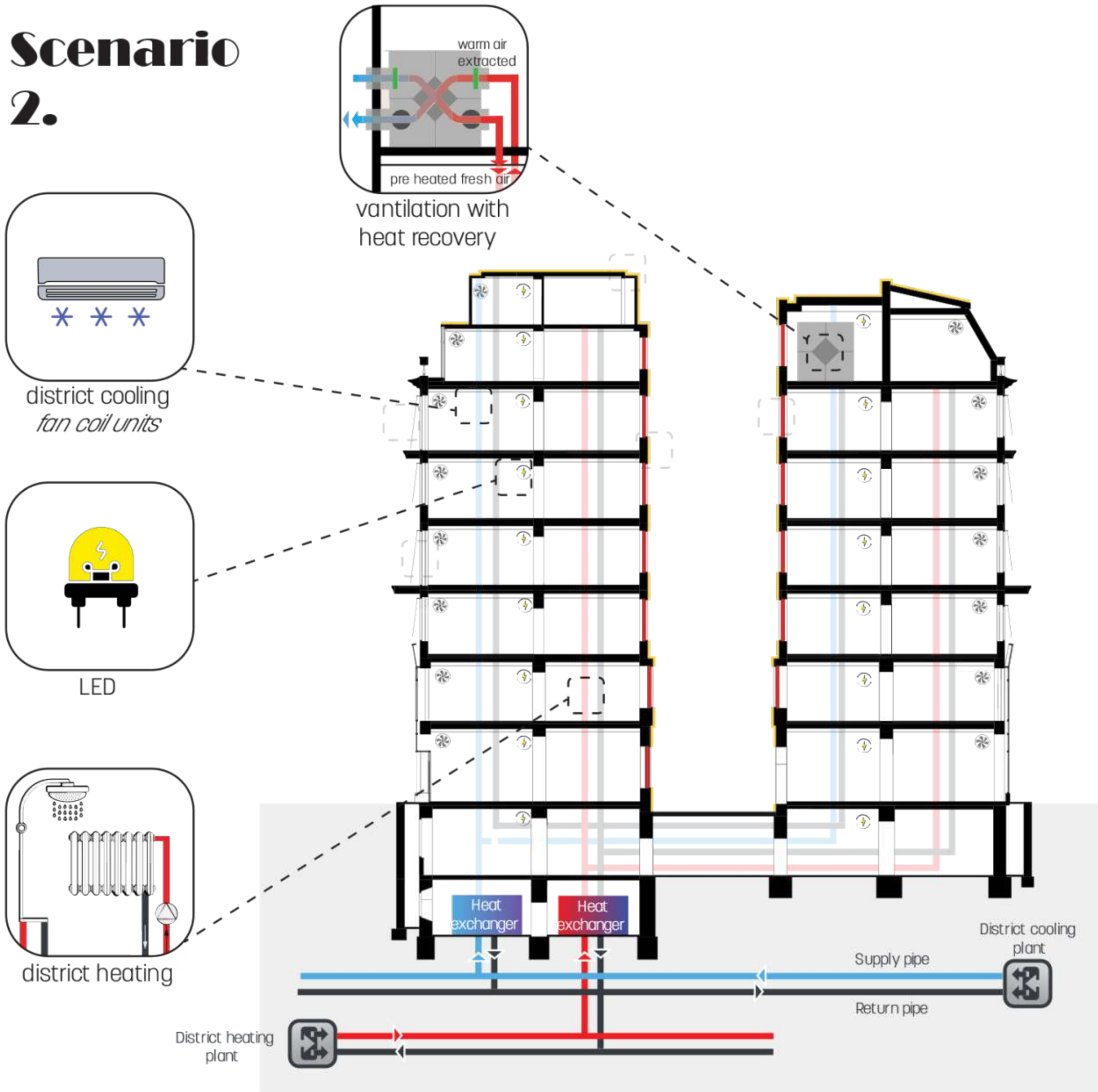

Fig.11 Scenario 2: Scenario 1 + district heating & cooling, ventilation with heat recovery, LED lighting

Scenario 3 builds on Scenario 2 by incorporating renewable energy measures. In this scenario, district heating and cooling are replaced with geothermal heating and cooling. Geothermal heating systems operate most efficiently when distributing low-temperature heat over a large area. Since floor heating systems typically function at lower temperatures (e.g. 30°C), they are well-suited for use with geothermal systems (AGORIA n.d.). Scenario 3 combines these two systems.

For geothermal cooling, a chilled beam system is employed. This system is designed to heat and cool large buildings using water. It consists of a heat exchanger enclosed in a unit that is either suspended from or recessed into the ceiling. As the beam cools the air around it, the air becomes denser and falls to the floor. It is replaced by warmer air moving up from below, causing a constant passive air movement called convection, to cool the room (MEPAcademy 2022).

Solar PV panels are installed to generate renewable electricity for the building, reducing reliance on grid-supplied power and decreasing carbon emissions. These panels are particularly effective when combined with LED lighting, as the low energy consumption of LED systems aligns well with the energy output of solar panels, maximising the efficiency of the renewable energy integration.

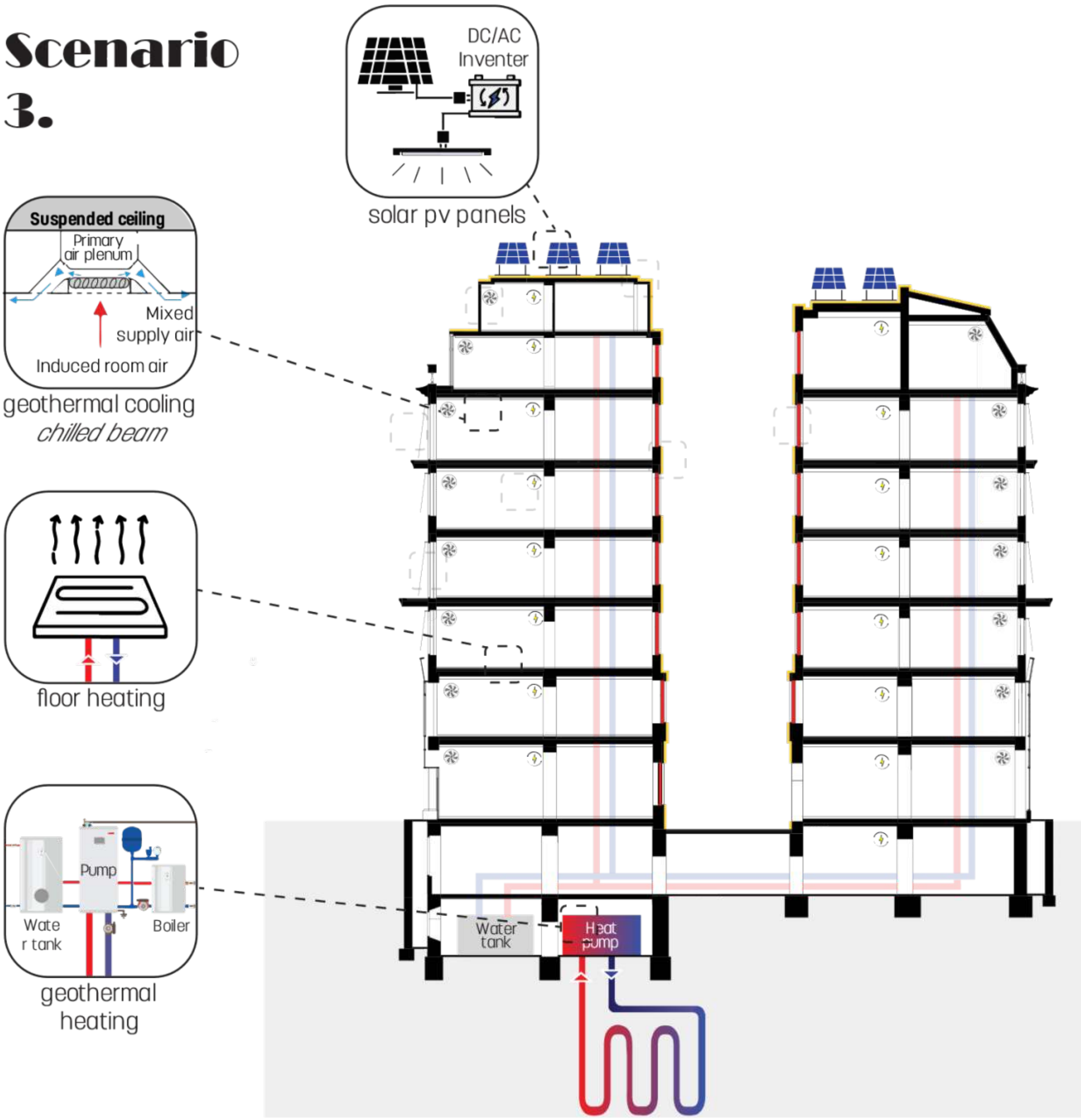

Fig.12 Scenario 3: Scenario 1 + ventilation with heat recovery, LED lightening, grey water recovery, geothermal heating and cooling, and solar PV panels.

6.4 Current energy performance results and energy certification

The energy performance certificate of the case study building (see Annex 1) was assessed under the latest standards issued in May 2023, providing detailed insights into the building's energy utilisation and environmental impact. The building's characteristics and assumed climate region values can be seen below in Table 10.

Table 10
Building characteristics & climate region values

Gross floor area	6,317.6 m²	Heating days	303 d
Reference area	5,054.1 m²	Heating degree days	3,646 Kd
Groos volume	24,603.6 m³	Climate region	N
Building envelope	5,654.7 m²	Standard outdoor temperature	-11.3
Surface-area-to-volume ratio	0.23 1/m	Setpoint indoor temperature	22.0
Characteristic length	4.35 m	Average U-value	1,650 W/m²K

According to the energy certificate, the building's energy performance falls into energy efficiency class D. This rating suggests moderate energy efficiency, highlighting substantial opportunities for improvement through targeted retrofitting measures. The document reports a HWBRef of 127.7 kWh/m²a, which measures the theoretical heating energy required per square meter per year to maintain a specified indoor temperature, assuming no energy returns from heat recovery. The HWB for the site climate indicates 130.6 kWh/m²a, which is close to the predicted reference value. Final energy demand accounts for all energy utilised, including losses throughout the energy supply chain and indicates 258.3 kWh/m²a. This measure includes the combined energy required for heating, cooling, lighting, operating electricity and other utilities necessary for the building's operation. C02 Emissions showed 48.6 kg /m²a, which indicates the amount of carbon dioxide emitted per square meter per year due to the building's energy consumption. The overall energy efficiency factor is derived by comparing the net energy consumption (including auxiliary energy needs and subtracting any energy returns) to a benchmark energy demand. A higher fGEE indicates a less efficient building, suggesting more energy is used compared to the baseline expectation. Key values of the building's energy performance summarised in Table 11.

Table 11
Studied building energy certificate - key values

Energy efficiency rating:	D
Heating energy demand (HWB SK)	130.6 kWh/m²a
Final Energy Demand (EEB)	258.3 kWh/m²a
C02 Emissions ($C02_{eq,SK}$)	48.6 kg /m²a
Overall energy efficiency factor (fGEE,SK):	1.97

The building spans an area of 6,317.62 m². The whole area is divided into 3 zones: retail stores, office space and apartment. Fig 13. outlines how energy demand is distributed within the zones in the studied building.

Since apartments make up less than 10 % of the gross floor area, retail stores less than 15% and offices nearly 75 %, the order of distribution of the energy demand by zone is not surprising. However, relative to the differences in gross floor areas, office spaces showed the best performance with an energy demand of 67.16 kWh/m^{2}a, followed by apartments with 333.40 kWh/m^{2}a. Retail stores showed the worst performance with 449.1 kWh/m^2.

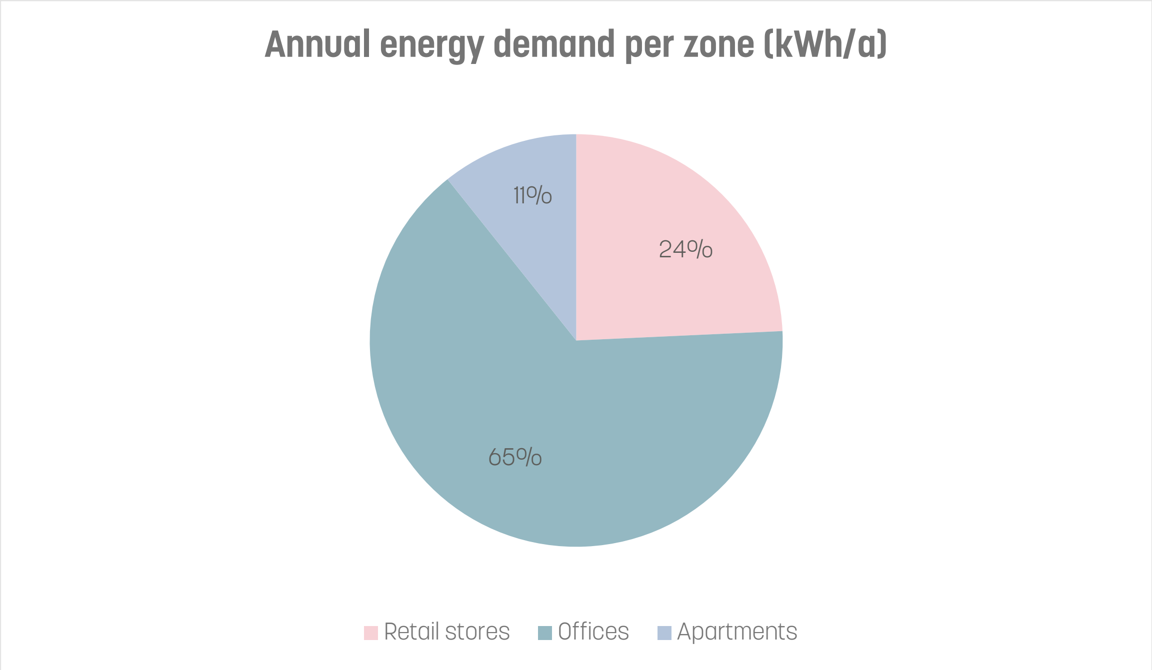

Fig.13 Energy demand per zone kWh/a

The retail stores show the lowest energy performance due to their outdated windows, which are mostly single-glazed and in poor condition. In contrast, the offices have moderate-quality glazing and benefit from thick brick walls. The additional and primary reason, why the offices have the best values is because part of the neighbouring building has also been taken into account. While only the external walls facing the outside are considered, the separating ceilings between the offices and the heated residential units in the adjacent building are not accounted for. This results in a larger heated volume relative to the external surface area, leading to the great performance.

The results of the current energy performance of the studied building suggest that while the building's operational systems are functioning within a typical range for urban commercial/residential mixed-use buildings, there is potential for energy efficiency improvements.

Table 12
Energy demand per zone

	Gross floor area m²	Energy demand kWh/a	ED per m² kWh/m²a
Retail stores (ground floor)			
Heating		301,401	362.5
Warm water		12,173	14.6
Mechanical ventilation	831.37		
Lighting		46,955	56.5
Cooling (through ventilation)		8,844	10.6
Operational electricity		4,107	4.9
Total	**831.37**	**373,480**	**449.1**
Office spaces (mezzanine to the top floor)			
Heating		65,991	13.2
Warm water		2,860	0.6
Mechanical ventilation	5,018.27		
Lighting		129,270	25.8
Cooling (through ventilation)		53,384	10.6
Operational electricity		85,106	17.0
Total	**5,018.27**	**336,611**	**67.16**
Apartments (4th floor and top floors)			
Heating		36,873	286.1
Warm water	467.98	2,414	22.1
Household electricity		10,658	22.8
Total	**467.98**	**49,945**	**333.4**
Total energy demand in 3 zones	**6,317.62**	**760,036**	**120.3**

7 Analysis

7.1 Comparison of scenarios

To assess the impact of each scenario on the overall energy performance of the case study building, annual final energy demand and CO2 emissions were analysed. Fig 14. illustrates the results, showing the distribution of energy demand across heating, cooling, lighting, and auxiliary systems. All energy values given in kWh/m²a refer specifically to the conditioned gross floor area (GFA).

In Scenario 1, significant changes in heating demand are achieved solely by improving the building's thermal envelope. Adding insulation and upgrading windows and glazing substantially reduce heat loss, resulting in a 45.6 % decrease in heating energy demand compared to the base case. In Scenario 2, cooling performance is 1.7 kWh/m²a worse than in the base case, despite no changes to the cooling systems. This is because the increased thermal mass of the walls causes the building's internal climate to retain more heat, leading to a bigger need for cooling in warmer seasons. Overall, the total energy demand decreased from 258.30 to 178.30 kWh/m^{2}a, which makes a reduction of 31 %.

Scenario 2 integrates district heating into the improved thermal envelope, replacing gas-boilers. This further reduces heating demand by an additional 31.7% compared to the base case. By replacing conventional lighting with LED, the energy demand for lighting falls to one-third of the initial consumption. However, cooling demand rises again by 4.8 kWh/m²a due to the energy required to operate district cooling (fan coil units). Overall, the total energy demand decreases significantly by 46 % to 139.6 kWh/m²a compared to the base case.

Scenario 3 delivers the best overall results, with total energy consumption reduced to 93.0 kWh/m²a, or 64 %. This improvement is primarily due to the use of the geothermal system, which decreases heating demand by 79.6 % compared to the base case. Similarly to Scenario 2, cooling systems slightly increase energy demand by 2.5 kWh/m²a and LED lights decrease it by 18.7 kWh/m²a.

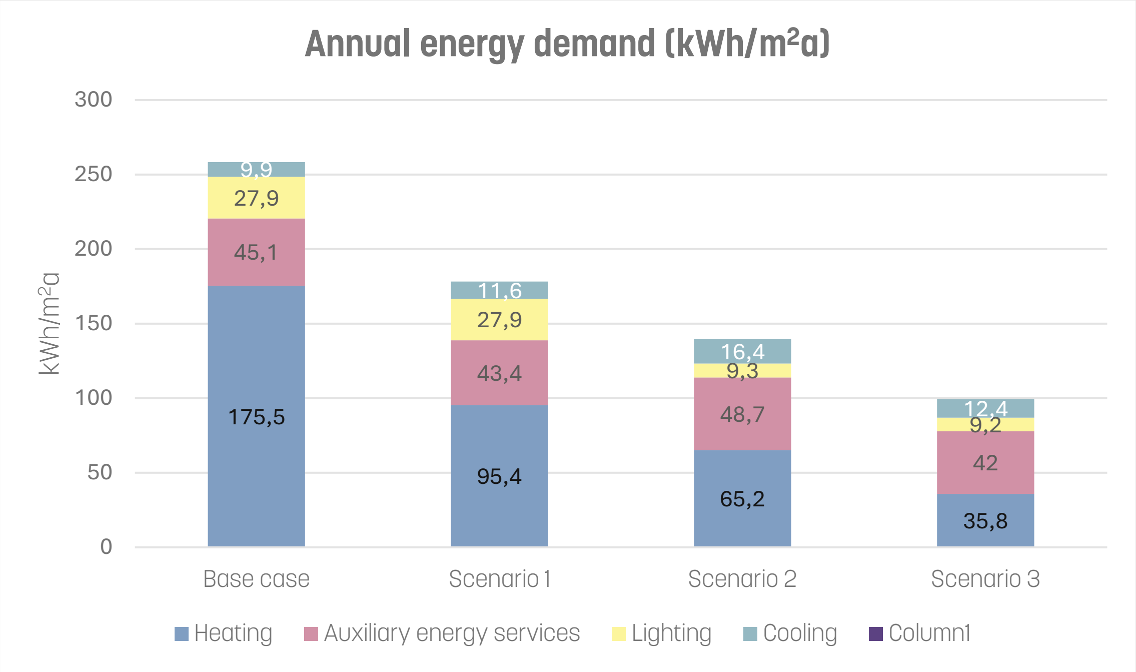

Fig.14 Annual energy demand kWh/m²a - local climate

Due to the energy production nature of the PV solar panels, the effect on energy performance can only be depicted in the overall reduction of CO2 Emissions. Overall energy demand of buildings is often measured as total consumption and does not differentiate between where this or that consumed energy was sourced (e.g., electricity, gas, solar).

Table 13
PV solar panels parameters per zone

Zone	P PK (kW)	Reduction (kWh/a)	Reduction (kWh/m²a)
Retail	5.0	4,156	5.0
Offices	35.0	32,450	6.5
Residential	5.0	4,107	8.8
Total		**40,713**	**6.44**

Synthetically, ArchiPHYSIK can capture the hypothetical substitution of energy source when PV solar panels are installed and used. According to this, the PV solar panels cover

40,713 kWh/a, or 6.44 kWh/m²a of the 99.4 kWh/m²a overall energy demand of Scenario 3. Additionally, only a certain percentage of the energy required for heating, hot water, lighting and other energy needs can be counted towards overall energy demand PV solar reductions, due to the OIB RL 6 standard[3] (OIB 2023). The next chart shown in Fig 15. analyses CO2 emissions across the base model and three scenarios. Scenarios 2 and 3 show highly effective, each achieving around a 70% reduction in overall CO2 emissions compared to the base case. Scenario 1, while less impactful than Scenarios 2 and 3, still offers a substantial reduction by 33%.

In Scenario 1, CO2 are primarily achieved through improved heating demand, resulting in a 45.6 % decrease in emissions compared to the base case model. Total CO2 emissions drop from 48.6 to 32.50 kg/m²a, an overall reduction of 33.1 %.

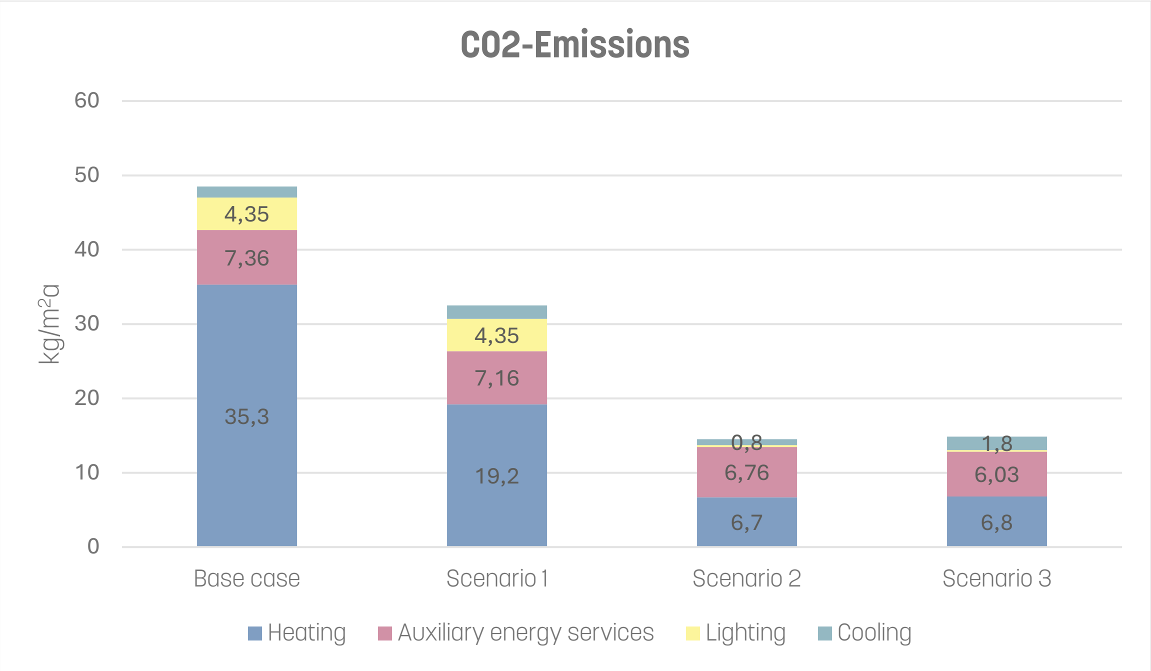

Fig.15 CO2-Emissions kg/m²a - local climate

Scenario 2, utilizing district heating, achieves significant CO2 reductions in heating, lowering emissions from 35.30 to 6.70 kg/m²a. LED lighting nearly eliminates lighting-related emissions, reducing them by 94%. The cooling system performs best across all scenarios, resulting in CO2 emissions of just 0.80 kg/m²a. Overall, total CO2 emissions in Scenario 2 are reduced by 70.2%, reaching 14.50 kg/m²a - indicating an excellent outcome.

Scenario 3 performs slightly less effectively than Scenario 2, reducing total CO2 emissions to 14.90 kg/m²a, a reduction of 69.3%. Cooling systems increase emissions to 1.80 kg/m²a, while LED lighting decreases it to 0.23 kg/m²a. The primary reason geothermal systems

[3] OIB RL 6, point 4.14 stipulates that self-generated green electricity may only be partially included in the energy balance for the preparation of the energy performance certificate. The caps range between 25% for lightning to 100% for auxiliary energy demand for the PV panels.

underperform compared to district heating & cooling in reducing CO2 emissions lies in the energy source. Geothermal heating & cooling relies on heat pumps powered by electricity, which, according to the standard, produces 156 grams of CO2 per kWh. In contrast, district heating in Vienna, supplied directly as hot water from the Vienna heating plant, is rated at just 22 grams of CO2 per kWh–a sevenfold difference. This difference in heating and cooling is offset by integrating in Scenario 3 photovoltaic (PV) solar panels and floor heating, bringing overall CO2 emissions in line with those of Scenario 2.

7.2 *Potential impact on Vienna's total building stock*

EU member states are required to reduce the average primary energy demand of all residential buildings by 16% and 22% (compared to 2020) by 2030 and 2035 respectively (EU 2024). Primary energy demand (PED) refers to the total energy from a raw energy source that is converted into consumable energy (Janet Chikofsky 2023). Fig 16. illustrates the PED across the base model and three scenarios.

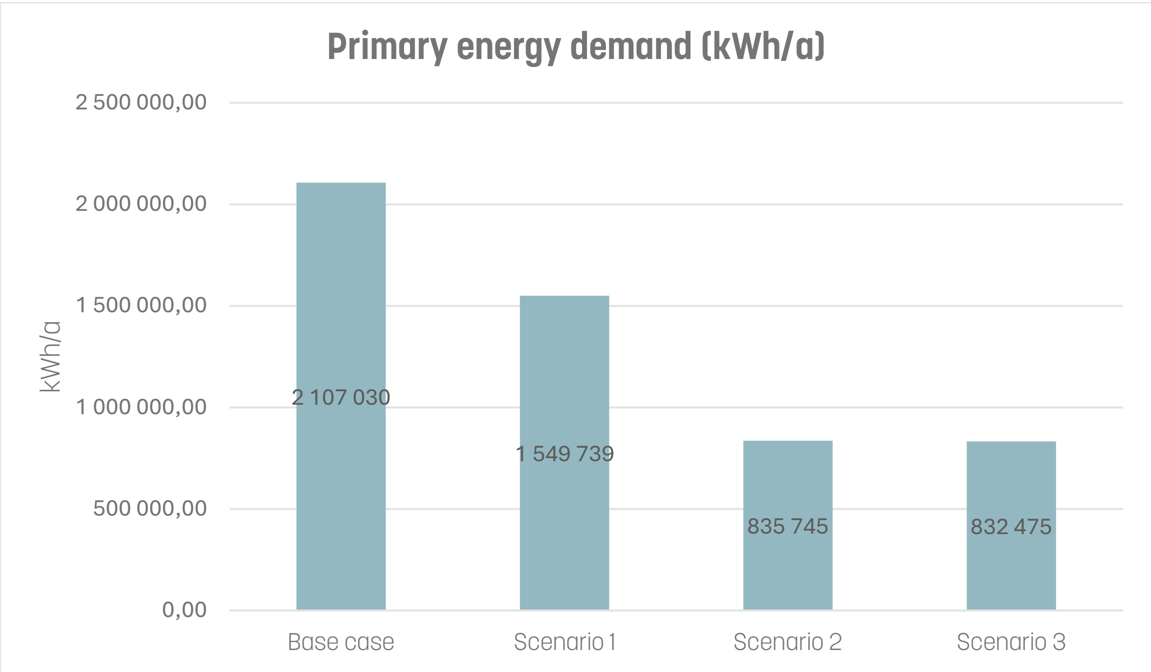

Fig.16 PED in kWh/a - local climate

As illustrated above, Scenario 1 reduces PED by 31% compared to the base case. Scenario 2 achieves a 46% reduction, while Scenario 3 delivers the highest reduction of 74%.

The extent to which scaling these renovation scenarios to other comparable buildings contributes to the required overall reduction in primary energy demand of residential buildings depends on the overall primary energy demand of Austria. According to Eurostat the *disaggregated final energy consumption in Austrian residential buildings in 2022* was 278,575.258 TJ/year (EU Commission Database 2022).

Table 14

Reduction of total annual energy demand by scenario

Scenario	Annual energy demand base case kWh/m²a	Total annual energy demand base case kWh/a	Reduction base case TJ/year
Base case	258.4	1,632,467.84	0
Scenario 1	178.3	1,126,428.08	1.82174
Scenario 2	139.6	881,936.96	2.70191
Scenario 3	99.4	629,864.72	3.60937

As illustrated in Table 14, the reduction in total annual energy demand is 1.82, 2.70 and 3.61 TJ/year for scenarios 1, 2 and 3, respectively. According to Article 9(2) of the EPBD, member states shall ensure that the average primary energy use in kWh/(m^2/y) of the entire residential building stock:

(a) decreases by at least 16 % compared to 2020 by 2030;
(b) decreases by at least 20-22 % compared to 2020 by 2035.

By applying these reduction targets to Austria's disaggregated final energy consumption in residential buildings in 2022 (278,575.258 TJ/year), the required reductions amount to 44,572.043 TJ/year (16%) by 2030 and 61,286.557 TJ/year (22%) by 2035. Since there is no detailed information on energy demand of buildings in Vienna by building type, size and construction period, estimating the impact of scaling these strategies is difficult. What we can say for sure, is how many buildings, identical or very similar to the case study building, would need to be renovated by 2030 and 2035 in order to reach the EPBD targets (see Table 15 below).

Table 15

Number of buildings similar to the case study that would need to be renovated

Decreases by	Scenario 1	Scenario 2	Scenario 3
16 % by 2030	24,467 buildings	16,496 buildings	12,349 buildings
22 % by 2035	33,642 buildings	22,683 buildings	16,980 buildings

24,467, 16,496, and 12,349 comparable buildings would need to be renovated by 2030 to achieve the target for Austria as a whole for Scenario 1, 2, and 3 respectively. An additional 9,175, 6,187, and 4,631 comparable buildings until 2035. Typically, older buildings - in this case, buildings constructed before 1945 - have lower energy performance levels. Given that member states need to ensure that at least 55 % of the decrease in the average primary energy use is achieved through the renovation of the 43 % worst-performing residential buildings (EU 2024), a replication of these scenarios on comparable buildings would also fulfil this condition.

8 Conclusions

This study presents a comprehensive assessment for retrofitting a protected building to evaluate the energy efficiency of selected retrofitting measures. The case study focuses on a historic bourgeois apartment- and office building, constructed in 1904 in Vienna's 1st district - a designated conservation area and UNESCO World Heritage site. Through expert interviews, the study examines regulatory constraints and current renovation practices for protected and traditional buildings in Vienna. An innovative measures matrix is developed, offering a structured overview of potential retrofit solutions for historically significant buildings. Using a BIM model, energy certificates are calculated for the base case and three retrofit scenarios with selected measures. A comparison of the scenarios quantifies possible energy savings for the case study building. These allow for an estimation of potential energy savings across the entirety of Vienna's total building stock.

The research starts by establishing a comprehensive theoretical framework, which includes an analysis of Vienna's building stock, an exploration on renovation challenges associated with protected zones and UNESCO World Heritage sites, and a review of reference projects on energy retrofits for historical buildings. Interviews with various experts, including the architect renovating the case study building, a building technology specialist, local government officials, and academic researchers, provided insights on the regulatory boundaries for building interventions as well as the benefits and challenges behind different retrofitting measures.

To select appropriate retrofitting measures for the case study building, it is essential to define the scope of intervention and to determine which renovations are permissible and which are restricted. In protected zones, renovation restrictions mainly target the building's exterior– for example sures like insulating the front façade or adding shades are generally not permitted, as these would alter the building's integrity. UNESCO heritage status imposes additional constraints, for instance on roof modifications, as roofs contribute to the city's skyline and are deemed to be preserved. Interior interventions, however, are generally not subject to strict regulations for the buildings located in protected zones unless specific historical elements in buildings interior are protected. In the case study, no such interior restrictions are present, offering more flexibility for energy-efficient upgrades.

Drawing on the analysis on the effectiveness and suitability of retrofitting measures, three retrofitting scenarios are proposed for the case study building. The first scenario focuses solely on passive measures (external insulation on the back yard, roof and cellar floor insulation, window and glazing upgrades, and shades). The second scenario combines passive with active measures (ERV, DHS and LED), and the third incorporates both approaches alongside renewable energy solutions (PV panels and geothermal heating and cooling).

Using ArchiPHYSIK software, the current energy performance is calculated. The combinations of retrofitting measures in the three respective scenarios are then compared to evaluate the effect on energy performance in terms of final energy demand, C02 emissions and primary energy demand.

The analysis demonstrates significant energy reduction in Scenario 1, with an estimated 31% of annual energy savings achieved by upgrading windows and insulating the cellar floor, roof, and yard walls. Notably, this reduction is achieved without insulating the front façade, which would enhance the efficiency even more. The estimated annual reduction of C02 emissions from these measures is 33.1 %. In Scenario 2, additional upgrades to DHC, HRV system and LED lighting improve the building's overall energy efficiency by 46% and reduce C02 emissions by 70% compared to the base scenario. In Scenario 3, the implementation of geothermal heating & cooling and solar PV panels delivers the highest energy savings by reducing total energy demand by 64% and the second-best result in reducing C02 emissions – by 69% compared the base case.

This study contributes to existing research by estimating the potential impact of scaling retrofit measures across total Vienna's building stock. To meet the targets set by the EPBD, upgrading only the building envelope, as in Scenario 1, would require renovating approximately 24,500 thousand comparable buildings by 2030 and 33.6 thousand by 2035. With the additional integration of active measures in Scenario 2, these numbers decrease to 16,500 thousand by 2030 and 22,700 thousand by 2035. Scenario 3 offers the most efficient solution, requiring the renovation of just 12,400 thousand comparable buildings by 2030 and 17,000 thousand by 2035.

Given the historic value of protected buildings, the EPBD allows EU member states to exclude these from the scope of the renovation targets. One might assume that most member states will take advantage of this exemption. However, this study highlights the potential opportunities of retrofitting historically significant buildings, which are exempt from mandatory renovation laws, despite the possibility of achieving both energy efficiency and conservation goals.

Historic buildings come with their own unique set of conservation constraints, meaning retrofitting solutions have to be carefully considered on a case-by-case basis. Not all protected buildings are the same, nor do they have the same level of preservation requirements. So, it is crucial to distinguish between different types of protection. Consequently, buildings from before 1945 are often among the lowest energy performers. This thesis emphasizes great potential in retrofitting protected buildings and suggests options compatible with conservation requirements in order to meet the agreed targets for energy efficiency.

8.1 Limitations

While this study adds valuable findings in the field of energy performance retrofits, certain limitations must also be considered.

Firstly, data availability limitations arise as the research focuses on final energy demand in Austrian residential buildings and its potential savings through building renovations. The EPBD's main target is the reduction of primary energy demand, which represents the aggregate form of consumed energy, including losses from production, conversion, and distribution. However, data on Austria's primary energy demand was not found for this study, so final energy demand was used for comparison instead. This means that while the study effectively demonstrates an energy-saving potential in retrofitting protected buildings, a full assessment of their impact on Austria's primary energy consumption remains incomplete.

Another limitation is the building's generalisability. While this study focuses on a *residential* building based on Vienna's land-use and zoning plan, since the 1970s, it has been primarily used as an office space. Consequently, the energy-saving potential from retrofitting may vary when projected to the building stock, and the results of this study may not fully reflect the performance of buildings that maintain a purely residential function. This comes from the fact that hot water demand would likely be higher in purely residential buildings when compared to residential buildings used for office purposes, and heating remains one of the largest energy consumers.

In addition to these concerns, economic feasibility presents another limitation. Even when a protected building faces less stringent conservation constraints, the cost of retrofitting can be prohibitive. Older structures might require extensive, specialized interventions–such as reinforcing outdated construction substance or installing modern energy systems. These additional technical challenges can drive up costs to a point where the retrofitting is not economically viable, undermining the potential benefits of improved energy performance.

While initial retrofitting costs can be high, improvements in energy efficiency, durability, and reduced operational expenses can lead to long-term savings, even more so given increasing CO2 prices. However, some materials and technologies used in retrofitting may have shorter life spans or require specialised maintenance, affecting long-term sustainability. That is why it is also important to consider the life-cycle.

Last but not least, there are certain measures, such as grey water recovery systems or soil de-sealing, which cannot be accurately measured in terms of energy performance impact using the ArchiPHYSIK software. These interventions, while potentially beneficial for sustainability and overall environmental performance, fall outside the scope of the software's capabilities, meaning their full impact on energy consumption and resource use cannot be fully assessed within this study.

8.2 Future research

The above limitations highlight potential areas for future research. To more accurately predict the impact of scaling the proposed retrofitting strategies, future studies could focus on case studies of protected residential buildings used exclusively for residential purposes. With more comprehensive data on all existing types of protected residential buildings, including their size and actual use, extrapolations to the entire building stock in Vienna would be more robust.

Along with exploring the building stock, economic feasibility studies on individual measures and their combinations would provide a clearer understanding of the viability of large-scale urban renovation efforts. Future research should incorporate life cycle assessments to evaluate the long-term environmental and economic impacts of different retrofitting strategies. A "life cycle" perspective would help to ensure that material choices, construction processes, and operational energy savings are considered holistically, leading to more sustainable renovation approaches.

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10 Annex

Coding the interview responses under each theme

Theme 1: Regulatory: Energy efficiency and sustainability in historical buildings	
Q1: AUSTRIAN GOVERNMENT AND EPBD	
A. Markus Wimmer BHÖ	- ***Transposition of Directive:*** *"Typically, when an EU directive is issued, it will be eventually incorporated into national law. This is the purpose of the EU: to develop directives collaboratively across Europe. Each member state's parliament is then tasked with transposing these directives into national legislation. Sometimes, this process includes "gold-plating" where stricter regulations than those outlined in the original EU directive are adopted. This is the usual legislative process for EU directives being implemented within Austria. "* - ***Strategic priority:*** *"Preserving buildings instead of demolishing and rebuilding is becoming a stronger priority in Austria, especially in city centers. Some countries manage land use and preservation better than Austria, but the approach is shifting toward greater emphasis on maintaining existing structures."* - ***Historic buildings & CO2:*** *"Historic buildings have the advantage of not contributing to new CO2 emissions, unlike new constructions."*
B. Gerald Wagenhofer EHA	- ***Flexible renovation for traditional buildings:*** *"The EPBD now includes an exception for the renovation of traditional buildings, which we find very positive. It gives more room for government to decide rather how or if to proceed with the renovation of traditionally built buildings (buildings built before 1945)."* - ***Classification in Austria:*** *"Austria does not distinguish between protected monuments and traditionally built structures. Approximately 20% of the Austrias building stock consists of traditionally built structures, of which less than 1% are under monument protection. If we only treat this 1% as special, like many in the cultural sector do, we're making a big mistake. The remaining 19% would be treated incorrectly, similar to how women are sometimes assessed for heart attacks based on criteria designed for men. The same logic applies to how we handle buildings.".*
C. Georg Kolmayr MA19	- ***Trade of preservation and ecology:*** *"A key conflict exists between promoting ecological initiatives and preserving the cityscape. Both energy efficiency and cityscape preservation have become more important over recent years. And since these are fields where technological development usually happens quickly and there are, so to speak, very rapid possibilities for adaptation, I think it's fair to say that solutions can be found in most cases."*

D. Michael Haugeneder ATP sustain	- ***Types of EU regulations:*** *"Regarding the different types of EU regulations, two key requirements must be considered:* *EU Directives:* - *Must be adapted and integrated into national legislation.* - *Example: EPBD 2024 (Energy Performance of Buildings Directive) needs to be implemented into building regulations within a 2-year period.* *EU Regulations:* - *Apply directly in all member states from the date of publication or within a specified timeframe.* - *Example: EU Taxonomy.* - *No need for country-specific legislation.* *Important Note: Many regulations reference directives in their text, requiring interpretation for each country.*
E. Martin Mittermair Mittermair Achitects	- ***Human behaviour & energy efficiency:*** *"A key issue often overlooked in discussions is the role of human behaviour. People have rigid usage habits, expecting buildings to maintain constant temperatures year-round, regardless of season. For instance, in offices, employees wearing suits expect temperatures of 18-20°C in both summer and winter. In summer, this requires cooling, while in winter, it demands heating. If people adjusted by wearing lighter clothing in summer and warmer clothes in winter, buildings would need far less energy to maintain comfort."* - ***Human behaviour over building standards:*** *"Buildings are required to meet stringent safety, fire, noise, and thermal standards, while it would be more sustainable for people to adapt their behaviour. For example, carpets and/or soft-soled shoes would reduce noise, and safer electrical devices could prevent fire risks. Yet, the focus remains on buildings meeting constant demands, rather than encouraging people to make simple changes that could significantly reduce energy consumption and improve sustainability."*
Q2: INVOLVED PARTIES	
A. Markus Wimmer BHÖ	- ***MA19 involvement:*** *"The first district of Vienna falls under a "Schutzzone" (protection zone), not to be confused with ensemble or monument protection. The MA19 (Department for Architecture and Urban Design) is responsible for ensuring that changes to buildings in this zone harmonise with the city's appearance."* - ***Monument protection & involved authorities:*** *"Certain buildings, like the Vienna Hofburg, are protected as ensembles or historic monuments. If any restoration or renovation is planned for such building, in addition to a construction permit from Federal Monuments Office, other authorities such as MA37 (Building Authority), MA19, the district, and possibly MA46 (if the project affects outdoor spaces) must provide approvals through a coordinated process. "*

	- ***Multistep regulatory approvals:*** *"According to The Vienna State Building Code (Landesbauordnung) different projects may apply various procedures."* - *"Operating a restaurant or business may require multiple submissions, like e.g. compliance with commercial regulations for ventilation systems etc."* - *"Employee rights laws are also relevant in order to employ people, thus a labour inspectors may need to be involved."* - *"If the venue serves as an event space, authorities will assess escape routes and fire safety measures."*
B. Gerald Wagenhofer EHA	- ***Owner rights as stakeholder:*** *"The City of Vienna aims to transition from gas to district heating in the city's first district. However, building owners retain full rights to decide whether to accept the city's offer to switch energy systems. Even with assurances from the City of Vienna that the contracts and long-term plans are solid, the final decision rests with the owners. They must ask themselves: Do I trust this? Can I rely on it? This decision is ultimately crucial."*
C. Georg Kolmayr MA19	- ***Monument protection & involved authorities:*** *"The common institutions involved in the renovation projects are the Federal Monuments Office, MA 19, and MA 37 as well as Advisory Board for urban planning, design, and world heritage preservation (Fachbeirat)".* - ***Federal Monuments Office vs. MA19 involvement:*** *"While MA19 focuses on the impact on the cityscape and ensemble effect, the Federal Monument Office focuses more on the preservation of individual objects, protecting the substance and interior of it".* - ***Advisory Board involvement:*** *"For significant construction projects, or those potentially impacting world heritage, renovation proposals must be presented to the advisory board, as established in the building regulations (Bauordnung), for discussion. The board consists of twelve members, including architects, heritage conservation experts, landscape planners, and cultural engineers, among others."* - ***Protection zone: "****The regulations are essentially the same in all protected zones, including the first district of Vienna and surrounding areas."* - ***Protection zone in the 1st district difference: "****A key difference in the first district is the additional consideration of the UNESCO World Heritage status."* - *"The World Heritage status has been incorporated into the latest amendments to the building code."* - *"Authorities must take into account the aspects and attributes of the World Heritage site when reviewing projects in protected zones."*

	- ***Stricter rooftop regulations:*** *"Special attention is given to elements like roofs, requiring a more detailed review to ensure compliance with heritage preservation."* - *"Historically, a key argument has been whether modifications are visible from St. Stephen's Cathedral (Stephansdom) and what impact they have on the surrounding roofscape."* - *"A related aspect, which has been updated in the latest building code amendment, is the inclusion of new regulations for building services in Paragraphs 85. These regulations are especially relevant in the first district and protected zones, where there's a trend of installing air conditioning units, external devices, and cooling systems on rooftops. The updated rules aim to address this tendency by regulating the placement and visibility of such equipment, ensuring it doesn't negatively affect the appearance of the area."*
E. Martin **Mittermair** Mittermair Achitects	- ***Current designation of the case study building:*** *"Legally, today the building is properly designated as an office building, and as residential housing for four apartments at the rooftop. If there is no change in use to be made, there is an official consensus."* - ***Regulations apply to usage changes:*** *"The construction law (Baurecht) cannot force anyone to upgrade the property, if there is no change in use planned while renovating, but it can force to renovate e.g. broken windows."* - *"Any thermal renovation (e.g., insulation) done by the property owner is voluntary, though sensible."* - *"It's difficult, sometimes nearly impossible throughout renovation to fully meet modern building regulations with an older property."* - *"If the usage is changed (e.g., from office to residential), current building and energy efficiency regulations must be met."* - ***UNESCO advisory board involvement:*** *"Since the project is located in the first district, which is part of a UNESCO World Heritage, the UNESCO advisory board was also involved in the review."* - ***Advisory board (Fachbeirat) involvement:*** *"The project was also presented to the design advisory board (Fachbeirat) due to its significance. "* - ***Stricter rooftop regulations:*** *"To ensure the modifications do not alter the skyline, photos were taken from the top of St. Stephen's Cathedral to assess the impact on the roof landscape."* - *"The project received positive feedback and approval."*
Theme 2: Material compatibility and renovation techniques	
Q5: RENOVATION TECHNIQUES	
A. Markus Wimmer BHÖ	- ***Energy improvements possible in historic preservation:*** *"Improvements can be made by updating heating, cooling, and*

	ventilation systems, replacing gas or oil heating with renewable energy, and applying energy-saving measures like window sealing even within the scope of historic preservation." - ***Renovation strategy:*** *"We are collaborating currently with students from TU Wien and Stanford University to create a closed-loop system using smart technology that monitors room temperatures and occupancy. The shift to home office during the pandemic has resulted in lower occupancy rates in offices, particularly on Mondays and Fridays. By reducing heating, cooling, and ventilation during these low-occupancy periods, we can achieve significant energy savings. On high-occupancy days, like Tuesday through Thursday, we can adjust systems as needed to maintain comfort."* - *"This strategy also takes into account meteorological data and occupancy information processed through advanced computing systems to optimise energy use further, particularly during unpredictable weather changes."*
B. Gerald Wagenhofer EHA	- ***Austrian approach:*** *"There is no standard solution. In Austria, the philosophy is clear - we focus on an individualised approach."* - ***Calculation failures:*** *"Once, we developed a guide for implementing BIM in existing buildings and conducted the <u>energy manager project</u>, analysing best practices and existing measurements. Findings revealed that historical buildings are often underestimated in calculations by 40%, 50%, or even 70%, while modern buildings perform better in calculations than their actual performance is."* - ***Assessment for historic restoration:*** *"When dealing with historic buildings, the first step is to assess the significance and value of the building. Then, the existing structure and condition are analysed to define a restoration goal - a strategy that clearly outlines the possibilities for restoration".*
C. Georg Kolmayr MA19	- ***Austrian approach:*** *"I think that something we're used to in Vienna is that each building must be considered individually. We always look at the buildings, in their surroundings and the case is always different."* - **Generalising approach:** *"To generalise the approach - is a complex and extensive process that requires collection and implementation of various aspects. I really believe that it is necessary to address this at a regulatory level and I believe that something is already happening."* - **Common energy efficiency:** *"Common energy measures include insulating courtyard-facing facades, basement ceilings, top-floor ceilings, and upgrading windows."*

D. Michael Haugeneder ATP sustain	- ***Key considerations for building laws and environment:*** *"Based on the hierarchical structure of legislation, buildings fall within the scope of rulings and decisions. This level classifies the approval of measures as an individual sovereign act. As a result, specific decisions must be made for each aspect according to the applicable regional or building laws."* - *„Personally, I believe that, in the future, prioritising the preservation of heritage over environmental protection will be unconstitutional, as we must take measures to protect both people and nature. Currently, this is not yet enshrined, but with the EU Green Deal and the 2030 interim target, this issue will need to be addressed."* - ***Assessment for historic restoration*** *"The first step is to reduce energy consumption, but only up to a certain limit, where it makes sense from a building physics perspective, especially in terms of moisture protection ".* - ***Renovation strategy:*** *"The approach for reducing energy demand for protected or listed buildings after defining the possibilities of intervention in the building consists of following steps/measures:* *1. applying passive measures* *2. applying active measures* *3. integrating renewable energies onsite* *4. integrating renewable energies offsite (to offset remaining CO2 emissions)"* - *"While the first two measures (passive and active) focus on saving both energy and CO2, the latter two measures (renewable and offsite) are solely aimed at reducing CO2 emissions."*
E. Martin Mittermair Mittermair Architects	***Actual renovation plan for the case study building:*** *"The entire building is being outfitted with new building services and, where possible, thermally renovated. The building is located in a protected zone, meaning no changes can be made to the external facade. Therefor exterior insulation will be added to the courtyard walls and to the roof, where's no public interest in preserving its original appearance."*
Q6: MODERN VS. ORIGINAL MATERIALS	
A. Markus Wimmer BHÖ	- ***Revival of natural building materials:*** *"There is a notable interest in using natural materials like clay, which is becoming trendy as a historical building material."* - *"More initiatives are emerging around clay, and architects are exploring new applications, reflecting a broader trend toward sustainable construction practices."* - *"There is a hope for a similar resurgence in the use of lime as a building material, emphasising the potential for its revitalisation."*

B. Gerald Wagenhofer EHA	- ***Façade reproduction and materials:*** *"Ensemble protection, primarily focuses on preserving the outward appearance of a street or group of buildings. Reproductions with the use of modern materials are considerable as long as the material characteristics are compatible."* - *"The Federal Monuments Office recommends sticking to original materials where possible to maintain the building's longevity and authenticity".* - ***Material properties matching:*** *"Modern materials can be combined with original materials, but it is essential to match the material properties closely, particularly in terms of breathability and moisture regulation".* - *"For instance, traditional lime-based materials, like the one in the case study, is breathable and can absorb and release water; if another material does not have these properties, joint problems and thermal bridges can occur".*
C. Georg Kolmayr MA19	- ***Material approach:*** *"There is an option to replicate building decorations and details either with new or old materials, but in practice, using 21st-century methods leads to quite different result as from the original techniques of e.g. the Gründerzeit period."* - *"We try to avoid this approach (replication with new materials) for Gründerzeit buildings and prefer preserving the original facade and structure. Gründerzeit buildings often have strong construction with good physical properties, so major changes aren't always necessary."*
D. Michael Haugeneder ATP sustain	- ***Sustainable use of materials:*** *"<u>Old materials:</u>* - *Should be used whenever possible as they present fewer building physics issues.* - *Support the principle of circularity.* - *Often have a lower carbon footprint due to their reuse in the cycle.* *<u>New materials:</u>* - *In areas like windows and roofing, new materials offer significant advantages.* - *Circularity is also possible with modern solutions, such as:* - *Viennese box windows* - *Colored PV (photovoltaic) sheets* - *PV roof tiles etc."*
Theme 3: Permitted Structural and Aesthetic Changes in Protected Buildings	
Q3: ALTERATIONS TO WINDOWS, DOORS OR FAÇADE DESIGNES	
A. Markus Wimmer BHÖ	- ***Glazing upgrade:*** *"Glazing upgrade is only possible if the window frame is still in good condition. The window frame must be able to bear the added weight of the thermal glazing. In older buildings, like high-baroque castles with original windows, thermal glazing is typically not feasible."*

	- *"If the windows are too damaged to be restored, they will be rebuilt according to the historical model, with the profile reinforced to accommodate thermal glazing."* - ***Natural ventilation:*** *"Building, built before World War I, usually utilises a natural ventilation system implemented in structures. This relatively simple system draws air from the cellar, typically over a garden, maintaining a consistent temperature year-round. In summer, the cooler air from the cellar is used to lower room temperatures, while in winter, air heated to around 16-18 degrees Celsius is circulated into the living spaces, reducing the need for additional heating. Special ventilation channels and fans are employed to facilitate this process: warm air naturally rises while cooler air descends, allowing for efficient temperature management throughout the building."* - ***Sun-reflective roof coatings:*** *"We had a research study on sun-reflective roof coatings, which revealed a negligible temperature yield of only 0.1% without additional measures, indicating that the coating do not provide significant energy efficiency improvements."*
B. Gerald Wagenhofer EHA	- ***Glazing upgrade:*** *"Well- and regularly maintained box windows can achieve insulation values between 1.2 and 1.4, while modern windows despite being rated at 0.8-0.9, often only slightly exceed 1, showing that the difference is minimal".* - ***Windows upgrade:*** *"Historically, well-maintained windows have lasted over 100 years. Today, however, the industry encourages replacements after 30 years, driven by sales motives, portraying the old as inferior and the new as superior. In a marketing-driven world, we are often told what is best for us".* - *"Insulated glass windows often lose their gas after 5-7 years. The standard warranty for the window typically covers a 10-years period. However, no guarantee is given specifically for the gas retention within the window, leading to decreased effectiveness over time".* - ***Natural ventilation:*** *"Historical buildings often feature intelligent, natural ventilation systems. Before installing mechanical ventilation, it is crucial to check if the existing system is still functional, as mechanical solutions can counteract and reduce the overall system's efficiency".* - ***Sun-reflective roofing materials:*** *"When deciding on sun-reflective roofing materials, such as tiles, the key consideration is not their utility but whether the change aligns with the values of the historic building. The utility matters, but so does the extent to which the appearance is altered".*
C. Georg Kolmayr MA19	- ***Windows upgrade:*** *"Well-maintained wooden box windows can offer quite good thermal performance. By restoring the outer frames and*

	upgrading the inner ones, windows can reach energy efficiency levels often comparable to modern triple-glazed windows." - *"The key factor for wooden windows is proper maintenance and care, whereas plastic windows typically need to be replaced after 30 years and cannot be easily repaired."* - ***Changes to the roofs:*** *„With the inclusion of world heritage considerations in the Austrian building regulations, there is now a stronger focus on Vienna's rooftops and roof landscapes. The roof is seen as a "fifth facade," and attention is given to its design, even if it's not visible from the street."* - *"There is also the issue of air conditioning and cooling systems being placed on roofs, causing not only a conflict with preserving the cityscape but also noise pollution for residents."* - *"In response, the latest building code amendment has been updated recently, with the inclusion of new regulations for building services in Paragraphs 85. These regulations aim to regulate the placement and visibility of such equipment, ensuring it doesn't negatively affect the appearance of the area."* - ***Shading:*** *"Sun protection is an issue in protected zones, especially for decorated buildings, as the solutions that are on offer today like e.g. standard industrial roller shutters are not compatible with the cityscape."* - *"Historical or period-appropriate solutions are preferred, such as using wooden box window gaps, folding shutters or textile alternatives (which were actually quite common in the Gründerzeit era). "* - *"There's also the aspect of uniformity. Achieving uniformity can be challenging, especially in residential buildings where individual units are often renovated separately. But solutions can be found. "*
D. Michael Haugeneder ATP sustain	- ***Glazing upgrade:*** *"Yes, the glazing change works for retrofitting. There are various types of glass available for box windows, including thinner versions that provide excellent U-values. In addition to the energy benefits, there are often also sound insulation and airtightness benefits that improve the indoor quality. However, this usually requires a ventilation system (moisture protection) "*. - ***Windows upgrade:*** *"In many cases, the inner pane can be upgraded, even to a different type of window. There are windows, specifically designed for the renovation of Gründerzeit buildings, offer options approved by MA 19 and the Federal Monuments Office (Denkmalamt). These windows look like traditional box windows on the outside but feature a modern insulating pane on the inside, which may be made of plastic or, for higher costs, wood. This solution can greatly improve energy efficiency, particularly by reducing air leaks and addressing heat loss due to poor ventilation in older buildings. "*

	- ***Sun-reflective roofing materials:*** *"Roofing with highly reflective shingles is a new construction method that should be openly discussed from a heritage conservation perspective, as shingles are often an important part of historical preservation."* - *"The use of highly reflective shingles primarily reduces solar heat gain and lowers the cooling load of the top floor in multi-story buildings. While it contributes to energy savings, its overall impact depends largely on the building's roof size and the ratio of roof area to total building footprint. In buildings with large roofs, this approach can significantly reduce energy demand, in others with smaller roof surfaces - the effect is negligible"*
E. Martin **Mittermair** Mittermair Architects	- ***Glazing upgrade (actual renovation plan of the case study building):*** *"The glass surfaces for apartments in the roof top will be replaced because they are over 30 years old and have lost their technical and professional qualities. The insulation standards from the 1990s, it's when the glass was latest upgraded, are no longer sufficient."* - *"The current standard is to use triple-glazed insulating glass, whereas the existing windows have only double glazing."* - *"Modern triple-glazed windows consist of three panes with two gas-filled chambers in between, which enhances insulation."* - *"During the production of insulating glass, a noble gas is injected and sealed within the layers. However, the seal around the frame is never 100% gas-tight, meaning that noble gas can escape over time."* - ***Windows upgrade (actual renovation plan for the case study building):*** *"New windows will be installed on the courtyard-facing side. In the mezzanine level, new windows will be installed on the interior side, while the exterior façade remains unchanged."* - ***Changes to the roof (actual renovation plan for the case study building): "****All small current cooling devices will be removed and replaced by a centralised cooling system. The flat roof will be used as a roof terrace."*
Q4: CHANGES TO INTERIORS, EXTERIORS AND THE ROOF	
A. Markus Wimmer BHÖ	- ***PV systems: "****Here are the three questions I need:* *1. Visibility: Can the photovoltaic system be seen from outside the historic building?* *2. Structural Suitability: Is the roof strong enough to support the system?* *3. Orientation: Is the roof positioned to optimise sunlight exposure for energy production?"* - ***Insulation:*** *"Insulating the top floor ceiling can be a highly effective measure with great success."* - *"The thick walls (up to 1 meter) provide substantial thermal mass, keeping the building cool in summer and warm in winter due to its slow energy transfer. Adding external insulation to such buildings offers*

	minimal additional benefit because of the building's inherent thermal inertia." - *"The main area for insulation improvement is the windows, specifically preserving the Vienna box windows and improving the inner panes with insulation."* - *"Attention must be taken not to over-insulate old buildings, as they rely on a breathable system that should not be sealed too tightly to avoid suffocation."* - *„Addressing moisture issues in basements through proper waterproofing should be considered."*
B. Gerald Wagenhofer EHA	- ***PV systems:*** *"Normally, most roof structures are not suitable for photovoltaic installations and would require reinforcing the roof structure, which could significantly alter the entire roof landscape. There are very few cases where it would work without interference."* - ***Extensive green roof vs PV panels:*** *"In the case of an extensive green roof, like in the current case study building, prioritising biodiversity over installing photovoltaic panels is preferable. Greenery reduces solar heat gain and offers greater ecological benefits with minimal effort."*
C. Georg Kolmayr MA19	- ***Changes to interior & responsible authorities:*** *"Interior changes are not within MA19's responsibility; we focus on the exterior and cityscape. MA19's role is limited to protecting the public interest regarding the building's external appearance."* - *"Interior alterations, are handled by MA37 (Building Authority) together with safety, accessibility, and similar concerns."* - *"The Federal Monuments Office may also protect the building's interior and structural integrity. Some buildings, those which are listed, have full protection from the Monuments Office, covering both the exterior and interior. "* - ***Exterior envelope insulation of courtyard facades:*** *"If the courtyard is small and mainly serves for ventilation or lighting, there is typically less public interest in preserving its original appearance."* - ***PV systems:*** *"Options like color adjustments and placement PV systems on the roof areas that are not visible from the public space allow for a balance between preserving the cityscape and implementing ecological measures. "*
D. Michael Haugeneder ATP sustain	- ***Importance of dynamic behaviour:*** *"Depending on the building structure, the dynamic behaviour must be taken into account, as solid components may respond with delays of several weeks. Thus, it is not solely the static behaviour (calculations for new construction) that dictates all measures, but rather the dynamic behaviour, often influenced by moisture. Building services systems should address the mass rather than just the interior space."*

- *"Airborne systems combined with radiant systems are therefore suitable for this type of building structure."*

- ***Internal envelope insulation:*** *"Internal insulation often works only in theory because it needs to be vapor-tight, which requires a complex construction (insulation, vapor barrier, and a free-standing protective layer)".*
  "In commercial and rental properties, internal insulation is difficult to implement, as tenants could easily damage the moisture protection, for example, by hammering a nail into the wall. Internal insulation is more suitable for owner-occupied apartments, where the owner can be informed about necessary protection measures".
  "If only the walls are insulated without addressing window frames and reveals, moisture problems and mold will occur".

- ***PV systems:*** *"There are now companies that produce PV systems designed to replicate historical roofing materials, including metal roofs and traditional tiles, with options to match the colors of the roofing surfaces. These integrated PV systems are 12-20% less efficient than conventional black solar panels but provide an truly great solution for maintaining aesthetic standards in protected or historic architecture."*

- ***Solar thermal collectors:*** *"Solar collectors make sense in buildings with high hot water demand, such as residential. In the case, with mostly office space, they are not practical."*
- *"However, if there is a restaurant on the ground floor, solar collectors could still be beneficial. For example, 20-30 square meters of solar collectors could cover 60% of the restaurant's annual hot water needs. The remaining hot water could also be shared with the offices, especially if there are showers or other uses."*
- *"Without key consumers like residential units or a restaurant, solar thermal systems are not worth installing."*
- *"Solar thermal systems perform poorly in transitional seasons (September to May) due to high humidity, which reduces solar radiation on the collector, even in good weather. Only when land winds increase during summer, clearing the moisture from the air, solar thermal collectors operate at full capacity."*
- *"In Central Europe, moisture levels vary by region, impacting solar collectors' effectiveness. For example, Vienna and the Weinviertel have better conditions, while areas like Wiener Neustadt struggle with humidity affecting solar gain."*
- *" Solar thermal collectors stop working in foggy or humid conditions, whereas PV panels still generate electricity on cloudy or rainy days, albeit less efficiently. In locations with low hot water demand, PV systems are a better choice since they continue producing power in varying weather".*
- *"In regions like the Alps, solar thermal collectors perform excellently due to low humidity and high solar radiation, even in winter with sub-zero temperatures. Geothermal energy paired with a heat pump offers*

	the highest efficiency, with the COP (Coefficient of Performance) increasing under optimal conditions". - ***LED:*** *"LED solar-powered lighting is essential for reducing energy consumption."* - *"It's important to cover a portion of electricity needs through battery systems to relieve the network. In office buildings, nighttime energy demand (from 6 PM to 6 AM) should ideally be supplied by the battery, avoiding external electricity sources".* - *"Since nighttime energy demand is low in office buildings, the battery size can be relatively small."* - *"In residential buildings, peak electricity demand happens between 6 PM and 9 PM and again from 6 AM to 8 AM. Coffee machines, dishwashers, stoves, microwaves, and TVs - all of it needs to be powered necessitating a larger battery".*
E. Martin Mittermair Mittermair Architects	- ***Changes to Interior (actual renovation plan for the case study building):*** *"The fronts of the flats will be slightly changed, the flooring will be renewed, and office space will become transformable. The idea is to remove all the partitions to create a large open-plan office space, which allows for the entire floor to be utilised as a whole, providing flexibility in the office layout. Users can choose to create individual offices (cells), group spaces, or maintain an open-plan layout, depending on their needs. By eliminating the existing partitions, the design offers various options for furniture arrangements, making it adaptable for different purposes (e.g., editorial offices, architectural firms). "* - ***Roof insulation (actual renovation plan for the case study building):*** *"The roof structure will be insulated. Although it was insulated in the 1990s with standard 6 to 8 cm layer of insulation, modern standards now require thicker layer - around 30 cm."* - *„The insulation material is a rigid foam, such as extruded polystyrene, for enhanced thermal protection. "*
Q7: ALTERNATIVE ENERGY SYSTEMS AND OTHER HVAC	
A. Markus Wimmer BHÖ	- ***Mechanical ventilation: "****Implementing ventilation systems from the basement to each individual room in a historic building requires significant technical installations. These systems involve large ventilation ducts and machinery, sometimes including air conditioning units that take up considerable space. Such installations consume electricity, require maintenance, and increase operating costs."* - *"Ventilation through windows, a simpler and traditional method, has been largely forgotten in modern living."* - ***District heating: "****Urban district heating provides building owners with reliable supply security and manageable maintenance, making it an appealing option."*

	- *"Despite its benefits, there are concerns about the economic viability and environmental impact, as district heating to today relies largely on gas."* - ***Geothermal heating:*** *"Geothermal energy can be an effective source of heating, but its implementation is complex, especially in older buildings, requiring significant investment and often depending on electricity."* - ***Sand / gravel storage:*** *"The use of sand or gravel storage for thermal energy storage is currently being explored, as heated sand can retain its temperature for a long time."* - *"By using a closed system, heat generated from various energy sources like photovoltaics can be stored in the sand and released later when heat is needed."* - *"This method has the potential for significant energy gains and is being considered for further development in the coming years."* - ***Cisterns and greywater systems:*** *"Efficient water usage is important, especially in urban areas; reactivating cisterns and greywater systems can be beneficial."* - ***Optimising Building Performance:*** *„Smart measurement, control, and regulation technology, as mentioned earlier, also plays a key role in optimising building performance."*
B. Gerald Wagenhofer EHA	- ***District heating:*** *"The planned central heating system for Vienna's first district will primarily use gas-based district heating, which raises concerns about long-term sustainability."* - ***Combining a gas heating system with air-based systems:*** *"Caution is advised when combining a gas heating system with air-based systems like air conditioning, as the gas boiler can affect the low pressure.".*
C. Georg Kolmayr MA 19	- ***District heating or alternative energy systems:*** *"Vienna expects that its existing district heating network will sufficiently cover densely populated areas, but there are also significant opportunities for alternative energy systems to meet heat demand locally, fostering synergies among nearby buildings."*
D. Michael Haugeneder ATP sustain	- ***Mechanical ventilation:*** *"To protect a building (specifically against moisture), it is necessary to install mechanical ventilation systems. Purely natural ventilation is ineffective due to the building's cold mass, leading to insufficient pressure differences to move air."* - *„Mechanical ventilation also allows for air treatment and heat recovery. This ensures indoor comfort, temperature control, and moisture protection with minimal energy consumption."*

- ***Chimneys and cellars for modern HVAC systems:*** *"Older buildings, especially those built before 1945 or 1960, often have chimneys in every room, which can be repurposed as ideal shafts for heating and cooling distribution. The cellars, often raised about a meter above ground level, allow natural ventilation and can support technologies that require external air, like ventilation or cooling systems."*
- *"Modern retrofitting can leverage technologies that operate at lower temperatures but still deliver high heating capacities, such as fan coils and air circulation systems."*
- *"While buildings without courtyards may lack certain retrofitting options, efficient solutions can still be achieved using existing structures like chimneys and cellars."*

- ***District heating:*** *"The idea in Vienna is to expand the district heating network, moving out of gas in some areas of the city, like e.g. the whole 1st district."*
- *"To achieve this with existing power plants, each building would need to reduce its energy consumption by 70% to cover the city's heating needs with the available megawatt-hours."*
- *"However, not all buildings can implement these energy-saving measures, particularly in the historic first district where monument and ensemble protection limit energy efficiency upgrades."*
- *"Protected buildings will always have higher energy demand and cannot reach near-zero energy standards like new builds. Some inner-city buildings must be independent of district heating to balance the city's energy system."*
- *"For buildings with courtyards or green spaces, alternative energy sources like geothermal should be considered. Neighboring buildings without such spaces may need to rely on district heating to achieve C02 neutrality."*

- ***District cooling:*** *"The Vienna district cooling network is expanding, currently covering 7 streets in the 1st district, with plans to supply the entire area by 2040. It is primarily powered by Danube, and is a good solution for reducing C02 emissions, especially in mixed-use areas like the first district, where cooling for commercial spaces is essential ".*
- *"Connecting to district cooling eliminates the need for individual cooling machines in buildings, reducing electricity consumption on-site and freeing up energy capacity in the local grid. This allows for improved energy management and can support other systems like mobility and ventilation".*

- ***Air-to-water heat pumps:*** *"…are becoming more popular but have a major drawback: noise. While the technology is optimised, larger systems (such as those needed for bigger buildings) require significant airflow to extract heat, increasing the noise level."*
- *"A possible solution is to combine systems: using geothermal energy to cover 30-40% of the load and supplementing the reduced*

	demand with an air-to-water heat pump. This hybrid approach could balance performance and noise concerns." - ***Geothermal heating:*** *"If a property has potential for on-site energy solutions, the priority is always to utilise that potential. Only after maximising on-site options external sources of green energy should be considered."* - *"Geothermal systems involve different drilling methods; the simplest, hammering in ("Hineinhämmern"), is not suitable for urban areas."* - *"The "Spülbohrverfahren" or flush drilling method, is a gentle technique that uses water to help drive the drill forward, making it effective in areas like Vienna where loose materials are prevalent."* - *"This method can efficiently remove soil and rock but generates a significant amount of mud, which needs to be collected and transported away. Despite the mud production, this method is manageable for around six to seven boreholes (this number refers to the case study building), especially during renovation projects."* - *"More boreholes can be installed, and with recent slant drilling techniques or „ Schrägbohrverfahren", larger areas can be accessed even in restricted spaces, though performance decreases from 55 W/lfm to 45 W/lfm."*
E. Martin Mittermair Mittermair Architects	- ***District heating (actual renovation plan for the case study building):*** *"The building in Plankengasse is now connected to district heating, and this connection will be extended to supply both buildings being merged with hot water. "* - ***Cooling system (actual renovation plan for the case study building):*** *"A central ventilation and cooling system will be installed in the roof top, serving office and residential areas. The cooling system will be hidden from the street and located in the courtyard, with cooling machines placed in the basement. "* - *"There will be a central technical shaft running through all floors, where the ventilation and cooling lines will be routed and distributed across each level."* - *"The air intake is from the top of the building, collecting air from the outside and directing it downwards. Air is channelled through long ventilation ducts, where it is filtered to ensure only clean air enters the system."* - *"In the ventilation system, the air is either cooled or heated depending on the needs. This system ensures consistent air quality and temperature regulation across the entire building."* - ***Natural ventilation through chimneys:*** - *"Historically, there were no centralised heating systems like gas or district heating. Instead, each room had its own stove, leading to more chimneys on higher floors."* - *"The number of chimneys increases with each floor because each room had its own chimney, resulting in more chimneys as you go higher in the building."*

	- *"Chimneys typically have small cross-sections, around 15x15 cm, which is unusable for effective ventilation."* - *"Without mechanical assistance, like installing fans or other devices, natural ventilation won't work in this context."* - ***District cooling & heating:*** *"District cooling works similarly to district heating. With district cooling, cold water at around 15°C is supplied to the building. For district heating, hot water is supplied to the building at guaranteed temperatures of 60, 70, or 80°C, ready for use."* - *"Both district heating and cooling are generated elsewhere, whether from wind and geothermal energy, thermal power plants, or waste incineration."*

Energy certificates

Datenblatt - ArchiPHYSIK
Seilergasse 16 (Base case)

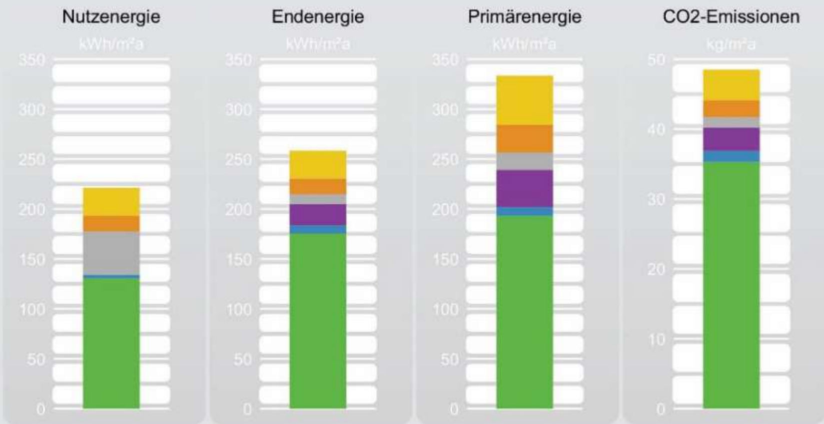
OIB-Richtlinie 6, Ausgabe: Mai 2023

Gebäudedaten: Gesamtenergieausweis

Brutto-Grundfläche	6 317,62 m²	charakteristische Länge (lc)	4,35 m
Konditioniertes Brutto-Volumen	24 603,60 m³	Kompaktheit (A/V)	0,23 1/m
Gebäudehüllfläche	5 654,74 m²		

Energiebedarf Bürogebäude, ...

Standortklima



	NEB absolut kWh/a	NEB spezifisch kWh/m²a	EEB absolut kWh/a	EEB spezifisch kWh/m²a	PEB absolut kWh/a	PEB spezifisch kWh/m²a	CO2 absolut kg/a	CO2 spezifisch kg/m²a
Befeuchtung			0	0,00	0	0,00	0	0,00
Beleuchtung	176 227	27,90	176 227	27,90	310 158	49,09	27 491	4,35
Betriebsstrom	99 873	15,80	99 873	15,80	175 776	27,82	15 580	2,46
Kühlung	275 378	43,59	62 229	9,90	109 523	17,30	9 708	1,50
Hilfsenergie			134 316	21,30	236 396	37,40	20 953	3,30
Warmwasser	21 149	3,30	50 441	8,00	55 485	8,80	10 139	1,60
Heizung	825 167	130,61	1 108 810	175,50	1 219 691	193,10	222 871	35,30
Gesamt	1 397 795	221,30	1 631 895	258,30	2 107 030	333,50	306 742	48,60

HWB SK	130,61 kWh/m²a	HEB SK	204,80 kWh/m²a	KEB SK	9,90 kWh/m²a	EEB SK	258,30 kWh/m²a
HWB Ref,SK	127,70 kWh/m²a	Q Umw,WP				f GEE	1,97 -

ArchiPHYSIK - Demo-Version - A-NULL Demo 23.01.2025

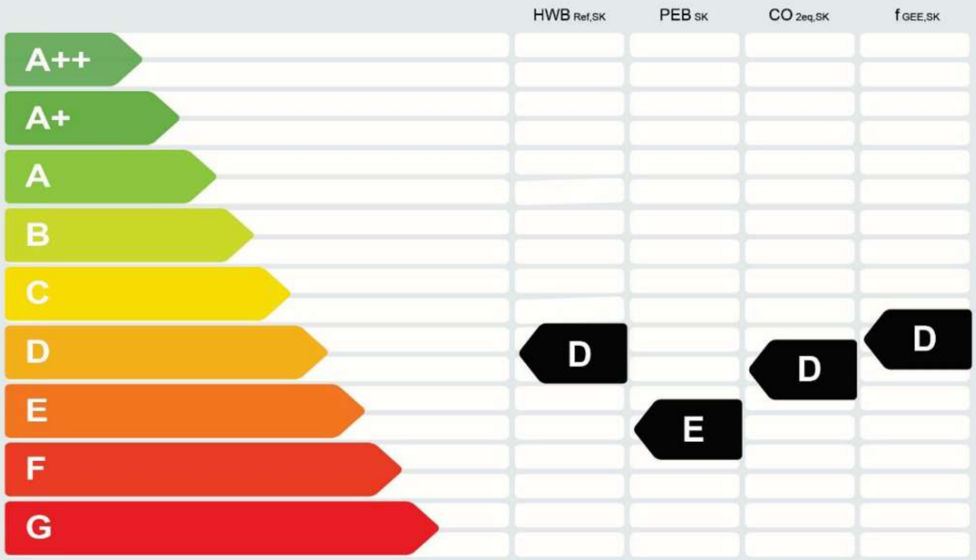
Gesamt-Energieausweis (Base case)

OIB ÖSTERREICHISCHES INSTITUT FÜR BAUTECHNIK

OIB-Richtlinie 6
Ausgabe: Mai 2023

BEZEICHNUNG	Seilergasse 16 (Bestand)	**Umsetzungsstand**	
Gebäude(-teil)	Gesamtenergieausweis	Baujahr	2026
Nutzungsprofil	Bürogebäude, ...	Letzte Veränderung	
Straße	Seilergasse 16	Katastralgemeinde	Innere Stadt
PLZ/Ort	1010 Wien-Innere Stadt	KG-Nr.	01004
Grundstücksnr.	1098	Seehöhe	174 m

SPEZIFISCHER REFERENZ-HEIZWÄRMEBEDARF, PRIMÄRENERGIEBEDARF, KOHLENDIOXIDEMISSIONEN und GESAMTENERGIEEFFIZIENZ-FAKTOR jeweils unter STANDORTKLIMA-(SK)-Bedingungen



HWB$_{Ref}$: Der **Referenz-Heizwärmebedarf** ist jene Wärmemenge, die in den Räumen bereitgestellt werden muss, um diese auf einer normativ geforderten Raumtemperatur, ohne Berücksichtigung allfälliger Erträge aus Wärmerückgewinnung, zu halten.

WWWB: Der **Warmwasserwärmebedarf** ist in Abhängigkeit der Gebäudekategorie als flächenbezogener Defaultwert festgelegt.

HEB: Beim **Heizenergiebedarf** werden zusätzlich zum Heiz- und Warmwasserwärmebedarf die Verluste des gebäudetechnischen Systems berücksichtigt, dazu zählen insbesondere die Verluste der Wärmebereitstellung, der Wärmeverteilung, der Wärmespeicherung und der Wärmeabgabe sowie allfälliger Hilfsenergie.

KB: Der **Kühlbedarf** ist jene Wärmemenge, welche aus den Räumen abgeführt werden muss, um unter der Solltemperatur zu bleiben. Er errechnet sich aus den nicht nutzbaren inneren und solaren Gewinnen.

BefEB: Beim **Befeuchtungsenergiebedarf** wird der allfällige Energiebedarf zur Befeuchtung dargestellt.

KEB: Beim **Kühlenergiebedarf** werden zusätzlich zum Kühlbedarf die Verluste des Kühlsystems und der Kältebereitstellung berücksichtigt.

RK: Das **Referenzklima** ist ein virtuelles Klima. Es dient zur Ermittlung von Energiekennzahlen.

BelEB: Der **Beleuchtungsenergiebedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht dem Energiebedarf zur nutzungsgerechten Beleuchtung.

BSB: Der **Betriebsstrombedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht der Hälfte der mittleren innenren Lasten.

EEB: Der **Endenergiebedarf** umfasst zusätzlich zum Heizenergiebedarf den jeweils allfälligen Betriebsstrombedarf, Kühlenergiebedarf und Beleuchtungsenergiebedarf, abzüglich allfälliger Endenergieerträge und zuzüglich eines dafür notwendigen Hilfsenergiebedarfs. Der Endenergiebedarf entspricht jener Energiemenge, die eingekauft werden muss (Lieferenergiebedarf).

f_{GEE}: Der **Gesamtenergieeffizienz-Faktor** ist der Quotient aus einerseits dem Endenergiebedarf abzüglich allfälliger Endenergieerträge und zuzüglich des dafür notwendigen Hilfsenergiebedarfs und andererseits einem Referenz-Endenergiebedarf (Anforderung 2007).

PEB: Der **Primärenergiebedarf** ist der Endenergiebedarf einschließlich der Verluste in Vorketten. Der Primärenergiebedarf weist einen erneuerbaren ($PEB_{ern.}$) und einen nicht erneuerbaren ($PEB_{n.ern.}$) Anteil auf.

CO_{2eq}: Gesamte dem Endenergiebedarf zuzurechnenden **äquivalenten Kohlendioxidemissionen** (Treibhausgase), einschließlich jener für Vorketten.

SK: Das **Standortklima** ist das reale Klima am Gebäudestandort. Dieses Klimamodell wurde auf Basis der Primärdaten (1970 bis 1999) der Zentralanstalt für Meteorologie und Geodynamik für die Jahre 1978 bis 2007 gegenüber der Vorfassung aktualisiert.

Alle Werte gelten unter der Annahme eines normierten BenutzerInnenverhaltens. Sie geben den Jahresbedarf pro Quadratmeter beheizter Brutto-Grundfläche an.

Dieser Energieausweis entspricht den Vorgaben der OIB-Richtlinie 6 „Energieeinsparung und Wärmeschutz" des Österreichischen Instituts für Bautechnik in Umsetzung der Richtlinie 2010/31/EU vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden bzw. 2018/844/EU vom 30. Mai 2018 und des Energieausweis-Vorlage-Gesetzes (EAVG). Der Ermittlungszeitraum für die Konversionsfaktoren für Primärenergie und Kohlendioxidemissionen ist für Strom: 2018-01 – 2021-12, und es wurden übliche Allokationsregeln unterstellt.

ArchiPHYSIK - Demo-Version - A-NULL   Demo   23.01.2025

Datenblatt - ArchiPHYSIK
Seilergasse 16 (Scenario 1) thermal enevelope

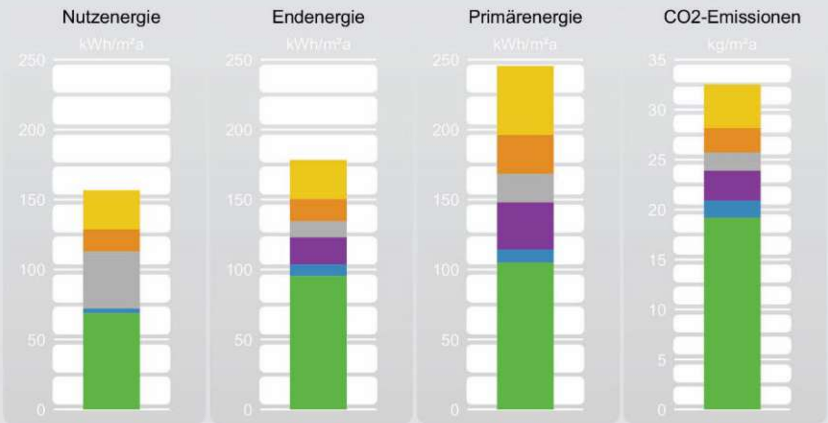
OIB-Richtlinie 6, Ausgabe: Mai 2023

Gebäudedaten: Gesamtenergieausweis

Brutto-Grundfläche	6 317,62 m²	charakteristische Länge (lc)	4,35 m
Konditioniertes Brutto-Volumen	24 603,60 m³	Kompaktheit (A/V)	0,23 1/m
Gebäudehüllfläche	5 654,74 m²		

Energiebedarf Bürogebäude, ...

Standortklima



	NEB absolut kWh/a	NEB spezifisch kWh/m²a	EEB absolut kWh/a	EEB spezifisch kWh/m²a	PEB absolut kWh/a	PEB spezifisch kWh/m²a	CO2 absolut kg/a	CO2 spezifisch kg/m²a
Befeuchtung			0	0,00	0	0,00	0	0,00
Beleuchtung	176 227	27,90	176 227	27,90	310 158	49,09	27 491	4,35
Betriebsstrom	99 873	15,80	99 873	15,80	175 776	27,82	15 580	2,46
Kühlung	257 566	40,77	73 360	11,60	129 114	20,40	11 444	1,80
Hilfsenergie			121 156	19,20	213 235	33,80	18 900	3,00
Warmwasser	21 149	3,30	53 105	8,40	58 415	9,20	10 674	1,70
Heizung	435 173	68,88	602 764	95,40	663 040	105,00	121 156	19,20
Gesamt	989 987	156,70	1 126 484	178,30	1 549 739	245,30	205 246	32,50

HWB_{SK}	68,88 kWh/m²a	HEB_{SK}	123,00 kWh/m²a	KEB_{SK}	11,60 kWh/m²a	EEB_{SK}	178,30 kWh/m²a
$HWB_{Ref,SK}$	65,80 kWh/m²a	$Q_{Umw,WP}$				f_{GEE}	1,38 -

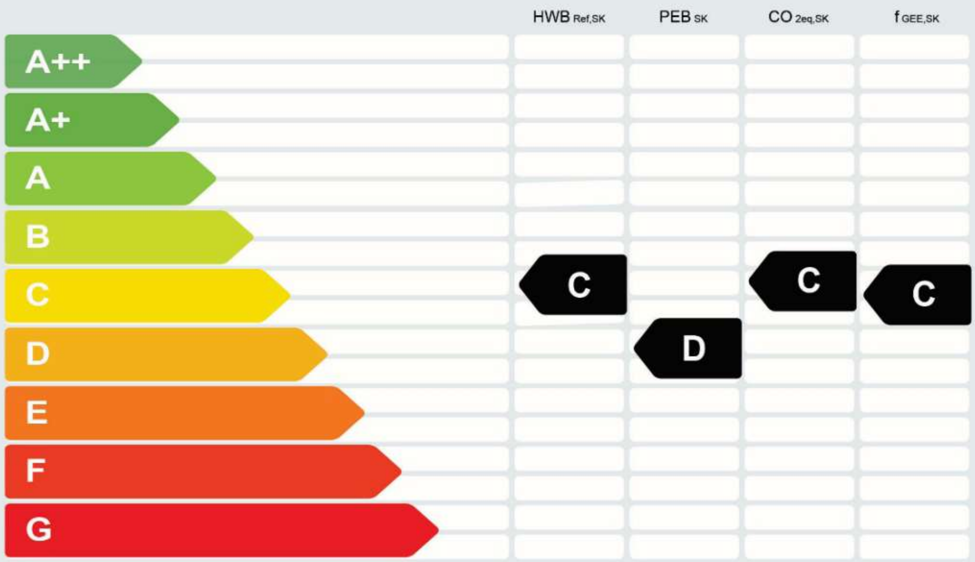
Gesamt-Energieausweis (Scenario 1) thermal envelope

OIB ÖSTERREICHISCHES INSTITUT FÜR BAUTECHNIK

OIB-Richtlinie 6
Ausgabe: Mai 2023

BEZEICHNUNG	Seilergasse 16 (Scenario 0) thermische Maßnahmen	**Umsetzungsstand**	
Gebäude(-teil)	Gesamtenergieausweis	Baujahr	2026
Nutzungsprofil	Bürogebäude, ...	Letzte Veränderung	
Straße	Seilergasse 16	Katastralgemeinde	Innere Stadt
PLZ/Ort	1010 Wien-Innere Stadt	KG-Nr.	01004
Grundstücksnr.	1098	Seehöhe	174 m

SPEZIFISCHER REFERENZ-HEIZWÄRMEBEDARF, PRIMÄRENERGIEBEDARF, KOHLENDIOXIDEMISSIONEN und GESAMTENERGIEEFFIZIENZ-FAKTOR jeweils unter STANDORTKLIMA-(SK)-Bedingungen



HWB_{Ref}: Der **Referenz-Heizwärmebedarf** ist jene Wärmemenge, die in den Räumen bereitgestellt werden muss, um diese auf einer normativ geforderten Raumtemperatur, ohne Berücksichtigung allfälliger Erträge aus Wärmerückgewinnung, zu halten.

WWWB: Der **Warmwasserwärmebedarf** ist in Abhängigkeit der Gebäudekategorie als flächenbezogener Defaultwert festgelegt.

HEB: Beim **Heizenergiebedarf** werden zusätzlich zum Heiz- und Warmwasserwärmebedarf die Verluste des gebäudetechnischen Systems berücksichtigt, dazu zählen insbesondere die Verluste der Wärmebereitstellung, der Wärmeverteilung, der Wärmespeicherung und der Wärmeabgabe sowie allfälliger Hilfsenergie.

KB: Der **Kühlbedarf** ist jene Wärmemenge, welche aus den Räumen abgeführt werden muss, um unter der Solltemperatur zu bleiben. Er errechnet sich aus den nicht nutzbaren inneren und solaren Gewinnen.

BefEB: Beim **Befeuchtungsenergiebedarf** wird der allfällige Energiebedarf zur Befeuchtung dargestellt.

KEB: Beim **Kühlenergiebedarf** werden zusätzlich zum Kühlbedarf die Verluste des Kühlsystems und der Kältebereitstellung berücksichtigt.

RK: Das **Referenzklima** ist ein virtuelles Klima. Es dient zur Ermittlung von Energiekennzahlen.

BelEB: Der **Beleuchtungsenergiebedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht dem Energiebedarf zur nutzungsgerechten Beleuchtung.

BSB: Der **Betriebsstrombedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht der Hälfte der mittleren innenren Lasten.

EEB: Der **Endenergiebedarf** umfasst zusätzlich zum Heizenergiebedarf den jeweils allfälligen Betriebsstrombedarf, Kühlenergiebedarf und Beleuchtungsenergiebedarf, abzüglich allfälliger Endenergieerträge und zuzüglich eines dafür notwendigen Hilfsenergiebedarfs. Der Endenergiebedarf entspricht jener Energiemenge, die eingekauft werden muss (Lieferenergiebedarf).

f_{GEE}: Der **Gesamtenergieeffizienz-Faktor** ist der Quotient aus einerseits dem Endenergiebedarf abzüglich allfälliger Endenergieerträge und zuzüglich des dafür notwendigen Hilfsenergiebedarfs und andererseits einem Referenz-Endenergiebedarf (Anforderung 2007).

PEB: Der **Primärenergiebedarf** ist der Endenergiebedarf einschließlich der Verluste in Vorketten. Der Primärenergiebedarf weist einen erneuerbaren ($PEB_{ern.}$) und einen nicht erneuerbaren ($PEB_{n.ern.}$) Anteil auf.

CO_{2eq}: Gesamte dem Endenergiebedarf zuzurechnenden **äquivalenten Kohlendioxidemissionen** (Treibhausgase), einschließlich jener für Vorketten.

SK: Das **Standortklima** ist das reale Klima am Gebäudestandort. Dieses Klimamodell wurde auf Basis der Primärdaten (1970 bis 1999) der Zentralanstalt für Meteorologie und Geodynamik für die Jahre 1978 bis 2007 gegenüber der Vorfassung aktualisiert.

Alle Werte gelten unter der Annahme eines normierten BenutzerInnenverhaltens. Sie geben den Jahresbedarf pro Quadratmeter beheizter Brutto-Grundfläche an.

Dieser Energieausweis entspricht den Vorgaben der OIB-Richtlinie 6 „Energieeinsparung und Wärmeschutz" des Österreichischen Instituts für Bautechnik in Umsetzung der Richtlinie 2010/31/EU vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden bzw. 2018/844/EU vom 30. Mai 2018 und des Energieausweis-Vorlage-Gesetzes (EAVG). Der Ermittlungszeitraum für die Konversionsfaktoren für Primärenergie und Kohlendioxidemissionen ist für Strom: 2018-01 – 2021-12, und es wurden übliche Allokationsregeln unterstellt.

Datenblatt - ArchiPHYSIK
Seilergasse 16 (Scenario 2)

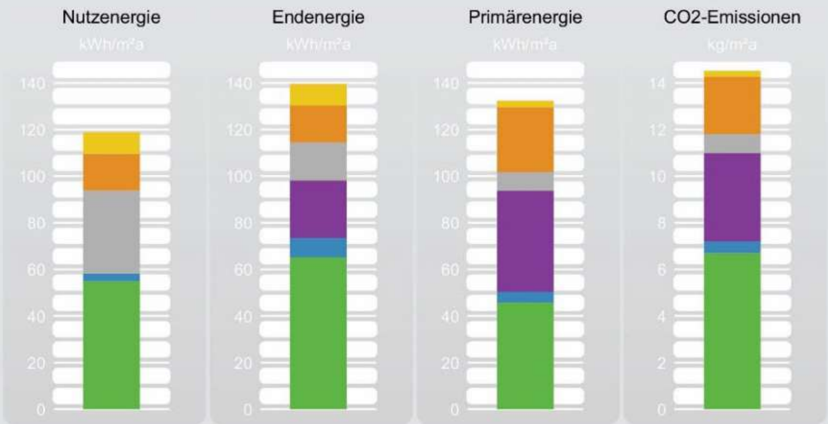
OIB-Richtlinie 6, Ausgabe: Mai 2023

Gebäudedaten: Gesamtenergieausweis

Brutto-Grundfläche	6 317,62 m²	charakteristische Länge (lc)	4,35 m
Konditioniertes Brutto-Volumen	24 603,60 m³	Kompaktheit (A/V)	0,23 1/m
Gebäudehüllfläche	5 654,74 m²		

Energiebedarf Bürogebäude, ...

Standortklima



	NEB absolut kWh/a	NEB spezifisch kWh/m²a	EEB absolut kWh/a	EEB spezifisch kWh/m²a	PEB absolut kWh/a	PEB spezifisch kWh/m²a	CO2 absolut kg/a	CO2 spezifisch kg/m²a
Befeuchtung			0	0,00	0	0,00	0	0,00
Beleuchtung	58 609	9,30	58 609	9,30	18 279	2,89	1 620	0,25
Betriebsstrom	99 873	15,80	99 873	15,80	175 776	27,82	15 580	2,46
Kühlung	225 316	35,66	103 650	16,40	50 268	8,00	4 926	0,80
Hilfsenergie			155 458	24,60	273 607	43,30	24 251	3,80
Warmwasser	21 149	3,30	52 707	8,30	28 769	4,60	3 333	0,50
Heizung	346 682	54,88	411 766	65,20	289 046	45,80	42 018	6,70
Gesamt	751 631	119,00	882 063	139,60	835 745	132,30	91 729	14,50

HWB SK	54,88 kWh/m²a	HEB SK	98,10 kWh/m²a	KEB SK	16,40 kWh/m²a	EEB SK	139,60 kWh/m²a
HWB Ref,SK	65,80 kWh/m²a	Q Umw,WP				f GEE	0,70 -

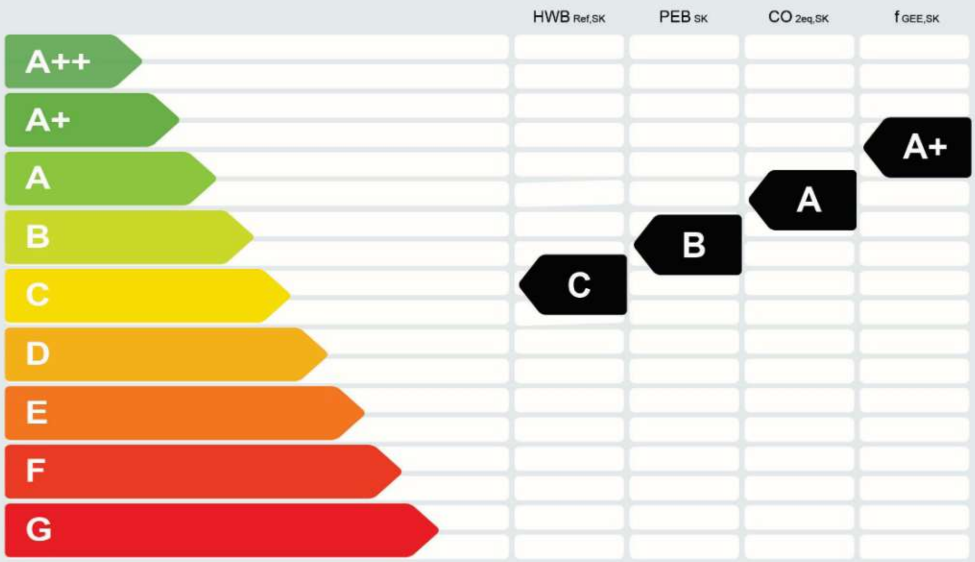
Gesamt-Energieausweis (Scenario 2)

OIB ÖSTERREICHISCHES INSTITUT FÜR BAUTECHNIK

OIB-Richtlinie 6
Ausgabe: Mai 2023

BEZEICHNUNG	Seilergasse 16 (Scenario 2)	**Umsetzungsstand**	
Gebäude(-teil)	Gesamtenergieausweis	Baujahr	2026
Nutzungsprofil	Bürogebäude, ...	Letzte Veränderung	
Straße	Seilergasse 16	Katastralgemeinde	Innere Stadt
PLZ/Ort	1010 Wien-Innere Stadt	KG-Nr.	01004
Grundstücksnr.	1098	Seehöhe	174 m

SPEZIFISCHER REFERENZ-HEIZWÄRMEBEDARF, PRIMÄRENERGIEBEDARF, KOHLENDIOXIDEMISSIONEN und GESAMTENERGIEEFFIZIENZ-FAKTOR jeweils unter STANDORTKLIMA-(SK)-Bedingungen



HWB$_{Ref}$: Der **Referenz-Heizwärmebedarf** ist jene Wärmemenge, die in den Räumen bereitgestellt werden muss, um diese auf einer normativ geforderten Raumtemperatur, ohne Berücksichtigung allfälliger Erträge aus Wärmerückgewinnung, zu halten.

WWWB: Der **Warmwasserwärmebedarf** ist in Abhängigkeit der Gebäudekategorie als flächenbezogener Defaultwert festgelegt.

HEB: Beim **Heizenergiebedarf** werden zusätzlich zum Heiz- und Warmwasserwärmebedarf die Verluste des gebäudetechnischen Systems berücksichtigt, dazu zählen insbesondere die Verluste der Wärmebereitstellung, der Wärmeverteilung, der Wärmespeicherung und der Wärmeabgabe sowie allfälliger Hilfsenergie.

KB: Der **Kühlbedarf** ist jene Wärmemenge, welche aus den Räumen abgeführt werden muss, um unter der Solltemperatur zu bleiben. Er errechnet sich aus den nicht nutzbaren inneren und solaren Gewinnen.

BefEB: Beim **Befeuchtungsenergiebedarf** wird der allfällige Energiebedarf zur Befeuchtung dargestellt.

KEB: Beim **Kühlenergiebedarf** werden zusätzlich zum Kühlbedarf die Verluste des Kühlsystems und der Kältebereitstellung berücksichtigt.

RK: Das **Referenzklima** ist ein virtuelles Klima. Es dient zur Ermittlung von Energiekennzahlen.

BelEB: Der **Beleuchtungsenergiebedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht dem Energiebedarf zur nutzungsgerechten Beleuchtung.

BSB: Der **Betriebsstrombedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht der Hälfte der mittleren innenren Lasten.

EEB: Der **Endenergiebedarf** umfasst zusätzlich zum Heizenergiebedarf den jeweils allfälligen Betriebsstrombedarf, Kühlenergiebedarf und Beleuchtungsenergiebedarf, abzüglich allfälliger Endenergieerträge und zuzüglich eines dafür notwendigen Hilfsenergiebedarfs. Der Endenergiebedarf entspricht jener Energiemenge, die eingekauft werden muss (Lieferenergiebedarf).

f$_{GEE}$: Der **Gesamtenergieeffizienz-Faktor** ist der Quotient aus einerseits dem Endenergiebedarf abzüglich allfälliger Endenergieerträge und zuzüglich des dafür notwendigen Hilfsenergiebedarfs und andererseits einem Referenz-Endenergiebedarf (Anforderung 2007).

PEB: Der **Primärenergiebedarf** ist der Endenergiebedarf einschließlich der Verluste in Vorketten. Der Primärenergiebedarf weist einen erneuerbaren (PEB$_{ern}$) und einen nicht erneuerbaren (PEB$_{n.ern}$) Anteil auf.

CO_{2eq}: Gesamte dem Endenergiebedarf zuzurechnenden **äquivalenten Kohlendioxidemissionen** (Treibhausgase), einschließlich jener für Vorketten.

SK: Das **Standortklima** ist das reale Klima am Gebäudestandort. Dieses Klimamodell wurde auf Basis der Primärdaten (1970 bis 1999) der Zentralanstalt für Meteorologie und Geodynamik für die Jahre 1978 bis 2007 gegenüber der Vorfassung aktualisiert.

Alle Werte gelten unter der Annahme eines normierten BenutzerInnenverhaltens. Sie geben den Jahresbedarf pro Quadratmeter beheizter Brutto-Grundfläche an.

Dieser Energieausweis entspricht den Vorgaben der OIB-Richtlinie 6 „Energieeinsparung und Wärmeschutz" des Österreichischen Instituts für Bautechnik in Umsetzung der Richtlinie 2010/31/EU vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden bzw. 2018/844/EU vom 30. Mai 2018 und des Energieausweis-Vorlage-Gesetzes (EAVG). Der Ermittlungszeitraum für die Konversionsfaktoren für Primärenergie und Kohlendioxidemissionen ist für Strom: 2018-01 – 2021-12, und es wurden übliche Allokationsregeln unterstellt.

ArchiPHYSIK - Demo-Version - A-NULL   Demo   23.01.2025

Datenblatt - ArchiPHYSIK
Seilergasse 16 (Scenario 3)

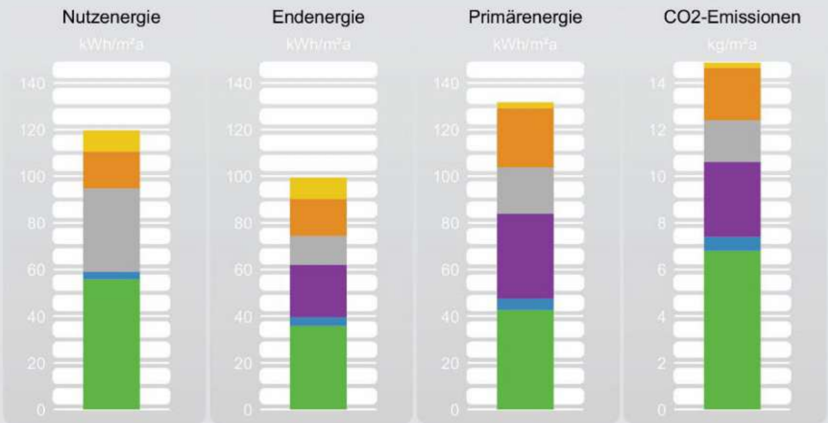
OIB-Richtlinie 6, Ausgabe: Mai 2023

Gebäudedaten: Gesamtenergieausweis

Brutto-Grundfläche	6 317,62 m²	charakteristische Länge (lc)	4,35 m
Konditioniertes Brutto-Volumen	24 603,60 m³	Kompaktheit (A/V)	0,23 1/m
Gebäudehüllfläche	5 654,74 m²		

Energiebedarf Bürogebäude, ...

Standortklima



	NEB absolut kWh/a	NEB spezifisch kWh/m²a	EEB absolut kWh/a	EEB spezifisch kWh/m²a	PEB absolut kWh/a	PEB spezifisch kWh/m²a	CO2 absolut kg/a	CO2 spezifisch kg/m²a
Befeuchtung			0	0,00	0	0,00	0	0,00
Beleuchtung	58 174	9,20	58 174	9,20	16 469	2,60	1 459	0,23
Betriebsstrom	99 873	15,80	99 873	15,80	159 208	25,20	14 111	2,23
Kühlung	225 091	35,63	78 212	12,40	126 545	20,00	11 216	1,80
Hilfsenergie			142 412	22,50	229 659	36,40	20 356	3,20
Warmwasser	21 149	3,30	23 581	3,70	31 193	4,90	4 021	0,60
Heizung	352 487	55,79	226 159	35,80	269 401	42,60	42 956	6,80
Gesamt	756 774	119,80	587 699	93,00	832 475	131,80	94 121	14,90

HWB_{SK}	55,79 kWh/m²a	HEB_{SK}	62,10 kWh/m²a	KEB_{SK}	12,40 kWh/m²a	EEB_{SK}	93,00 kWh/m²a
$HWB_{Ref,SK}$	65,80 kWh/m²a	$Q_{Umw,WP}$	30,30 kWh/m²a				
		$Q_{Umw,WP,Bew}$	27,40 kWh/m²a			f_{GEE}	0,91 -

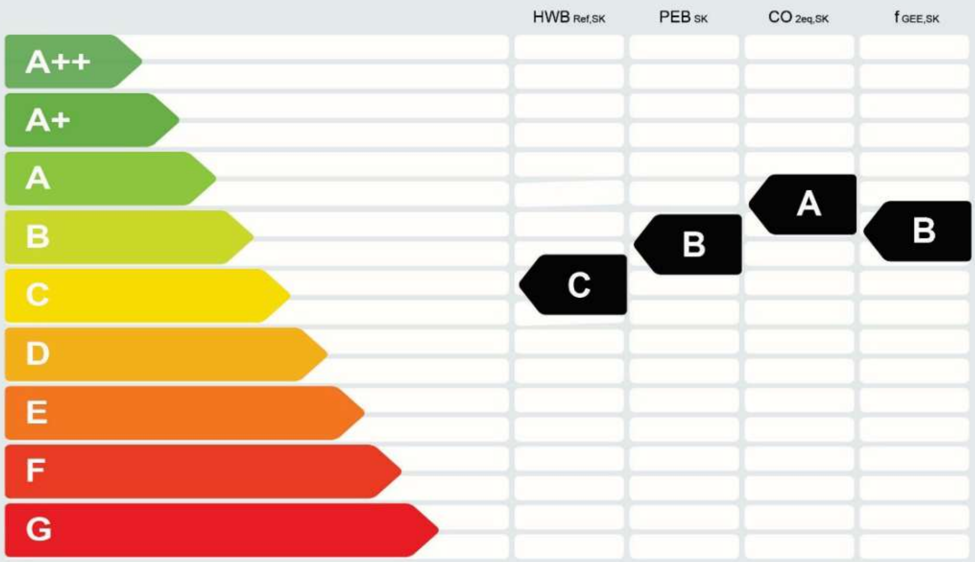
Gesamt-Energieausweis (Scenario 3)

OIB Österreichisches Institut für Bautechnik

OIB-Richtlinie 6
Ausgabe: Mai 2023

BEZEICHNUNG	Seilergasse 16 (Scenario 3)	**Umsetzungsstand**	
Gebäude(-teil)	Gesamtenergieausweis	Baujahr	2026
Nutzungsprofil	Bürogebäude, ...	Letzte Veränderung	
Straße	Seilergasse 16	Katastralgemeinde	Innere Stadt
PLZ/Ort	1010 Wien-Innere Stadt	KG-Nr.	01004
Grundstücksnr.	1098	Seehöhe	174 m

SPEZIFISCHER REFERENZ-HEIZWÄRMEBEDARF, PRIMÄRENERGIEBEDARF, KOHLENDIOXIDEMISSIONEN und GESAMTENERGIEEFFIZIENZ-FAKTOR jeweils unter STANDORTKLIMA-(SK)-Bedingungen



HWB_{Ref}: Der **Referenz-Heizwärmebedarf** ist jene Wärmemenge, die in den Räumen bereitgestellt werden muss, um diese auf einer normativ geforderten Raumtemperatur, ohne Berücksichtigung allfälliger Erträge aus Wärmerückgewinnung, zu halten.

WWWB: Der **Warmwasserwärmebedarf** ist in Abhängigkeit der Gebäudekategorie als flächenbezogener Defaultwert festgelegt.

HEB: Beim **Heizenergiebedarf** werden zusätzlich zum Heiz- und Warmwasserwärmebedarf die Verluste des gebäudetechnischen Systems berücksichtigt, dazu zählen insbesondere die Verluste der Wärmebereitstellung, der Wärmeverteilung, der Wärmespeicherung und der Wärmeabgabe sowie allfälliger Hilfsenergie.

KB: Der **Kühlbedarf** ist jene Wärmemenge, welche aus den Räumen abgeführt werden muss, um unter der Solltemperatur zu bleiben. Er errechnet sich aus den nicht nutzbaren inneren und solaren Gewinnen.

BefEB: Beim **Befeuchtungsenergiebedarf** wird der allfällige Energiebedarf zur Befeuchtung dargestellt.

KEB: Beim **Kühlenergiebedarf** werden zusätzlich zum Kühlbedarf die Verluste des Kühlsystems und der Kältebereitstellung berücksichtigt.

RK: Das **Referenzklima** ist ein virtuelles Klima. Es dient zur Ermittlung von Energiekennzahlen.

BelEB: Der **Beleuchtungsenergiebedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht dem Energiebedarf zur nutzungsgerechten Beleuchtung.

BSB: Der **Betriebsstrombedarf** ist als flächenbezogener Defaultwert festgelegt und entspricht der Hälfte der mittleren innenren Lasten.

EEB: Der **Endenergiebedarf** umfasst zusätzlich zum Heizenergiebedarf den jeweils allfälligen Betriebsstrombedarf, Kühlenergiebedarf und Beleuchtungsenergiebedarf, abzüglich allfälliger Endenergieerträge und zuzüglich eines dafür notwendigen Hilfsenergiebedarfs. Der Endenergiebedarf entspricht jener Energiemenge, die eingekauft werden muss (Lieferenergiebedarf).

f_{GEE}: Der **Gesamtenergieeffizienz-Faktor** ist der Quotient aus einerseits dem Endenergiebedarf abzüglich allfälliger Endenergieerträge und zuzüglich des dafür notwendigen Hilfsenergiebedarfs und andererseits einem Referenz-Endenergiebedarf (Anforderung 2007).

PEB: Der **Primärenergiebedarf** ist der Endenergiebedarf einschließlich der Verluste in Vorketten. Der Primärenergiebedarf weist einen erneuerbaren ($PEB_{ern.}$) und einen nicht erneuerbaren ($PEB_{n.ern.}$) Anteil auf.

CO_{2eq}: Gesamte dem Endenergiebedarf zuzurechnenden **äquivalenten Kohlendioxidemissionen** (Treibhausgase), einschließlich jener für Vorketten.

SK: Das **Standortklima** ist das reale Klima am Gebäudestandort. Dieses Klimamodell wurde auf Basis der Primärdaten (1970 bis 1999) der Zentralanstalt für Meteorologie und Geodynamik für die Jahre 1978 bis 2007 gegenüber der Vorfassung aktualisiert.

Alle Werte gelten unter der Annahme eines normierten BenutzerInnenverhaltens. Sie geben den Jahresbedarf pro Quadratmeter beheizter Brutto-Grundfläche an.

Dieser Energieausweis entspricht den Vorgaben der OIB-Richtlinie 6 „Energieeinsparung und Wärmeschutz" des Österreichischen Instituts für Bautechnik in Umsetzung der Richtlinie 2010/31/EU vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden bzw. 2018/844/EU vom 30. Mai 2018 und des Energieausweis-Vorlage-Gesetzes (EAVG). Der Ermittlungszeitraum für die Konversionsfaktoren für Primärenergie und Kohlendioxidemissionen ist für Strom: 2018-01 – 2021-12, und es wurden übliche Allokationsregeln unterstellt.

ArchiPHYSIK - Demo-Version - A-NULL | Demo | 23.01.2025

Collaborative research efforts

RESEARCHER	Valeriya Gridneva	Together	Marija Nakeva
CASE STUDY DATA ANALYSIS			
Photographic documentation of data retrieved from the state plan archive (MA37)	from 1980		till 1980
Documentation survey	full documentation		
BUILDING VIEWING			
Viewing	whole building		everything but the souterrain & cellar
Photographic documentation	from the cellar to the roof top		from parterre to the roof top with details
On-site analysis	whole building		from parterre to the roof top
BIM MODELING			
Constructive elements	Whole building outside envelope, existing inside walls, windows Plankgasse 4	Windows till 4. floor, new inside walls, façade Plankgasse 4, doors Plankgasse 4, walls material attribution	Façades ground floor, slabs, floor composition, wall composition, suspended ceilings, cellar, roof, beams, footing, stairs, lift(s), windows roof top, openings (incl. arches), balconies, railings, roof composition, cornices
Settings			Classification, modification status, position & load bearing status, construction materials, multi-layered components, layers, collision checks
CONDUCTING INTERVIEWS WITH EXPERTS			
Contact	Haugeneder, Wagenhofer, Wimmer, Kolmayr	Hunger & Kolar	Silvestru, Teichmann, Mittemair
Interview conducted	Wimmer, Kolmayr	Haugeneder, Wagenhofer, Hunger & Kolar, Teichmann, Mittermair	Silvestru
Question	Is the installation of external shading systems or shutters on building windows permitted in protected zones?"	What is the significance of the inner-city protection zone in Vienna's first district in relation to building interventions? Is only the outer shell/the external appearance protected as part of the	"What were the typical materials and construction methods used at the beginning of the 20th century?"

		ensemble of Vienna's inner city?	
	Does the protected zone of the first district differ from those in other districts?	"To what extent can the substance of a protected building be changed during renovation - e.g. rebuilding the cornices with new materials?"	"Are material values available for "historical"materials?"
	"What will the long-term future of renovation of listed buildings in Vienna look like? Who is the responsible and decision-making department in renovation cases? Is there room for negotiation in these decisions?	"To what extent can windows, doors, or façade designs be altered?"	"Can the materials that are dismantled be reused elsewhere in the building or outside of the building?"
	What challenges and opportunities do you see for renovation in line with the monument's requirements in view of the increasing demands on energy efficiency?"	"To what extent can changes be made to the interior of the buildings in protected zones?"	"Are there specific dismantling processes for waste disposal following a renovation?"
	"The first district of Vienna is set to be equipped with central heating by 2040, as described in the "Get off Gas" program by Wien Energie. In this context, is there still a need to consider alternative heating systems? If yes, which alternatives would be particularly suitable from a heritage conservation perspective?"	"How well can the materials used in renovations be combined with the original materials from the early 20th century?"	"Does the multifunctional or flexible design influence the building's life cycle?"
	"How will the Austrian government implement the new EU directives on the energy performance of buildings (EPBD)? The regulation excludes listed buildings, but national governments have the option of	"What are the best or most effective renovation strategies for the buildings in protected zones or/and buildings under monument protection, especially to improve energy efficiency?"	What happens if valuable parts of the building (e.g. cast-iron elevator) no longer comply with building regulations?

	carrying out renovations to increase energy efficiency in these buildings as well. Will Austria become active in this area? If so, in what form could this happen?"		
	"How big are the chances of transforming an existing building into a zero-emission building?"		"Where is the boundary between the energy savings achieved through energy-efficient renovations and the emissions caused by the production and disposal of the materials used (e.g. thickness of thermal insulation, double vs. triple glazing)?"
Transcription	Silvestru, Haugeneder, Wagenhofer, Wimmer, Kolmayr, Hunger & Kolar, Teichmann, Mittermair		Mittermair