# Renovation and retrofitting of old buildings in times of climate crisis

edited by Tomasz Jeleński

Sendzimir Foundation · Croatia Green Building Council
2022

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**Authors**
**Introduction and Chapters: 1, 2.1, 2.2, 2.4, 3.1, 3.2, 3.6, 3.7, 5, 7**
Tomasz Jeleński (Cracow University of Technology)
**Chapters: 2.3, 2.5**
Łukasz Konarzewski (Silesian Regional Heritage Office) and Tomasz Jeleński (CUT)
**Chapters: 3.2, 3.5**
Tomasz Jeleński (CUT) and Cezary Czemplik (Polish Natural Building Association)
**Chapters: 3.3, 4**
Anna Zaręba (Nicolaus Copernicus University in Toruń) and Tomasz Jeleński (CUT)
**Chapter 3.4**
Robert Wójcik and Piotr Kosiński (University of Warmia and Mazury in Olsztyn)
**Chapter 6**
Mihaela Zamolo (Croatia Green Building Council)
**Chapter 8**
Tomasz Jeleński (CUT), Ewelina Pękała and Agnieszka Czachowska (Sendzimir Foundation)
**Preface and Introduction to the Case Studies**
Ewelina Pękała (SF)

**Scientific editor**
Tomasz Jeleński, PhD Arch (CUT)
**Reviewers**
Anna Ostańska, PhD DSc Arch Assoc Prof (Lublin University of Technology)
Filip Suchoń, PhD Arch (Cracow University of Technology)
**Translation**
Tomasz Jeleński (CUT)
**Managing editor**
Ewelina Pękała (SF)
**Proofreading**
Magda Konopka, Stephen Russell
**Cover, DTP and graphic design**
Marcelina Michalczyk
**Cover photo**
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# Contents

# Preface

**Ewelina Pękała** · Sendzimir Foundation

In the 1990s, when the Sendzimir Foundation started its activity, a small group of scientists, activists, and public figures was aware of how climate change may be catastrophic for humanity and biodiversity. Our goal was to disseminate academic and practical knowledge about the principles of sustainable development so that it would become an inspiration for a larger group of people representing various social and professional groups. We knew that the effectiveness of education requires the cooperation of many milieus, so in our projects, we focused on the exchange of experiences as well as participatory processes of identifying challenges and opportunities. Courses, workshops, summer academies, post-graduate programmes, and the development of a variety of publications have been aimed at raising awareness and disseminating expert knowledge.

By 2022, mitigation of climate change and adaptation to its effects became the aim of many organisations and governments of all levels. Striving to meet climate goals affects almost every area of science and public life. Ambitious assumptions and plans must be followed by actions that require practical guidelines, catalogues of possible solutions and good practices. One of the most important challenges today is to reduce the energy consumption and carbon footprint of buildings and the building sector.

In various countries, especially in the European Union, tangible measures have already been taken to increase the energy efficiency of new and renovated buildings. There are also many publications on the energy modernisation of late modernist buildings, mainly mass housing constructions from the second half of the 20th century. Historical buildings, erected with the use of traditional technologies and including those under conservation protection, remain a major challenge.

Adequate maintenance, renovation or modernisation of such buildings is necessary to achieve carbon neutrality by 2050, but most old buildings are not subject to the obligation to adapt to technical conditions that minimize energy consumption. They are subject to various types of thermal renovation and modernisation treatments mostly due to the increasing costs of heating. Insufficient knowledge about the specifics of traditional construction among the owners and caretakers of old buildings, as well as building contractors, is the cause of frequent errors resulting in thermal modernisation being ineffective and even harmful.

In 2020, we launched the project “Climate Mitigation in Heritage Buildings” in cooperation with the Croatia Green Building Council. The project received funding from the European Climate Initiative (EUKI). We started with identifying the challenges and available solutions through a series of in-depth interviews with conservators, architects, investors, managers of historical buildings and building contractors. The next step was to develop e-learning courses available in Polish and English. The courses were attended by several hundred people professionally related to the subject. From among the graduates of the training courses, we selected over one hundred people who took part in design workshops in Bielsko-Biała, Koprivnica, Mysłowice, Olsztyn, Rijeka and Zagreb (the results of their work are described briefly in Chapter 8).

The publication “Renovation and retrofitting of old buildings in times of climate crisis” is the culmination of this two-year process and results from the work of an interdisciplinary group of experts.
The book is addressed to a wide audience who are looking for guidance on:

- how to improve welfare, well-being, and quality of life in old buildings, while simultaneously decreasing carbon footprint,
- how to properly ventilate the interior, avoid dampness, and decrease the risk of inundation and flooding, while reducing heating costs, dust pollution and $CO_2$ emissions,
- how not to jeopardize the historic and aesthetic value of old buildings, but to ensure their durability for future generations as valuable elements of the cultural environment.

An important group of readers are public and private investors, as well as employees of local government units who plan large-scale energy renovation works. We hope that the guidelines contained in this publication will make it easier for them to choose the optimal scope of renovation measures, technologies and materials that are safe for buildings and effectively reduce the financial and environmental costs of work undertaken, the costs of using objects after renovation and their total carbon footprint.

We thank all our interlocutors, academic experts and practitioners representing various sides and phases of the heritage conservation and energy renovation processes, who found time to share their knowledge with us. We believe that the diversity of perspectives is the fundamental value of our project. We also thank the participants of the workshops who tested the algorithms presented in this publication and helped to refine them. We are convinced that only through broad participation and dialogue is it possible to better understand the challenges and the real potential for the renovation and modernisation of historic buildings in times of climate crisis.

# Introduction

**Tomasz Jeleński**
· Cracow University of Technology

# Challenges of resource-efficient and climate-friendly renovations and retrofits

Building retrofits currently affect only 0.5–1% of the building stock per year. To achieve the emission reduction target set out in the Paris Agreement, it is necessary to significantly increase the pace and scope of energy renovation and retrofitting.[1]

Better use of the existing building stock is one of the main ways to reduce the need for new construction, and thus reduce the carbon footprint of the building sector. This can only be achieved by increasing the usability and energy performance of old buildings to extend their usefulness, especially in the context of an ageing society.

More and more old buildings are abandoned or inhabited only by elderly people of minimal means. These buildings do not provide thermal comfort or wellbeing, and most often they do not have elevators. It is necessary to tackle energy poverty and improve living and working conditions through the installation of clean and efficient heating, fighting dampness, and improving ventilation and thermal insulation. The basic requirements also include universal design factors that overcome architectural barriers and other accessibility constraints (see Chapter 1.4).

According to the assumptions of Poland's Long-term Renovation Strategy, by 2050, 66% of buildings in Poland will be brought to a very low-energy building standard (VLEB; $UE_{15}$; 15 kWh/$m^2$/a), and 21% to a low-energy standard (LEB; $UE_{40}$; 40 kWh/$m^2$/a). The remaining 13% of buildings that cannot be so deeply modernised for technical or economic reasons, will be in the efficiency range of UE=90–150 kWh/$m^2$/a.[2] Residential buildings built before 1944 constitute as much as 26% of the national housing stock.[3] The comparison of this data shows that at least half of the housing stock built before 1944 will have to be brought to a low or very low-energy standard. The remaining part needs to be adapted either to power supplies from low-temperature heating networks or to generate their own energy from renewable sources.

Considering only the residential buildings in Poland, economically viable energy modernisation will allow for **final energy (FE) savings** of 147 TWh (approx. 75% of the FE demand in 2021), **reduction of $CO_2$ emissions** by over 37 million tonnes per year (approx. 10% of the total annual greenhouse gas (GHG) emissions in Poland) and **reduction of particulate matter (PM) emissions** by approximately 89,000 tonnes per year (approx. 25% of the total national PM emission).[4]

The impact of buildings on the environment is most often specified by universal indicators such as energy efficiency and carbon footprint (see Chapter 1). The impact also applies to the local environment, e.g. the building's share in the emission of particle pollution, its contribution to the generation of the urban heat island effect and stormwater runoff problems. The prospects for successful renovation reducing the environmental and climate impact of a building depend on its location, structure, insulation

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[1] Architecture2030, *Why the building sector?* https://architecture2030.org/why-the-building-sector/ (August 2021).

[2] BIP, *Projekt uchwały Rady Ministrów w sprawie przyjęcia „Długoterminowej strategii renowacji budynków", MRPiT, Warszawa 09.06.2021.* https://www.gov.pl/web/premier/projekt-uchwaly-rady-ministrow-w-sprawie-przyjecia-dlugoterminowej-strategii-renowacji-budynkow2 (September 2021).

[3] Mańkowski, Stanisław, Edward Szczechowiak (ed.), *Opracowanie optymalnych energetycznie typowych rozwiązań strukturalno-materiałowych i instalacyjnych budynków* [in] Zamieszkane Budynki. Narodowy Spis Powszechny Ludności i Mieszkań 2011, GUS, Warszawa 2013.

[4] BIP, op.cit.

and internal installations including heating, ventilation and own energy generation systems (see Chapter 3 and 5). They are also often dependent on external factors such as the possibility of connecting to a heating network.

An important, often underestimated element improving the climatic end energy performance of the built environment is greenery – integrated with buildings and laid out in their surroundings. Plants cool the air and shade the building in summer, protecting it from overheating or glare. Gardens and green roofs limit or delay the discharge of rainwater to the collectors reducing stormwater runoff and flood hazards. Greenery improves physical and mental health, and may improve the appearance of a building and its climate resilience (see Chapter 4).

## Challenges in built heritage protection

For heritage buildings, the most important external factors are cultural, legislative and policy frameworks that protect the historic environment and determine the scope of permissible renovation (see Chapter 2.1–2.3). Not all solutions improving a building's performance and serving climate protection can be applied to historic buildings. Each building has a different history – therefore, the scope of renovation or retrofitting must be determined individually for each building, with applied conservation knowledge. This expertise must be applied not just to listed monuments but all other buildings built with traditional techniques and materials.

However, an insufficient number of conservation specialists and problems in communication between the various actors of the renovation processes: investors, architects, designers, and conservators, make it very difficult to apply practical building conservation knowledge widely (see Chapter 2.4).

Our interviews show that even basic knowledge about the maintenance of traditional buildings is poorly disseminated. In addition, conservation recommendations and guidelines are often ignored. They are blurred by popular myths, e.g. about the high cost of conservation measures, their purely aesthetic significance, or the greater effectiveness of modern technologies. The subsequent threat to the health of the building and its users is not only neglect, but also, and perhaps most importantly, reckless, inadequate action. The conservation approach aims to protect buildings against the destructive effects of time and human error. When it comes to renovations and retrofits, mistakes happen very often, leading to the climatic imbalance of a building, then deterioration: of its substance, the internal climate, the wellbeing of its users, and a rise in energy consumption.

During the renovation or retrofitting of historic buildings, a number of interdependent applied measures, elements, materials and technologies will require a very broad analysis of their impact on human health, building physics and performance, preservation of historical substance and cultural heritage. In this publication, we try to look at these various issues from several perspectives – conservation, modernisation, heritage, climate, theory and practice.

The basic issue relevant to theory and practice that requires knowledge of the principles of traditional building conservation and the true potential of new technologies, is how to define the criteria applied to the scope of conservation or modernisation, the depth of intervention, and the use of specific technologies and materials. Such decisions must of course pay regard to human health, be environmentally friendly, economically sustainable and not threaten the cultural values of the building and its surroundings (see Chapter 2).

Sustainable design is based on understanding the relationships between various interdependent phenomena and predicting the long-term effects of design decisions. One needs to look for solutions that bring positive results in several aspects. Appropriate scope of interventions and the proper selection of solutions can improve thermal comfort and indoor climate, protect against sick building syndrome and at the same time reduce energy consumption, the emission of air pollutants and greenhouse gases (see Chapters 3–5). It is therefore about the synergy effect, in which we increase the usability and economic efficiency of the building, protect its heritage value, reduce external costs (including the impact on the climate) and increase the building's resistance to phenomena that threaten its technical condition and the condition of its users.

A more place-specific challenge concerns the improvement of a building's resistance to seismic actions. All European seismically active countries struggle to protect heritage buildings against seismic risks or to repair, recover, or reconstruct them to prolong their life after earthquake damage occurs. The recent earthquakes in Croatia have become another premise for seismic retrofitting to historic buildings that should be implemented alongside climate renovation (see Chapter 6).

# 1

# Renovation strategies

**Tomasz Jeleński**
· Cracow University of Technology

## 1.1. Energy renovation

Renovation is an umbrella term which may describe a variety of interventions in a building: from routine upgrades to restoration, rehabilitation, modernisation and retrofitting (see Chapter 2.4). Minor renovations correspond to 0–30% of final energy savings, moderate to 30–60%, and deep to 60–90%, while nZEB renovations represent savings beyond 90%. They mostly focus on insulation of the building envelope and replacement of inefficient heating, cooling, ventilation and hot water systems.[5]

In Poland, energy renovation, more popularly known as 'thermal modernisation', is often mistakenly associated with façade insulation. The legal concept of 'thermal modernisation' is, however, much broader and means an investment aimed at **reducing primary energy consumption** for heating and hot water.[6] This can be accomplished through a series of interrelated activities improving the thermal and humidity parameters of the building structure and the efficiency of its systems:

- repair or correction of the gutters, downspouts and drainage systems,
- moisture protection of the building – drying the walls and protecting them against capillary soaking,
- insulation of the roof, ceilings and floors,
- elimination of thermal bridges and air leaks around windows and doors,
- renovation or modernisation of windows and doors,
- insulation of external walls,
- heat recovery ventilation,
- modernisation of the heating system, including connection of the building to a centralized heat source (e.g. heating network) or replacement (total or partial) of the energy source with a zero- or low-emission one, preferably renewable,
- planting greenery supporting the energy efficiency of the building and improving the external and internal climate.

The thermal losses of an average building through the external walls are estimated at approximately 20–30% of the total energy losses. The remaining 70–80% escapes through an ineffective ventilation system, leaks in the windows and doors, uninsulated roofs, floors, and thermal bridges at the connections of various structural elements.

Therefore, a popular approach to energy renovation that mainly consists of covering the building with a thick layer of insulation is often incorrect. It may bring an **inadequate decrease in useful energy** demand, at the same time deforming the building visually and exposing its users to the risk of deterioration of the quality of the internal environment. In the case of historical buildings, the result is often a loss of architectural value: covering architectural details and original materials such as stone or brick or a specific plaster grain and texture as well as altering the depth of windows' recess. Modification of the thickness and width of the walls disturbs their

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[5] Economidou, Marina. *Energy renovation*, European Energy Efficiency Platform (E3P). https://e3p.jrc.ec.europa.eu/articles/energy-renovation (May 2022).

[6] Dz.U. 2008 nr 223 poz. 1459 – *Ustawa z dnia 21 listopada 2008 r. o wspieraniu termomodernizacji i remontów oraz o centralnej ewidencji emisyjności budynków* (*Dz.U. z 2018 r. poz. 966*).

proportions in relation to the plinth, eaves, cornice, and roof ridge. Defective or ill-considered insulation may also lead to accelerated degradation of the building and its interior climate.

> **Scope of energy renovation**
>
> The decision on the scope and selection of energy renovation measures should be preceded by an analysis covering, inter alia, the architectural value and condition of the building, the available solutions and potential changes in the building's physics and interior climate.
>
> A very helpful, although expensive method of analysis is the thorough **energy audit** (see Chapter 1.2). If the goal is not only to reduce energy consumption but also to mitigate climate change in a broader sense, decisions should also be preceded by a **carbon footprint analysis** (see Chapter 1.3).

Thermal insulation of the façade without preliminary study may lead to the insulation of damp objects which would cause the insulation itself to be ineffective and – in the case of insulation from the outside – promote mould growth in the interior, while insulation from the inside may cause frost bursting of the façade. The use of polystyrene insulation and airtight windows in the absence of adequate ventilation of the interior may lead to rapid degradation of the building due to water condensation.

A condition essential to correct design of the insulation is a full assessment of the original building envelope and the solution being considered, according to the following criteria:

- thermal properties (resistance, stability, expansion),
- heat capacity,
- depth of freezing,
- water vapour diffusion,
- thermal bridges and places of surface moisture condensation.

If one cannot or does not want to insulate the façade due to its architectural value, it is best to leave it without any interference except for repairing the wear and tear. The walls of historical buildings, especially those built before the 20th century, are thicker, which increases their thermal resistance R (K/W) (this depends on the thickness of the material), and have a high thermal capacity. **Old buildings with wall thicknesses exceeding 40 cm, do not necessarily require thermal insulation of the external walls.** However, the possibility of energy renovation of the remaining elements of the building should be considered: revamping windows and sealing their embedment in the wall (see Chapter 3.3), insulation of the roof and basement ceiling or floor (see Chapters 3.4 and 3.5). Another step that significantly reduces energy consumption, although more difficult to implement, would be the modernisation of the ventilation system, enabling energy recovery from the exhaust air (see Chapter 3.6). Then, it may be beneficial to insulate the building from the inside, but this solution is safe only if the ventilation is very efficient (we pay a lot of attention to this issue in Chapters 3.2–3.4 and 3.6.).

The possibilities of modernising heat sources should always be considered: connection to the heating network or modernisation of internal systems preferably using energy from renewable sources – use of a heat pump, photovoltaic cells, or solar collectors (see Chapter 5).

Each building has different internal and external conditions; therefore, the designer should analyse all the problems related to the scope of energy renovation individually. If possible, it is recommended that projects be based on an **energy audit**, which should show what benefits can be obtained by using specific solutions that reduce energy consumption, carbon footprint, and other internal and external costs while maintaining the historical, cultural, and aesthetic values of the building.

# 1.2. Energy efficiency and demand

Each building, during construction, operation (use) and demolition, contributes to energy consumption. This consumption is described by the following indicators:

- **Useful energy (UE)** [kWh/m$^2$a] is the indicator of the energy needed for heating/cooling, ventilation, and domestic hot water (DHW) preparation. It is calculated from the heat balance of heat gains and losses through the building envelope and ventilation. The UE value does not depend on the type or efficiency of heating and ventilation systems. It is used to evaluate architectural and building solutions.
- **Final energy (FE)** [kWh/m$^2$a] is the indicator of the **operational energy efficiency** balanced at the building boundary, i.e. the energy that must be purchased for heating/cooling, ventilation and domestic hot water (DHW) systems, and in public buildings also for built-in lighting systems. The FE indicator depends on losses and gains resulting from both the architectural/building solutions and the efficiency of the systems. If the FE value is slightly higher than the UE value, it means that the building is equipped with highly efficient systems. FE may be even lower than UE, if renewable energy is used in the building. FE is particularly important for the user of the building, as it is directly related to the expenses for its use. A building with a low FE is economical to operate.
- **Non-renewable primary energy (NRPE)** [kWh/m$^2$a] is an indicator of the building's non-renewable energy demand for heating/cooling, lighting, ventilation and DHW. This indicator regards environmental costs and losses in the production and transmission of energy considering the type of energy carrier. NRPE may be greater than FE: from 10% in the case of gas supply to the building, up to 300% when using electricity generated in coal-fired power plants. Low NRPE values indicate high heating and ventilation efficiency and low energy demand of the building or the production of renewable energy on site. A building with low NRPE is climate friendly.
- **Embodied energy (EE)** is the energy consumed by all the processes associated with the production of the building, from the mining and processing of natural resources, manufacturing and transport of materials, construction of the building and its systems, to all repairs and modernisations. Embodied energy does not include the building operational energy consumption nor its end-of-life stage, which would be considered in a life cycle approach.
- **Cumulative energy demand (CED)** is a lifecycle-based indicator, which includes NPRE, EE, and the energy associated with the building end-of-life: demolition or disassembly and disposal of waste. This indicator enables the design of buildings of reduced negative impact on the environment throughout their life cycle. Life cycle thinking is a good approach to be used for environmental decision-support, although the complexity of the Life Cycle Assessment (LCA) sometimes prevents its wide use (we discuss LCA in Chapter 1.3).[7]

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[7] For basic building materials one can find indicators quantifying the extraction of raw materials, energy consumption in the production process, water consumption, waste generation, and $CO_2$ emissions. However, the indicators may vary. Differences result from various production processes and different sources of raw materials and energy. There is also a range of LCA databases and CAD applications, but mostly prepared for a specific market. Therefore, applications and databases for design with the use of LCA should be used within the same market, if possible. Węglarz, Arkadiusz and Piotr Ziembicki, *Optymalizacja projektowania budynków przyjaznych dla środowiska z wykorzystaniem oceny LCA* [in] Fizyka budowli w teorii i praktyce, t. VII, Nr 44/2015. To harmonize information on the impact of products and construction work on the environment, the EU has introduced a voluntary Environmental Product Declaration (EPD) based on the standards ISO 14025 and EN 15804.

### Energy audit

An energy audit is a procedure that determines the energy consumption profile of a given building or complex of buildings and the range of solutions (technical, organisational, and formal) to rationalize and reduce energy consumption. The audit is carried out before the energy modernisation project. It is an objective opinion on the profitability of certain solutions that supports optimal decision making.

The audit carried out by an authorised energy auditor should include:

- Assessment of the thermal properties of the building, inventory of energy-consuming systems and determination of the energy performance of the building.
- Indication of rational ways to reduce energy consumption.
- Assessment of the profitability of each solution including internal and external costs.
- Indication of which solutions are optimal for the examined building in terms of costs and outcomes: reduction of energy consumption and $CO_2$ emissions.

The procedure is complicated, but its effect is a breakdown of costs, profits, payback period, and other economic indicators for each type of modernisation.[8] The audit is therefore a good basis for making an informed decision on how to renovate or modernise the building cost-effectively. Some subsidies for the renovation of buildings or their systems can be granted only if the audit is performed. This applies, inter alia, to projects co-financed from European funds.

Building **energy performance** upgrades (to limit **UE**) rely on reducing energy losses through:

- optimised building geometry – compactness and functional arrangement of the interior
- thermal insulation of the envelope, including elimination of thermal bridges
- increased thermal capacity of the building
- airtightness that allows the elimination of uncontrolled heat losses and penetration of moisture
- energy efficiency of external glazing – thermal insulation and solar energy transmittance of architectural glass

To improve the **operational energy efficiency** of a building (to limit **FE** and **NRPE**) additional factors must be considered:

- natural air-conditioning
- efficient heating and DHW systems
- efficient energy recovery ventilation
- energy-saving lighting
- energy management
- generation and/or procurement of renewable energy that allows balancing or limiting the demand of energy drawn from the grid

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[8] Dz.U. 2009 nr 43, poz. 346. *Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009 r. w sprawie szczegółowego zakresu i form audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a także algorytmu oceny opłacalności przedsięwzięcia termomodernizacyjnego.*

The amount of embodied energy and cumulative energy demand (CED) can be minimized by:[9]

- designing durable buildings for a long period of use, of stable material that do not require frequent repair
- preferring materials produced in processes that are low-emission and without troublesome waste
- ensuring the ease of separating various elements and materials
- using materials available locally with a high degree of recyclability

It is recommended to use natural, renewable, and diffusion-open materials such as wood, lime mortars, clay, straw, hemp, cork, cellulose, and natural wools. They are more sustainable and will regulate the indoor climate.

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[9] Architecture 2030, *Carbon Smart Materials Palette*. https://materialspalette.org/insulation (August 2021).

# 1.3. Carbon footprint and life cycle approach

A carbon footprint is a type of ecological footprint that translates into the total sum of GHG emissions directly or indirectly related to a building over its entire life cycle. The carbon footprint includes emissions related to:

- extraction and/or production and transport of building materials, as well as construction, renovation and modernisation processes (embodied carbon footprint),
- building operations (use stage carbon footprint),
- demolition or disassembly (end-of-life carbon footprint).

Currently, the materials and construction of new facilities account for 11% of annual GHG emissions globally, and the use of existing buildings (building operations carbon footprint) accounts for 28% of global emissions (Fig. 1).

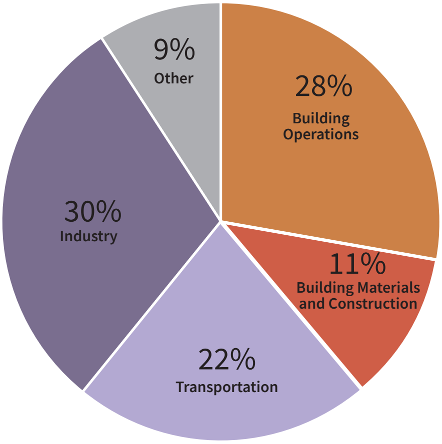

**Fig. 1.** Global $CO_2$ emissions by sectors.[10]

The footprint of the use stage can be reduced over time by improving the energy efficiency of existing buildings or the use of renewable energy in them. In effect, the new standards of building energy efficiency and planned mass renovation/modernisation (including the Renovation Wave program[11]) will cause the construction of new buildings to become the primary source of emissions. It is already the case that in the period 2020–2050, the share of embodied carbon will almost equal the footprint of building use. [12]

Therefore, the basic principle of sustainable urbanization and building is to continue to use existing buildings and limit new construction. Most older buildings should undergo deep energy renovation or modernisation and, in some cases, adaptation to new functions – a kind of recycling, giving them a new life. Even a significant retrofit process will have a much smaller impact on the environment than a new structure, even of the highest energy standards. As a result of energy modernisation, the embodied

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[10] Global Alliance for Buildings and Construction, International Energy Agency, UN Environment Global Status Report 2017. https://worldgbc.org/wp-content/uploads/2022/03/UNEP-188_GABC_en-web.pdf (August 2022).

[11] UE, *Fala renowacji: KR i Komisja Europejska rozpoczynają współpracę w celu pobudzenia modernizacji budynków*, 18/03/2021. https://cor.europa.eu/pl/news/Pages/renovation-wave-CoR-and-Commission-launch-cooperation-to-boost-building-overhaul.aspx (August 2021).

[12] Architecture2030, *Embodied Carbon Actions*. https://architecture2030.org/new-buildings-embodied (August 2021).

carbon footprint grows relatively insignificantly, while the reduction of the building's energy demand (NRPE) may considerably reduce the operational carbon. At the same time, the emissions related to the end-of-life stage (disassembly and/or demolition and disposal of waste) are avoided or postponed.

Even if, due to conservation or budgetary constraints, a deep modernisation of a given building is impossible, its operational carbon will still be much smaller than that embodied in an entirely new facility. Therefore, **it is important to make every effort to fully use existing buildings before deciding on a new construction**.

### 1.3.1. Carbon footprint analysis

Dedicated tools are used to assess the environmental impact of buildings. The most important is the Life Cycle Assessment (LCA).

In accordance with the EN 15978: 2012 standard, the following stages of the life cycle are analysed (Fig. 2):

- **Product stage** (A1 – A3) – includes emissions related to the acquisition and transport of raw materials and primary energy used in the production of all materials and products used to construct the building.
- **Construction process stage** (A4 and A5) – includes processes from the gates of construction product factories to the completion of construction work: transport of materials and products, including storage and distribution, as well as processes related to erecting and equipping the building with systems, installations, and fixed elements.
- **Use stage** (B1 – B7) – covers the time from the completion of construction works to demolition or disassembly, i.e. a wide range of emissions related to the operations of the building: ventilation, heating, cooling, lighting, water supply and other utilities, as well as maintenance, repairs, refurbishments and adaptations.
- **End-of-life stage** (C1 – C4) – covers demolition or disassembly and any impacts caused by them, e.g. transport and disposal of demolition components and materials.
- **External Influences** (D) – includes demolition or disassembly as a source of items and materials that can be reused or recycled.

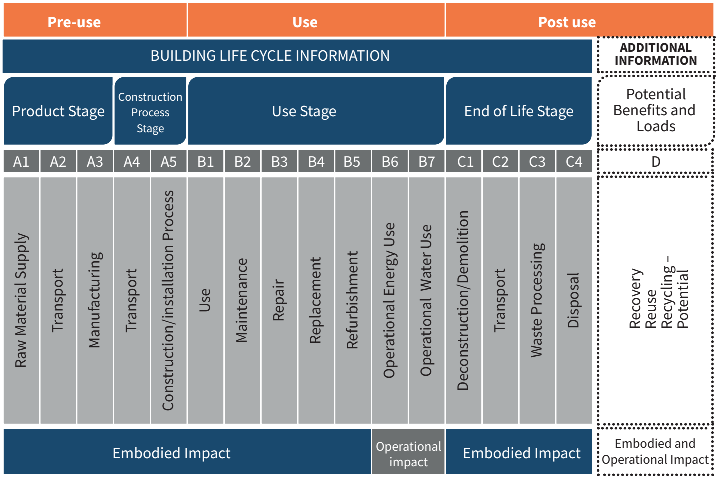

**Fig. 2.** Stages of whole-building life cycle assessment (wbLCA), according to EN 15978:2011.[13]

The analysis should be carried out at the stage of designing a construction, renovation, or modernisation. This allows the implementation of long-term solutions to limit the negative environmental impact of the building.

## 1.3.2. Design for carbon footprint reduction

When designing an energy renovation or retrofit, the key to reducing carbon emissions may be the selection of the best available products for the needs of a specific project.

### Carbon footprint of construction materials

One of the recommended directions is the design of structural elements with optimized dimensions in relation to the provided load capacity and reduction of the share of cement-containing materials (mainly concrete and cement plasters). Popular construction materials such as aluminium and steel also have a high carbon footprint but cement stands out as its production is responsible for 8% of global $CO_2$ emissions. Cement also has unfavourable properties considering building physics, especially in conservation applications, where cement mortars, joints, and plasters often cause irreversible damage to the historical substance.

The lowest carbon footprint characterises natural and local materials, unprocessed or low processed, the production and transport of which do not consume much energy.

To choose the optimum solution, one can look for low-carbon options comparing EPDs[14] of products of the same function, for example, the carbon

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[13] Illustration *Stages of whole-building life cycle assessment (wbLCA), according to EN 15978:2011* from: Silva, Vanessa, Lizzie Pulgrossi, *When part is too little: cutoff rules' influence on LCA application to whole-building studies.* Conference Windsor 2020: Resilient Comfort, Windsor, UK 2020. https://www.researchgate.net/publication/341494301_When_part_is_too_little_cutoff_rules'_influence_on_LCA_application_to_whole-building_studies (September 2021).

[14] EPD – Environmental Product Declaration is a document detailing the environmental performance of a product during its entire life cycle (LCA). It is defined in the ISO 14025 standard, which should make it possible to compare products of the same function. The basic standard ISO 14025 (for EPD) was supplemented in 2012 with the standard EN 15804 which defines the basic procedures for the preparation of EPDs for construction products.

footprint of engineered wood vs. dimensional lumber or oriented strand board (OSB) vs. plywood boards.

Such a comparison must consider the design properties of each material. Although engineered wood products typically have a higher carbon impact per unit weight than dimensional lumber, they are stronger and therefore require fewer members, which may reduce emissions overall. OSB has comparable characteristics to plywood sheathing, but OSB has about double the carbon footprint of plywood.[15] Engineered wood products such as Laminated Veneer Lumber (LVL) and Parallel Strand Lumber (PSL) have a larger embodied carbon impact than sawn lumber, even accounting for their greater strength.[16]

**Carbon impact of wood products**

Wood is increasingly returning to widespread use in construction as a low-carbon, renewable alternative to concrete, steel, and aluminium. Trees sequester carbon during their life, pulling $CO_2$ from the atmosphere and storing it in their mass and surrounding soil.[17] Using reclaimed wood or wood from climate-smart forests, manufacturing wood without the use of fossil fuels, and prioritizing the longevity of wood-constructed buildings are the best ways to reduce the carbon footprint of wood products.

Climate-smart forestry[18] is key to reducing carbon emissions and sequestering atmospheric carbon. Specifying wood from climate-smart forests helps ensure that harvested trees are replaced and that forests are not degraded, so that working forests maintain a consistent or increasing level of carbon sequestration.[19]

Carbon emissions occur during the transportation, milling and manufacturing of wood products. Specifying wood as locally as possible reduces the greenhouse gas emissions from transportation. It needs to be considered that road transport uses several times more energy than rail transport and several dozen times more than water transport.[20]

Part of a sawmill's energy consumption is electricity-based, meaning that the grid mix that supplies the sawmill has a significant impact on its carbon intensity. Most of the remaining energy consumption is from on-site biomass (wood residues) or fossil fuel combustion in kilns to dry the wood products. When locally available, one should specify wood products that are partially or fully air-dried or, as a second choice, dried using biomass from the sawing process, which is a carbon-free alternative. Engineered wood products then undergo further manufacturing, requiring more energy consumption and associated emissions. Responsible sawmills and wood product manufacturers should keep a detailed inventory of material and energy consumption.

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[16] Ibidem.

[15] ASCE/SEI, *Sustainability Guidelines for the Structural Engineer* (Wood/Timber chapter). https://sites.google.com/site/seisustainabilitycommittee/resources/publications/guideline-toc (August 2021).

[17] Carbon Smart Materials Palette, *Carbon impact of wood products*. https://materialspalette.org/wood/ (August 2021).

[18] While there is no agreed upon definition of 'climate-smart forestry' yet, attributes can include: use of long rotation periods, addressing issues of health, water quality and retention, and habitat protection. Most importantly, one should specify wood that is not harvested from primary (old growth) forests since they store more carbon in vegetation and in soils than do younger forests. Logging them also undermines biodiversity and ecological complexity.

[19] Rainforest Alliance, *What is Sustainable Forestry?* https://www.rainforest-alliance.org/insights/what-is-sustainable-forestry (August 2021).

[20] Ibidem.

## Carbon footprint of insulating materials

When choosing an insulation system or material, considerations of operational efficiency (thermal performance, climate requirements, airtightness, resistance to moisture) and the emissions generated during the production, transport, use and disposal of the insulation material should be balanced.

The most popular insulation materials, such as polystyrenes and – to a lesser but still significant extent – mineral wool, have high carbon footprints of the production phase. Meanwhile, natural insulations, made of materials such as cellulose, hemp, straw, as well as sheep and wood wool, naturally sequester carbon and store it over their useful life. Their use significantly reduces the total carbon footprint of the building, not only in the use/operation stage but also in the construction/modernisation and utilization stage (Fig. 3).

Where project requirements allow, one should choose lower-carbon alternatives to Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), Polyisocyanurate (PIR), Structurally Insulated Panel Systems (SIPS), and Polyurethane (PUR). All of them (but for some bio-derived Polyurethanes produced from vegetable oils) are petroleum-based products that require significant energy to manufacture. It results in their high-embodied carbon footprint (Polystyrenes: 86.4–109.2 MJ/kg; Polyurethane: 72.1 MJ/kg). The lowest embodied energy and carbon footprint characterises materials such as cellulose (0.94–3.3 MJ/kg), cork (4 MJ/kg) and woodwool (10.8 MJ/kg).[22]

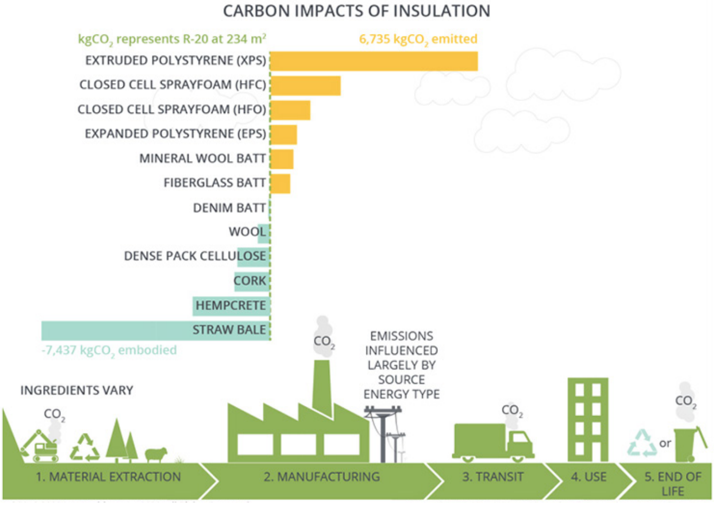

**Fig. 3.** Carbon footprint of some insulation materials.[21]

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[22] Hammond, Geoff and Craig Jones, *Inventory of Carbon & Energy (ICE), version 1.6a*. University of Bath 2008. https://perigordvacance.typepad.com/files/inventoryofcarbonandenergy.pdf (August 2021).

[21] Illustration *Carbon footprint of some insulation materials* from: Architecture2030, *Why the building sector?* https://architecture2030.org/why-the-building-sector/ (August 2021). Data Source: Builders for Climate Action – 2019 White Paper *Low-Rise Buildings as a Climate Change Solution*.

### 1.3.3. Life cycle costing

A wise alternative to pricing criteria, which too often determine the selection of the cheapest, yet low-quality materials and low-performance technologies, is the **Life Cycle Cost Analysis (LCCA/LCC).** It is an approach that allows evaluation of internal and external costs, benefits, and values (including non-monetary benefits) of a given solution or a whole building over its lifetime.

LCCA may confirm the validity of solutions that increase capital investment costs, but are more durable, and give better return and benefits at the use stage, both in terms of environmental and financial gains, and increase residual values of the building. Examples are the use of LED lighting, photovoltaic panels, or the multi-layer glazing of windows. The analysis may include less obvious relationships, which allow an increase in the sustainability of the building, including its resistance to environmental threats.

Externalities (external effects or spillovers) and non-monetary effects (benefits or costs) should also be considered, such as the preservation of cultural and historical resources, and the benefits derived from aesthetics, safety, or morale.[23] Examples of non-monetary attributes may include a particularly quiet ventilation system and an expected, but hard-to-quantify, productivity gain due to an improved working environment. These effects are external to the standard LCCA and are usually treated in detail as part of the Environmental Impact Assessment of construction projects. However, if they are significant, the mention of anticipated impacts (both quantified and qualitative) should be included in the project LCCA and considered in the final investment decision.[24]

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[23] WBDG Historic Preservation Committee, *Historic Preservation*. Updated: 08–23–2019, WBDG, Washington, DC. https://www.wbdg.org/design-objectives/cost-effective/consider-non-monetary-benefits (September 2021).

[24] Fuller, Sieglinde, National Institute of Standards and Technology (NIST), *Life-Cycle Cost Analysis (LCCA)*, Updated: 09-19-2016, WBDG, Washington, DC. https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca (November 2022).

# 1.4. Retrofit for all – universal design

When designing the renovation or modernisation of a historical building, along with the aspects of energy, climate and culture, other features related to the sustainability and usability of the building should be considered, including its accessibility for people with special needs.

The ramp for wheelchairs and strollers should be designed in a way that unambiguously preserves the composition and integrity of the historical form of the building. Openwork structures, not directly adjacent to the façade, are usually recommended. In the case of listed buildings, it is recommended to use high-quality, traditional materials, that refer to the character of the building. If possible, and where they do not impede access, ramps should be located at unexposed façades.

Design of a prospective elevator should respect compositional values, articulation and material of the façade, architectural detail such as cornices, friezes, etc., as well as the shape and angle of the roof. Due to these limitations, the installation of an elevator is usually recommended inside the building, provided that its implementation will not substantially affect the communication and the historical elements of the building interior.

Universal design increases the usability of a building and extends its life, especially in the context of an ageing society. It allows for a more complete use of the existing building stock and reduces the need for new buildings, thus reducing the carbon footprint of the construction sector.

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# 2

# Protection of built heritage

**Łukasz Konarzewski**
· Silesian Regional Heritage Office
**Tomasz Jeleński**
· Cracow University of Technology

# 2.1. Aims and principles of protection of architectural and building heritage

An outstanding architectural work or a modest structure might be considered a heritage building if it has acquired cultural significance over time. The protection of heritage buildings consists of examining them, formulating theories and principles of conservation, creating appropriate legislation, and taking official and administrative actions.

## 2.1.1. Development of built heritage conservation

The scientific approach to the protection of monuments has been developing ever since the 18th century. It was then that the first theories of the protection of material cultural heritage were formulated and discussion on the ways of preserving and displaying historic buildings, making them available, and disseminating knowledge about heritage began. The first monument protection offices were established in the 19th century. Cracow was the first city in Europe to establish such an office in 1820. Feliks Radwański – an architect, professor at Jagiellonian University, and senator of the Republic of Cracow, was authorized as a Commissioner for Built Heritage to issue opinions on all projects relating to historical buildings.

The 19th-century theory of built heritage conservation developed from disputes over various ideas – from the purist and functionalist views of Viollet-le-Duc to Ruskin's utopian concept of non-intervention, the application of which would lead to the inevitable destruction of historic matter. In conservation works (particularly the reconstruction of Cracow after the Fire of 1850), the value of layers from different historical periods in one building was noticed increasingly often. Camilo Boito – one of the first conservators using reliable historical research and studies in practice, appreciated the complexity of spatial, functional, and formal structures in historic buildings, which are the result of additions, transformations and modernisations. At the turn of the 19th century, the participants of the International Architects' Congress agreed that in the restoration of monuments one cannot stick to strict rules and that optimal solutions should be sought individually for each object (IV International Congress of Architects, Brussels, 1897).

In 1903, Alois Riegl's fundamental work was published, defining the terms: monument, monument protection and heritage value. Riegl's theory indicates the subjectivity of value assessment, which changes over time, has different national and cultural connotations and is also different for specialists and for the public. To avoid conflicts of interpretation, Riegl decided that a monument is merely constituted by historical, ancient, and monumental values. As a result, respect for the historical form and substance has become the guiding principle of conservation.[25] This theory was further developed by Walter Frodel, who additionally appreciated the utility value of the monument. Value in use makes it possible to protect the old building thanks to its integration into the contemporary cultural, social, and economic environment.

In the 20th century, the protection of monuments took on an international character. In 1931 in Athens, at the First International Congress of Architects and Technicians of Historic Monuments, universal principles of conservation activities were defined. The Athens Charter raised, inter alia, two important points:

- integration of monuments with the modern world, i.e. the use of historic buildings to ensure the continuity of their existence;
- preserving the character of historic cities by protecting entire complexes and views.

Since then, several dozen international documents have been created, mainly by UNESCO and ICOMOS, specifying the principles and guidelines for the protection and conservation of material cultural heritage – buildings, building complexes, and cultural landscapes.[26]

### 2.1.2. Guiding principles in the conservation of built heritage

Despite the changes that appear over time in the definition of what constitutes a heritage building and methodological disputes regarding the scope and forms of protection, the basic principle of conservation might be reduced to a simple saying: “Better preserve than repair, better repair than restore, better restore than construct.”

It is also essential to consider conservation as a process in which it is important to think ahead rather than to focus on the needs of today. The overriding goal is to sustain the heritage for future generations. Thus, the theory of monument protection is, in a sense, a precursor of sustainability thinking. The challenge is to find methods that will effectively protect the cultural heritage, respect authenticity and the principle of minimum intervention while maintaining the usefulness of historic buildings, limit their negative impact on the environment and climate, and strengthen their resilience and resistance to threats. Among the most important threats are seismic shocks, military actions and violent weather events, including those caused by climate change, such as flash floods.[27]

The principles of the protection of historic buildings can also be considered from the technical or operational perspective. From the utility viewpoint, a building with an aesthetic and functional value is usually better protected. Beautiful and useful objects are habitually well-kept. Beauty can be a relative value, so the role of buildings is primarily determined by their utility.

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[25] Szmygin, Bogusław, *Teoria zabytku Aloisa Riegla*, Ochrona Zabytków, nr 3/4, 2003, nr 3/4, 148–153.

[26] Szmygin, Bogusław, *Vademecum konserwatora zabytków: międzynarodowe normy ochrony dziedzictwa kultury*, Polski Komitet Narodowy ICOMOS Międzynarodowej Rady Ochrony Dziedzictwa Kultury, Warszawa 2015.

[27] DW, *How can we prepare for extreme flooding*? https://www.dw.com/en/germany-belgium-floods-climate-crisis-adaptation/a-58318340 (August 2021).

Therefore, the adaptation of heritage buildings to contemporary functions, and the improvement of their utility standards, including energy efficiency, is acceptable from the conservation perspective.

Speaking more practically, buildings should first be kept in good condition (by means of preservation) and their original substance should be possibly strengthened against chemical factors, pests, microorganisms, and above all against water and dampness.

### 2.1.3. Basic threats and protection needs

Water, in any form, is a major threat to any building. Whether interior or exterior, it can cause significant damage to the structural integrity of a historic building and create numerous types of damage that may need to be addressed during conservation and renovation. Water damage also includes mould growth and internal deterioration due to incorrect humidity levels or a lack of humidity control within the building.

Moisture also reduces the effectiveness of thermal protection of the building. It can therefore significantly increase the energy consumption for heating, and indirectly, the carbon footprint of the building.

In seismically active and mining areas, earthquakes and tremors are factors that require preventive and reconstructive conservation and retrofit (see Chapter 6). Threats of a similar nature for historical buildings are posed by military conflicts and climate change. Protective action against all kinds of disasters may include research, inventory, and creating documentation that will enable correct reconstruction after damage.[28]

Reconstructions can be purely restorative or contain modifications that increase the building's resistance to future events (e.g. earthquakes or climate change), and/or increase the functionality of the building and reduce its operating costs, energy consumption and environmental impact, including its carbon footprint.

A functional building of low operating costs is easier to maintain and more durable because it is not in danger of being abandoned. Abandonment always results in a rapid degradation of a building's substance. The continuity of use of old buildings is primarily threatened by high operating costs, especially heating and repairs, and the growing requirements of users, e.g. in terms of sanitary facilities, elevators and interior comfort.

The most common threat to an old building is neglect. It can be counteracted by raising public awareness of heritage values and by targeting the owners and managers of old buildings with support programs to encourage conservation activities.

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[28] Jeleński, Tomasz, *Practices of Built Heritage Post-Disaster Reconstruction for Resilient Cities*, Buildings 8, no. 4: 53, 2018. DOI: 10.3390/buildings8040053.

## 2.2. Heritage conservation areas

Buildings that make up historic urban and rural complexes do not have to be of high architectural value. What should be protected are not necessarily just features that distinguish them among other buildings, but those qualities that organically bind them into spatial wholes of historic significance or landscape significance.

Heritage conservation might also apply to the townscape as part of the wider landscape. Therefore, it requires the integration of various types of spatial, social, economic, and environmental aspects. A town, which is not an open-air museum, must evolve and adapt to a changing society. Interventions are inevitable, the degree of an intervention, its scale and scope fundamentally need to be discussed.

If the continuation of a historical urban or rural complex is related to the process of change and transformation, conservation activities primarily involve the control and management of change. Equally important is risk identification and emergency plans that mostly apply to seismic and environmental threats including climate change.

## 2.3. The system of monument protection in Poland

The cultural landscape is a public good that undergoes transformations over time. These unfortunately include various deformations, degradations, and even destruction. The main goal of protection is to preserve heritage buildings and places in their original form, as unchanged as possible, and in the best architectural and technical shape. In this context, special responsibility for the condition of heritage buildings lies with their owners or holders, whilst Monument Protection Offices are legally empowered to supervise their protection.

Immovable monuments such as buildings and structures, having historical or artistic (architectural) or scientific value, are protected in several ways. The most common forms of legal protection are:

- entry in the **national heritage list** (strict protection of the external form and the interior – if these have been preserved and their elements have been included in the listing decision), [29]
- recognition in the regional and simultaneously municipal **heritage registers** (protection of the external form of buildings and, usually, also those internal zones that are publicly accessible). [30]

Another way to protect heritage is to establish **conservation areas** that cover sites with historic buildings in towns and villages, as well as manor or palace and garden complexes. Not all buildings that make up historic complexes or sites are necessarily of high architectural value. However, they are protected due to the qualities that bind them organically in a spatial whole.

The most important element of the heritage protection system in Poland is the network of Regional Monument Protection Offices (WKZ). Their main goal, in accordance with the title of the relevant Act,[31] is the protection of monuments and supervision over their maintenance. **The maintenance itself is the responsibility of their owner, tenant, or user.**[32]

A person who has the legal title to use a monument may request WKZ for recommendations regarding the use, upkeep, restoration, renovation, modernisation, or adaptation of the object. WKZ may also order the person holding the legal title to the monument to perform conservation or construction works if they appear necessary due to the risk of destruction or significant damage to that object.

Regional monument protection officers (regional conservators) act directly and indirectly through municipal conservators with whom they constitute conservation services in the regions. The position of the regional conservator is unique compared to other public administration institutions. While protecting historic buildings and the cultural landscape, WKZ must have influence

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[29] Art. 7 of the Act of 23 July 2003 on the protection and care of monuments (Dz.U. 2003 nr 162 poz. 1568 – Ustawa z dnia 23 lipca 2003 r. o ochronie zabytków i opiece nad zabytkami).

[30] Art. 22 of the Act of 23 July 2003 on the protection…, ibidem.

[31] Dz.U. 2003 nr 162 poz. 1568, op.cit.

[32] Art. 5 of the Act of 23 July 2003 on the protection…, op.cit.

over the architectural forms and artistic elements that shape the public space. The consent of the regional or municipal conservator is required for:

- all conservation-restoration, rehabilitation, renovation, adaptation, or modernisation activities in the listed building
- any activities that could lead to the violation of the substance or appearance of the monument, e.g. placing technical devices on it, such as solar panels, solar collectors, or HVAC devices
- division, change of purpose, or change of use of the historic building
- any construction works in the vicinity of the listed property
- removal of trees or shrubs from the area of a listed property

The conservator is obliged to issue a decision or order that usually determines the scope of work, the manner of its conduct, the term and the contractor. The necessity to consult the WKZ may also apply to non-historical real estate located in the conservation area or result from the provisions of the local plan.

Due to the complexity of tasks undertaken by the conservation services, they fulfil the law (in the substantive sense) to a large extent intuitively. It is impossible to legislate for all the criteria protecting historical, scientific, and artistic values of historic buildings and cultural landscapes. The protection of monuments and places is not an exact science in which hypotheses can be verified by experiments and evidence determined, but it is partly based on humanistic values and requires an understanding of why a given object has a cultural value and therefore needs special protection.

The selection of criteria, therefore, results from knowledge in the fields of aesthetics, history of architecture, professional conservation experience, and ultimately, also historical and aesthetic intuition. Each case is different and requires individual consideration, but also negotiations with the owners and users of monuments. Conservators pay special attention to this aspect. Investors should use the possibility of agreeing solutions with the office at the design stage of future intervention with the substance or appearance of a historic building.

Regional conservators may delegate some of their powers to municipal conservators, who often act as intermediaries between the regional office and the property's owner or user who plans some renovation or retrofit. The role of an intermediary agreeing detailed solutions should also be played by architects and other experts involved in the conservation of a given building who are responsible for the course of planned works. In this role it is important that architects and designers have adequate knowledge and experience in working with monuments.

## 2.4. Scope of approaches and interventions in historical buildings

Contrary to the simplified image of the preservation-modernisation relationship, there are no inherent contradictions between the conservation approach (focused on the protection of heritage) and the present-day modernisation approach (focused on the sustainability, wellbeing, saving energy and climate). Architectural and building heritage requires careful protection because it is a non-renewable resource of important social value. Effective conservation allows the historical buildings to be kept in good technical condition, enabling their further use, providing safety and comfort, and reducing the need for new construction. This latter point, as discussed in Chapter 1, has a significant climate mitigation potential. Also, most cases do not exclude measures to reduce energy consumption and operational carbon footprint.

Problems arise with the practical approach, when some concepts may be distorted, misunderstandings grow around conservation theories, and in the practice of renovation, incorrect and even harmful solutions are routinely repeated. One of the detrimental myths is the alleged costliness of conservation measures. In fact, the conservation paradigm of minimal intervention causes a fundamental reduction in the scope and depth of measures and thus also in their costs. Renovation or modernisation, carried out with the

Photo: Jan Piotrowski

**Fig. 4.** August Abegg Palace, the building of the Forest Inspectorate in Elbląg, built at the beginning of the 19th century, listed on the National Heritage List for Poland. After modernisation in 2017–2019, a decrease in energy consumption was achieved by 992.82 GJ/year (90–95% Primary Energy savings). Among others, mechanical ventilation with heat recovery, new wooden windows, heat pumps (ground and air source) and underfloor heating have been installed.[33]

[33] Stowarzyszenie Ochrony Narodowego Dziedzictwa Materialnego, *Konkurs Modernizacja Roku*. https://www.modernizacjaroku.org.pl/pl/edition/1691/object/1836/budynek-biurowy-nadlesnictwa-elblag (July 2022).

use of popular, widely advertised 'modern' methods and materials, can be much more expensive and, moreover, not durable or possibly even harmful.

There is a continuum of approaches and methods between the pure protection approach and the radical retrofit, which allows for the selection of appropriate measures to be applied in specific cases of historical buildings (we discuss these measures in more detail in Chapters 3–8).

In order to avoid unnecessary expenses and costly errors, it is worth, at the design stage and before commissioning the works, analysing and comparing the cost estimates of activities in various variants, from modern renovation to orthodox conservation solutions. Experience shows that in many cases, the traditional conservation variant, which is always the safest and most aesthetic solution, may also turn out to be by far the least expensive.[34]

Specific terms are used to describe the various conservation and retrofit approaches. It is necessary to precisely define them to avoid misunderstandings. In this section, we present short definitions of conservation terminology. The terms described here are arranged in an order that covers the entire spectrum of interventions, from minimum maintenance to deep modernisation and refurbishment.

## Preservation

Focuses on the maintenance and repair of existing historic materials and retention of all historic fabric and a property's form as it has evolved over time. It aims to keep the building in its existing state. Repairs must be carried out when necessary to prevent further decay. Damage and destruction caused by water in all its forms, by chemical agents, and by all types of pests and micro-organisms must be stopped to preserve the structure.[35] The process of preservation also involves a broad range of physical methods of maintenance and stabilization, as well as applied knowledge disseminated through education.[36]

## Conservation

This term means the wise use and management of a building to prevent unwanted change such as unsympathetic or incompatible alteration, decay, destruction, misuse, or neglect.

## Conservation-restoration

The term adopted by international conventions – covers all activities concerned with the protection and rehabilitation of cultural heritage. It was established to end discussions and remove doubts about what 'conservation' and 'restoration' are and how much the two areas overlap.

It means "any action, whether direct or indirect, on an object or a monument, performed to safeguard its material integrity and to guarantee respect for its cultural, historical, aesthetic or artistic significance. This definition conditions the nature, extent and limitations of the measures that can be adopted, as well as the interventions that may be made on cultural heritage."[37]

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[34] This observation is confirmed i.a. by analyses conducted by Professor Bogumiła J. Rouba. For example: calculations of the costs of works were made for a historic building, in which the total plaster area is approx. 1000 m², of which 20% of the plaster is irreversibly damaged. The calculations, prepared by a professional cost estimator, considered all costs (scaffolding, security measures, materials, cleaning, waste disposal, etc.) and differences in service prices in several Polish cities. The costs of works were calculated for three variants of the works: Variant A – radical renovation – assumed chipping off of the whole layer of old plaster, laying on a new one, and painting with modern silicate paints. Option B – renovation generally consistent with the conservation theory – assumed plaster replacement only where damaged, with modern plaster and painting the whole with modern silicate paints. Option C – conservative, fully compliant with the conservation theory – assumed replacement of plaster only where damaged with traditional (lime-sand or vintage) plaster, supplementing the color scheme only in the places of reconstructed plasters, with possible correction of the aesthetics of the whole. Variant C – conservative conservation (the safest and most durable) turned out to be, contrary to the prevailing misconception, twice as cheap as Variant B and four times cheaper than Variant A.

[35] Feilden, Bernard M., *Conservation of Historic Buildings*, Architectural Press, Oxford, Burlington, MA 1997, 9.

[36] Bucher, Ward, A.I.A. (ed.), *Dictionary of Building Preservation*, Preservation Press, John Wiley & Sons, New York 1996.

[37] ICCROM & Smithsonian Institution, *First Aid to Cultural Heritage In Times of Crisis: Course Glossary*, Smithsonian Institution, Washington, DC 2016.

## Restoration

The term means a set of activities applied to technically and aesthetically damaged monuments to restore their former architectural form as well as artistic and functional value. It includes treatments such as **reconstruction** or **extension** (reintegration, recomposition, integration) but first and foremost, it is about extracting the values that have been preserved in their authentic form. Restoration is conducted based on the preserved archival materials and with the preserved fragments of the building. New elements should harmonize with the whole, but one should be able to distinguish new elements added to the historic fabric.

The term can also mean a process or product of returning an existing building to its condition at a particular time in its history using, where possible, the same construction materials and methods. Typically, the period of greatest historical significance or aesthetic integrity is chosen. Restoration focuses on the retention of materials from the most significant time in a property's history, while permitting the removal of anything which postdates the intended period (after thorough documentation).[38]

## Rehabilitation

It is an act or process of reviving artistic, cultural, technical and use values of a building that acknowledges the need to alter or add to a historic property, to meet continuing or changing uses while retaining the property's historic character. It returns a property to a state of utility through repair or alteration which makes possible an efficient use in the structure of modern society while preserving those portions or features of the property which are significant to its historical, architectural, and cultural values.

## Renovation

The term refers to the process of returning a building to a good state of repair and improving it for modern use, so that it is functionally equal to a new building; thus, renovation may include major changes.

In listed buildings, renovation usually involves the repair or replacement of secondary or heavily used elements that have little or no historic value, and in their current technical condition have a negative impact on the aesthetics and functionality of the building. The most common renovations in historic buildings include roof elements and roof trusses, apartment interiors without any architectural details, staircases that do not require restoration, technical installations, and the damp-proof insulation of foundations.[39]

## Refurbishment

A term not used in the theory of monument conservation but very popular. It implies a process of improvement by cleaning, decorating, and re-equipping. It may include elements of retrofitting.

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[38] Weeks, Kay, *Historic Preservation Treatment: Toward a Common Language*, Cultural Resources Management Vol 19, No. 1, 1996.

[39] Narodowy Instytut Dziedzictwa, *Podstawowe pojęcia z zakresu konserwacji i rewitalizacji*. https://samorzad.nid.pl/baza_wiedzy/podstawowe-pojecia-z-zakresu-konserwacji-i-rewitalizacji (August 2021).

## Remodelling / Modernisation

The process of modifying an existing building or space for current use. Tends to be more focused on the aesthetics and appearance rather than the pure functionality of a building, typically with an attempt to make it look new or fashionable, as opposed to its restoration or rehabilitation.

## Retrofit

A term not used in the theory of monument conservation, but very popular and used in the fields of architecture and urbanism.

The goal of a retrofit is to improve some specific functionality of a building by adding new technology, systems or equipment, thereby making a building

Photo: IMage Produkcija

Photo: IMage Produkcija

Photo: Tomasz Jeleński

**Fig. 5.** Castle in Zabok, Croatia, built in 1889, listed on the Register of Cultural Goods of Croatia, currently functions as the Bračak Energy Center. The ruined building has been restored and its installations have been modernised in line with low-energy standards. Energy consumption for heating was reduced by almost 70%, from an initial 213.0 kWh/$m^2$ to 64.0 kWh/$m^2$. This changed the energy efficiency class from E to a low-energy level B with the use of 88% renewable energy. The building was dried and thermally insulated from the inside. The retrofit has included the installation of a pellet boiler with a capacity of 80 kW and efficiency of up to 94.9%, a highly efficient VRF system with an installed power of 95.2 kW, ventilation with over 90% of heat recovery, a natural gas micro-cogenerator for DHW with an installed electrical capacity of 6 kW and thermal power of 14.9 kW, energy-saving LED and T5 lighting, central monitoring and control system managing heating, ventilation, air conditioning and internal lighting, a fast charging station for two electric vehicles (2 x 22 kW) and a rainwater flushing system.

more efficient. Retrofit often involves the installation of modern heating and/or ventilation, or HVAC systems, additional insulation, or multi-pane glazing, so it serves to reduce energy consumption, carbon footprint and the emission of pollutants.

A retrofit may also improve the life expectancy of a building and allow for lower maintenance.

Seismic retrofitting projects improve a structure's ability to handle earthquakes or ground motion.

## Adaptive re-use

It means adapting an object to new functions. From the conservation point of view, adaptation permission is conditional to the preservation of all the characteristic features of the fabric and structure of the monument, which carry artistic and historical values.

# 2.5. Retrofit of historic buildings in practice

From the conservation offices’ perspective, energy renovation of historic buildings and their adaptation to climate change may be difficult, but to some extent possible. If the proposed technical solutions do not conflict with the objectives of heritage protection, the conservation services accept them. Moreover, if these solutions improve usability of old buildings, and thus the extension of their existence, they are not only accepted but recommended.

Therefore, it is worth answering the question of what the most common problems and difficulties with retrofit solutions are from the conservation viewpoint.

## 2.5.1. Protection of historical interiors

When introducing technical innovations in historic buildings, most of the changes concern the interior. If the historical interiors and their furnishings have been transformed and there are no reliable sources enabling their restoration, and an improvement of their usability is essential for practical reasons, there are no restrictions for accepting new technologies.

Examples include the recently restored wing of the Tiele-Winckler Palace in Bytom-Miechowice and the Donnersmarck/Mieroszewski Palace in Siemianowice Śląskie. In both buildings, due to transformations and significant damage, the historical interiors have not been preserved. The meagre iconographic information did not allow for their reconstruction. The change in function also made it necessary to install technical devices that meet modern standards.

Photo: 🅭 Ewa Waryś

Photo: © Jan – stock.adobe.com

**Fig. 6.** The Tiele-Winckler Palace in Bytom-Miechowice, built in 1817, listed on the National Heritage List for Poland as an element of the former palace-and-park complex. Left: the ruin of the palace annexe, view from the west (2018). Right: restored building (2022).

In Bytom-Miechowice, there was a need to arrange a conference room, exhibition rooms and offices. Therefore, internal insulation was applied and air-conditioning introduced, and an elevator was successfully built inside the staircase without any significant architectural heritage losses. Without damaging the interior, also plumbing and sanitary facilities as well as ICT and CCTV systems were installed throughout the building.

In the interiors of the Siemianowice palace, only the door woodwork had been partially preserved. That part was restored, and the rest was reconstructed. New conference and exhibition rooms; meeting places with back and utility rooms; brewing, gastronomic and commercial facilities with the necessary back-up have been introduced with adequate systems and installations. The building's upper ceiling and roof slopes were also insulated. The consent of the WKZ to the entire project was preceded by an archival query and an on-site architectural and stratigraphic study for the possible presence of polychrome decoration.[40]

These examples show that when an interior devoid of original décor is in question, it becomes necessary to first consider new functions and energy-saving solutions, and only in the next step a reconstruction or a new creation of the interior (if determined by the lack of source materials) that could harmonize or reference the style of the era from which the building originates.

Where the original interiors and furnishings are largely preserved, the possibility of introducing new technological solutions is not entirely excluded either. However, the scale of the difficulties and the costs of such activities are increasing.

Having the status of a monument has wide ranging, and sometimes decisive, importance for the possibility of introducing new solutions. Although ranks no longer exist in legal transactions in Poland (formerly listed buildings were classified in five or six grades), it is obvious that the standards of solutions will differ, for example between a baroque ducal palace and an average tenement house from the turn of the 19th century.

## 2.5.2. Protection of historical façades

Modernisation of the exterior is most often associated with the additional insulation of façades and the installation of devices that produce or save energy. It is unacceptable, from a conservation viewpoint, to use an insulation that covers architectural details and/or changes the stereometry of a building, especially a listed one. The alternative solution to insulate the building envelope may be to use thermal insulation from the inside. It is allowed if the original interior design is not preserved.

Large ventilation devices or PV panels on the visible roof slopes of a listed building or in the conservation area are also hardly acceptable. An example may be a conservation area in the centre of Miasteczko Śląskie (Tarnowskie Góry County, Poland) where, for scenic reasons, permission was not given to install PV panels on several buildings. Decisions were preceded by a scenic analysis performed from the street-level observation points. The views from

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[40] Documentation in the Archives of the Silesian Regional Monuments Protection Office, passim.

higher levels were not considered, because there are no significant dominant heights in the area. As many buildings in the area come from more modern times, the panels can be installed where they are not visible or will become practically imperceptible.

The conservation market is awaiting the development of BAPV (building-applied) PV solutions for roofs, windows, and solar blinds, similar in appearance to traditional materials.

## 2.5.3. The most common mistakes

From the perspective of conservation services, some of the greatest problems are caused by the irresponsible and inept attempts to modernise historical buildings, which aim to improve thermal comfort and save energy, but result in physical degradation of the historic substance and indirectly may also provoke threats to human health.

The most common mistakes are:

- Removal and replacement of old, original plasters.
- The use of mortars containing cement in places where cement or cement-lime mortars were not used. The mortar and plaster must correspond, in terms of parameters and composition, to the original ones.
- Replacing old structural elements with new ones, without stress analysis, resulting in different thermal expansion and different capillarity, which then cause degradation of the original substance.
- Interior painting with low vapor permeability paints.
- Introduction of modern damp-proof courses, vapour barriers, and membranes, which are all standard in modern construction but limit the ability of the old building to ‘breathe’ (allow moisture to evaporate).
- The replacement of the original window joinery. The woodwork made with new technologies (even if imitating the original), may change the microclimate of the interior and result in damage to its decor and furnishings and the emergence of health threats.
- Replacing the original flooring or using adhesives with cement. The old ceramic and stone floors were laid on a sand bed, sometimes with an addition of lime mortar or clay. New gluing technologies tightly insulate the substrate and increase the level of moisture in the construction.

The durability of a building and its cultural value are also significantly influenced by changes in the adjacent ground and landscape. The site is integral to a heritage object, requiring the same care and protection as the monument itself. Particular attention should be paid to proper maintenance of the landscaping and pavements, protecting or recreating the historic composition of greenery and properties of the ground. Removal of trees or other plantings, and sealing of the surface around the building, may change ground moisture and cause the building to get damp.

More about typical mistakes in renovation of historical buildings and how to avoid them can be read in following chapters.

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# Building Elements: Renovation and retrofit solutions

**Tomasz Jeleński**
- Cracow University of Technology

**Cezary Czemplik**
- Polish Natural Building Association

**Anna Zaręba**
- Nicolaus Copernicus University in Toruń

**Robert Wójcik**
- University of Warmia and Mazury in Olsztyn

**Piotr Kosiński**
- University of Warmia and Mazury in Olsztyn

# 3.1. Foundation and basement

**Tomasz Jeleński** · Cracow University of Technology

## 3.1.1. Moisture in foundations, cellars and basements

Building substructure and solid ground floors are endangered by ground moisture and groundwater if it occurs at a shallow depth. However, most problems in the basement zone are caused by penetrating stormwater, splash water and water vapour condensation (Fig. 7).

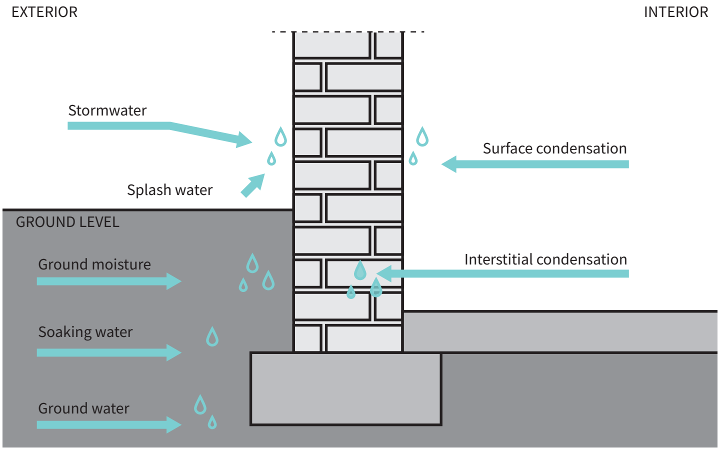

**Fig. 7.** Sources of moisture in the building substructure and plinth course.

Damp at ground level threatens not only the underground parts of the building. It can be transferred higher due to the capillary rise. Capillarity is a spontaneous rise of water (against gravity) in the voids of a porous material. Capillary water penetrates and soaks into the material that does not come into direct contact with the source of moisture.

Capillary action starting from the building substructure may cause the walls to become damp up to several meters above the ground. The height of capillary action depends on the building material – more cohesive materials, e.g. ceramics, raise the water higher than macroporous materials.[41] This phenomenon is one of the most common causes of damage to buildings. The visible effect of capillary rising is peeling plaster, defects in the material and joints, salt efflorescence and the development of microorganisms.

The effects of damp also include:[42]

- **Lowering the thermal resistance** of materials

  Even a few percent increase in moisture causes an increase in heat loss. For example, a ceramic brick in moderately humid conditions has a thermal

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[41] Rouba, Bogumiła J., *Zawilgocenie jako problem w ochronie obiektów budowlanych i zbiorów muzealnych* (*Dampness as a problem in the context of the protection of buildings and museum exhibition items*). MNRiPR-S, Szreniawa 2017, 35–58: 39.

[42] Trochonowicz, Maciej, *Wilgoć w obiektach budowlanych. Problematyka badań wilgotnościowych*, Budownictwo i Architektura vol. 7, nr 2/2010, 131–144. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BPL2-0019-0023 (August 2021).

conductivity coefficient of λ = 0.77 W/m·K, but with humidity of 15%, it is already about 1.6 W/mK. More than a twofold increase in λ of the wall causes an analogous decrease in its thermal resistance.

- **Decreasing the strength of materials** and the load-bearing capacity of structural elements

  Excessive moisture causes degradation of finishing materials: paints, plasters, facing materials as well as wooden and wood-based elements. The influence of moisture on the structural elements of the building might be even more dangerous. Some building materials soften under the influence of moisture, which is accompanied by a decrease in their strength. The moisture movement dissolves the substances that bind the walls and reduces their load-bearing capacity. The damp building envelope can also be severely damaged because of cyclic freezing and thawing of water contained in pores and capillaries.

- **Biological corrosion**

  Increased humidity very often leads to destructive processes caused by fungi, insects, algae, mosses, lichens, and bacteria. Biological corrosion changes and destroys the structure of the building, its insulation, and finishing materials. It also affects people staying in infected rooms – it may cause diseases of the respiratory tract, eyes, joints, and weakening of the body's immunity.

- Destructive processes related to the **action of salt**

  Water-soluble salts are among the most dangerous factors that destroy buildings, especially within the basement zone. Their high concentrations can lead to the complete destruction of the saline parts of the building. Water is the carrier of salt in building materials and damage occurs because of salt crystallization processes during its evaporation and the occurrence of the so-called crystallization pressure.

## 3.1.2. Damp-proofing strategy

The main task in conserving or retrofitting damp buildings is their drying, understood as a coordinated set of actions aimed at permanent reduction of moisture (usually to the level of 3–6% of mass humidity).[43] The process leads to the reduction of energy losses and energy demand of the building and possibly enables further energy modernisation works.

The first basic phase of the drying process is the removal of the source of dampness. Unfortunately, there are no universal methods to do so (see Chapter 3.1.5). The experience of the person undertaking damp investigations is often of greater importance than the technology they carry. It is important not only to counteract specific causes of dampness but also to **limit unnecessary actions**.[44]

Before planning damp-proofing, one needs to make sure that the dampness is not partially or entirely due to defects in the building's guttering and downpipes, water and wastewater systems, and drainage. The ground and

[43] Monczyński, Bartłomiej, *Wtórna hydroizolacja przyziemnych części budynków*, Izolacje 4/2019. https://www.izolacje.com.pl/artykul/fundamenty/190197,wtorna-hydroizolacja-przyziemnych-czesci-budynkow (August 2021).

[44] Monczyński, Bartłomiej, *Przyczyny zawilgacania budynków*, Izolacje 1/2020. https://www.izolacje.com.pl/artykul/fundamenty/194437,przyczyny-zawilgacania-budynkow (August 2021).

water conditions should also be assessed: the type and properties of the ground, its water load, and the possibility of improving those conditions.

Implementation of damp-proofing in a building that has been damp due to damage, technical wear or capillary penetration of fluid from the ground is a complex issue and practically every case should be considered individually. Modern methods of damp-proofing will not always be right to use, especially in buildings constructed with traditional technologies.

Traditional buildings were not equipped with damp-proofing insulation in the form of foil or bituminous or chemical membranes, nonetheless, they were effectively protected against dampness. The main strategy of damp-proofing was ground levelling around the building with the proper slope to move stormwater away. Natural material with a low infiltration rate such as clay mixed with loam (greasy clay) was put under the foundation and glued to the foundation walls, providing excellent damp-proofing.[45] The terrain gently sloping from the building was usually covered with grass or other plants. Additionally, façade gardens were being planted, increasing the evapotranspiration of excess water from the ground.[46]

These solutions were effective and durable. Problems may appear if drains and soakaways are damaged or blocked, or as an effect of excavation or elevation of the ground around a building.[47] Excavation may damage the original damp-proofing whilst raising the external ground level above the internal floor level causes the stormwater to soak into the building.

### 3.1.3. Causes of structural damp in historical buildings

Structural damp in buildings is the presence of unwanted moisture, either resulting from rain penetration or condensation within structures. A high proportion of the most difficult dampness problems concern the building substructure and plinth course.

#### Penetrating damp

Stormwater penetration is a common form of dampness that can occur through walls, roofs or openings. Common defects include roof, brickwork or masonry faults, missing or cracked pointing, missing or defective mastic around doors and windows, blocked weep holes, missing or defective trays in cavity walls, and holes in walls, e.g. where pipes or cables protrude. All those defects may contribute to building damp. What directly affects the building substructure is faulty guttering and drainage. Water penetrating the building substructure and plinth can quickly rise into walls contributing to structural damp.

#### Structural damp

From the 19th century onwards, the modernisation of cities sped up, with the raising and sealing of roads and sidewalks, and dissemination of water-repellent cement used for renders and mortars. Limiting the surface of moisture

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[45] Krause, Paweł, Agnieszka Szymanowska-Gwiżdż, *Sposoby uszczelnień i metody renowacji zawilgoconych ścian piwnic*. Izolacje 6/2018. https://www.izolacje.com.pl/artykul/sciany-stropy/186228,sposoby-uszczelnien-i-metody-renowacji-zawilgoconych-scian-piwnic (August 2021).

[46] Rouba, Bogumiła J., *Zawilgocenie jako problem w ochronie obiektów budowlanych i zbiorów muzealnych* (*Dampness as a problem in the context of the protection of buildings and museum exhibition items*), MNRiPR-S, Szreniawa 2017, 35–58: 42.

[47] The Society for the Protection of Ancient Buildings, *Historic Floors Guidance Note*, SPAB, London 2007. https://www.spab.org.uk/sites/default/files/documents/MainSociety/Advice/Historic%20Floors%20Guidance%20Note.pdf (June 2022).

evaporation from the buildings and the ground around them resulted in the accumulation of water in substructures and increasing problems with permanent damp.

Liquidating façade gardens and replacing them with concrete around the walls – introduced at the beginning of the 20th century to protect the buildings from stormwater – accelerated the processes of structural dampness and increased the salinity of the walls. The general assumption that covering the ground with concrete would prevent water from soaking underneath and keep the soil dry was completely wrong. On the contrary, sealing the ground increases the accumulation of moisture that cannot naturally evaporate.

Another common mistake was to apply bituminous insulation (effective for most new buildings) also to old substructures. Impermeable secondary insulation has been routinely used from the outside but sometimes also from the inside of the basement walls and to seal the basement floor. It incurred the risk of exacerbating any existing moisture-related issues and of causing problems in adjacent construction such as diverting moisture up into the walls.[48] Trapping and holding the moisture in the foundation and basement structure exacerbates the symptoms of rising damp. The only way of water migrating is through the walls of the ground floor, and sometimes also the first floor, that absorb excess moisture through capillary action.

The situation has been additionally worsened because of alterations of basement ventilation and the introduction of heating to previously unheated cellars and basements, which has resulted in the intensification of water vapour condensation.

## 3.1.4. Common damp-proofing problems

The first attempt to eliminate the problem of structural damp was the introduction of a horizontal damp proof course (DPC), which would cut off the capillary rising of water through the walls.[49] DPCs became a standard solution at the turn of the 19th century.[50] Their durability depends on proper care and maintenance.

Until the 1980s, scientists tried to explain the mechanisms of the formation of moisture and its effects, and engineers worked on improving technical methods of controlling moisture. Land-drains were recommended around the buildings and ‘breathable’ renovation plasters instead of cement-based plasters and acrylic masonry paints.

Systemic drying and damp-proofing measures have been increasingly widely used – systems of products from one producer implemented under the supervision of a specialized consultant. Those solutions have their advantages, but sometimes bad consequences as well, resulting from the elimination of conservation knowledge and the use of technology not always well adapted to the problems of a given building and the specific causes of dampness (Fig. 8).[51]

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[48] Historic England, *Energy Efficiency and Historic Buildings: Insulating Solid Ground Floors*, English Heritage, Swindon 2016.

[49] Rouba, Bogumiła J., op.cit., 46.

[50] Adamowski, Józef, Jerzy Hoła, Zygmunt Matkowski, *Skuteczność zabezpieczeń przeciwwilgociowych wykonanych w obiekcie zabytkowym*, Materiały Budowlane 3/2010, 50533.

[51] Rouba, Bogumiła J., op.cit., 52.

Photo: Bogumiła J. Rouba

**Fig. 8.** Stiff foil wrapped around the foundations of a church built of large erratic boulders. The foil will stop water evaporation, and if the joints were filled with mortar, conditions are created for evaporation-limited capillary penetration and structural damp.

Currently, there is a wealth of construction and conservation knowledge that enables effective solutions, even to very difficult cases. On the other hand, the pattern of using typical solutions, often expensive and sometimes ineffective or even harmful, has become established. For example, drainage is commonly employed in places where it is unnecessary and creates a risk of loosening the soil. There are situations when drainage, instead of removing water, begins to additionally moisturize the foundation of the building, especially when water from the roof also gets to it. Ill-considered drainage has disturbed the statics of many valuable buildings.[52]

## 3.1.5. Identification of the sources of damp

The most common causes of dampness in historical buildings are:

- Raising the adjoining ground above the 'line 0'[53] of the building, which results in direct water infiltration, often combined with capillary rising.
- Defective profile of the adjoining ground (no slope or even the opposite slope – toward the building),
- Hard surface of the adjoining ground resulting in wetting the wall or plinth with splashing water.[54]
- Barriers (such as high curbs) preventing rapid water runoff from the adjacency of the building.
- Faulty downspout drainage causing infiltration of rainwater in the adjacency of the building.

The cases of structural damp caused by the sealing of the adjacent surface are particularly difficult, especially in connection with ground profile (levelling) errors. The higher the ground level is than the original one, the more water may infiltrate the building.

[52] Rouba, Bogumiła J., *Projektowanie konserwatorskie*. Ochrona Zabytków 56/1 (240), 57–78: 61.

[53] The concept of the 'line 0' was introduced by B.J. Rouba to denote the level where two structures with different physical properties: non-absorbent (usually stone) foundations and absorbent walls meet. Recognition of the 'line 0' in relation to the ground level around the building allows a determination of whether there is a problem of side water infiltration into the walls.

[54] Rouba, Bogumiła J., *Zawilgocenie jako problem w ochronie obiektów budowlanych i zbiorów muzealnych (Dampness as a problem in the context of the protection of buildings and museum exhibition items)*, MNRiPR-S, Szreniawa 2017, 35–58: 37.

The cases of damp caused by disturbance of hydrological relationships are relatively rare. The groundwater level changes mostly because of various types of interference with the environment – the construction of dams, river regulation, but also extensive installations and underground structures.[55]

In practice, simple methods for identifying the causes of damp can be helpful. First, it is possible for anyone to measure the height of the ground level outside and the level of the floor inside. It is worth photographing or filming what happens to the water during rain – whether it is properly and quickly moved away and drained, or splashes the wall, or stays next to the building in puddles. Such observations often allow simple but effective actions to be taken immediately. [56]

## 3.1.6. Basic rules of damp elimination

Drying can be a lengthy, complicated and costly procedure, and yet ineffective. Often undertaken symptomatic treatment of dampness leads to hiding moisture, which is sufficient for the period of a five-year warranty provided by contractors. Technical measures applied ad hoc, without analysing the history of the facility and the chronology and scope of subsequent repairs and modernisations, will not remove unfavourable changes leading to excessive moisture.

The basic principle when drying a historical building is to spread the drying over time and escalate the methods (from the simplest to the more complex). Invasive methods such as drilling holes or digging deep into the ground should be avoided in accordance with the principle of minimal intervention. The safest is respecting the integrity of the building and returning it to its initial state.[57]

Photo: Bogumiła J. Rouba

**Fig. 9.** Defective ground levelling and drainage: pavement above the 'line 0' of the building; new curb that will keep water next to the wall, and gravel from which the rain will bounce and moisten the wall.

[55] Ibidem, 40.

[56] Ibidem, 55.

[57] Ibidem, 57.

Photo: Bogumiła J. Rouba

**Fig. 10.** This building illustrates the destructive effect of splash water bouncing from a hard concrete surface. The clinker cladding of the wall is deteriorated and detached. The other elevation, with a lawn adjacent to it, is in excellent condition.

To restore the original (appropriate) moisture level of elements recessed in the ground, reconstruction of the original or the shaping of new inclines should be carried out around the building. Re-profiling the ground adjoining the building needs to be done in such a way that rainwater flows freely away from the building to the outside. Any curb in the drainage zone blocking the outflow of water needs to be removed (Fig. 9).[58]

Photo: © LOGORYTM – stock.adobe.com

Photo: © Frans – stock.adobe.com

**Fig. 11.** Façade gardens at old buildings play an important role, protecting the plinth course against splash water and transpiring excess moisture from the ground at the foundation walls. Left: a façade garden in Katowice-Nikiszowiec. Right: a façade garden in Rotterdam.

[58] Ibidem, 54–57.

Damage caused by the destructive effects of stormwater, splash water, residual and melting snow, usually occurs in the plinth zone. If peeling paint, salt efflorescence, or even plaster detachment appears on the plinth course, it is necessary to protect the plinth from excessive moisture permanently. A soft and permeable green ground should adjoin the plinth course, which enables evaporation. A common mistake is that gravel or other hard material is left on the surface, which causes the water to splash. If possible, it is best to cover it with grass or other plants that absorb water droplets and transpire the moisture from around the building (Fig. 10) (see more about this in Chapter 4).[59]

If the underground zone of the building has been or needs to be waterproofed, the condition for correct renovation of the plinth is the precise connection of secondary plinth course sealing or a sufficiently waterproof existing plinth surface connecting with the insulation of the basement.[60]

The building can be additionally protected against the penetration of water and moisture by means of external drainage. However, this should be preceded by a groundwater survey. The use of pipe drainage in the presence of bound water or capillary water is pointless as it cannot be drained off with drainage pipes.[61]

Possible drainage should be placed away from existing buildings. To avoid uncovering the foundations, drainage pipes should be placed, if possible, at a distance of several metres from the strip footings. When sufficiently large space is available and the ground is sufficiently absorbent, distribution of drainage water over the site surface should be considered.

It is always worth considering green solutions that will help with soil drainage. There are known cases of very rapid physical degradation of historic buildings due to the felling of nearby trees. A large tree can absorb and transpire hundreds of litres of water from the ground a day. The removal of the tree results in a disturbance of water management. Climbers, shrubs and even grasses also contribute to the natural regulation of soil moisture (as discussed in more detail in Chapter 4).

In cases of serious disturbances in the humidity balance in historical buildings, permanent effects can be obtained only as a result of combining conservation knowledge (of old techniques, water management, climate, natural ventilation, strengthening traditional materials, principles of combining natural materials with new ones, and architectural aesthetics) and technical knowledge (building survey, physics, statics, strength tests, optimization of methods and materials).

Before applying technical solutions, the degree of moisture content should be assessed in relation to the permissible values of moisture in each of the materials. In the literature, one can find different values of permissible humidity for each material. The methods of measuring humidity are often based on the experience of the experts who perform the tests. One of the solutions is the use of combined measurements, allowing for quick mapping of the tested elements with meters, and then the selection of places from which the material for laboratory tests will be collected.[62]

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[59] Ibidem, 54.

[60] Monczyński, Bartłomiej, *Uszczelnianie i renowacja cokołów w istniejących budynkach*. Izolacje 10/2020. https://www.izolacje.com.pl/artykul/fundamenty/222347,uszczelnianie-i-renowacja-cokolow-w-istniejacych-budynkach (August 2021).

[61] Monczyński, Bartłomiej, *Przyczyny zawilgacania budynków*, Izolacje 1/2020. https://www.izolacje.com.pl/artykul/fundamenty/194437,przyczyny-zawilgacania-budynkow (August 2021).

[62] Trochonowicz, Maciej, op.cit.

## 3.1.7. Conditions for application of modern damp-proofing or moisture-resistant insulation

The selection of insulation technology should consider the external and internal conditions of the building, such as foundation material, groundwater level, soil type (permeable/impermeable) and the character of a site around the building. The project should also consider the issues of fumigation, desalination and drying.

A procedure that is often recommended in the event of building dampness, but which raises serious controversies, is vertical **moisture resistant insulation**. Experience shows that without a thorough examination of the causes of damp, that kind of insulation can lead to the aggravation of the problem instead of solving it. After installing improper moisture-proofing, water still penetrates the structure of the building, whilst new insulation does not allow it to drain and evaporate naturally. [63]

The basic rule regarding the foundation and basement is therefore not to use moisture resistant insulation where it was not originally applied. The decision to insulate the basement walls should always be preceded by an analysis of the state of preservation of the facility, determination of the causes of the observed damage, and an assessment of whether the planned solution is necessary and will solve the problem.

If the walls of the building are seriously affected by the capillary rising of damp, an effective method may be to (re)create a **damp proof course (DPC)** that prevents the penetration of moisture from the foundation into the wall. Before taking such a measure, diagnostics are necessary, based on which the renovation concept is developed including diaphragm location, materials and the method of application, accompanying (additional) measures and, necessarily, a method of long-term verification of the measures after their completion. [64]

## 3.1.8. Application of damp-proofing measures

### Damp proof course

DPC can be made using **mechanical methods** or **chemical injections**. Mechanical methods of restoring a physical damp proof course in masonry have been proven in practice for decades and are considered the most reliable way to inhibit the capillary rising of moisture.[65] Their disadvantage, however, is the need for a very serious interference in the structure of the wall, which is usually associated with the introduction of additional loads. This method is not recommended for older, massive walls due to the risk of cracks and even loss of wall stability.

[63] Bajno, Dariusz, Anna Rawska-Skotniczny, *Wybrane zagadnienia dotyczące zabezpieczeń podziemnych części istniejących budynków przed wilgocią*. Izolacje 7–8/2017. https://www.izolacje.com.pl/artykul/fundamenty/180430,wybrane-zagadnienia-dotyczace-zabezpieczen-podziemnych-czesci-istniejacych-budynkow-przed-wilgocia (August 2021).

[64] Monczyński, Bartłomiej, Mechaniczne metody wykonywania wtórnych hydroizolacji poziomych, Izolacje 9/2019. https://www.izolacje.com.pl/artykul/fundamenty/190197,wtorna-hydroizolacja-przyziemnych-czesci-budynkow (August 2021).

[65] WTA Merkblatt 4–7-15/D, „Nachträgliche mechanische Horizontalsperre", Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., München 2015: 11.

A relatively simple and effective, but also invasive and costly way to restore DPC, is an injection. If there are cracks or voids in the wall, they are filled with a suitable injection mortar or silicate-based liquid. If the wall has no cracks or voids, one can immediately apply injection of a liquid or cream making a horizontal diaphragm using gravity or pressure injection.

The latter can only be used for walls with high mechanical strength. Thermo-injection might also be performed to speed up drying and making the hydrophobic diaphragm. It allows a solid brick wall to be dried at up to 3% of mass moisture per day. In historic buildings, however, minimally invasive techniques are recommended. For highly damp walls, rapid drying may be dangerous due to shrinkage stresses, causing cracking, delamination, and peeling of plaster or damage to polychrome decoration, etc.

**Damp-proofing rods** is another method of DPC creation. They use similar active ingredients to those found in liquid or cream-based rising damp treatments, but the method of installation is simply to insert the rods into the correct sized holes drilled into a mortar.

However, before applying costly solutions that seriously interfere with the structure of the building, it is worth considering the use of **non-invasive electro osmotic systems**. This technique is still being developed and for years was treated with reserve by conservators. Only the latest solutions, confirmed by a few studies, allow the building to be dried efficiently and safely without interfering with its structure and with negligible electricity consumption.[66]

## Basement and cellar walls

In the case of walls with a low level of moisture and salinity, it is often sufficient to remove damaged plaster, especially if it is cement-based and impermeable. It can be replaced with inexpensive lime-sand plaster or renovation plaster, which has excellent vapour permeability and hydrophobicity. It enables damage-free drying and desalination of walls. Due to the high porosity of renovation plasters, salts (crystallising when the wall dries) accumulate in the pores of the plaster, without causing any blooms on the walls or damage to paints. To increase thermal insulation, heat-insulating plasters with high vapour permeability can be used.

If basements and cellars are to be heated, they should be additionally protected against excessive heat loss. The outer walls of basements can be finished from the inside with mineral thermal boards. They regulate air humidity and the microclimate of the interior, and thanks to thermal insulation properties, they reduce the possibility of water vapour condensation on the walls. High alkalinity and quick drying of the surface inhibit the growth of mould. If the wall surface is to be painted, paint with high vapour permeability must be used.

The most important measure accompanying the insulation of basements or cellars must be the appropriate improvement of ventilation. Cellars in historical buildings were not heated but naturally ventilated. Repurposing them into usable, heated cellars usually requires efficient mechanical

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[66] Ekodocieplenia, *Elektrosmoza – osuszanie budynków z 30 letnią gwarancją*. https://ekodocieplenia.com/elektroosmoza-osuszanie/ (September 2021); Aquapol, *Rozwiązanie – Zawilgocenie kapilarne*. https://www.aquapol.pl (July 2022).).

ventilation. When the warm, moist air comes into contact with a colder wall, the moisture in the air condenses on the cold surface, making the wall damp. Very effective ventilation is the only way to dry the interior and protect it from deterioration.

## Basement and cellar floor

The usefulness of insulating floors on the ground primarily depends on the way the rooms are used. If they are intended for storage functions, then the insulation of the floor is unnecessary, and in the case of storage of food or agricultural produce, it is even harmful. It should be considered that the isotherm of the ground under the building is usually approx. 8°C.

Thermally uninsulated floors must not be sealed. Traditional floors on the ground allow excess moisture to evaporate, which helps to maintain a thermal and humidity balance. Therefore, it is unacceptable to use vapour-tight flooring materials, bituminous seals, membranes, or cement-based adhesives and joints.[67]

In the case of heated rooms, thermal insulation of the floors should be considered. Non-absorbent materials should be used, e.g. rigid extruded polystyrene (XPS) or a lower carbon footprint replacement thereof, e.g. cellular glass insulation that is recycled, chemically inert and durable. The thickness of the layer is typically 12–16cm, but it needs to be selected to meet the currently applicable heat transfer coefficient for floors on the ground.

On such an insulated floor, underfloor heating may be used, which improves the thermal conditions of the rooms. Low-temperature heating is recommended, especially in interiors with valuable furnishings. However, it should be remembered that concrete structural elements used with underfloor heating are rigid and react to displacements and structural stresses differently than traditional structures, which are characterized by greater flexibility. This may have unexpected and unintended consequences for maintaining the structural integrity of the building so such solutions are not recommended for use in listed buildings.[68]

[67] Historic England, *Energy Efficiency and Historic Buildings: Insulating Solid Ground Floors*, English Heritage, Swindon 2016, 20.

[68] The Society for the Protection of Ancient Buildings, *Historic Floors Guidance Note*, SPAB, London 2007. https://www.spab.org.uk/sites/default/files/documents/MainSociety/Advice/Historic%20Floors%20Guidance%20Note.pdf (June 2022).

# 3.2. External walls

**Tomasz Jeleński** · Cracow University of Technology
**Cezary Czemplik** · Polish Natural Building Association

The external wall is the building element of which potential modernisation causes the most controversy and requires consideration in various aspects i.e. resource efficiency, climate mitigation and adaptation as well as building physics and the need for preservation of aesthetic and heritage values. In some cases, the best solution may be to leave the walls as they are or make only necessary repairs. In other cases, wall insulation may not only improve the technical condition and durability of the building, increase comfort, and reduce energy consumption, but also contribute to restoring the splendour of the façade, reconstructing its original appearance.

For energy losses the walls are statistically the second or third element of the building – after ventilation and possibly the roofs, where the greatest energy losses occur. From an energy point of view, heat loss is the main problem, but the different climatic conditions on counter sides of the outer wall cause complex physical processes related to the migration of heat and moisture. Moisture and temperature differences are, in turn, the cause of water condensation on the surfaces and interstitial condensation inside the wall.[69]

Moisture is the greatest threat to the building and its users. It is the main cause of the so-called sick building syndrome and physical degradation of the building structures. Increased humidity of a wall also changes its insulating properties since heat is lost faster through a damp envelope. When considering the construction of walls and their different layers, one needs to discuss not only thermal properties but also more complex thermo-humidity


Photo: Ana Šenhold

**Fig. 12.** The skyscraper at 7–9 Laginjina St. in Zagreb, built between 1957 and 1960, designed by Ivan Vitic – one of the most outstanding Croatian architects, listed on the Register of Cultural Goods of Croatia. The energy renovation of the building in 2016–2017 resulted in 68% primary energy (PE) savings and a change in energy class from E to C, with an annual calculated heat demand of 60.62 kWh/m$^2$.

[69] Monczyński, Bartłomiej, *Przyczyny zawilgacania budynków*, Izolacje 1/2020. https://www.izolacje.com.pl/artykul/fundamenty/194437,przyczyny-zawilgacania-budynkow (August 2021).

phenomena, paying attention to the migration of water or water vapour through the wall, condensation of vapour and the possibility of removing the excess moisture.

The second fundamental issue to consider in the context of potential insulation of external walls is the façade, which, apart from practical functions, has aesthetic and sometimes also historic value. In many cases interfering with the appearance and substance of the façade is not allowed, as this would result in the loss of scenic and/or heritage value. Therefore, the optimal method of thermal insulation, that is insulation from the outside (see Chapter 3.2.3), cannot be used sometimes. In such cases, one should focus on other elements of the building to be retrofitted or consider alternative solutions, e.g. internal insulation and/or application of thermal insulation plaster or paint approved by conservators. Those may improve the physical parameters of the façade without significantly changing the appearance of the building.

Insulating walls may be unreasonable, not only due to the protection of heritage values but also for the energy balance and economic calculations. This applies, for example, to facilities used periodically and to those where the lack of full thermal comfort (+ 20°C) is allowed, e.g. in churches, temples, exhibition or sport halls, and warehouse buildings. Even if they were insulated, initial heating of their walls and maintaining a comfortable temperature in their interiors might still require a large amount of energy. A better solution could be to provide local thermal comfort by means of low-temperature infrared heating (IR-C) panels or mats placed under workstations or benches (pew heating).[70]

## 3.2.1. Walls, insulation and building physics

Convection, diffusion and condensation of water are closely related to the insulation properties of the building envelope. Water in the external walls can appear as a result of precipitation, capillary rise from the ground through the foundations, and in the form of vapour in the air that penetrates the structure of the building. The most difficult task is to protect the walls against the penetration of large amounts of moisture in the air. This occurs mostly in the autumn and winter periods.

When the air cools down, some of the water vapour it contains is transformed into water (water vapour condensate). This may occur on cold surfaces of the building envelope.[71] The condensate may appear inside the wall too, due to the vapour diffusion that occurs between the various material layers, and temperature differences.[72] In both cases, damp causes various hazards including the growth of mould/mildew.

When designing a building envelope, one uses several physical factors describing heat conduction and heat resistance, and diffusion resistance:

- **λ** (lambda) [W/(m·K)] – denotes the thermal conductivity value for each building material. A low λ value means low thermal conductivity and the possibility of obtaining a relatively high thermal resistance.

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[70] In the case of listed buildings, care should be taken to protect the historical substance of the building and furnishings against localised overheating that can produce dimensional stresses, the cumulative effects of which can lead to mechanical damage. However, low-temperature radiant heating is relatively harmless and, unlike convection heating, does not pose a risk of increased humidity in the interior (see Chapter 3.7.2).

[71] At high air humidity, the risk of mould growth occurs even before the condensate appears. To assess the influence of air humidity on the processes of water condensation and mould development, the relative humidity parameter is employed.

[72] “Interstitial condensation can occur when moisture accumulates within the material’s pores or when vapour migrating through the envelope meets layers at a temperature that is lower than the dew point”. Brambilla, Arianna, Alberto Sangiorgio, *3 – Durability, condensation assessment and prevention*, [in] Arianna Brambilla, Alberto Sangiorgio (ed.), *Woodhead Publishing Series in Civil and Structural Engineering, Moisture and Buildings*, Woodhead Publishing, 2021, DOI: 10.1016/B978-0-12-821097-0.00006-0, 27–62.

- **$R = d/\lambda$** $[(m^2\cdot K)/W]$ – denotes thermal resistance that is proportional to the thickness of a layer of the construction component (such as a wall) and inversely proportional to its conductivity. The smaller the thermal conductivity value of a building component ($\lambda$) and the greater the layer thickness (d), the greater the thermal resistance of the component. In building components comprising several layers, the thermal resistances of the individual layers are added together.
- **$U = 1/\Sigma R$** $[W/(m^2\cdot K)]$ – an overall heat transfer coefficient, known as a U-factor, indicates the amount of energy that penetrates through the component in relation to the area of the component and the temperature difference on both sides. For non-listed buildings being renovated or adapted to a new function, it is required to raise the U-value of external walls to the standard of modern building regulations ($U = 0.15\ W/(m^2\cdot K)$). This should also be the target value in the case of retrofits not subject to a building permit.
- **$\mu$** (dimensionless) – water vapour diffusion resistance factor that determines the diffusivity, i.e. the movement of water vapour in the material resulting from the temperature difference.
- **sd** = $\mu\cdot d$ [m] – diffusion resistance factor specifies the diffusion resistance of construction materials, membranes, and paint coatings with a specified $\mu$-value and layer thickness (d).

A **diffusion-tight** wall is a barrier into which water vapour cannot diffuse and an arrangement of its layers ensures that it is not endangered by internal condensation at low temperatures. Diffusion tightness, i.e. the ability to limit the penetration of vapour through the building envelope, is of decisive importance in some modern strategies of thermal insulation of new and retrofitted buildings, especially when designing and implementing thermal insulation from the inside.

In historical or traditional buildings, the opposite strategy has been used. **Diffusion-open** / **capillary active** envelopes (popularly known as 'breathable') have provided minimal resistance to vapour. Diffusion openness allows excess moisture to escape beyond the wall, preventing dampness and biological corrosion. Diffusion openness characterizes most traditional constructions insulated with wood and natural fibres mixed with lime or clay.

Another important parameter describing the properties of a building envelope is **airtightness**, expressed by the $n_{50}$ coefficient. The technical and construction regulations include the following recommendations regarding the airtightness of the building:[73]

- building with natural or hybrid ventilation: $n_{50} \leq 3.0\ h^{-1}$
- building with mechanical ventilation or air conditioning: $n_{50} \leq 1.5\ h^{-1}$

Ensuring the airtightness of an envelope is primarily a condition for the effective use of ventilation systems with recuperation (described in more detail in Chapter 3.6.2). It is recommended that this parameter should reach even lower values: $n_{50} = 0.5–1$ when the verification of the level of air leakage (blower door test)[74] is performed. Adapting the walls to such levels of airtightness requires the elimination of air leaks around windows and doors and the insulation of technical culverts.

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[73] Ministerstwo Rozwoju, *Szczelność dyfuzyjna*, Budowlane ABC. https://budowlaneabc.gov.pl/charakterystyka-energetyczna-budynkow/informacje-poradnik/okreslenie-oplacalnych-sposobow-poprawy-efektywnosci-energetycznej-wlasciwych-dla-typow-budynkow/szczelnosc-dyfuzyjna (July 2021).

[74] The aim of the test is to investigate how permeable a building is to air infiltration. To perform this evaluation, the building is subjected to controlled differences of pressure and temperature.

The blower door test should be performed after sealing the joinery and before the thermal insulation of the walls. This will allow the identification of air leaks in the existing structure of the building. The second test, performed after insulation of the walls, will be helpful in determining the precision in the fit of the insulation, which is especially important for diffusion-closed internal insulation. The test result is also an element of the assessment of the energy performance of the building after the thermal retrofit. It can be combined with infrared thermography and manual measurements with anemometers to identify the exact location of air leaks.[75]

The airtightness of a building is closely related to, but not always necessary for, thermal insulation. Some thermal retrofit strategies require high airtightness, which must be coupled with mechanical ventilation with heat recovery. This applies, for example, to the *Passive House* standard (15 kWh/m$^2$) and its equivalent for historical buildings – EnerPHit (*Energy Retrofit with Passive House Components*) (25 kWh/m$^2$).[76] However, it should be noted that this is only one of the methods of thermal retrofitting and a thermally well insulated building does not necessarily need to be airtight (especially when it is naturally ventilated) and an extremely airtight building may still lose energy without proper thermal insulation of its envelope.

## 3.2.2. Wall materials

The choice of the method of wall insulation depends on the materials from which the wall is built. Most historic buildings in Poland have brick walls (83.43%). One in ten is built with wood and has a log structure (9.44%) or a timber-frame structure filled with various materials (1.85%). About 3% are stone buildings. The remaining buildings hide, under a layer of plaster, a variety of structures, from concrete and silicate to earth and adobe clay or bricks. The clay in the walls is usually combined with straw or wood chips to increase thermal insulation.[77]

The properties of walls, which determine energy losses and thermal comfort in interiors, result from both the insulating properties of materials and technological solutions. Light, porous, and fibrous materials are usually characterized by better thermal insulation (low λ value). This is due to the air contained in their structure, which is a good insulator. Heavy materials such as stone or ceramic and silicate bricks are characterized by higher thermal conductivity (higher λ value), which results in higher energy losses.

Uninsulated masonry walls allow for faster heat transfer to the outside, so they radiate relatively large amounts of energy to the environment, but can also accumulate energy in their mass. The high heat capacity of masonry walls stabilizes the interior climate, which is a very desirable feature because it reduces the need to cool the interior in summer. Heavy wall materials (of greater specific mass) have other advantages too, such as high compressive strength and greater sound absorbing capabilities.

Since the thermal resistance of a wall (R) is proportional to its thickness (d) and inversely proportional to its thermal conductivity (λ), obtaining good thermal parameters in a masonry building without additional insulation

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[75] Troi, Alexandra, Zeno Bastian (ed.), *Energy Efficiency Solutions for Historic Buildings: A Handbook*. Birkhäuser, Basel 2015, 253.

[76] 3encult, *Efficient Energy for EU Cultural Heritage*, Funded within FP7, GA No. 260162. https://www.3encult.eu/en/project/welcome/default.html (August 2021).

[77] Rozbicka, Małgorzata (ed.), *Raport o stanie zachowania zabytków nieruchomych w Polsce: Zabytki wpisane do rejestru zabytków (ksiegi rejestru A i C)*, Warszawa, NID 2017, 52.

layers requires very thick walls and a large amount of energy to pre-heat the building in the fall and winter season. Today it is very unusual to build walls thick enough to achieve good energy performance, but there is increasing evidence that the energy efficiency levels of traditional buildings, e.g. pre-1890 European public buildings, can be very high and at least match, and sometimes exceed, the levels in some highly technologically sophisticated modern buildings.[78] One of the reasons is that traditional buildings do not need to be air-conditioned thanks to the thermal mass of their thick masonry walls.

To achieve the best structural and thermal parameters of external walls, various technologies in multi-layered walls have been used. Traditional insulation of brick buildings used to have a form of ventilated hollow space (cavity) between two layers of the wall. Its main function was to reduce the passage of moisture into the interior of the building. Water is drained through weep holes at the base of the cavity wall and above windows. The weep holes also allow wind to create an air stream through the cavity that exports moisture from the cavity to the outside.[79] The effectiveness of a cavity wall in reducing heat loss is low due to air convection in the cavity. Moreover, in the case of disturbed air exchange or filling the air space with improper insulation material, the cavity may become a place for moisture condensation.

The most common type of insulated wall is presently a three-layer wall, in which the thermal insulation layer is separated from the ventilation void by a vapor-permeable membrane, and a two-layer wall, allowing for an optimal combination of physical properties (advantages) of heavy materials (with a high $\lambda$ but with very good load-bearing and thermal capacity and acoustic insulation properties) and light thermal insulation materials. The key decision is the location and material of the insulation layer.

### 3.2.3. Location of the thermal insulation layer

Although insulation on the inside makes it possible to maintain the original appearance of the façade, it changes the interior design and reduces the usable area. Another significant disadvantage of internal thermal insulation might be an obstruction of the heat flow from the interior to the external layers of the wall to such an extent that it makes the façade vulnerable to freezing (see more in Chapter 3.2.8 and 3.4).

According to building physics, external thermal insulation is a better choice, because it protects the original wall against stormwater and freezing, reduces temperature fluctuations and thus the risk of moisture condensation in the wall. With thermal insulation on the outside, it is also easier to ensure the tightness of the insulation. Therefore, behind the external insulation layer, the original structure can be well protected against moisture, frost, and thermal stress. This type of insulation also allows preservation of the original interiors.

Retrofit strategies with the use of commonly available external insulation systems may, however, encounter limitations resulting from aesthetic

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[78] CHCfE Consortium, *Cultural Heritage Counts for Europe: Full Report*, International Cultural Centre, Cracow 2015.

[79] Matthys, John H., *Masonry: components to assemblages*. ASTM, Philadelphia 1990.


Photo: Jacek Przetakiewicz

Photo: Jacek Przetakiewicz

**Fig. 13.** Reconstruction of the historic façade using polystyrene profiles.

reasons or heritage conservation. Original proportions of the façade and its elements such as architectural decoration, frescoes and sgraffiti, original plaster, or masonry and mortar joints, should be protected. For this reason, interventions such as external insulation are not possible in most cases of listed buildings or in conservation areas. If an elevation is not visible from the public space and has no special architectural value, conservators can allow external insulation, but reversibility of its application is important, hence materials such as dry cellulose/wood fibre and clay-based glue are preferred.

Regarding historical buildings of no heritage value, external insulation should always be considered. Solutions that apply external insulation (which increases the wall thickness) while keeping the original proportions of the façade can be found. To keep the original window recess and their visible dimensions, windows should be shifted towards the outside as much as the thickness of the applied insulation. Such repositioning of windows also increases the amount of light reaching the interior and helps to reduce thermal bridges, because in the new position the window is embedded in the insulation layer. To reconstruct lost character of a historical façade (e.g. on buildings stripped of decorations in the 20th century), replicas true to the original decorative elements can be made in the traditional stucco technique (most recommended), or alternatively in 3D printing or polystyrene as a last resort, and mounted on the insulation layer (Fig. 13).[80]

[80] Sobotka, Anna, Kazimierz Linczowski, Aleksandra Radziejowska, *Substitution of Building Components in Historic Buildings*, Sustainability 13, no. 16: 9211, 2021. DOI: 10.3390/su13169211; PPHU STYRO Jacek Przetakiewicz, *Sztukateria styropianowa na ścianę*, Lider budowlany. https://www.liderbudowlany.pl/artykul/wyposazenie-wnetrz/sztukateria/sztukateria-styropianowa-na-sciane (July 2021).

### 3.2.4. Insulation materials and vapour diffusion

To make a technically appropriate choice of insulation materials, it is important to first define the structure of the existing wall and to assess its vapour permeability (the sum of the diffusion resistance of all its layers). The moisture will penetrate in places with the relatively lowest diffusion resistance, e.g. through lime mortar or insufficient insulation around windows.

For walls with higher diffusion resistance, e.g. made of concrete, plastered with cement, or faced with clinker bricks on a cement-lime mortar, it is possible to use insulation with a higher diffusion resistance. For walls made of more diffusion-open materials, e.g. wood, silicates, clay or lime, insulation systems with lower diffusion resistance should be used, while still ensuring the hydrophobicity of external finishing layers, which will protect the wall against moisture penetration.

The distribution of moisture in the wall should be analysed in accordance with the ISO-13788-2003 Standard or by more advanced numerical methods.[81] They make it possible to determine the risk of condensation inside the wall considering the flows resulting from the pressure and temperature differences. On this basis, it is possible to calculate the rate of moisture evaporation and the risk of its long-term accumulation.

For organic materials, the risk of mould and fungi development can be determined (e.g. with WUFI® Mould software).[82] In practice, this risk is greatest in the case of initial dampness and in the period of moisture evaporation after building works, and then in the autumn and spring periods, the latter especially in cases of increased moisture content of materials after winter.

It is worth ensuring that the selected insulation technologies allow for the removal of moisture from insulated walls. Any potential dampness in the wall should decide the choice in favour of diffusion-open / capillary active materials, which (after removing sources of dampness and providing proper ventilation), should reduce moisture levels. However, one should always try to remove excess moisture before insulation is applied.

As for conditions allowing the formation of fungi on the internal surfaces, they depend not only on insulating materials but primarily on the efficiency of ventilation. A common mistake is to try to dry the walls by only heating the interior, without active removal of moisture by airing. Efficient ventilation is necessary, and it is often needed to additionally increase air circulation through fans or to use professional air dryers.

### 3.2.5. Preparation of the wall for thermal insulation

Before the application of the insulation layer (inside or outside), the walls should be protected against water penetration:

- in places of connection of various elements of the façade such as eaves, gutters, and downspouts; balconies and windowsills,

[81] For the simulation evaluation of walls, extended data on the physical characteristics of the materials are necessary. Fraunhofer IBP, *WUFI-Materialmessung EN*. https://wufi.de/de/service/downloads (July 2021).

[82] Vereecken, Evy, Staf Roels, *Review of mould prediction models and their influence on mould risk evaluation*, Building Physics Section, Building and Environment, Vol. 51, May 2012, 296–310.

- from the foundations (by proper drainage of stormwater, increased evapotranspiration, and as a last resort, application of horizontal damp proof course (DPC) if the capillary rising continues – see Chapter 3.1.7).

It is particularly important when insulating from the inside, because of the increased risk of freezing of the outer layers of the elevation. Water particles freezing inside the wall can cause micro-damage leading to the destruction of plaster and masonry mortars, and even damage to ceramic and stone façades. Therefore, simultaneously to insulating from the inside, it is recommended to thoroughly repair the façade. High-quality products for impregnation of façades may be used that protect them against the ingress of rainwater and condensate while allowing the migration of moisture from the wall and its evaporation.

The existing walls, including the plaster layers, must be structurally stable, without cracks through which heat and moisture can penetrate. For façades with curves and irregular textures, a solution needs to be chosen, which will not leave empty spaces between the old and new layers of the insulated wall.

Identification of the structure of the existing wall is an equally important issue. In **masonry** walls, special attention should be paid to the possible presence of a cavity. When renovating a **cavity wall**, it is necessary to take care of the **weep holes that provide air exchange**. The air stream through the cavity is necessary to avoid moisture condensation. Filling the cavity wall with insulation of fibre or granulate structure blown into the air space can substantially reduce heat loss, but insulation material must be selected with care to not affect the wall's 'breathing' performance. Materials recommended by experts include cellulose, hydrophobized perlite, and 'green' (low carbon footprint) polyurethane foam with a delayed foaming reaction.[83]

In the case of **timber** buildings, they used to be coated with paints of different properties. Before thermal retrofitting, it is important to **remove diffusion-limiting coatings** and protect the wood with fungicidal and insecticidal protection agents.

A separate issue is to meet the fire requirements of the structure. Sometimes it is necessary to secure the wooden façade to the fire retardation class, which is troublesome for ventilated walls. Suitable agents usually form a diffusion-reducing coating. This problem is characteristic especially for the Polish market due to the national specificity of the assessment of Fire Classification of non-fire spread, which limits the use of paints recognized abroad for not having the national attestation for specific façade systems.

## 3.2.6. External insulation

External thermal insulation needs to be applied on the entire façade. Leaving exposed fragments, e.g. due to existing decorations, not only deforms the façade but also leads to the formation of thermal bridges, increasing the transmission of heat and moisture through the exposed fragments.

Equally important, especially for mineral wool insulation, is to ensure the airtightness of the walls from the inside, and windproofness from the outside.

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[83] Podwysocka, Zuzanna, *Pozbądź się pustki!, Ocieplanie ścian szczelinowych,* Murator 5/2018. https://miesiecznik.murator.pl/budowa/pozbadz-sie-pustki_4128.html (July 2021).

In the case of constant infiltration of external air, the temperature inside the layer may drop, which may lead to water condensation. Windproofing is achieved using external membranes or tight plastering systems, with care for the tightness of window and door installation (see Chapter 3.3.3).

## Light-wet method: External Thermal Insulation Composite Systems (ETICS)

ETICS is currently the most popular method of wall insulation. There are various systems available on the market, consisting of layers of insulation, assembly, reinforcement and finishing elements. The properties of a particular system depend on the insulation, adhesives and plasters used in it. Therefore, when choosing a system, one should pay attention to:

- thermal conductivity (λ) value,
- volumetric mass density,
- sound absorbing capabilities,
- water vapour resistance (μ-value),
- sensitivity to biological and chemical factors,
- fire-resistance rating.

For the thermal insulation of historic buildings, capillary active systems with lower vapour resistance (μ) are generally better suited. The greater density of the insulating material signifies its better sound-absorbing capabilities and energy storage capacity. Important properties are also the ability to dry (release moisture), and the level of humidity at which the material loses its thermal insulation properties. For example, some mineral wools lose much of their insulating properties at the level of 2% of mass moisture content, while wood, cellulose or sheep wool maintain thermal insulation properties even at a higher level of dampness. These materials, due to their natural origin, also have a much lower carbon footprint.

Insulation based on wood or other plant-based material reduces the carbon footprint of a building since plants during their growth had accumulated atmospheric carbon in their mass. Plant fibres are recommended particularly, but not exclusively, for insulating wood, timber and other traditional constructions with clay and limestone. They require the use of diffusion open external layers (plasters, finishing coats, paints). Plaster systems dedicated to organic external insulation must have high vapour permeability and be water resistant.

Thus, if one does not use systemic solutions, all subsequent layers should be properly selected, because each layer will affect the ability to evaporate excess moisture from the wall. Coatings with the lowest diffusion resistance include mineral silicate plasters, on which paints with equally low diffusion resistance should be used. This also refers to renovating buildings already insulated.

Any errors involving the combination of diffusion open plasters with a finishing layer with higher diffusion resistance may result in the accumulation of moisture in the plaster layers, their freezing, and faster degradation. It should also be noted that just as the heat penetrates places with the lowest thermal resistance, moisture (in a stream of warm air) will quickly penetrate every air gap.

The visual effect of wall insulation also depends to a large extent on the type of plaster or paint. These have a variety of parameters, not only regarding their diffusion resistance but also impact resistance, structure, texture, and light reflection.[84] They can sometimes have special properties such as limiting the growth of algae and moss, self-cleaning, and even breaking down air pollutants such as nitrogen oxides ($NO_x$).

When insulating the façades of historic buildings, one should remember the necessary reversibility of all solutions. Capillary active insulation fixed with clay-based glue allows residue-free removal of the insulation if required at any time in the future.

For special applications, products with specific properties may be considered, e.g.:

- fire-resistant limestone silicate boards with increased passive fire resistance;
- resole, XPS, and polyurethane foam boards with high thermal insulation parameters;
- foamed glass plates to stop capillary rise in walls;
- aerogel insulations – capillary active, light-permeable, with a low thermal conductivity $\lambda = 0.012–0.030$ W/(m·K) to be used, for example, in the treatment of window details and to prevent other thermal bridges.

## Light-dry method: walls with a ventilated cavity

Light-dry external insulation refers to traditional façade techniques with a siding or cladding. Current solutions consist of adding a layer of diffusion-open insulation material: mineral wool or less popular but noteworthy products made of hemp, linen, cellulose fibres, or soft wood wool. Windproofing and a ventilated air gap are important between the insulation layer and the external siding or cladding. They guarantee airtightness of the wall and reduce the transmission of ambient moisture to the insulation layer while maintaining the possibility of moisture evaporation from the insulated wall (Fig. 14). This is especially necessary in walls made of materials with low diffusion resistance such as wood, or half-timbered with clay, limestone, or adobe.

Obtaining the desirable properties of a wall with a ventilated void also requires the use of materials with a controlled diffusion resistance around components such as woodwork details. The safest solution is to use tape made from expansion foam, sheep wool, linen wool, or hemp fibres, rather than popular polyurethane-based foams.

With the light-dry method, one can also use blown and spray insulation – recommended especially for insulating walls with irregular surfaces. Alternatives to popular materials for blown insulation such as mineral wool and cellulose, could be wood wool or straw fibres. The biological corrosion resistance of organic insulation is guaranteed by the nontoxic impregnates:

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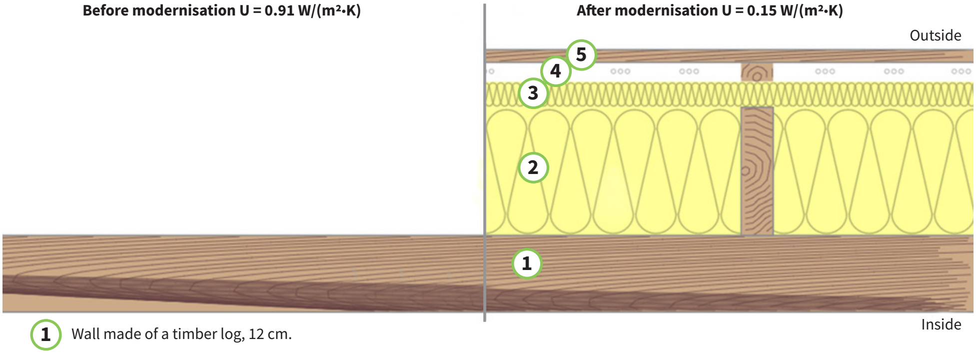
[84] Chłądzyński, Sławomir, Sławomir Zalewski, *Farby elewacyjne – rodzaje, właściwości i zastosowanie*, Izolacje 3/2010. https://www.izolacje.com.pl/artykul/sciany-stropy/155410,farby-elewacyjne-rodzaje-wlasciwosci-i-zastosowanie (September 2021).

sodium ammonia or boric acids. When choosing a manufacturer, it is worth paying attention to the material settlement class (S for mineral wool and SH for cellulose) corresponding to the limiting possibility of the material settling within 50 years of use.

Apart from wood, other materials with a relatively low carbon footprint can be used as external cladding of modern buildings: gypsum-fibre boards for external use and hard wood-based lignocellulosic boards, or those based on straw and other natural plant fibres. This group of façade products includes, for example, some of high-pressure laminates (HPL) consisting of layers of paper impregnated with thermosetting resins. Some manufacturers guarantee that the material consists of 30% non-toxic resins and almost 70% wood converted into paper – a natural material that stores carbon.

**Construction of the wall with light-dry external insulation: horizontal cross-section**



① Wall made of a timber log, 12 cm.

② Insulation made of soft wood wool on a wooden substructure (alternatively: mineral wool, cellulose or blown straw).

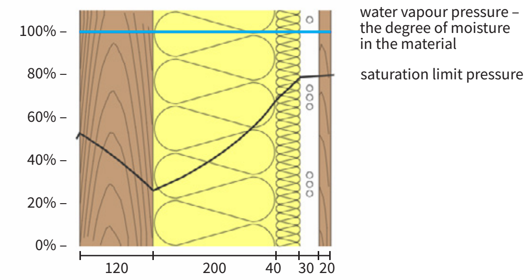
③ Windproofing: semi-hard wood-based panels made of straw or hemp.

④ Ventilated air void.

⑤ Finishing with façade boards.

Alternatively, a suitable membrane can be used as windproofing, and a lime, clay, or perlite plaster as a finishing layer to protect against fire.

**Water vapour pressure distribution**



**The possible distribution of moisture in the building envelope, based on the example of a timber wall insulated with wood fibre.**

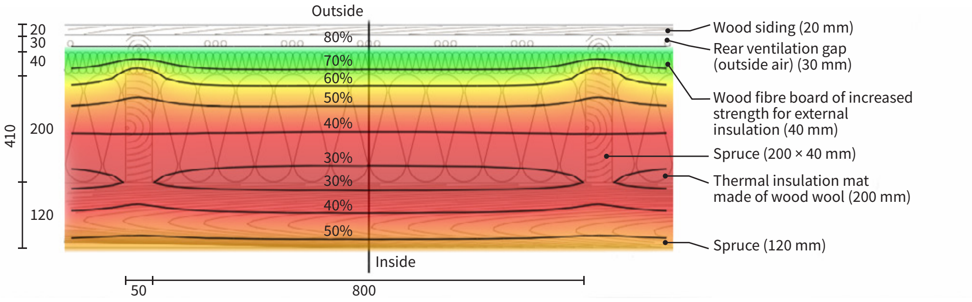


**Fig. 14.** Thermal insulation of a timber building with technologies characteristic for diffusion-open frame construction. In addition to improving insulation, it reduces the moisture in the existing structure and maintains the construction layers at temperatures above 0°C.[85]

[85] Illustration from: U-wert.net, *Ubakus*. www.ubakus.de (July 2021).

## 3.2.7. Thermal insulation techniques used in natural building

Technologies called natural are based on minimally processed organic raw materials that are combined with clay or lime-based materials with low diffusion resistance. The natural building movement aims to minimize the negative ecological impact, producing healthy living environments and maintaining indoor air quality. It is a means for creating bottom-up organic innovations that, along with growing popularity, are also effectively used in certified products that can be used in the renovation of public utility buildings or residential buildings managed by public entities.

Organic building materials have several basic features desirable for climate protection: no need for thermal treatment, the $CO_2$ accumulation in the matter, and their supply is quickly renewed. They are low energy and low carbon (often with a negative carbon footprint) because they are based on unprocessed organic matter. Straw and hemp can be obtained as agricultural waste. These are combined with locally available lime or clay. Combining organic materials with lime and clay mortars is possible due to their low diffusion resistance and high moisture capacity, ensuring no external condensation on the material structure.

The durability of organic materials is confirmed by centuries-old traditions of their use in difficult climatic conditions. Straw and other organic materials have traditionally been used to fill half-timbered structures to obtain good thermal properties. Ropes covered with clay plaster have ensured the tightness of walls of wood, straw or clay or with lime finishes. At the beginning of the 20th century, the potential of organic insulation material in the form of machine-diced straw was noticed in professional applications, as were buildings made of hempcrete in the 1980s.[86] There are uncertified solutions that allow the use of these materials in an unprocessed form for thermal insulation in single-family housing, as a unit-use product. [87]

For spray insulation, popular alternatives to foams are cellulose produced from wastepaper or hemp shives with hydraulic lime that provide higher resistance to moisture and biological agents, with better insulation parameters ($\lambda = 0.066$ W/(m·K)) than hempcrete (hemp concrete/hemoplite) made in formwork ($\lambda = 0.08$ W/(m·K)). The so-called Armenian plaster based on wood shavings, cement, and lime or clay has similar characteristics. These materials can also be used on the inside.

Materials based on natural organic resources, including recycled ones, which through the natural building movement have entered a wider production and distribution, include:

- Sheep wool insulation, in the form of soft boards, as well as ropes used in detail, e.g. when assembling woodwork,
- natural cork insulation,
- straw panel insulation in a wooden structure,
- cotton mats made of recycled denim,

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[86] Brzyski, Przemysław, *Historia. Budynki z konopii.* http://budynkizkonopi.pl/technologia-budowy/historia (July 2021).

[87] Gruber, Herbert, Helmuth Santler, BuildStrawPro-Team, STEP, *Strawbale building Training for European Professionals – U4 Handbuch Wrapping*, ASBN: Austrian Strawbale Network 2017. https://issuu.com/herbertgruber/docs/u4-handbuch-de-web_48699ea3f6068c (July 2021).

- straw insulation,
- hemp sheets (fibres and shives),
- soft hemp insulation ($\lambda = 0.04$ W/(m·K)) – as an alternative to wood wool and mineral wool,
- straw and reed mats.

The following are used as an external finishing layer of insulation made from natural materials:

- traditional clay plasters, protected with nano-silicate or casein paints,
- a mixture of layered clay plaster with admixed floated lime, not requiring paint coatings,
- traditional sand-lime plasters applied in layers, with possible additives, e.g. coloured in the mass.

Individual character can be given to buildings by using dispersion-silicate paints or craft paints dedicated to natural construction, usually devoid of biocidal additives. Traditional craftsmanship methods may restore the characteristic ‘historical’ appearance of hand-applied plasters.

### 3.2.8. External and internal insulating plasters

A favourable solution for walls that cannot be insulated with thick insulation layers are insulating plasters based on perlite, vermiculite, expanded clay, sawdust or polystyrene, usually bonded with lime mortar, and stabilized with cement. Their thermal insulation is worse than that of typical insulation materials, but such plasters are diffusion-open ($\mu \leq 7$–$10$) and can be used in layers with a thickness of 1 to 6 cm. This allows them to be used on heritage buildings when recreating historic façades, without increasing the volume with an additional layer of insulation. They can also be treated as a complement to the insulation continuity, limiting the occurrence of thermal bridges. Thanks to the plasticity, and the possibility of varying the thickness of the material, it is possible to restore the historical appearance of the building – hand-made plaster or rustication.

Insulating plasters increase the temperature of existing walls in winter, preventing them from freezing, and so make it possible to use thicker internal insulation. However, this interdependence of external and internal insulation requires, in each case, a hygrothermal assessment of the effects of thermal renovation *ex ante*.

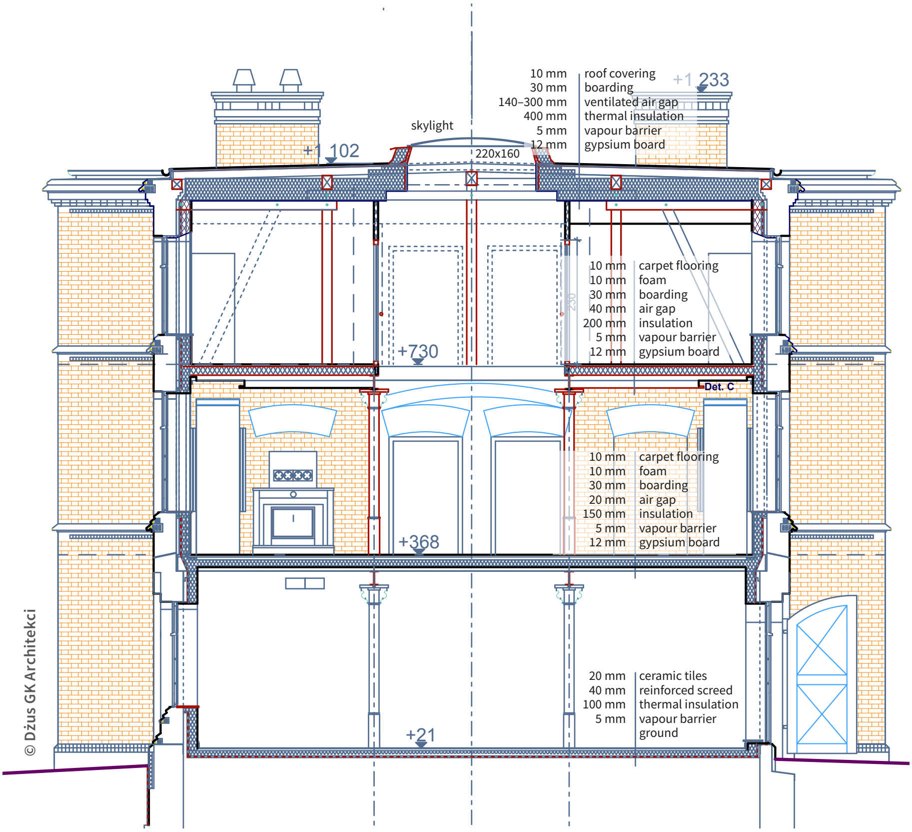
Insulating plasters are also used as internal insulation between heated and unheated spaces. Their fire protection properties are used to insulate walls and ceilings in communication spaces and staircases.

Insulating plasters that require finishing must be covered with coatings or paints with sufficiently high vapor permeability.

## 3.2.9. Internal insulation

If it is not possible to install external thermal insulation, e.g. due to aesthetic reasons or conservation restrictions, it may be possible to reduce energy losses and increase thermal comfort by means of internal insulation. It is estimated that insulation of the wall from the inside with a layer of 4–6 cm of natural wool can reduce heat loss by 55%.[88]

Its application is safe, provided that the façade is well **protected against the ingress of water**. After insulating the wall from the inside with a thick layer of insulation, it will be exposed to freezing (see Chapter 3.4). Therefore, the wall must remain dry, and its outer layer must be unconditionally and completely



© Dżus GK Architekci

**Fig. 15.** 19th-century post-military warehouse and office building at 3H Artyleryjska St. in Olsztyn, adapted for mixed service and residential uses. Cross-section with visible insulation from the inside.

[88] Claytec, *Rozwiązania z gliny dla izolacji wnętrz.* https://docplayer.pl/9257392-Izolacji-wnetrz-claytec-rozwiazania-zgliny-dla-regulacje-techniczne-wykladnia-sily-izolacji-wspolczynnik-u-oraz-wartosc.html (July 2021).

tight in protecting the wall against water penetration. It is equally important to carefully protect the wall against capillary rising from the ground (see Chapter 3.1).

It should also be considered that this type of insulation increases the **risk of thermal bridges** in the places where walls are connected to ceilings and joinery (see Chapter 3.4). Therefore, it is necessary to provide in these sensitive places, full protection against the ingress of moisture from the internal air and adjacent internal partitions.

The risk of accumulation of moisture inside the wall is also influenced by the interior **air humidity**, which is why internal insulation is mainly used in rooms that are dry or only heated occasionally. The risk increases for rooms with a constant source of moisture: bathrooms, kitchens, classrooms, where the ventilation systems are not efficient enough to remove excess humid air, especially in winter.

Photo: Jakub Obarek

Photo: Dżus GK Architekci

**Fig. 16.** The adaptation of the 19th-century post-military warehouse and office building at 3H Artyleryjska St. in Olsztyn for mixed service and residential uses was designed by the Dżus GK Architekci studio, which drew on over 20 years of experience in adapting historic buildings. A layer of internal insulation has been introduced, separated from the original structure by an air void ventilated at the ridge of the roof. When replacing the floor beams, to avoid thermal bridges, insulated and properly ventilated joints of wooden beams have been introduced, and the reinforced concrete ceilings were anchored to the perimeter walls at points. Heat recovery ventilation has been implemented. For air supply and exhaust, the designers always try to use the existing openings, and stack ventilation ducts and chimneys, to minimize the impact of new installations on the shape of the roof. Historical window joinery is supplemented by internal glazing, and when windows need to be reconstructed, the replicas have high thermal parameters. The studio implements this method of adapting various historical buildings, from 17th-century monasteries to 19th-century barracks. For each building, the solutions are appropriately adjusted to their character and original construction technologies so that they do not adversely affect the historic substance.

The use of internal insulation allows the interior to heat up faster and for a reduction in the power of heat sources, but at the same time, the interior will partially lose the ability to avoid becoming overheated in summer.[89] This is especially important in the context of climate change and the high cost of air conditioning.

## Capillary active internal insulation

The materials recommended for internal insulation include: mineral insulation boards made of a very light type of AAC with a diffusion resistance factor $\mu = 3$, climatic boards made of lime silicate of $\mu = 3–6$, and thermal insulation renovation plasters containing extremely light granules of foamed glass and perlite, which gives them exceptional thermal insulation properties ($\lambda = 0.06–0.11$ W/(m·K).[90]

The specificity of diffusion-open internal insulation is to allow a temporary increase in the level of moisture content in the wall in the winter period, and its removal through diffusion-open layers in warmer periods. Regulations (ISO 13788:2003) allow for it, provided that the moisture content does not increase year to year.[91]

It is possible to confirm effective protection against long term moisture accumulation in walls by using software simulations in two dimensional assessments, e.g. U-WERT, WUFI, DELFINE,[92] or the assessment of three-dimensional thermal bridges with the use of applications such as TRiSCO[93] or WUFI 3D.

The designers responsible for the selection of thermal insulation technology must assess the possibility of exposing historical walls to greater amplitudes of temperature and humidity differences throughout the year. After the application of internal insulation, the lowering of the temperature of the wall is inevitable (see Chapter 3.2 and 3.4) so the interstitial condensation inside the insulated wall at the interface between different layers may occur. If a limited evaporation potential reduces the drying ability, it will lead to significant destructive consequences over time.[94] Condensation in outer layers exposed to freezing will lead to the degradation of walls, especially joints. Condensation in inner layers and on internal surfaces will lead to damp and mould growth.

To reduce the amount of moisture in diffusion-open systems, it is possible to use wall heating. Low-temperature wall heating works well with clay and lime mortars having high heat and humidity capacity. Increased accumulation and release of moisture improves moisture regulation and the overall climate in the interior.

Diffusion-open insulating layers may assist in drying previously damp walls. Clay plasters, without organic additives, can be applied directly even on wet walls in a well-ventilated room, and assist in the extraction of moisture and salinity. Special lime plasters, foamed or with the addition of perlite, can also drain moisture and bind salts in the material structure.

[89] Kisilewicz, Tomasz, *Pojemność cieplna a komfort termiczny w budynkach energooszczędnych* (*Heat capacity versus thermal comfort in low energy buildings*), Materiały Budowlane, 9/2014 (505). https://www.materialybudowlane.info.pl/images/2014/09/s51-55.pdf (July 2021).

[90] Pawłowski, Krzysztof, *Innowacyjne rozwiązania materiałów termoizolacyjnych w aspekcie modernizacji budynków w Polsce*, Izolacje 3/2018. https://www.izolacje.com.pl/artykul/sciany-stropy/182305,innowacyjne-rozwiazaniamaterialow-termoizolacyjnych-w-aspekcie-modernizacji-budynkow-w-polsce (July 2021).

[91] Patoka, Krzysztof, *Skropliny i PN-EN ISO 13788:2003*, Materiały Budowlane, 533 (1), 82-84, DOI:10.15199/33.2017.01.16.

[92] LOCJA.PL, *PN-EN 13788 Cieplno-wilgotnościowe właściwości komponentów budowlanych i elementów budynku*, 31.08.2017. https://www.locja.pl/haslo/pn-en-13788-cieplno-wilgotnosciowe-wlasciwosci-komponentow-budowlanych-i-elementow-budynku,649 (July 2021).

[93] Dylla, A., *Numeryczne projektowanie parametrów cieplno-wilgotnościowych złączy budowlanych*, [in] Budownictwo energooszczędne i ekologiczne: I konferencja naukowa: Suwałki, 10–11.06.2010. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-AGHM-0016-0080 (July 2021).

[94] Brambilla, Arianna, Alberto Sangiorgio, op.cit.

### Internal insulation with a vapour barrier

When using airtight insulation membranes (vapor barriers), which block warm air and moisture migration from the interior to the walls, it is possible to apply wood wool or mineral wool, as well as airtight systems based on PIR, PUR, polystyrene or XPS foams. However, the latter, being synthetic and petroleum-derived materials have much larger carbon footprints.

It is necessary to use a vapour barrier with a min. resistance of sd = 100, tightly sealed at the joints, because even the smallest leak in the membrane may allow moisture to enter the wall, which will then not be able to dry.

Protection against possible future damage or puncturing of the vapour barrier is another problem to be considered. One of the recommended solutions to protect the membrane is to add a layer of protective material in which all installations are distributed. This layer can be diffusion-open and capillary active, acting as a buffer regulating the internal humidity.

### Thermoreflective insulations

Thermoreflective insulation based on aluminium foil is used mostly in attics. This solution has high diffusion resistance.

Thermoreflective photocatalytic plasters and paints of low diffusion resistance are suitable for application both on inner and outer surfaces. Their small thickness allows them to be used in the renovation of heritage buildings. According to the producers, their simultaneous application on both sides of the wall, internal and external, can significantly reduce heat losses, comparable to the use of thick conventional insulation.[95] However, since their performance is not based on limiting heat transfer (slowing conductive heat flow) but on reflection of infrared waves, it is not possible to assess their effectiveness using the current rules for calculating thermal insulation.

The effectiveness of thermoreflective insulation requires confirmation by independent tests on a larger number of buildings. Comparing their effectiveness with other methods of insulation also requires changes in regulations on the methodology of calculating heat losses and allowing an equivalent to thermal resistance.

## 3.2.10. Green façades

It is a myth that ivy and other climbers have a negative impact on the durability of the façade. On the contrary, due to the limitation of insolation and protection against wind and stormwater, greenery may alleviate UV exposure and thermal stress of the wall surface in both summer and winter.

Ivy exudes mucilage, as it climbs up surfaces like brick walls, which is able to seep into microscopic cracks and pores on the plant's climbing surface. After sticking to the façade, the compound quickly hardens, and the plant becomes woody, which means it does not exchange moisture with the wall.[96]

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[95] Afon Casa, *AfonTermo il Nano Cappotto, isolamento termico a basso spessore*. http://www.afoncasa.it/prodotti-edilizia/afontermo-il-nanocappotto.html (July 2021).

[96] Borowski, Jacek, *Czy pnącza niszczą elewację?* https://www.clematis.com.pl/informacje-o-roslinach/eksperci-radza/dr-hab-jacek-borowski/1133-czy-pnacza-niszcza-elewacje/ (July 2021).

However, special attention should be paid to the weight of the plants on the façade, which can be up to several tons and should be considered when designing thermal retrofit. It is possible to design special substructures (trellises) which will not significantly interfere with the structure of the façade.

Vegetation will always be a friendly place for urban biodiversity, especially for harmless insects and birds. Gaps of various sizes have been home to red mason bees and bumblebees for centuries. During the thermal retrofit, it is necessary to protect the nesting places of birds during the breeding season and, if possible, provide the dedicated solution of integrated nesting boxes[97] as well as design appropriate places for insects, for which historical elevations have been a natural environment.

Photo: © makasana photo – stock.adobe.com

Photo: © promesaartstudio stock.adobe.com

**Fig. 17.** National Museum in Wrocław, built in the years 1883–1886, listed on the National Heritage List for Poland, covered with ivy. The first climbers were planted over 25 years ago. Currently, plants are at their peak of growth, they will live for several dozen years more.[98]

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[97] Dworak, Michał, *Termomodernizacja w Okresie Lęgowym Ptaków*, 11.04.2021, Ptasi Dom. https://www.ptasidom.com/budki-legowe-do-termomodernizacji/termomodernizacja-w-okresie-legowym-ptakow/ (July 2021).

[98] Muzeum Narodowe we Wrocławiu, Bluszcz. https://mnwr.pl/ciekawostki (June 2022).

# 3.3. Woodwork

**Anna Zaręba** · Nicolaus Copernicus University in Toruń
**Tomasz Jeleński** · Cracow University of Technology

Windows and doors are among the most important elements of architectural form and décor of the historical façade. They often have individually designed shapes and colours, which emphasise the harmonious proportions of walls and openings and affect the style and character of the entire building.[99] The picturesqueness of the historical urban environment is in the detail, of which the woodwork is an important part that significantly influences the reception of a building and a townscape. Thus, original woodwork as well as metalwork and glazing (cast glass, drawn, rolled, stained, etc.) in listed buildings and conservation areas, is subject to conservation protection.

Unfortunately, for many decades, the pursuit of thermal modernisation and the effect of insufficient understanding of the significance of historic substance, has led to many historical windows and doors being uncontrollably replaced by new ones.[100] The conviction of the superiority of new technologies over the old and the lack of legal knowledge[101] has resulted in woodwork elements whose appearance often disturbs façades and brings aesthetic chaos into the streetscape. Moreover, modern windows may cause new problems, including health hazards, since they disturb the thermal and humidity balance of modernised buildings.

Although historical joinery certainly does not provide thermal insulation as good as triple or quadruple glazed windows made in the latest technologies, they work better than single pane double glazed windows. Thanks to the depth of the case, around 9–11 cm, they provide slow circulation of heated air between the outer and inner glazing.

Newly-made windows, both plastic and wooden, are often too air-tight, which may lead to impaired natural ventilation and condensation resulting in the development of mould and fungi in the interior and deterioration of the furnishings. It should be noted that the health and comfort of building occupants requires 1.5 air changes per hour but not less than 20 $m^3$ of outdoor air per hour per person. These are minimum requirements, and the fresh air flow needs to be additionally adjusted to the function of the room. In a kitchen with a gas stove, it needs to be at least 70 $m^3/h$.[102] None of the new windows will provide that without unsealing.[103] In most cases, new windows must be supplemented with highly efficient interior ventilation.

## 3.3.1. Renovation of windows and doors

If the existing windows are not of historic value from the conservator's point of view, they can be replaced with a historic window reproduction that is highly energy-efficient (Uw≤ 0.9 W/m²K I Ud≤1.3 W/m²K) and fulfils the aesthetic demands of the building. However, because of the overriding need to preserve cultural heritage and not waste natural resources,[104] the best solution is to renovate original doors and windows, including the old glazing.

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[99] Tajchman, Jan, *Dawna stolarka okienna i jej problematyka konserwatorska wobec nowych zagrożeń*, [in] Emanuel Okoń (ed.), Zabytkowe budowle drewniane i stolarka architektoniczna wobec współczesnych zagrożeń, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń 2005, 290.

[100] Including PVC Windows.

[101] Filipowicz, Paweł, *Rola zaleceń konserwatorskich w procesie inwestycyjnym realizowanym w obiekcie zabytkowym w świetle oczekiwań projektanta i inwestora*, Kurier konserwatorski, 6 (2010), 7.

[102] According to Polish Standard PN-83/B-03430 and PN-83/B-03430/Az3:2000 Wentylacja w budynkach mieszkalnych zamieszkania zbiorowego i użyteczności publicznej – Wymagania.

[103] Tajchman, Jan, *Chrońmy dawne okna: nowe nie tylko niszczą kompozycję elewacji, ale przede wszystkim nasze zdrowie*, [in] Wojciech Przybyszewski (ed.), Aedifico et Conservo – eskalacja jakości kształtowania zawodowego w Polsce, Fundacja Hereditas, Warszawa 2010, 24.

[104] Tajchman, Jan, *Stolarka okienna w Polsce. Rozwój i problematyka konserwatorska*, [in] Krzysztof Nowiński (ed.), Biblioteka Muzealnictwa i Ochrony Zabytków, Seria C, Studia i materiały, Vol.5, Ośrodek Dokumentacji Zabytków, Warszawa 1990.

Contrary to popular opinion, the procedure may be as simple as removing the old paint coatings, filling small cavities, repairing the putty and adjusting the fittings. This may allow the window to be tightly closed which would significantly improve its thermal efficiency. The process of renovation might seem very complicated, time-consuming, and expensive, but when done with care and specialist advice it can be carried out on one's own. Most importantly, such a procedure may improve the condition of the woodwork without disturbing the natural ventilation of the interior, which is necessary for old buildings to avoid the development of fungi and mould.

The quality of the old woodwork and glazing is usually very high. When restored to their original shape, they do not cause large heat losses. After decades or centuries of exposure to the elements, old wood is very well seasoned, and the risk of further warping is minimal.[105]

To further improve thermal insulation in winter, an additional layer of temporary insulation may be put into the window case. It can be a cloth of sheep wool or similar material.

## 3.3.2. Modernisation of windows

If historic glazing is not present, new glazing can be improved by a low-e coating which reduces the emission of infrared radiation. Using a coated pane as the only measure is not enough to raise the thermal performance of a historic window to a state-of-the-art level, but it might be a good idea if there are no other options.[106]

The energy efficiency of traditional windows can be improved, according to modern standards, by replacing internal window sashes with new ones, with the same proportions in the bars but with double or triple glazing. From the building physics perspective, it would be better to introduce multiple glazing in the outer sashes. From the conservator's point of view, however, especially in the listed buildings or protected areas, two aspects of the original appearance of historic windows should be maintained: 1) the original proportions between the glass area, sash bars, and window frame; 2) the appearance of the original glazing. Changing single craft-glazing to modern multiple glazing changes the look of the façade because of different tints and finishes, as well as altered reflection and mirroring. A more regular, modern-looking reflection also appears when muntin bars no longer cause slightly different inclinations of lights (small panes of glass).

Thus, if historical windows are preserved, they could be complemented by an additional interior layer of triple-glazed windows that takes over the thermal insulation function, while the exterior views are not compromised. Such a solution may increase humidity in the interior and thus usually must be supplemented with highly efficient ventilation.

Possible improvements also include triple glazing installed in the original frame but since the frame is not deep enough, one possibility is to cut the

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[105] Tajchman, Jan, *Chrońmy…*, op.cit., 25.

[106] Troi, Alexandra, Zeno Bastian (ed.), op.cit.

frame into two shells and insert a new layer, ideally consisting of an insulation material such as nano-insulation fleece.[107] It needs to be noted, however, that compared to historical glass panes, standard triple glazing is not only thick (48 mm) but also heavy (30 kg/m²). This often does not fit the character and stability of historic frames. One way to reduce this problem (although at a higher cost) is to use thin-layer glazing with comparable U-values but only twice as heavy as a 3 mm single pane. Combined with krypton, the thickness can be reduced to 26 mm.[108]

Replacing old single glazing with modern low-e triple-pane units saves energy and improves comfort, but as a side-effect, the additional glass panes and coating reduce the transmission of visual light. Significant technological advances have been made lately to deal with this problem. Low-e triple glazing with the same luminous transmission index as conventional double glazing can be produced with the help of antireflection coatings on the glass surfaces. An enhancement can also be achieved by daylight redirection elements (such as lamellae or prisms) integrated into the glazing.[109]

## 3.3.3. Embedding windows and doors

An often-underestimated aspect of the building renovation and energy modernisation is the existence of thermal bridges around old windows and doors that were attached with metal anchors and sealed with paper and gypsum or similar materials. The impression of a leaky window or the so-called ‘cold draught’ often results not from the bad condition of a window itself but from the way the joinery is set in the wall. In the renovation process, it is important to improve the way windows and doors are fitted and to eliminate thermal bridges using modern insulation materials. An additional improvement would be to finish linings with thermally insulating materials in the form of special plasters or thermal boards, with high vapour permeability to avoid condensation.

## 3.3.4. Woodwork replacement

When replacement or reconstruction of joinery is necessary, it should exactly repeat the proportions, divisions of glazing bars, the colour of original woodwork and type of glass, as well as all decorative details: profiles of slats, carving elements and fittings. Replacing the woodwork in a listed building requires the submission of a detailed design to a heritage officer (or another appropriate person taking care of the listed buildings) to verify the correctness of recreating the features of the original windows or doors.

In any case, it should be considered that most carpenters do not faithfully repeat the old technology of making joinery and often use wider profiles. What is equally problematic, modern woodwork is mainly made from degummed and dried wood that does not ensure longevity and may warp in time. Involving traditional carpentry might be thus beneficial not only for aesthetics but also for practical reasons.

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[107] Ibidem, 146.

[108] Ibidem, 144.

[109] Ibidem, 25.

It is unacceptable to replace woodwork with PVC products due to the inability to recreate the original frame proportions, the thickness of the muntin bars and their profiling. In PVC windows, the depths of glazing in the sashes and sashes in the frame are also different, which results in a reduction in size of the glazing (and light penetrating the interior) by an average of 20%. Moreover, the PVC windows are intended for use only for about fifteen to twenty years.[110]


Photo: Anna Zaręba

**Fig. 18.** The Saski Palace in Kutno, built in 1750, listed on the National Heritage List for Poland, was destroyed by a fire in 2003 and recently restored. The photo shows a window that meets anti-burglary standards, with restoration glass, visually corresponding to the original baroque windows.

## 3.3.5. Window shading

The old types of windows (casement, loom, and Polish type) let more light into the interiors than the modern ones, which is an unquestionable advantage in the winter months, but in the summer, especially in the context of climate change, it can be problematic.

The easiest solution for shading is to use shutters or roller blinds reflecting heat radiation but those are truly effective only from the outside. Interior shading devices are ineffective in the summer: they allow sunlight to enter the room, increasing cooling loads. If the conservation restrictions do not allow exterior shading, lamella blinds in the air gap between two glazing units of casement or box-type windows may be considered. They provide glare protection and are weatherproof. Slat blinds are recommended, because their shading coefficient is variable, and they can also redirect daylight. Thus, anti-glareprotection and daylighting can be provided by one system (Fig. 19).

If no air gap is available, glazing-integrated slat blinds are an option, but if they get damaged, the whole glazing unit must be removed. Slat blinds need a wider gas gap and thicker panes, which are harder to integrate into the slim frame. If the window frame must be wider to cover the slats, less solar gain can be harvested in winter.[111] Also for aesthetic and conservation reasons, such solutions could be hardly acceptable in more prominent locations as the integrated slat blinds would not correspond with the historic appearance.

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[111] Troi, Alexandra, Zeno Bastian (ed.), op.cit., 151.

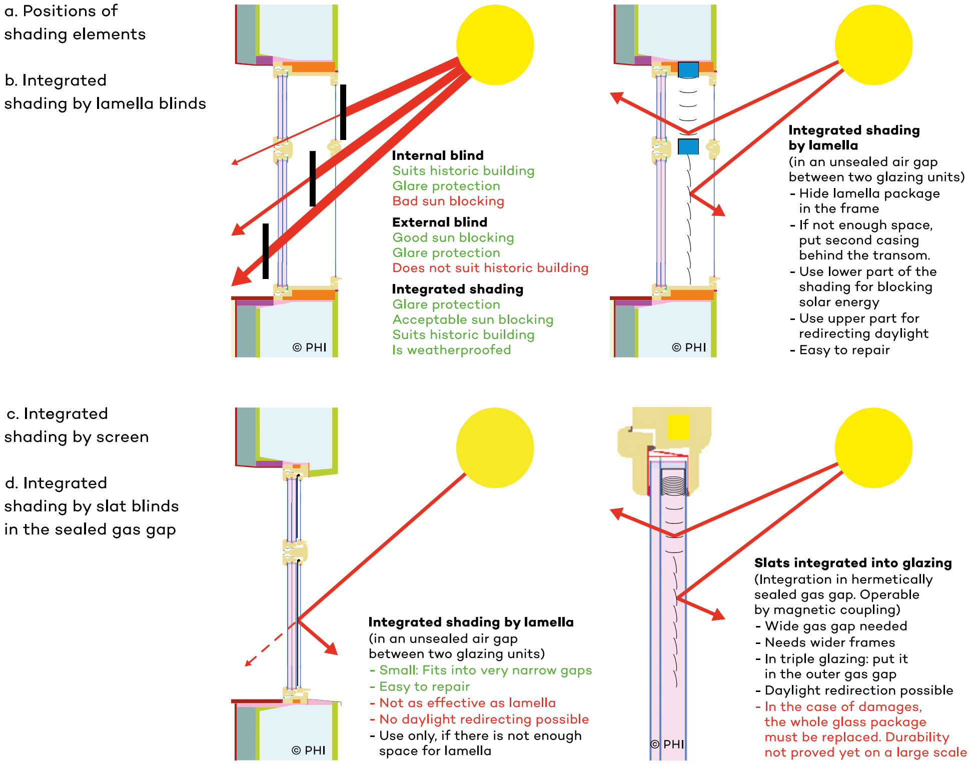

**Fig. 19** Various types of shading solutions.[112]

A less effective but very aesthetic solution could be an arrangement of window mini gardens, with high or hanging plants, greening balconies, etc.

However, the best solution for window shading is greening the surroundings of the building. Sufficiently tall deciduous trees provide natural shade in the summer season whilst in the winter season, trees devoid of leaves allow sunlight to penetrate the interior of the building. Other benefits of trees and other plants include the effect of evapotranspiration which lowers the ambient temperature in summer and better quality of air – cleaner and richer in oxygen and moisture.

[112] Illustration from: Troi, Alexandra, Zeno Bastian (ed.), *Energy Efficiency Solutions for Historic Buildings: A Handbook*, Birkhäuser, Basel 2015, 150. Drawings: © Passive House Institute.

# 3.4. Floors, ceilings and flat roofs

**Robert Wójcik and Piotr Kosiński** · University of Warmia and Mazury in Olsztyn

Floors are related to energy modernisation mainly due to the phenomena that occur where they connect with the building envelope. In winter, local increases in heat flux density occur within the joints of external walls with floors. This can lead to linear thermal bridges and a drop in temperature that can result in water vapour condensation.[113]

Therefore, in the design process, it is necessary to determine the thermal coupling coefficient of the partition in which the thermal bridges occur. The heat and moisture flow can be analyzed there in detail using advanced computational methods. Computer applications make it possible to visually determine the temperature fields and calculate the linear heat transfer coefficients characterizing linear bridges.

The use of such applications for numerical analysis of heat flow[114] enables the determination of its distribution and presentation in the form of colour diagrams. Moreover, during the quantitative assessment of thermal bridges, the temperature coefficients and minimum internal temperatures are determined. This allows investigation of the influence of the designed insulation on thermal and humidity phenomena in interiors subjected to thermal modernisation.

The application of thermal insulation from the outside protects the original structure of the building against thermal stress (we describe it in more detail in Chapter 3.2), while the thermal insulation from the inside adversely changes the original temperature field, which is shown in Fig. 20.

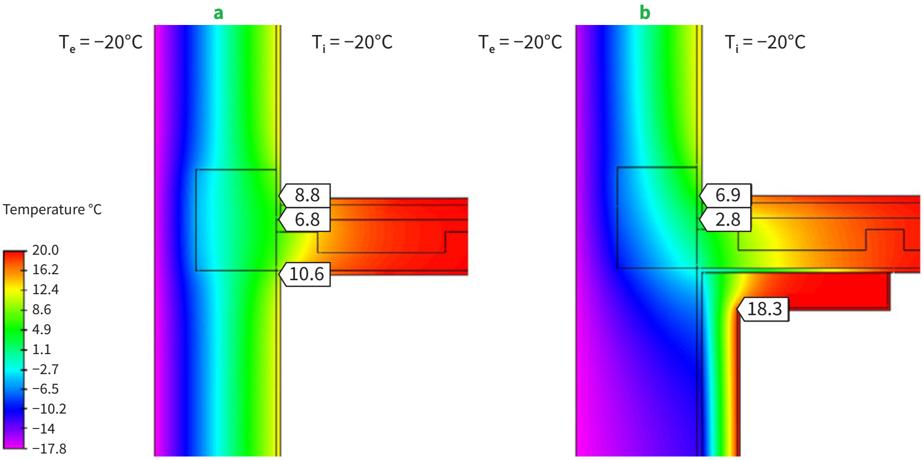

**Fig. 20.** Change of the 2D temperature field in the joint between the beam and block floor (Klein type) and the external wall as a result of one-sided wall insulation on the lower consignment with the extension to the ceiling surface: a – temperature field before insulation, b – temperature field after insulation.

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[113] Klemm, Piotr, et al., *Budownictwo ogólne*, Vol 2. *Fizyka Budowli*. Arkady, Warszawa 2005.

[114] For example, the Algor app used by the authors.

Insulation from the inside limits the intensity of the heat flux from the interior to the external wall and makes the wall more susceptible to freezing. The changes are especially visible within the ceilings, as they are structurally connected to the original external wall, creating a linear thermal bridge. As a result, the temperature of the internal surface in the edge zone decreases compared to the state before insulation. The temperature in the upper-internal edge drops from 6.8°C before thermal insulation to 2.8°C after insulation. Therefore, as a result of such one-sided interior wall insulation the risk of condensation and damp on the internal wall increases significantly. Similar effects are also observed, e.g. in the case of covering the entire internal side of the outer wall with wall units, bookcases or wardrobes.

The biggest problem concerns the walls on the north side of the building and the outer corners. Heat can escape from corners intensively through relatively large external surfaces. The lowering of the temperature on the inner surface of the corners is additionally caused by the limited air circulation in the corner.

Figures 21 and 22 illustrate this problem on the example of the former Piast Brewery in Wrocław. Fig. 21 summarizes the analysis of the spatial temperature field in the connection of external walls of varying thickness with the beam and block floor. After the walls were insulated from the inside with the use of 12 cm thick mineral wool ($\lambda = 0.45$ W/(m·K)), under the boundary conditions: $t_i = 20$°C, $t_e = -18$°C the temperature in the corner drops from 4.7°C before thermal insulation to 1.7°C after insulation.

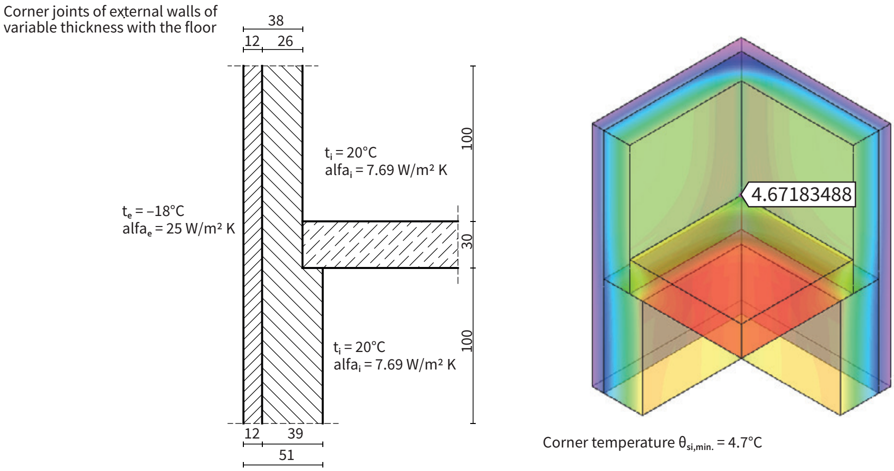
Figure 22 shows the analysis of the sharp-angled corner of a brick building. After thermal insulation, there is a temperature drop at the floor level from 8.9°C before insulation to – 0.3°C after insulation. It results in not only surface condensation but also freezing of the moisture and condensate in the entire thickness of the wall and in the interior.

If the thermal insulation of walls is applied from the inside, it is not possible to completely avoid thermal bridges. The presented examples show that defective internal insulation increases the risk of condensation on the internal surfaces. It is necessary to assess the risk of condensation and mould development in the places of lowered temperature and counteract the unfavourable phenomena. Possible solutions include:

- extension of the insulation to an internal partition adjacent to the external wall,
- additional ventilation or heating of problematic edges/surfaces with the use of infrared (IR-C) radiators, floor or wall heating, etc.,
- an anti-condensation installation that will increase the temperature of excessively cooled places.

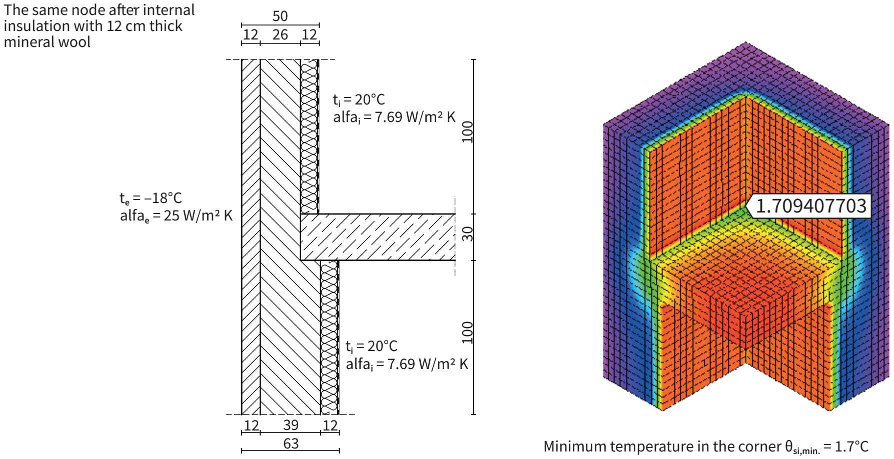
Extension of the insulation on internal partitions (ceilings and walls), to the width of the edge-cooling effect (usually about 50 cm), can be made in the form of a flat plate or a wedge protruding from the corner and tapering towards the interior. Figures 20b and 23 present the recommended method of insulating corner thermal bridges with the use of the insulation wedge.

**3D temperature field in the connection of the external walls with the floor in the corner before thermal insulation**



Corner temperature $\theta_{si,min.}$ = 4.7°C

**3D temperature field after thermal insulation from the inside**



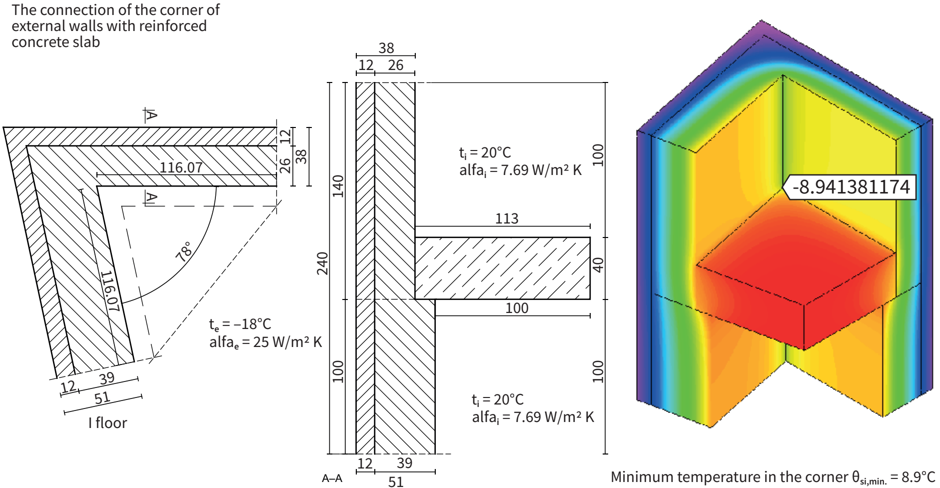
Minimum temperature in the corner $\theta_{si,min.}$ = 1.7°C

**Fig. 21.** Influence of internal wall insulation on the minimum temperature on the internal surface of the node.

It is not always possible to use insulation extended to the ceiling surface. Then, alternative solutions should be used, e.g. a surface heating or IR-C radiators. Also, the sub-window location of convectors, criticized for the low efficiency of heating, is fully justified when the internal thermal insulation is applied. In the case of mechanical ventilation, targeted ventilation outlets can be used to increase heat transfer and drying of cool places.

Locally, in the corners where the ceiling and floor meet the external wall, it is possible to use an anti-condensation system or other heating devices to fight the thermal bridge effect.

**3D temperature field in the connection of the external walls with the floor in the corner at an angle of 78°**



**3D temperature field after thermal insulation from the inside**

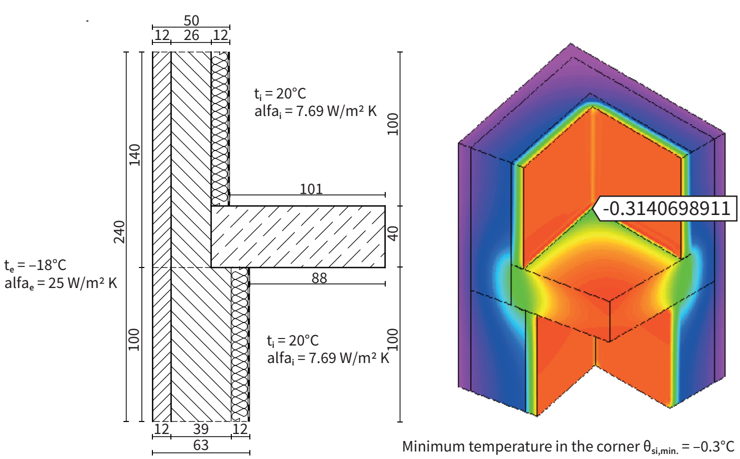


**Fig. 22.** Influence of internal wall insulation on the change of the minimum temperature on the internal surface of the corner.

## 3.4.1. Anti-condensation system

Problems related to a thermal bridge can be solved by introducing heating wire into the cold corner. In this way, the surface temperature can be raised by a few degrees, which is sufficient to prevent condensation.[115]

This effect is used, for example, in the IN system.[116] Its installation is easy and enables the internal thermal insulation to be applied to any level of thermal resistance, without the side effects of dampness in the edge zones of the insulated walls.

The system consists of heating cables that detect other heat sources, such as solar radiation, and automatically adjust their heating power to the ambient

[115] Wójcik, Robert, *Docieplanie budynków od wewnątrz*, Grupa Medium, Warszawa 2017.

[116] Wójcik, Robert, *Sposób docieplania przegród budynków od strony wewnętrznej*. 30.11.2012. Poland Patent no 212791.

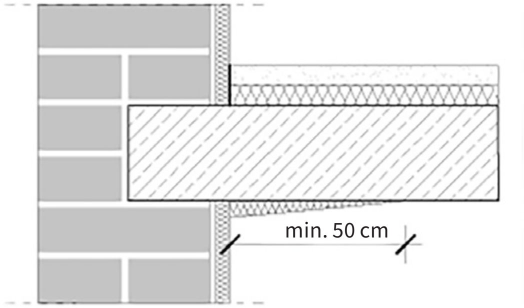


**Fig. 23.** Insulating the thermal bridge in the joint between the monolithic ceiling and the outer wall – with the use of a flat insulation board on the wall and wedge-shaped insulation on the bottom of the ceiling.

heat. The lower ambient temperature results in increased heat generation. Thus, more heat is generated in colder places (e.g. in the corners or around window frames) and less in warmer places (e.g. close to radiator). Thanks to the variable power of the heating cable, the system is highly energy-efficient and only slightly increases heating costs.

The heating cable installed in sensitive areas of thermal insulation can be treated as a supplement to the existing heating system, but due to the low and variable power of 5 to 20 W/m (depending on the ambient temperature), its impact range is limited to the coldest places of linear thermal bridges, which sufficiently eliminates the harmful phenomena: condensation and the growth of mould. During warmer spring and autumn days, when the basic heating is turned off, the building envelope can still be effectively protected by an automatically regulating anti-condensation system. It is worth noting that heating cables generate a negligible electric field, thanks to which they do not adversely affect human health.

Fig. 24 and 25 show the effect of the IN anti-condensation system.

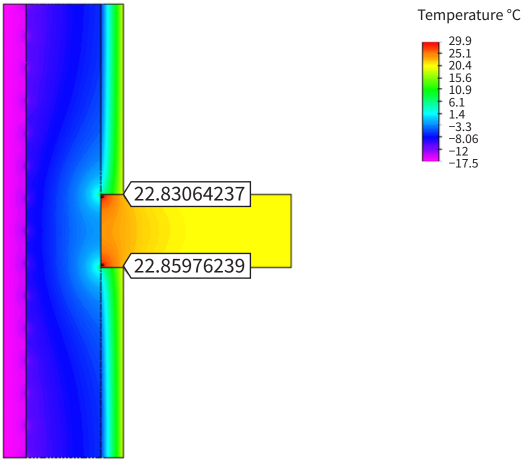


**Fig. 24.** Change in the temperature field due to the activation of the anti-condensation system.

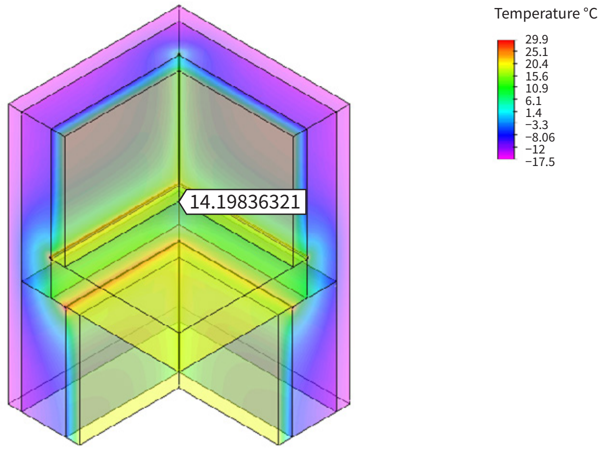


**Fig. 25.** The effect of heating the insulated corner with an anti-condensation system (3D analysis).

The technical data of an exemplary system made with the use of the T2RED (Raychem) component:

| | |
|---|---|
| heating power | 5–15 W/m |
| maximum length of the heating circuit | up to 100 m at 10 A |
| minimum bending radius | 35 mm |
| maximum produced temperature | 45°C |
| maximum impact temperature | 65°C |
| maximum dimensions (W × H) | 6.0 mm × 8.7 mm |

Analyses of climatic conditions carried out, for example, for Warsaw and Wrocław, indicated that the anti-condensation system will be used from 12 to 18 days a year. Practical experience gathered, for example, in historical buildings in Mrągowo proves that the time when the system is on is even shorter, despite its location in a colder climatic zone.

## 3.4.2. Insulation of ceilings above unheated cellars

Insulating ceilings above unheated cellars can be problematic. This is a special case of heat flow, the vector of which is directed vertically downwards. Therefore, the best solution is to insulate the ceilings from the cellar side. Here, however, several conditions must be met, which include the use of fire-retardant materials (mainly fibre-cement boards) and leaving the required height of the cellar rooms after the ceiling is insulated. It is not necessary to extend the insulation to the walls in this case.

### 3.4.3. Insulation of flat roofs

Thermal insulation of the building envelope always carries the risk of serious changes in the humidity of the originally embodied materials. On the one hand, the problem of great heat losses may be solved, on the other hand, insulation materials can block the diffusive flow of vapour.

Bearing this in mind, when designing and executing the energy renovation of a flat roof, it is necessary to analyze in detail the method for draining the moisture that accumulates between the existing structure and the designed thermal insulation.

The most popular solution is to make a **warm roof with vents** (Fig. 26). It can be applied above dry and moderately humid rooms (with a maximum water vapour pressure in the air from 1200 Pa to 1600 Pa). Over the layer of thermal insulation and under the waterproofing layer, a network of interconnected air channels needs to be created to ventilate excess vapour that penetrates the roof, mostly from the interior. Channels (of small cross-sections) are created by the use of appropriate materials, e.g. roofing felt with a coarse grain or perforated roofing felt, or the channels profiled in thermal insulation. Ventilation of vapour is possible through appropriately shaped flashing at the edges of the roof and a system of air vents (mushroom vents) placed on the roof. Care is needed not to damage the vents when removing snow from the roof.

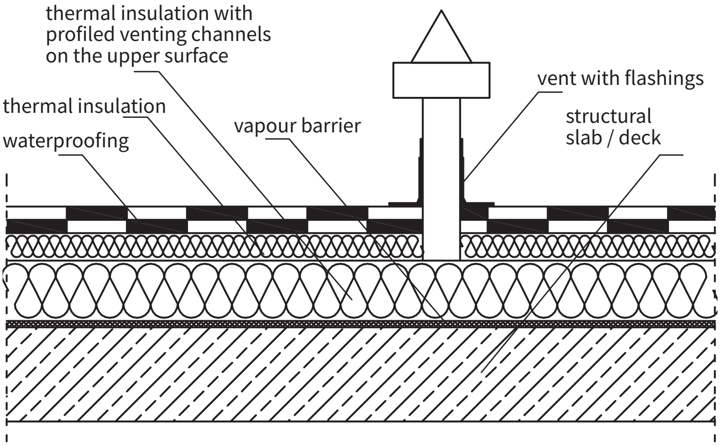


**Fig. 26.** The warm flat roof with mushroom vents – vertical section.

Another solution is to make a **warm roof with ventilation channels** above the thermal insulation (Fig. 27). This can be done, for example, by loading the thermal insulation with a concrete screed on a corrugated sheet. The channels created between the thermal insulation and the corrugated sheet should be ventilated by means of appropriately shaped flashing with soffit or fascia vents, or parapet venting (depending on the construction of the roof) or by mushroom vents on the roof.

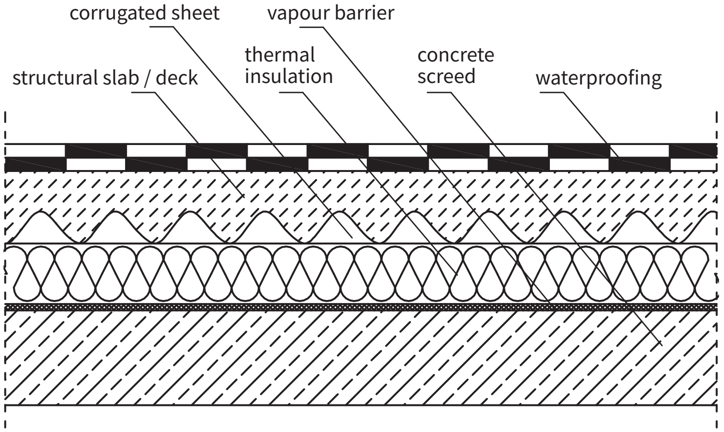


**Fig. 27.** The warm flat roof with ventilation channels – vertical section.

Mineral wool can be used as thermal insulation, or natural materials with much lower carbon footprints, e.g. cellulose or wood fibres in the form of moulded plates or backfills.

## Green roof

Flat roofs with sufficiently high stability and strength may be thermally insulated by an inverted roof covered with greenery. A very tight waterproofing is laid directly on the original structure (it needs to have a minimum fall of at least 1:80 to ensure that rainwater can run off), and on top of it the insulation material; then the retention-drainage layer and the vegetation layer. In the extensive version, which is the most common, the weight of the vegetation layer and plants ranges from 20 to 30 kg/m².

One of the advantages of the inverted roof is that the waterproof covering prevents water vapour from inside the building reaching the insulation to condense within it, whilst the insulation keeps the structure warm, thereby reducing condensation risk within.[117]

The advantages of green roofing, apart from aesthetic values, include protection against noise, much better protection against overheating, a **mitigating effect on the climate**, increasing biodiversity and air purification. A green roof also protects roofing from external influences such as temperature fluctuations, insolation, wind, and rain.[118]

In the context of **adaptation to climate change**, an important feature of green roofs is their hydrologic performance since they reduce stormwater runoff volume by 30 to 86%, reduce the peak flow rate by 22 to 93% and delay the peak flow up to 30 min. Thus, in addition to having a positive impact on the environment and the building, they can reduce risks of flash floods, flooding and erosion during violent rainfalls (see more about green roofs in Chapter 4.2).[119]

[117] Historic England, *Energy Efficiency and Historic Buildings: Insulating Solid Ground Floors*, English Heritage, Swindon 2016, 20.

[118] However, care should be taken to ensure proper drainage of excess rainwater.

[119] Yanling, Li, Roger W. Babcock, *Green roof hydrologic performance and modeling: a review*, Water Sci Technol 1 February 2014; 69 (4), 727–738, DOI: 10.2166/wst.2013.770.

# 3.5. Pitched roof

**Tomasz Jeleński** · Cracow University of Technology
**Cezary Czemplik** · Polish Natural Building Association

## 3.5.1. Roof conservation and repair

It is assumed that roofs presently generate approximately 8–17% of all thermal losses in buildings.[120] Even more significant improvement in thermal-humidity parameters and in building energy efficiency can be achieved, mostly through the elimination of causes of damp in the building. It is therefore recommended to first inspect and, if necessary, repair the tightness of the roofing, the structure of the roof, the flashings, gutters and downpipes.

Mistakes made during the retrofitting of roofs include particularly the elimination of eaves, incorrect angle of suspension of gutters, missing or insufficient size of downpipe hoppers, insufficient cross-sections of downpipes, and insufficiently long endings of downpipes, resulting in the outflow of water too close to the foundations. All these mistakes may result in the structural dampness of the building (see Chapter 3.1).

Problems may also be caused by the change of roofing, modification of the roof truss, and disruption, or even destruction of the integrity of the roof structure. Instead of protecting the building, the disrupted roof may begin to destroy it (e.g. by bursting the walls with previously absent horizontal forces).[121]

In the case of listed buildings, it is recommended that the original roofing should only be restored with necessary repairs, using materials resembling the original shape and colour as closely as possible. If the technical condition of the roofing disqualifies it from further use, the heritage protection regulations do not prohibit the replacement of the roofing with a new one. However, the new roofing should retain the shape, colour and finishing of the original one (which does not exclude the possibility of using a different material, e.g. from recycling) and retain the original appearance of the flashings with the use of durable and non-corrosive material, such as a titanium-zinc sheet.

During the repair and replacement of elements of the roof truss, traditional woodworking joints should be used and any decorative profiles of original wooden elements (such as front boards, eaves combs and corbels) should be recreated. Chemical impregnation of wooden elements is acceptable if it does not change the colour of the wood. In the case of residential attics with full boarding, a vapour-permeable membrane can be used.[122]

If windows in the roof dormers are also of historic value, they should not be replaced but treated as described in Chapter 3.3.1. Re-bricking of damaged chimneys is allowed while maintaining their shape, original colours, and the method of finishing with the use of historically justified materials, e.g. sand-lime plasters.[123]

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[120] Narodowy Instytut Dziedzictwa, *Standardy termomodernizacji obiektów zabytkowych: Wytyczne Generalnego Konserwatora Zabytków dotyczące ochrony wartości dziedzictwa kulturowego w procesie poprawy charakterystyki energetycznej budowli zabytkowych* (The National Institute of Cultural Heritage, *Standards of thermal retrofitting of listed buildings: Recommendations of the General Conservator of Monuments on the protection of cultural heritage values in the process of the improvement of energy performance of listed buildings*) NID, Warszawa 2020.

[121] Rouba, Bogumiła J., *Zawilgocenie jako problem w ochronie obiektów budowlanych i zbiorów muzealnych (Dampness as a problem in the context of the protection of buildings and museum exhibition items)*, MNRiPR-S, Szreniawa 2017, 35–58.

[122] Bakalarczyk, Szymon, *Zasady remontowania obiektów zabytkowych (Rules of Renovation of Listed Buildings)*, WUOZ, Olsztyn. https://www.wuoz.olsztyn.pl/zasady-remontowania-zabytkow (August 2021).

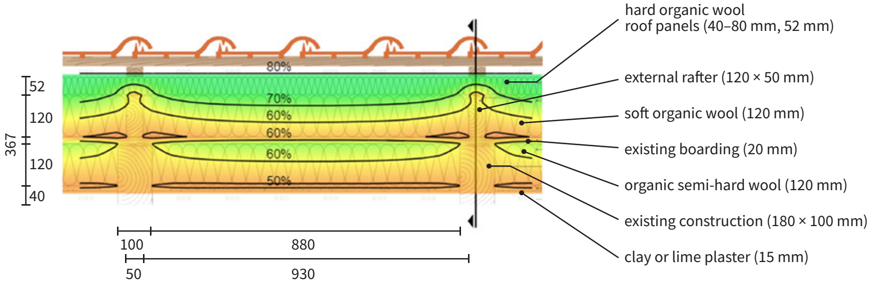
[123] Bakalarczyk, Szymon, op.cit.

In cases of buildings of the highest historic value,[124] no further insulation measures should be applied, but in most historical buildings, thermal insulation of the roof is possible provided that the changes are reversible and the load-bearing capacity of the existing structure is determined in terms of the possibility of carrying the weight of the insulation system.

## 3.5.2. Roof retrofitting: ventilation, vapour permeability, and air tightness

When the roof is to be thermally insulated, the safest renovation strategy is to provide diffusion openness of the thermal insulation material and good ventilation from the outside (between the thermal insulation and the roof covering), and a vapour barrier with full air tightness below the insulation. It is crucial to avoid the convection and diffusion of warm, humid indoor air that would lead to water condensation in the insulation layer. Dampness permanently damages the thermal insulating properties of popular insulating materials, such as mineral wool, which do not have high moisture capacity.

If the implementation of a tight vapour barrier is not possible from the inside, a system that is entirely open to diffusion should be applied. It is vital that none of the insulation or finishing materials act as a barrier to the evaporation of surplus moisture (Fig. 28 and 29). It is also important that the insulation material allows the temporary accumulation of moisture without substantial loss of insulating properties and can efficiently release moisture



**Water vapour pressure distribution**

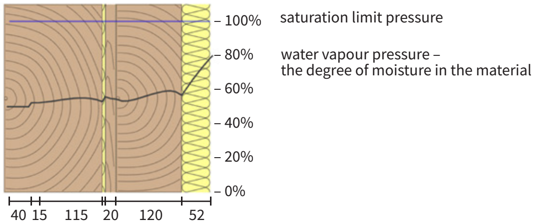


**Fig. 28.** Example: Diffusion-open organic insulation (U=0.15 W/m²K) does not necessarily require the use of a vapour barrier from the inside if its application is not possible. The **implementation of diffusion-open and capillary active materials** ensures lower differences in the moisture of wood and insulation. All wooden elements operate in optimum conditions. Attention must be paid, however, to the protection of structural elements visible from inside against fire.[125]

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[124] The Polish system officially does not include such a category, but it is used in practice. We have mentioned this in Chapter 2.

[125] Illustration from: U-wert.net, *Ubakus*. www.ubakus.de (July 2021).

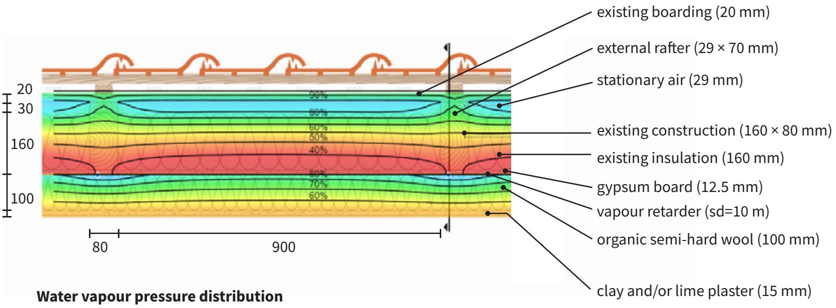
into the air. Such properties, most of all, belong to natural wool but also cellulose, silicates, and the finishing materials such as clay and lime plaster, and mineral paints.

High-humidity interiors require the use of membranes with variable diffusion. This stops the humid air from entering the interior and allows for getting rid of excess moisture from the insulation when the interior becomes dry.

Usually, it is necessary – as in the cases described above – to ensure diffusion openness and good ventilation under tiles or other covering. It is the safest solution that allows the thermal insulation layer to dry naturally in the event of its dampness.

If the diffusion and ventilation through the outer roof layers cannot be assured, the penetration of moisture into the construction and insulation layer must be limited by the use of membranes with specific diffusion coefficients. These can be membranes with variable diffusion, depending on the level of humidity in the interior.

If due to heritage protection or aesthetic reasons it is necessary to leave the rafters visible from the inside, the original roof construction may be covered from the top with insulation and additional strengthening rafters. Strengthening the structure is especially important in the context of changing climate conditions and new standards related to snow load. Existing beams and boarding may be covered in such a case with new construction and



**Water vapour pressure distribution**

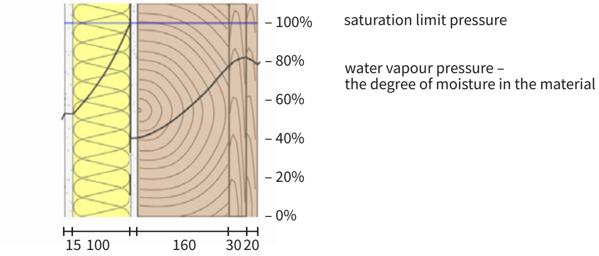


**Fig. 29.** Example: Achieving U=0.15 W/m$^2$K is possible also in the **retrofitting of previously insulated roofs**. The existing plasterboard (fire protection of previously applied mineral-wool insulation) has been covered with a membrane of Sd=10m, allowing an additional 10 cm of wood wool thermal insulation. Finishing with diffusion-open plaster (lime or clay) regulates humidity and provides a fire-retardant surface.[126]

[126] Illustration from: U-wert.net, *Ubakus*. www.ubakus.de (July 2021).

thermal insulation. Depending on the thickness of the new external insulation, the space between the original rafters might not need to be insulated, so the interior can retain its original appearance. However, the level of the roofing and the appearance of the eaves would change.

In the case of thermal insulation that is closed to diffusion, such as PUR foam, it is necessary to ensure the full water-tightness from the outside, because in the event of any leakage, moisture accumulated inside the roof has limited possibilities for evaporation.

If none of the thermal roof insulation solutions are possible and the roof space will not be heated, an insulation layer should be applied on the floor above the uppermost heated storey. Loose materials based on hemp or cellulose can be used. The downside of this solution is that the attic becomes an unheated space with limited usability.

## 3.5.3. Attic adaptation, roof renovation and upper storey addition

In the case of unused attics, their adaptation should be considered. This would result in the increase of a building's floor space and thus facilitate the funding of energy retrofitting – this especially applies to multifamily or non-residential buildings.

Even in the case of listed buildings, heritage conservators usually accept the adaptation of attics, although under certain conditions. It is usually recommended that roof windows are installed on non-visible surfaces, while their installation on frontal roof slopes or those visible from different directions can be problematic. The natural light illumination of frontal rooms is then recommended via tunnel skylights installed on a roof surface that is not exposed.[127]

In the event of renovation, replacement of the roof covering or reconstruction or adaptation of an unheated attic to a warm, usable attic, it is important to assess the load-bearing capacity of the existing roof structure and the weight of the insulation and/or new covering, and to adapt the structure to the new load-bearing capacity requirements. Due to material wear, cracks, and general weakening, many historical structures will not meet the new requirements without a thorough renovation.

If it is necessary to maintain a harmonious appearance of the roofscape, e.g. in the conservation area, it is unacceptable to raise the roofing to insulate it, which would change the profile and proportions of the roof, particularly eaves and roof edges with gutters. Thermal insulation from inside is usually allowed between the rafters, but the rafters should remain visible. In buildings with no historic value, roof insulation is also possible below the rafters.

In both listed and non-listed buildings, the location and arrangement of roof windows must be adapted to compositional axes defined by the façade windows. This is to preserve the harmony and integrity of the entire elevation. This principle should also be respected in the case of designing an additional top floor.

[127] Dz.U.2019 poz.1065 – *Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie.*

**Fig. 30.** Palace in Rzuchów, built in 1888, listed on the National Heritage List for Poland. The palace is undergoing modernisation carried out by the Foundation for the Protection of Cultural Property. So far, restoration has included façades and the roof, the truss of which is adapted to the load of photovoltaic panels planned for a non-visible flat part. The new roof also allows for the hiding of the technical elements of the heat recovery ventilation system. Replicas of historical windows with high thermal parameters were installed, and the ceilings above the first floor were insulated. The plans include a photovoltaic installation with an electrolyser to produce 'green' hydrogen and a hydrogen cell to supply the palace with electricity, as well as an energy-saving heating system and a sensor and automation system to manage energy consumption. Recreation of the historic park layout is also planned.

If the building's structure and the architectural/heritage context allow the construction of an additional top floor, then this is also beneficial in regard to climate protection. The floor addition is subject to an obligatory building permit, which requires the entire building to be adapted to the requirements of the 2021 building code that imposes nZEB standard.[128]

### 3.5.4. Roof covering

The main problem in roof retrofitting may arise from the recently increased roof load requirements. The key issue for the selection of new roofing and additional insulation is therefore their weight. The second important issue is the carbon footprint of the production of the roofing material. Aesthetics aside, the most advantageous options here are lighter roof coverings made of asphalt shingles or traditional sheet metals. The carbon footprint of a roof covering may be as high as +56 kg $CO_2$ in the case of aluminium sheet; +13–16 kg $CO_2$ in the case of tiles; 4.5 kg $CO_2$ in the case of asphalt shingles (Fig. 31) or it may even have a negative value in the case of thatching, reed, and wood shingles, which are capable of sequestrating (capturing, securing and storing) carbon from the atmosphere in their organic matter.

Organic materials also act as thermal insulation and protect the interior from overheating, which in the case of hard roofing may be achieved with limited scope and only through the application of light colours or reflective finishing, which might not be acceptable due to architectural/landscape requirements.

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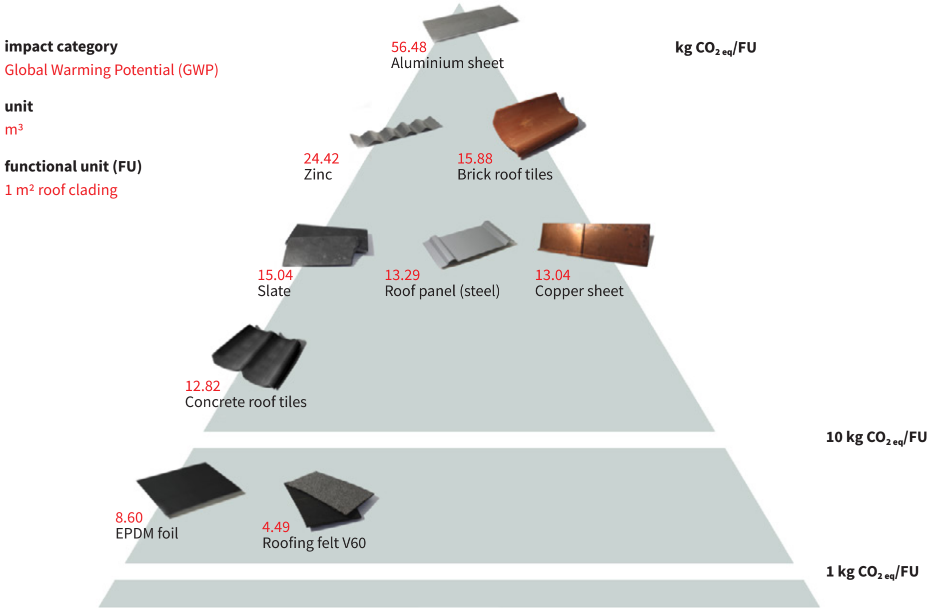
[128] Dz.U.2019 poz.1065, op.cit.

However, the use of organic roofing in multi-family and public-use buildings on a wider scale is limited by the fire-safety requirements and by obligatory maintenance every 5–10 years.

The calculation of the life cycle of materials should consider their durability, which is the highest for ceramic roofing, then for metal roofing made of copper and zinc, and the lowest for organic and bituminous materials. When a building is designed for long life, the use of durable materials may be beneficial for the carbon footprint, even if their production temporarily generates higher emissions of $CO_2$.

An interesting alternative to solutions based on ceramic or concrete tiles might be composite tiles made from recycled PET, which visually resemble ceramic tiles, but are 40% cheaper and 50% lighter. Lighter tiles can be mounted on an old roof truss without the need for its strengthening or total rebuild. Even if the need to replace the truss arises, the lower weight of the roofing generates a 40% reduction of the costs of the structural material and a 30% reduction of transport costs.[129]

A new but costly solution is solar tiles with integrated photovoltaic cells, which will gradually reduce the carbon footprint of a building. The reduction in cell prices, as well as the invention of Olga Malinkiewicz – printed, elastic and transparent perovskite solar cells, may soon improve the availability and range of materials with integrated photovoltaics, allowing them to be also used in listed buildings[131] (more on the use of photovoltaics can be found in Chapter 5.2).



© CINARK/The Royal Danish Academy and Vandkunsten Architects

**Fig. 31.** Characteristics of roofing materials in terms of the impact of their manufacturing processes on climate.[130]

[129] Tileco, *Dachówki kompozytowe – alternatywa w pokryciach dachowych. Dekarz i Cieśla*. (*Composite Tiles – An Alternative Solution to Roofing*). https://fachowydekarz.pl/dachowki-kompozytowe-alternatywa-pokryciach-dachowych/ (July 2021).

[131] Saule Technologies, *Building Attached Photovoltaics*. https://sauletech.com/bapv (June 2022).

[130] Illustration from: CINARK – Center for Industrialized Architecture, *Materialepyramiden*, The Royal Danish Academy – Architecture, Design, Conservation. https://www.materialepyramiden.dk/# (July 2021).

Another option may be green roofing. Green roofs have been applied since ancient times, both in southern and northern Europe. They may be implemented both on flat or sloping roofs and work well in most climates. As an additional insulation layer, they protect buildings against overheating, frost, noise, and very effectively prevent the spread of fire (more about green roofs see in Chapters 2.1.1.2 and 4.1.1).

## 3.5.5. Natural insulating materials

The production of insulating materials consumes large amounts of energy too. For example, 8 kWh of final energy is used to produce 1 kg of mineral wool, which means a high emission of $CO_2$, especially in the Polish power system conditions.[132]

Among low-emission materials, the most interesting are cellulose and wood wool, as well as the less-popular sheep wool, which has excellent water-resistant and temperature-regulating properties, neutralises harmful substances and provides noise insulation.[133] Insulating panels made of sheep wool have a thermal conductivity $\lambda = 0.0385$ W/(m·K) and bulk density of $\rho_{\cdot} = 14–100$ kg/$m^3$. The use of materials with higher density and thermal capacity additionally reduces overheating during the summer.

An especially low carbon footprint is a characteristic of expanded cork sheets that do not contain any polyurethane in their structure. Cork sheets for the thermal insulation of slanted wooden roofs have a thermal conductivity $\lambda = 0.037$ W/(m·K).[134]

More popular alternatives to the commonly used mineral wool combined with a vapour barrier may primarily be natural fibre materials: wood, hemp, and straw fibres. One of their advantages is that they do not necessarily require ventilated space underneath the boarding or tiles. Instead of full boarding, the rafters can be covered with diffusion-open semi-rigid insulation sheets and additionally insulated from underneath with cellulose, wood wool, or diffusion-open polyurethane foam. In such cases, residential attics need to be fire protected from the inside in accordance with class EI 30, by covering the insulation with, for example, fibreboards with fireproof plaster.

The potential accumulation of $CO_2$ in a roof retrofitting system based on organic materials is even greater than that of walls and may be as high as – 47 kg/$m^2$ $CO_2$.

## 3.5.6. Thermoreflective and vacuum insulations

Thermoreflective insulation is variously made from bubble film covered with aluminium foil or many layers of metalised foil, wadding, reflective inserts, and/or foams. Its effectiveness is based on the inhibition of convection and the reflection of thermal radiation into the interior of the building. These properties and effects are not represented in the thermal resistance coefficient (R-value) or calculation methodology of heat transfer coefficient

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[132] KAPE, *Ekspertyza w zakresie określenia opłacalnych podejść do modernizacji właściwych dla danego typu budynków i strefy klimatycznej (Analysis of the cost effectiveness of retrofitting strategies for different building types and climate zones)*. KAPE, Warszawa 2020, 160.

[133] The University of Waikato, Wool fibre properties, Science Learning Hub. https://www.sciencelearn.org.nz/resources/875-wool-fibre-properties (March 2022).

[134] Pawłowski, Krzysztof, *Innowacyjne rozwiązania materiałów termoizolacyjnych w aspekcie modernizacji budynków w Polsce (Innovative solutions for thermal insulation materials in the aspect of retrofitting of buildings in Poland*). Izolacje 3/2018. https://www.izolacje.com.pl/artykul/sciany-stropy/182305,innowacyjne-rozwiazania-materialowtermoizolacyjnych-w-aspekcie-modernizacji-budynkow-w-polsce (July 2021).

(U-value), therefore the effectiveness of such insulation cannot be directly compared with solutions described earlier. Manufacturers state that a thin thermoreflective sheet reduces the loss of thermal energy by as much as a 20 cm layer of mineral wool. However, such properties can only be achieved without any direct contact or heat exchange with other materials.[135] Therefore, reflective thermal insulation must be always suspended in an air void, e.g. between the rafters.

Thermoreflective insulation also demonstrates vapour-insulating properties of Sd= 5–50, so care must be taken to install it tightly. It is usually secured against damage with plasterboards. The entire system has a low internal thermal capacity.

Another alternative solution may be vacuum insulation (diffusion sealed) that allows a conductivity coefficient of about λ = 0.007 W/(m·K) based on the effect of vacuum trapped in the foil sheets. Thanks to the low thermal conductivity performance (λ or k), such insulation can meet the requirements for the theoretical verification of envelope thermal resistance. Unfortunately, the durability of this solution is not sufficiently proven to enable comparison with traditional organic insulations.

[135] Aluthermo, *Aluthermo®QUATTRO*. https://aluthermo.com.pl/produkty/aluthermo-quattro (July 2021).

# 3.6. Ventilation system

**Tomasz Jeleński** · Cracow University of Technology)

In most buildings the ventilation system is responsible for the greatest energy losses. Statistically, in residential buildings in Poland, 30–40% of energy is lost through ventilation.[136] At the same time, efficient ventilation is essential in every building. Insufficient air exchange causes serious threats to the health of people and buildings.

Most historical buildings depend on natural, passive ventilation. It relies on heat pressure caused by temperature and air density differences between indoor and outdoor, and the wind pressure caused by the outdoor wind. The used and heated air is removed through the stack ventilation ducts thanks to the chimney effect. The duct system is supplemented by various leaks, through which fresh and usually cooler air flows into the interior. An additional airing is provided by opening the windows.

Such a system does not enable control over the amount of air exchanged. Passive stack airflow rates are very much weather and occupant-dependent with a risk of over or under ventilating. Sometimes the air exchange is too high, causing unnecessarily large energy losses, and sometimes too low – due to obstruction or alteration of ventilation ducts or sealing of the building envelope. This frequently occurs after installing very tight replacement windows (see Chapter 3.3). Closing the air supply causes natural ventilation to basically stop working, which may result in high relative humidity of the indoor air, even exceeding 80%.[137]

If the moisture load produced by the occupants is not vented off, the risk of mould growth at thermal bridges increases (see Chapters 2 and 3). At a relative humidity of 60%, mould can occur at a surface temperature of 15.5°C and below.[138] Such surface temperatures are common inside old buildings with too little insulation.

There are three main requirements for the air change rates in buildings:[139]

- For the air flow to be sufficient to vent off humidity, odours, and $CO_2$ produced by the occupants, a supply air flow volume of 20–30 $m^3/h$ per person is recommended.
- Air contamination, odours and humidity emitted in 'wet' rooms should be carried off by an extract air volume flow ranging from 40–60 $m^3/h$ for kitchens and utility rooms to 40 $m^3/h$ for bathrooms and 20 $m^3/h$ for toilets.
- Regardless of the number of occupants, a minimum air change rate of 0.3 1/h should be always ensured, to vent off background contamination and odours. In old buildings, without any new furniture or building materials, the background contamination might be low, hence an air change rate of 0.2 1/h might be sufficient.

The recommended air changes per hour should not be exceeded by much so as not to waste the energy of the heated air during the heating period. On the other hand, insufficient air exchange may result in potential negative effects on the health and wellbeing of occupants. Symptoms of a poor ventilation

[136] Narodowy Instytut Dziedzictwa, op.cit., 32.

[137] Kaliszuk-Wietecka, Agnieszka, et al., *Opracowanie dotyczące możliwości termomodernizacji budynków zabytkowych ze szczególnym uwzględnieniem docieplenia przegród pionowych*, NID, Warszawa 2019, 17–19.

[138] Troi, Alexandra, Zeno Bastian (ed.), op.cit., 20.

[139] Ibidem.

system may include fatigue, irritated mucous membranes, respiratory diseases, or frequent headaches.

The usual goal is to control the air exchange i.e. to seal the building envelope (including joinery and installation culverts) and replace the passive ventilation system with a mechanical one with a recuperation function that recovers significant heat energy from the air and also cold or moisture if needed. Utilising a central heat exchanger or the coupling of smaller heat recovery units, it is possible to control the amount of exchanged air, which ensures healthy and comfortable conditions as well as energy savings.

## 3.6.1. Restoration of the passive ventilation system

If the installation of mechanical ventilation in the building is not possible and airtightness is improved during an energy retrofit, it is necessary to bring the passive ventilation system to a state of maximum efficiency by exposing clogged ventilation grilles, unblocking the ducts, and restoring the original layout of the rooms if they have been divided. Especially in the post-war period in CEE countries, the alterations of spacious bourgeois apartments were frequent, with partition walls separating smaller rooms, some of which were thus deprived of access to stack ventilation ducts.

If, after restoring the original efficiency of natural ventilation, the air is still too humid, recurrent full opening of windows at least four times a day is recommended for sufficient air quality and prevention of mould growth. Fully opening the windows for approx. 3–5 minutes will lead to much lower heat losses than leaving them ajar over a longer period while having the same effects on the air quality.[140]

If properly maintained and supported by regular airing through widows, the natural ventilation system works particularly well in buildings whose structure, especially walls, have a large heat capacity.

However, wherever acceptable and technically feasible, the installation of a mechanical ventilation system with heat recovery should be pursued. That way, ventilation heat losses can be reduced greatly (up to 90%).[141] Air quality is improved too, because the supply air is filtered and preheated by the heat recovery system and its proper supply needs not to rely on an occupant’s routine.

One of the greatest advantages of mechanical ventilation is that it enables improvement of the airtightness of the building envelope, which leads to further energy savings, and reduces risks, e.g. those resulting from the installation of internal insulation or introduction of heating into the adapted basement or attic (see Chapters 3.2 and 3.4).

[140] Ibidem.

[141] Ibidem.

## 3.6.2. Mechanical and heat recovery systems

Before starting retrofitting that includes insulation of external walls and/or joinery, it is necessary to assess the ventilation system. The assessment should follow legal regulations and standards.[142] It is the basis for formulating recommendations regarding the possible modernisation of the ventilation system. Secondly, a system which offers longevity, resource-efficiency and long-term cost-effective savings should be considered.

Widely used in new build developments, heat recovery works by removing moisture-laden air from the wet room areas of the building. It then extracts the energy from the air before expelling it out into the atmosphere and uses that energy to preheat fresh air which is delivered into the living or working areas of the interior. In terms of energy efficiency, heat recovery is very beneficial but installing the entire system requires extensive work, ducts running into various rooms, threatening the aesthetic and historic values of the building.

When designating routes for new ventilation ducts, it is necessary to respect historical substance and consider using existing shafts, risers, furrows, recesses, and openings from previous installations. New ventilation risers and air ducts should be located primarily within former passive ventilation and smoke risers should be equipped with appropriate inserts. If any visible elements must be installed, design of the installation should be adapted to the architectural forms of the building – both its elevations and interior.

When designing external elements, the composition of the façade and the roof must be considered. Ductwork needs to be hidden along cornices, eaves, downpipes, gutters, offsets, and other architectural elements.[143] The colours of new elements should blend into the colours of the walls.

Fresh air intakes and/or exhaust air outlets may be allowed on the roof if they are concealed. Above all, however, one should use available solutions that allow for hiding technical devices below ground level or in a free-standing form in a suitable architectural arrangement.

If the building is listed, interference with the original architectural and painting decor is not allowed. It is not acceptable to run installations aside the corners of rooms and wall planes. Installation within the thickness of the plaster should be preceded by a conservation survey to establish the possible presence of polychrome decorations. Generally, no vents or ducts are allowed on the visible façade. Conditionally (if no other possibilities have been found), some non-disfiguring elements of the installation on the rear elevation, without interfering with its historic substance, are allowed.

## 3.6.3. Choice of a mechanical ventilation system

There are several variants of mechanical ventilation heat recovery systems (MVHR). The basis for selecting the optimal solution is the decision of whether

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[142] Kaliszuk-Wietecka, Agnieszka, et al., op.cit., 18.

[143] Bakalarczyk, Szymon, *Zasady remontowania obiektów zabytkowych*, WUOZ, Olsztyn. https://www.wuoz.olsztyn.pl/zasady-remontowania-zabytkow (August 2021).

a central or decentralised system is more suitable for a given building. There are no general rules to follow in making this decision, either in terms of conservation requirements or costs. The choice should result from the analysis of the structure, conditions and needs of the building. It is also necessary to understand the features of the available ventilation devices and the differences between the systems.

**Central ventilation system (CVS)** is based on using one heat exchanger and two fans for supply and exhaust air for a whole building. The weight and size of the central unit and space for the supply and extract ductwork need to be considered.

Advantages of CVS:

- The number of openings that need to be made is significantly reduced. If the fresh air intake and the exhaust air outlet are placed on the roof or ducted underground, no openings in the façade are necessary.
- The central unit can be placed in a mechanical room or outside, which is a big advantage in terms of sound protection and maintenance.
- Highly efficient units are available in different sizes.
- In most cases, a CVS has lower investment and maintenance costs than decentralised ventilation system (DVS).

Disadvantages of CVS:

- The planning costs are relatively high, especially in historical buildings for which tailor-made solutions need to be found.
- A plant room for accommodating the central unit is not available in every case and space needs to be provided for the duct system. Old chimneys can sometimes be used for the vertical ventilation ducts, but horizontal distribution is also necessary.
- If a duct passes through a fire-rated compartment elements, additional fire-protection measures are necessary.

**Decentralised ventilation system (DVS)** uses several smaller heat recovery units for specific zones or dwellings.

Advantages of DVS:

- It helps to avoid installing ductwork if the unit is placed close to the building envelope or integrated into the wall.
- A dedicated plant room is not necessary and the heat recovery unit can be placed directly in the rooms.
- The rooms are not connected with each other by air ducts, which increases fire safety.
- The planning and installation costs are low because standardised systems are installed.
- Each unit can be controlled and operated directly by the user.

Disadvantages of DVS:

- Each unit needs fresh air supply and exhaust to the outside, usually through the façade (wall or window). It is usually not accepted in listed buildings and conservation zones. Solutions need to be found that are acceptable in respect of heritage conservation principles.

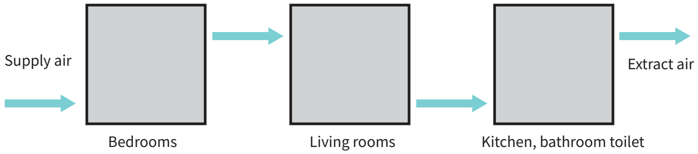

**Fig. 32.** Principle of cascade ventilation: supply air only in bedrooms.[145]

- Since the units are usually placed directly in the occupied rooms, sound protection must be ensured.
- Ease of access for maintenance and service may be another problematic requirement, especially in the case of multifamily buildings with rented flats.

The principle of **cascade ventilation** helps to find the optimum efficiency in terms of flow rate and ductwork. For example, the air is led from the supply air zone (bedrooms, living rooms, etc.) via a transfer zone (e.g. corridors) to the extract air zone (kitchens, bathrooms, WCs, and utility rooms). However, if the living rooms are regarded as a transfer zone too, then supply air needs to be provided only for bedrooms and transferred via the living rooms and the corridors to the extract air zones (Fig. 32). This principle makes it easier to build an energy-efficient and cost-effective ventilation system, allowing a reduction of the number and length of supply air ducts that is especially important for historic buildings. [144]

In some listed buildings, no supply air duct may be installed for architectural or conservation reasons. Application of the **active overflow ventilation system** may be a good solution then, especially when refurbishing a residential building. The heat recovery unit takes the extract air from toilets, kitchens, etc., e.g. through redundant stack ventilation channels. The unit supplies preheated fresh air to the distribution zone – corridors, staircase,

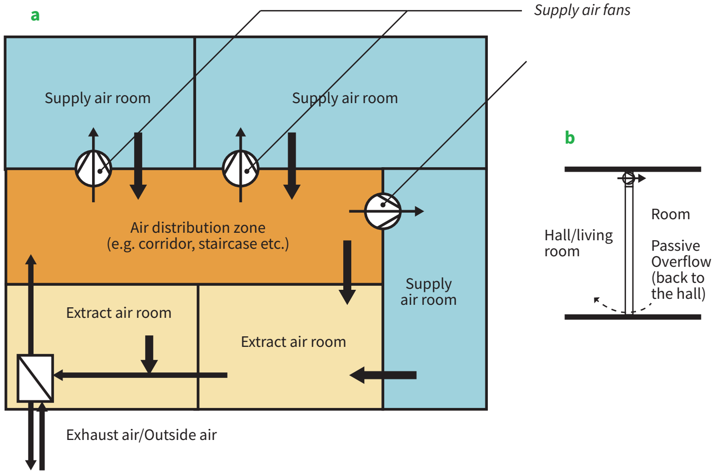

**Fig. 33** Active overflow ventilation system – supply air is fed into the distribution zone, small fans vent the supply air rooms individually.[146]

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[145] Illustration from: Troi, Alexandra, Zeno Bastian (ed.), *Energy Efficiency Solutions for Historic Buildings: A Handbook*, Birkh.user, Basel 2015, 159.

[144] Troi, Alexandra, Zeno Bastian (ed.), op.cit., 159.

[146] Illustration 33 a from: Troi, Alexandra, Zeno Bastian (ed.), *Energy Efficiency Solutions for Historic Buildings: A Handbook*, Birkhäuser, Basel 2015, 160.

etc. Small fans are necessary to lead the air from the corridor to the supply air rooms (active overflow) (Fig. 33). This avoids a network of vertical and horizontal supply air ducts because the staircase and corridors are used as a duct. The drawback of this system compared to cascade ventilation is that the ventilation efficiency is lower, because part of the used air goes to the distribution zone (due to passive overflow) where it mixes with the fresh air.

For projects on a smaller scale and in buildings where it is not possible to install comprehensive mechanical ventilation, one may consider installing one or more **single room heat recovery units**. They can be very beneficial for kitchens and bathrooms, recovering up to 80% of the heat that would normally be lost at extraction. Single room heat recovery units do not require duct runs and can utilise existing stack ventilation ducts and wall sleeves, which makes installation much easier and minimally invasive.

### 3.6.4. Installation of heat recovery units

In the case of a central ventilation system (CVS), the main unit is usually located in the attic or basement or outside the building. In a decentralised ventilation system (DVS), the units are usually installed on the internal surfaces of façades or in the ceiling space. In any case, the heat recovery unit should be placed as close as possible to the building envelope to keep ducts short. If the unit is placed outside the envelope, the warm duct (with extract and supply air) between the unit and the envelope must be well insulated. If the unit is integrated into the wall, the length of cold duct is reduced to the absolute minimum, thus saving material and installation costs as well as heat loss and maintenance costs. In the case of a listed building, it needs to be clarified whether a ventilation system may be mounted on the inner surface of an exterior wall or windows.

In the case of wall integration, there are various places where such a unit can be mounted: under the window (if there is no radiator), beside the window, or above the window (if there is enough space and this does not impair the load-bearing capacity of the lintel). The DVS heat exchangers are often flat to minimise the thickness of the unit placed on the wall or the depth of the suspended ceiling.

If conservation requirements forbid openings in the façade, a closer investigation of the building structure needs to be performed. If there are chimneys no longer in use, they could serve as shafts for ventilation ducts. The other possibility is to put the exhaust and supply air ducts in the ground and run them into the cellar or basement if the central system is to be placed there.

Generally, having fresh air intake and exhaust air outlet makes two ducts necessary – and consequently two openings in the building envelope. The coaxial duct systems can help to minimise the number of openings since one coaxial duct can simultaneously transfer air both ways. The fresh air is drawn into the building through the annular gap, whereas the exhaust air is blown out through the central tube.[147] There are also wall-mounted mini

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[147] Sibille, Elisabeth, et al., *Development of a coaxial-duct as outdoor air inlet and exhaust air outlet for ventilation units*. 18. Internationale Passivhaus TagungAt, Aachen 2014, DOI: 10.13140/2.1.1212.5448.

recuperators for decentralized systems that alternately supply and exhaust air through one opening.

When the building is insulated on the outside, a compact recuperator may be placed in the insulation layer, and the ventilation (supply and exhaust) grille may be installed in the window reveal. It is perhaps the most discreet way of installing a decentralized wall recuperator (Fig. 34).


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**Fig. 34.** An example of a decentralized recuperator installed in the external insulation layer. Visible on the window reveal is the external ventilation (supply and exhaust) grille. With the wall-mounted masking element inside, they are the only visible parts of the recuperator.

# 3.7. Heating system

**Tomasz Jeleński** · Cracow University of Technology

The role of the heating system is to heat the building and prepare domestic hot water. A properly selected and designed system improves the thermal comfort, protects the building against damage and reduces energy consumption.

The system usually includes a heat source or a connection to the heat network (district heating) and heat emitters such as radiators, convectors or surface emitters (underfloor, wall, ceiling). Heating systems that are not connected to the network and have no central heat source consist of heat emitters powered directly by electricity. They are used less frequently because of their higher utility costs.

## 3.7.1. Heat source

A heat source, as a basic element of a typical heating system, has the greatest influence on the system's environmental impact i.e. energy consumption; $CO_2$ emission; air pollutant emissions (particulate matter (PM), benzo(a)pyrene (B(a)P), sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$)), and the production of waste such as ash or slag.

With a comprehensive and deep energy renovation of a building using its own heat source, the old heat source is almost always replaced. If there is a heating network near the building, it is worth recognizing the possibility of connecting to it. This is often the most advantageous solution due to the reduction of emissions and usually the cost-effectiveness of heating too (see Table 3.7.4).

If the building is to have its own heat source, it is important to properly plan the renovation stages so that the installation of an effective heating system is preceded by a reduction in heat demand, e.g. by improving the thermal insulation of building envelope and ventilation system (see Chapters 3.1–3.6). If this reduction is not considered in advance, the new heating system may be oversized which would cause needlessly higher investment costs and usually, and more importantly, higher energy consumption after energy renovation.

Determining the building's thermal power requirement is part of the energy audit (see Chapter 1.2). If the professional audit procedure cannot be performed, one can use tools such as CiepłoWłaściwie.pl (https://cieplo.app). It helps people without specialist knowledge to estimate the thermal power needed to heat the building and the costs of heating by various systems and sources of energy, as well as calculate which solutions (e.g. insulation of the envelope, new ventilation system, replacement of the heating system, or a combination of these) would be the most effective in terms of costs and benefits.

To estimate the thermal power needs, energy performance assessment tools may also be used. One of the easiest to use, even if the most comprehensive (multi-criteria), is the Ekodom calculator (ekodom.edu.pl), which not only calculates the energy consumption but also $CO_2$ emissions. It includes a module for selecting energy modernisation solutions, enabling the observation of changes in the energy and emission values for different insolation conditions, various ventilation systems, types of windows, insulation materials and thicknesses of their layers, as well as different types of heat and electricity sources. The calculator is based on standards and climatic data from 27 EU countries. With such tools, one can check individual elements and systems (existing and projected) of a specific building, including heating systems, as well as consider their impact on energy consumption and emissions. Such tools perform a simplified energy audit, determining estimated costs and effects of modernisation.[148]

## Renewable heat energy sources

Heat is the world's largest energy end-use, accounting for almost half of global final energy consumption in 2021. The supply of heat, which contributed more than 40% (13.1 Gt) of global energy-related $CO_2$ emissions in 2020, remains heavily fossil-fuel dependent. 46% of the heat is consumed in buildings, mostly for space and water heating. Renewable energy sources (RES) contributed only 11% (23 EJ) of the energy used for heat in 2020.[149]

Due to climate mitigation needs and increasing profitability, the future undoubtedly belongs to heating systems powered by RES. Renewable heat technologies include biofuels, solar heating, and geothermal heating including ground source Heat Pump (GSHP) systems (see more in Chapter 5).

The most popular renewable fuel is biomass. Burning wood industry residues, energy crops, or agricultural residues is climate neutral. When the biomass is burned, only atmospheric $CO_2$ sequestered during plant growth is released back into the atmosphere. However, combustion of biomass in boilers supplying individual buildings causes the emission of exceptionally large amounts of particulate matter (PM) (see Chapters 3.7.2 and 3.8.5). Installations without appropriate electrostatic precipitators emit even greater amounts of PM than coal-fired ones. For this reason, it is not recommended, or may even be locally banned (e.g. in Cracow) to burn biomass in urbanized areas. Therefore, the use of RES in distributed heating is possible mainly in electricity-based systems.

## Electric heating systems

The carbon footprint of electric systems depends on the method of power generation. As the share of renewable energy in the energy system increases, the carbon footprint of heating buildings with electricity decreases.

The advantages of electric heating systems are the relatively low cost of the installation (including the cost of emitters) and the convenience of use (maintenance-free and control automation). The disadvantage is the high and growing cost of purchasing electricity. The lower the building energy demand, the more profitable it is to use electric heating devices. Currently, electric heating is cost-efficient mainly in buildings with the best energy standards and when the electricity is produced on-site.

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[148] The calculator is free of charge and very easy to use, however, to perform a professional assessment of the characteristics of the building, it is necessary to use dedicated software, e.g. Arcadia Thermo, Sankom, Certo, or Intersoft.

[149] IEA, *Renewables 2021*, Paris: IEA. https://www.iea.org/reports/renewables-2021 (June 2022).

To reduce the energy demand, a heat pump can be used, which consumes about three times less energy than simple electric heaters and – depending on the season – can generate heat or cold. By supplying the heat pump from own RES, e.g. photovoltaics (PV), one achieves a significant reduction in the building primary energy demand. The combination of a heat pump with a PV installation is currently the most effective method of bringing the building to the zero-energy or even plus-energy standard.

An alternative solution to the heat pump is an electric heater in the ventilation unit that heats the ventilation air. It increases the operating costs but eliminates the need to equip the building with a separate heating system. This solution can be used in buildings with minimal heat demand, e.g. in a passive standard. Domestic hot water can be prepared most days of the year in the installation of solar or hybrid collectors and heated with an electric heater only on cloudy days.

## 3.7.2. Selection of energy sources and heating devices

Several indicators can be used to assess energy sources in terms of their impact on the environment, e.g. the coefficient of **non-renewable primary energy expenditure** on the production and delivery of energy or an energy carrier (Wi). The values of this coefficient in Poland, in accordance with the ordinance of the Minister of Infrastructure and Development,[150] are presented in Table 3.7.1. The lower the Wi-value, the lower the consumption of non-renewable fossil fuels.

**Table 3.7.1.** The coefficient of non-renewable primary energy expenditure on the production and delivery of energy or an energy carrier (Wi).

| Method of supplying the building | Type of energy or energy carrier | Wi-value |
|---|---|---|
| Energy production in the building | Solar, wind, and geothermal energy | 0.00 |
| | Biomass | 0.20 |
| | Biogas | 0.50 |
| | Heating oil | 1.10 |
| | Gas | |
| | Coal | |
| District heat from cogeneration plant (CHP) | Biomass, biogas | 0.15 |
| | Bituminous coal or gas | 0.80 |
| District heat from combustion plant | Gas or heating oil | 1.20 |
| | Bituminous coal | 1.30 |
| Electric power system | Electricity | 3.00 |

Another indicator is the energy efficiency class of heating devices, which is crucial for **final energy consumption at the stage of building operation**. At the EU level, the framework obligations for the labelling of energy-using products (including heat sources) have been implemented by Regulation of

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[150] Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz.U. 2015 poz. 376).

the European Parliament and of the Council.[151] The values of energy classes of basic heat sources are presented in Table 3.7.2.

**Table 3.7.2.** Classes of energy efficiency of heating devices[152]

| Heat source | Energy efficiency class |
|---|---|
| Ground source heat pumps | A+++ |
| Air source heat pumps (gas and electric)<br>Cogeneration (gas)<br>Gas boilers combined with a heat pump or solar collector<br>Biomass boilers<br>Heat nodes (some) | A++, A+ |
| Condensing boilers<br>Biomass boilers<br>Heat nodes (some) | A |
| Solid fuel (coal) boilers<br>Non-condensing gas boilers | B, C, D |

The most important indicator determining the **impact of various heat sources on the climate** is the amount of **$CO_2$ emissions**. According to the National Energy Conservation Agency (KAPE, 2020), based on the data of the National Centre for Emissions Management (KOBIZE) for 2018,[153] the values of the $CO_2$ emission index, depending on the type of fuel or energy used, are those presented in Table 3.7.3.

**Table 3.7.3.** Impact of heat sources on the climate ($CO_2$ emissions) depending on the type of fuel or energy used.

| Method of supplying the building with energy | Type of energy or energy carrier | Emission of $CO_2$, kg/GJ |
|---|---|---|
| Local energy production in the building | Solar energy | 0.00 |
| | Wind energy | |
| | Geothermal energy | |
| | Biomass | |
| | Biogas | |
| | Heating oil | 77.4 |
| | Natural gas | 55.5 |
| | Liquefied gas | 63.1 |
| | Bituminous coal | 94.7 |
| | Lignite | 104.1 |
| District heat from cogeneration plant (CHP) | Biomass, biogas | 0.0 |
| | Bituminous coal | 136.0 |
| District heat from combustion plant | Gas | 74.4 |
| | Bituminous coal | 143.7 |
| Electric power system | Electricity | 216.1 |

[151] EUR-Lex, *Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU* (*Text with EEA relevance*). Document 32017R1369. https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32017R1369 (August 2021).

[152] The list has been supplemented with modern heat distribution units with an efficiency rating of 98–99%, not covered by the labelling system. KAPE, *Analiza inwestycji budowlanej pod kątem możliwości ograniczenia negatywnego oddziaływania na środowisko*. Warszawa 2020, 62.

[153] Ibidem, 63–64.

## Particle pollution and waste

One of the basic indicators in selecting the best heat source for a building is the value of PM10 particulate matter emission. PM emissions do not have a significant impact on the climate but pose a very serious threat to health and life in the region of the emission.

In 2020, KAPE compiled values of PM10 emissions produced in Poland, according to the type of fuel or energy carrier.[154] Renewable sources using solar, wind and geothermal energy do not cause any PM emissions. In the case of district heat and electricity, PM emission is negligible since installations are equipped with electrostatic precipitators.

Solid fuels have the highest PM10 emission indexes. Combustion of coal (even high-quality bituminous coal) in a boiler that meets the requirements of Class 5, causes the emission of 16 g/GJ.[155] An even worse indicator of PM10 emission is related to biomass (including wood), the combustion of which in a Class 5 boiler causes the emission of as much as 18 g/GJ. In this context, gaseous fuels are relatively clean: 0.5–0.7 g/GJ.

To further reduce the negative impact of buildings on the environment, heat sources which do not generate solid waste should be used. The amount and toxicity of waste are greatest in the case of burning coal. Ash is also produced in the process of biomass combustion, but its amount is much lower, and its toxicity is negligible.

Considering environmental impact, the best heat sources are those with both the lowest possible $CO_2$ and PM emissions. The record presented in Table 3.7.4 shows that heating solutions with zero impact on the environment in the operation stage are available. However, in historical buildings, their use may not be possible, mostly due to heritage conservation provisions and the limited availability of district heating.

**Table 3.7.4.** The values of the PM10 and $CO_2$ emission indexes depending on the type of heat source and heating system.[156]

| Heat source | Total efficiency of the heating system | PM10 emission (g/GJ) | $CO_2$ emission (kg/GJ) |
|---|---|---|---|
| Automated biomass boiler | 0.69 | 26.1 | 0.0 |
| Heating oil boiler | 0.73 | 4.1 | 106.0 |
| Condensing gas boiler | 0.79 | 0.6 | 70.3 |
| Liquid gas boiler | 0.79 | 0.9 | 83.0 |
| Automated coal boiler, Class 5 | 0.69 | 23.2 | 137.2 |
| Heat node – district heat from cogeneration plant (CHP) – biomass, biogas | 0.83 | 0.0 | 0.0 |
| Heat node – district heat from cogeneration plant (CHP) – coal | 0.83 | 0.0 | 163.9 |
| Heat node – district heat from combustion plant – gas | 0.83 | 0.0 | 89.6 |

[154] KAPE, op.cit., 63–64.

[155] According to the standard PN-EN 303-5:201218.

[156] KAPE, op.cit., 66.

| Heat source | Total efficiency of the heating system | PM10 emission (g/GJ) | $CO_2$ emission (kg/GJ) |
|---|---|---|---|
| Heat node – district heat from combustion plant – bituminous coal | 0.83 | 0.0 | 173.1 |
| Ground source heat pump (GSHP) | 2.97 | 0.0 | 72.8 |
| Ground source heat pump (GSHP) – 100% solar powered | 2.97 | 0.0 | 0.0 |
| Air source heat pump | 2.21 | 0.0 | 97.8 |
| Air source heat pump – 100% solar powered | 2.21 | 0.0 | 0.0 |
| Electric heating system | 0.90 | 0.0 | 240.1 |

Based on the above table, KAPE recommends solutions assigned to three categories: III – standard, II – better and I – the best (Table 3.7.5).

**Table 3.7.5.** Heat sources assigned to categories proposed by KAPE.

| Category | Example of heat source | | |
|---|---|---|---|
| III | Condensing gas boiler of energy efficiency Class A or higher | District heat – Wi coefficient up to 1.1 | Automated biomass boiler, Class 5, of energy efficiency Class A or higher |
| II | Condensing gas boiler of energy efficiency Class A+ or higher with Heat pump or Solar Collector | District heat from cogeneration plant (CHP) – Wi coefficient up to 0.8 | Ground source heat pump (GSHP) of energy efficiency Class A+ or higher |
| I | - | District heat from cogeneration plant (CHP) – Wi coefficient up to 0.5 | Ground source heat pump (GSHP) of energy efficiency Class A++ or higher – 100% solar powered |

It should be noted that Class 5 boilers can continuously produce low-temperature flue gases that, when discharged through a large, cold chimney, carry the risk of moisture condensation. To cope with that, a new, sulphuric acid-resistant ceramic chimney liner is often required.

## Selection of heat emitters

All heating systems, apart from air heating ones, require the installation of radiators, convectors, or surface emitters with parameters complementary to the chosen heat source and the needs of each room. A precise selection of emitters is required for concurrent thermal comfort with energy efficiency. The dominant method of heat exchange (convection or radiant) needs to be considered as well as the location of the emitters and, in the case of hydronic systems, also the supply and return temperatures.

Energy-saving heat sources, such as heat pumps and condensing boilers, achieve high efficiency when combined with low-temperature emitters. Surface heating is often recommended as an optimal solution: economical, with no visible emitters and giving a healthier, more stable indoor climate without heat and dust convection. However, the installation of underfloor or wall heating requires a very serious interference with the building substance. If it is not possible, then radiators and/or convectors with appropriately selected parameters can be used. The least recommended solution is to connect both a surface heating installation and radiators/collectors to one heat source. Such a system is less efficient and requires an expensive system enabling independent control of lower- and higher-temperature heating cycles.

In any case, it is best to entrust the selection of heat emitters to specialists. Alternatively, one can use tools to calculate the approximate heat energy requirements of emitters for each room, based on the basic parameters of the building.

Relatively easiest to design and control are systems without a central heat source, in which electricity supplies each heat emitter directly. However, such a system uses much more energy in operation than a system with one heat source such as a gas boiler or heat pump.

Among electric heat emitters, infrared panels or mats typically have the lowest energy consumption. They have been gaining popularity in recent years, mainly due to lower investment costs than central heating and lower operating costs than electric convectors, but they also have other favourable properties that may fit historical buildings. In particular, they do not heat the air, so there is no accumulation of moisture in it. Contrary to conventional heating (most often based on convection), infrared energy transfer is direct, without great losses to heating the air. Radiant energy is passed directly from the source to the object. This also applies to human skin and clothing that absorb infrared energy.

The non-absorption of infrared energy by the air results in remarkable energy savings, a healthier indoor climate, and more effective removal of damp. For interior heating, it is recommended to use emitters of long-wave infrared radiation (IR-C), with a wavelength of 3–1000 microns, which does not penetrate deep into the skin and may even promote some therapeutic benefits. The same type of radiation is emitted by traditional ceramic (tiled) stoves.

### 3.7.3. Heritage buildings and heating considerations

Each of the available solutions aiming to provide thermal comfort involves interference with the aesthetics and/or a substance of a historic building and its microclimate, thus may have a destructive effect on the heritage structure and furnishing.

In traditional buildings, spikes in the outside temperature and relative air humidity are naturally absorbed and smoothed out. The so-called natural microclimate of the interior of old buildings depends to a limited extent on external conditions.[157] Secondary, often inadequate heating is a destabilizing factor, especially in combination with:

- structural damp (see Chapter 3.1),
- incompatible isolation and finishing materials (e.g. polystyrene foam, cement-based or acrylic plasters, or acrylic paints) with too low vapour permeability (see Chapters 3.2, 3.4, and 3.5),
- insufficient or improper operation of ventilation systems (see Chapter 3.6).

**The more unstable the indoor climate is, the faster the deterioration processes occur.** The greatest threats are caused by systems operating only periodically, which destabilize the indoor climate. The consequence is progressive damage to furnishings and even the building structure, which may result from the cumulative effects of dimensional changes and stresses, water vapour condensation, microbiological hazards, salt migration and crystallization, migration of water-soluble matter components, corrosion of metals and wood, etc. Systems that primarily heat the air increase its moisture capacity. When a large amount of moisture is supplied to the warm air (e.g. during a gathering of people), water condensation may occur on colder surfaces of the interior. Systems with high temperature heating elements (e.g. space heaters, IR-A and IR-B radiators) may excessively dry and damage objects, dry out the air, and intensify its circulation, which accelerates surface contamination because of electrostatic phenomena.[158]

The most specific situation is in buildings with large cubic volumes and occasional use, such as churches or some market/exhibition halls. Not all of them should be heated. A large, unheated building absorbs fluctuations in the outside temperature and relative humidity.[159] For example, huge Gothic churches have exceptionally stable interior climates, where the daily temperature amplitudes for approx. 70–75% of days a year do not exceed 1 K, and the daily humidity fluctuations do not exceed 5%. The transition from autumn to winter and from winter to spring is extremely gentle in them. In these churches, there are almost never any condensation effects, even though both the vaults and the walls inside may have temperatures below O Celsius. The works of art collected there are usually in perfect condition. Even the periodic appearance of large groups of people causes only a slight increase in air humidity and temperature. But the introduction of heating may lead to a dangerous destabilization of their climate.[160] Conservators agree that such buildings should not be heated. The basic thermal comfort, due to the natural transmission of geothermal energy, is provided by an original, uninsulated, solid ground floor that has a stable year round temperature of about 8 Celsius (in a moderate climate zone, e.g. in Poland).[161]

The situation may be different in small buildings, especially stone ones, where the climatic conditions are often much worse. Carefully designed heating can help to improve the interior climate. However, proper heating cannot be realised if problems of dampness, faulty ventilation and condensation of water vapour are not solved.

Different heating systems have their advantages and disadvantages, and positive effects can be achieved when the system can be optimally adjusted to the interior.[162] The introduction of heating should improve the comfort for

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[157] Rouba, Bogumiła J. *Klimat we wnetrzach zabytkowych kościołów z punktu widzenia konserwatora dzieł sztuki.* Roczniki humanistyczne Tom L, zeszyt 4 – 2002, 239–248.

[158] Rouba, Bogumiła J. *Zagadnienia klimatu a bezpieczeństwo zabytków.* Chłodnictwo i Klimatyzacja: Miesięcznik dla praktyków, 7 (220), 48–56.

[159] Rouba, Bogumiła J. *Klimat…*, op.cit.

[160] Historic England, *Energy Efficiency and Historic Buildings: Insulating Solid Ground Floors*, English Heritage, Swindon 2016.

[161] The Society for the Protection of Ancient Buildings, *Historic Floors Guidance Note*, SPAB, London 2007. https://www.spab.org.uk/sites/default/files/documents/MainSociety/Advice/Historic%20Floors%20Guidance%20Note.pdf (June 2022).

[162] Cathedral and Church Buildings Division, *Church Heating: Approaches*. Church House Publishing, London 2021. https://www.churchofengland.org/sites/default/files/2021-09/Heating_approaches.pdf (June 20222).

people, safety for historic furnishings, and create conditions conducive to the preservation of the building itself, so it cannot disturb the building's climatic balance. The more one cares about slowing down the processes of deterioration, the more attention should be paid to climate stability and its optimal parameters.[163]

Therefore, when designing heating in heritage buildings, a few basic rules should be followed: [164]

- The heating system should stabilize the temperature and humidity, therefore some economical systems operating only for several days per month are not recommended.
- Gas heaters, which emit combustion products that are dangerous to people and historic interiors, must not be used.
- Ventilation heating, which increases the intensity of dust spreading and drying of furnishings, should not be used.
- Heating systems with low inertia and easy control should limit their heat output when the interior begins to be heated by the sun or a crowd of people. This condition, therefore, precludes, for example, storage heating, and limits the use of floor heating where large gatherings of people occur.
- Heating emitters must not be located in a way that could lead to overheating of elements of the building or valuable furnishings.

All installations should follow the principles of mitigation, minimisation, and reversibility. A heating installation should be considered a transitory feature in the life of the building, and thought should be given to how it will be removed and replaced when designing a new system. The way heat emitters are connected to the main infrastructure needs to be carefully thought out so that replacing parts of the system with shorter lives can be undertaken easily. The design should be sensitive to the aesthetics of the building and attention to detail is important.[165]

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[163] Rouba, Bogumiła J. *Zagadnienia…* op.cit.

[164] Rouba, Bogumiła J. *Klimat…* op.cit.

[165] Historic England, *Heating Design Considerations*. English Heritage 2021. https://historicengland.org.uk/advice/technical-advice/building-services-engineering/heating-historic-buildings/heating-design-considerations/ (June 2022).

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4

# Greenery

**Anna Zaręba**
· Nicolaus Copernicus University in Toruń
**Tomasz Jeleński**
· Cracow University of Technology

The rehabilitation, restoration and enhancement of urban green space is necessary to cope with the new climate challenges. Green solutions have the potential to improve both the outdoor and indoor climate without disturbing the heritage values of old towns and cities. In the context of progressing urbanization and climate change, the mitigation and adaptation potential of greenery and its ability to improve the quality of life in the urbanized environment are exceptionally valuable, which is increasingly confirmed by science and urban management practice.[166]

There are, however, several challenges to overcome. The baseline is to protect existing greenery, in particular large deciduous trees that absorb large amounts of $CO_2$ and release oxygen, moisturize and clean air from pollutants, fight the urban heat island effect and absorb rainwater reducing the risk of flash floods. Trees are at risk during renovation and construction works when their root system can be damaged or access to water and nutrients might be limited, e.g. by sealing the ground.[167]

[166] Naumann, Sandra, et al., (ed. Tomasz Jeleński), *Addressing climate change in cities. Policy instruments to promote urban nature-based solutions*, Berlin – Cracow: Sendzimir Foundation, 2020. https://sendzimir.org.pl/en/publications/policy-instruments-to-promote-urban-nature-based-solutions/ (September 2022).

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# 4.1. Nature-based solutions

There are many publications available on nature-based solutions (NBS), including a large collection of scientific sources, guides, and booklets, published by the Sendzimir Foundation.[168] NBS support the functions and services of ecosystems in the surroundings of buildings and in urban areas. They promote phytoremediation, urban biodiversity, and natural water management, improving the climate, quality of life, and urban resilience.[169]

There are various blue green solutions that may be integrated with historical buildings and sites.[170] Some of them have been used for centuries and therefore go well with the heritage structures.

Regardless of the character and context of a building and a site, the wide choice of NBS enables a maximising of potential ecosystem services in all kinds of environments, architectural contexts, and landscapes – from the countryside, scenic village and historic townscape to densely built urban areas and redefined cityscapes. The non-invasive character of greenery enables its integration with architecture by covering various surfaces of the building itself and the adjacent ground in yards and the streetscape.

Around buildings, it is important to search for methods to unseal surfaces and improve both their permeability and evaporation potential (see Chapter 3.1). It is particularly important in cities that are increasingly in danger of flash floods caused by heavy rainstorms and the withering of plants during long dry periods. Flash floods are the effects of the increasing amount of surface runoff from sealed surfaces that causes overloading of the sewage system. Increasing the permeability of the ground and harvesting rainwater from roofs is the best way to protect buildings, infrastructure and greenery against the growing risk of flood and drought.[171]

Photo: Natalia Szablowska

**Fig. 35.** Landscaping of the yard as part of the project to revitalize the quarters of the Main Town at Pończoszników St. in Gdańsk. Restrictions to car access have been adopted and the biodiversity was increased, including floral plantings and climbers along the façade.

[168] They are available in English and Polish at: Sendzimir Foundation, *Publications*. https://sendzimir.org.pl/en/publications/ (June 2022).

[169] Naumann, Sandra, et al., op.cit.

[170] Iwaszuk, Ewa, et al., *Catalogue of urban nature-based solutions*. Sendzimir Foundation, Berlin – Cracow 2019. https://sendzimir.org.pl/en/publications/catalogue-of-urban-nature-based-solutions/ (September 2022).

[171] Wagner, Iwona, Kinga Krauze, *Jak bezpiecznie zatrzymać wodę opadową w mieście?* [in] *Woda w mieście*, Zrównoważony Rozwój — Zastosowania 5, Fundacja Sendzimira, Kraków 2014, 77–95. https://sendzimir.org.pl/wp-content/uploads/2019/02/ZRZ5_all.pdf (June 2022).

The next step should be the development of front gardens and façade gardens, greening inner courtyards, walls and roofs. The green cover protects buildings against overheating in summer and cools the air that may be used to ventilate the interiors naturally, without air conditioning.

Front gardens, façade gardens and green yards are also oft-forgotten ways to naturally drain the ground adjacent to the building. Plants effectively regulate the amount of water in the ground, protecting the basements against damp. Root systems, like a natural pump, draw the stream of water up into the transpiration stream and transport it via the xylem to the leaves where the water evaporates. Low vegetation planted directly at the plinth course additionally protects walls from splashes of water bouncing off the ground (see Chapter 3.1.6).

The best urban ground dehumidifiers are water demanding trees such as willows, hornbeams, and alders, as well as climbing plants and street trees[172] that additionally give shade in the summer. As natural drainage of the building's fringe one can use tall perennials with thick stems, such as mallows, but also roses, hydrangeas and sunflowers as well as creeping plants with a developed system of branches, and decorative grasses that tolerate both dry and wet conditions.

It is important to select plants that fit the character and style of the building.[173] Mallows and sunflowers go well with rural buildings; roses and formed trees with manor houses and palaces; decorative grasses go with modern architecture whilst climbing plants are stylistically neutral and can be found next to almost all types of buildings.


Photo: Marcin Surowiec

**Fig. 36.** Landscaping of the yard of the tenement house at 11a Władysława IV St. in Gdańsk, listed on the municipal heritage register, located in the area listed on the National Heritage List for Poland within the historic urban complex of Nowy Port. During the revitalisation process, the stormwater runoff from the building was improved, the hard ground was replaced with permeable and semi-permeable surfaces and greenery was planted, including water-loving plants such as marsh oak, acacia, and various climbers.

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[172] Very good for shaping are linden, hornbeam, maple, hazel, and willow. Historically, fruit trees were most often chosen, mainly because the buildings protected them from the wind, which resulted in more effective crops, and the urban climate also supported more exotic and thermophilic species, such as apricots. Mitkowska Anna, Katarzyna Łakomy, Katarzyna Hodor, *Historia ogrodów europejskiego kręgu kulturowego, cz. II: Od manieryzmu do końca XIX wieku*, Wydawnictwo Politechniki Krakowskiej, Kraków 2013, 58; also Staniewska, Anna, Jan Skrzycki, *Sady w krajobrazie, między archetypem raju, a współczesnym ogrodem użytkowym,* Czasopismo Techniczne. Architektura, R. 109 (2012), Z. 30, 8-A, 114.

[173] Zachariasz, Agata, *Zabytkowe ogrody – problemy rewaloryzacji, utrzymania i zarządzania w świetle zaleceń Karty Florenckiej*, [in] *Zarządzanie krajobrazem kulturowym*. Prace Komisji Krajobrazu Kulturowego PTG, 10 (2008): 150–161: 155.

Photo: Joanna Janiak

Photo: Joanna Janiak

**Fig. 37.** Landscaping of the yard of a listed tenement house at 97 Gliwicka St. in Katowice, built at the beginning of the 20th century, administered by the Municipal Department of Housing Management. Residents supported by the Zielone Załęże Association planted many species of flowers, including hostas, phloxes, creeping junipers, rudbeckias, aubrietas, peonies, hydrangeas, geraniums, petunias, also ornamental grasses, sedums, and creepers such as Boston ivy and Virginia creeper, and herbs: mint, thyme, oregano... They are planted in the ground and large wooden crates. There is also a rainwater tank in the yard.

### 4.1.1. Stormwater management

Stormwater runoff can be stopped in rain gardens in the ground or in containers. Nature-based solutions may also include retention ponds and bioretention basins that allow water to infiltrate the ground.[174] However, ponds, basins, and plants with extensive root systems should not be applied directly next to the building but at a safe distance that depends on local ground conditions.[175]

Unsealing of surfaces and creating rain gardens that limit and delay surface runoff can be supplemented by collecting rainwater from the roof to use in the building (e.g. to flush toilets) and to water plants in dry periods. Even more beneficial to the climate might be greening the roof.[176]

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[174] Naumann, Sandra, et al., op.cit.

[175] Szmidt-Jaworska, Adriana, Jan Kopcewicz, *Fizjologia roślin*, Wydawnictwo Naukowe PWN, Warszawa 2012, 103.

[176] Green walls work similarly, although they are less effective.

# 4.2. Green roofing

There are many types of green roofs: light/extensive – designed for grasses and lichens, and heavier, intense, garden-like roofs, with various greenery and recreational functions. Due to the variety of solutions, greenery can be introduced both on flat and sloping roofs.

A green layer even a few centimetres high is enough to retain and accumulate rainwater, so it can relieve the city sewers and avoid overflow during heavy rainfall. It is always worth enriching the green roof with a retention-drainage system to manage the amount of rainwater required for a given area. Intensive green roofs may also serve as rooftop gardens (more about benefits from green roofs and their construction see in Chapter 3.4.3.1).

Implementation of a green roof on a historical building may be however more difficult than on a new one. The problem is usually not the load-bearing capacity of the walls, but the historical trusses. Their bearing capacity or technical condition may not be sufficient. They may also be subject to conservation protection. Replacing them with a construction of a new type would irreversibly destroy the building’s character and conflict with conservation ethics.

Therefore, it is worth considering, in justified cases, removing the load-bearing function from the historic trusses and building a new construction over the old one. The new construction of higher strength could bear thermal insulation and a green roof, both beneficial to climate change mitigation. At the same time, the replacement of old structural elements would not be necessary, they would stay visible from the inside, and the process of their conservation could be limited to the protection of trusses against fungi and mould.

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# 5

# Harvesting energy

**Tomasz Jeleński**
· Cracow University of Technology

Harvesting ambient energy is a very important way to reduce the building's energy demand and environmental impact. This is possible thanks to new renewable energy technologies, especially solar photovoltaic, heat pumps and solar water heaters (collectors). Their installation considerably decreases the operational energy efficiency of a building, but generates financial and environmental costs, temporarily increasing the embodied energy and carbon footprint of the building. The basic procedure in energy modernisation should therefore be the search for solutions optimizing passive use of solar radiation in winter and preventing interior overheating in summer.

# 5.1. Ambient energy gains

Energy modernisation through the insulation of the envelope or renovation/replacement of windows may to some extent reduce the passive energy gain, and therefore the purposefulness and effectiveness of thermal modernisation. Therefore, energy balances and audits should consider the gains of solar energy penetrating through the roofs, walls, and windows, as well as the possibility of passive protection against overheating (we discuss this in more detail in Chapters 3.2.10, 3.3, and 4).

Historical buildings erected with traditional masonry and carpentry techniques have used natural solutions that ensure climate safety and basic thermal comfort. The builders were taking care of the heat-accumulating structures, optimal location of the stoves, and good ventilation systems including open windows in basements, passive ventilation stacks, and roof vents. As a result, every historical building used to have its unique, well-established climatic balance, which included cool, never-heated cellars, basements and attics, cool staircases, and warm living spaces.

The introduction of envelope airtightness and a substantial change of the energy parameters of a historical building made of traditional materials destroy that balance, sometimes created over the centuries,[177] and instead of reducing costs, it may increase them. A rational justification for the incurred economic and environmental costs may be increasing the comfort of use and/or the usable area of the building by adapting the attic and/or basement to living/working spaces, as well as replacement of traditional heating systems based on the combustion of solid fuels with systems that use cleaner and renewable energy (see Chapter 3.7).

Striving to reduce the primary energy used for heating, renewable energy systems (RES) can be applied within retrofit projects to defray the high energy consumption with energy from sustainable sources. One of the most challenging problems with the integration of RES is preserving the original form of the building and the heritage value of the landscape. Therefore, the extent of substitution of conventional energy sources should be considered alongside a study of the impact of available RES on the aesthetic and physical form of the building.

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[177] Narodowy Instytut Dziedzictwa, *„Wytyczne generalnego konserwatora zabytków dotyczące ochrony wartości dziedzictwa kulturowego w procesie poprawy charakterystyki energetycznej budowli zabytkowych": Załącznik nr 1 do pisma Generalnego Konserwatora Zabytków o sygnaturze DOZ.070.2.2020. JW z dnia 28 lutego 2020.*

# 5.2. Photovoltaics

PV has significant advantages as an energy source. Once installed, its operation generates no pollution and no greenhouse gas emissions. It shows simple scalability in respect of power needs The silicon in the panels is widely available in the Earth's crust although other materials required are rare and will eventually constrain present PV technology.

Solar electric generation has the highest power density among renewable energy sources,[178] which makes it the most appropriate for urban areas. Its efficiency is quickly rising while mass-production costs are rapidly falling. Decreasing costs have allowed PV to grow as an affordable energy source. Due to the scalable nature of PV, many households in Europe are now able to produce their own electricity at a cost considerably lower than the rates demanded by grid utilities. PV installations could ideally operate for 100 years or even more[179] with little maintenance or intervention after their initial setup, so after the initial cost of building a solar installation, operating costs are extremely low compared to other power technologies.

The PV system should be sized, if possible, to match at least the individual needs of a property, but also future needs might be considered. From the technical perspective almost any part of the building that is well exposed to sunlight can be used for PV integration, the design of the installation offers a certain degree of freedom.

The basic requirement for this technology is a strong enough and unshaded surface for the solar cells, preferably facing to the south. Although PV works in diffuse radiation conditions, the efficiency of cells facing other directions is reduced because the gains of the solar array are directly proportional to solar radiation. Therefore, it also is important to ensure that possible building extensions and tree growth will not overshadow the solar cells in the future.

## 5.2.1. PV applications in heritage buildings and districts

The main elevations and dominant roof lines of historical buildings should be avoided when installing standard PV panels to reduce their visual impact. Sometimes the panels may have to be located beside the building if there are regulations that require maintaining its historic appearance and there is a suitable place on the site to place the PV installation without disturbing the view.

Heritage protection restrictions may be complied with through increasingly available solar technologies integrated with building elements. Building-Integrated Photovoltaics (BIPV) and Building Applied Photovoltaics (BAPV) products may be appropriately suited for direct applications on historic buildings.[180] PV installation could be timed to coincide with replacing the roof covering. Where a tiled or slated roof needs to be replaced, it can be increasingly cost-effective to install PV roof tiles as a new roof covering.

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[178] Smil, Vaclav, *Energy at the Crossroads: Global Perspectives and Uncertainties*, MIT Press, Cambridge, MA 2003.

[179] Chianese, Domenico, et al., *Analysis of weathered c-Si PV modules*. Proceedings of 3rd World Conference on Photovoltaic Energy Conversion. 3. 2922–2926 Vol.3 (2003). https://www.researchgate.net/publication/224749017_Analysis_of_weathered_c-Si_PV_modules (June 2021).

[180] Kandt, Alicen, et al., *Implementing Solar PV Projects on Historic Buildings and in Historic Districts*. National Renewable Energy Laboratory, Golden, Colorado 2011. https://www.researchgate.net/publication/255247360_Implementing_Solar_PV_Projects_on_Historic_Buildings_and_in_Historic_Districts (June 2022).

Polycrystalline modules may be produced to match the existing roof covering in shape and colour.[181]

The PV array is usually sited on roofs, although as the technology develops, PV cells may increasingly be incorporated into other elements of the building such as glazing, sunshades, and walls. Recently developed technologies include transparent perovskite cells to be printed on different materials, allowing low-impact interventions that could be accepted by conservators.[182]

One of the solutions might be the integration of PV with a building through the replacement of the glazing with a dim but transparent double-paned PV unit, providing a higher shade level inside that could be acceptable and even beneficial in some situations.[183] The most innovative solutions are 1-chamber and 2-chamber glazing units of high thermal insulation coefficients which, thanks to the coating of quantum dots on the glass, generate electricity while maintaining very good light transmission parameters (85%).[184] The only factor limiting the use of such PV glazing in some heritage buildings could be its slightly different tint, and character of reflection when compared to the original glass manufactured with the use of traditional technologies (see Chapter 3.3.2.).

An alternative solution to compensate for the cumulative energy demand and carbon footprint of a historic property would be the participation of its owner in an energy cooperative running a PV farm outside the heritage district.[185]

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[181] Troi, Alexandra, Zeno Bastian (ed.), op.cit., 179.

[182] Saule Technologies, *Building Attached Photovoltaics*. https://sauletech.com/bapv (June 2022).

[183] Troi, Alexandra, Zeno Bastian (ed.), op.cit., 180.

[184] ML System, *Q GLASS – New Quantum Era*. https://mlsystem.pl/q-glass-for-construction-industry/?lang=en (June 2022).

[185] Roberts, Josh, Frances Bodman, Robert Rybski, *Energetyka obywatelska: modelowe rozwiązania prawne promujące obywatelską własność* odnawialnych *źródeł energii*, ClientEarth, Warszawa 2015.

# 5.3. Solar thermal energy

Solar water heaters use natural solar radiation to heat water. The system includes a solar collector and storage tank, and is typically installed with a backup conventional heating device providing hot water on cloudy days and during times of high demand.

Solar water heaters are usually used to prepare domestic hot water. It is also possible to install an oversized system and use it to supplement the space heating. Solar thermal systems are also commonly used in swimming pool heating.

Two main types of solar collectors are manufactured: the flat plate and the evacuated tube collector (ETC). The latter outperforms flat plates in cloudy or cold conditions because the efficiency of ETCs does not fall off as quickly when the outside air temperatures drop.[186]

The basic requirements for these systems are space for solar collectors with direct sun radiation. They are most frequently sited on roof slopes with south-west to south-east orientation and at a pitch of 30–50 degrees. If the south-facing roof space is above the principal elevation and visible from a public space, the system may not be permitted. A potential solution is to install a collector on outbuildings or subordinate extensions where it is hidden from sight. This reduces the visual impact and may satisfy planning requirements.

Depending on the location of the installation, structural surveys are required, such as with roof integration. The existing structure must be strong enough to accommodate the weight of the collectors and wind load.

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[186] Hudon, Kate, *Chapter 20: Solar Energy – Water Heating*, Eds: Trevor M. Letcher, Future Energy (Second Edition), Elsevier 2014: 433–451, DOI: 10.1016/B978-0-08-099424-6.00020-X.

# 5.4. Geothermal energy and ground source heat pumps

The ground source heat pump (GSHP) takes advantage of the relative constancy of temperatures of the earth throughout the seasons. It uses buried pipes (a collector loop) to extract energy from the ground and increases the temperature of a heat transfer fluid inside the loop to around 50°C to use it to heat space and water. If there is enough space, the collector loop can be laid horizontally in a trench at least 1 m below ground. Where there is no room to do this, one can drill vertical boreholes to extract heat from between 90 m and 160 m underground. Boreholes tend to be more expensive to install and must be correctly spaced because if they are too close together, the efficiency of the system will be reduced.

The requirements for such a system are the space for the heat pump, ground space, a heating distribution system, and high levels of insulation and airtightness of the building envelope. GSHPs are not suitable for those historical buildings where improving airtightness and insulation is not possible.

GSHPs provide more efficiency when the temperature of the heating circuit is lower. It is good practice to distribute the energy from the pumps via underfloor heating or larger radiators, but the first option is preferable. Besides the best performance, under-floor heating is the most discreet, although where there is an original floor, careful consideration is needed to avoid damaging any original fabric. It should be possible to lift the original flooring and re-lay it on top of the under-floor system. Alternatively, new floor covering in keeping with the property character might be permitted in buildings without original flooring.

Where central heating systems are already present, it is sometimes possible to use old radiators if they are oversized for the needs of the retrofitted building. After improving the airtightness and thermal insulation of the envelope, the heat demand is lower and the large size of old radiators may compensate for the lower water temperature from GSHP. New, low-temperature radiators may also be an option, but they are bulky which makes them potentially more visually intrusive.

Some heat pumps can be reversed during warmer periods to cool a building. However, a heat pump is optimised for heating, so if there is no absolute requirement for cooling, it is better to choose a cheaper, non-reversible heat pump.

In the case of a listed building or area under conservation supervision, the visual impact of the heat pump system may be vital to planning and conservation permissions. If pipes will need to be run between the heat source and the heat pump, it will be necessary to find a path through or under the external wall that does not cause irreparable damage. If this is successful, a historic building may benefit from constant, low-temperature heating that is desirable to protect its fabric and contents.

# 5.5. Biomass

As a renewable energy source, biomass can be used directly to produce heat via combustion. Modern biomass heating systems can provide both space and water heating and come in a wide range of sizes, from individual room heaters to whole-house systems. They can satisfy all annual heating demands.

The basic requirements for these systems are an ongoing source of fuel (logs, pellets or woodchips), space for the heating system (stove or boiler and hot water cylinder if applicable), space for fuel storage (an existing shed, garage or outbuilding may sometimes be used), a flue (can be an existing chimney although it may have to be lined, which may be relatively expensive), and adequate ventilation. If there is no chimney, a new flue may be installed, exiting the building through the roof or a wall, as discreetly as possible and away from the front elevation.[187]

The fuel is either manually or automatically fed into the system. Automatic systems are generally more efficient.

Biomass systems must be appropriately sized for the property and for the occupants' heating needs. These systems operate more efficiently when working close to their maximum capacity, so over-sizing a system will lower its efficiency.

There are two main kinds of biomass systems:
- Stoves with a capacity of around 6–12 kW that provide direct heat to the room in which they are installed. This heat may spread to adjoining rooms and possibly to upstairs rooms. Stoves can also be connected to a back boiler providing hot water for domestic hot water needs or for space heating via a central heating system.
- Boilers with a capacity of at least 15 kW. They work by heating water that then can be stored in a large tank and used to provide space heating via a central heating system and domestic hot water. Water can be supplied at different temperatures and pressures depending on the selections of heat emitters (see Chapter 3.7.2.2).

Many old properties were designed and built with solid fuel heating systems and have fireplaces and chimneys ideal for siting modern stoves. It is a common retrofitting strategy because the low visual impact and the high efficiency even in poorly insulated buildings make them an excellent option for traditionally built properties which are often draughty and have less insulation. However, the ventilation system may need improvements to ventilate the equipment and piping and to supply the air required for combustion.[188]

A significant disadvantage of biomass stoves and boilers is the very high emission of particulate matter (PM) from the systems not equipped with expensive electrostatic precipitators. For this reason, such systems must not be used in areas where, due to air protection reasons, the use of solid fuels is prohibited (like in Cracow) and, in principle, should not be used in urban areas.

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[187] Troi, Alexandra, Zeno Bastian, op.cit., 184.

[188] Ibidem, 184–185.

## 5.6. Wind turbines

The basic requirements of wind systems are suitable site conditions with adequate wind speed and the space to install the turbine. Turbines must be placed in a reasonably exposed location and at heights where wind speeds are high (above 5–6 m/s), without obstructions, trees, or other objects that could cause turbulence and compromise the turbine's performance. Future obstacles should be considered, such as tree growth or new buildings. Thus, turbines are often difficult to integrate successfully into an urban environment and are more suitable for rural locations.

Most wind turbines have a horizontal axis. The vertical axis turbines are often less efficient but perform better in areas where air turbulence is common, which makes them potentially more viable for urban areas.

The main system components include the mast (fixed directly to a building or freestanding) and core electrical components. For building-mounted masts, a structural survey of the building is needed to ensure that it can support the installation without subsequent damage. The installation process or any vibration may also affect the building fabric. Building-mounted turbines are often not permitted on historic buildings also due to their visual impact. This makes freestanding mast-mounted turbines more viable for most heritage properties.

Two more potential problems need to be carefully considered:[189]

- Wind turbines produce some noise, which may be audible within a certain distance.
- The turning blades may create flickers and shadows. If they extend to a property or garden, they could be annoying.

[189] Ibidem, 181–182.

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6

# Seismic activity affecting historical buildings

**Mihaela Zamolo**
· Croatia Green Building Council

Seismic problems related to historical and particularly heritage buildings always present certain challenges to endeavours increasing their seismic resistance. The goal is to improve the mechanical resistance and stability as far as practicably possible before or after an earthquake, during conservation, repair, or reconstruction. The specific challenges concern the protection and preservation of cultural, architectural, and building heritage values, alongside safety and resistance to seismic actions. All European seismically active countries (Italy, Greece, Turkey, the Balkan countries, and Croatia) struggle to protect heritage buildings and prolong their life after an earthquake occurs.

# 6.1. Listed buildings in Croatia

Heritage buildings are present across the entire territory of the Republic of Croatia. They represent various architectural historical periods from prehistory to modern functionalism. Many heritage buildings, especially Baroque and Rococo, have valuable painted frescoes, sculptures, and inventory, which require preservation. Cultural monuments are entered in the Register of Cultural Heritage. The database contains information on protected properties and complexes. There are about 4,200 individual monument buildings in the Register of the Republic of Croatia, of which 1,643 are sacral, 1,100 are residential and mixed use residential/commercial. About 130 buildings are preventively protected and 10 are under the protection of UNESCO. Of 391 cultural and historical protected complexes, 184 are rural, 180 urban and other, while 9 are preventively protected. The number of buildings in protected cultural and historical areas exceeds 100,000, including 4,017 in Zagreb zone A and 9,371 in Zagreb zone B. Other cultural and historical complexes are much smaller.

## 6.1.1. Characteristics of heritage buildings in Croatia

These are mostly traditional buildings, built mostly before the mid-20th century. They are traditional due to the types of construction and materials. Most of them are masonry buildings. The vertical bearing elements are walls and pillars of stone (broken or carved) or of brick, with a lime mortar of low tensile strength. Floor constructions are mostly of wooden beam or vaults and arches. The use of concrete appears after 1920 and is minimally represented. Building heights vary from 2 floors in rural areas to 5 floors above the ground in urban areas, usually with cellars. In sacral buildings, the usual materials are stone, brick, wood, cast iron, and steel. A small number of monuments (houses, chapels, etc.) are of wooden/timber construction.

Heritage buildings in Croatia are also regarded as traditional because they were built before 1964 when the first regulations for the construction of earthquake-resistant buildings in the Republic of Croatia (former Yugoslavia) were adopted. Thus, they are expected to have sufficient resistance to vertical actions, but low seismic resistance to horizontal actions, as shown during earthquakes. Compared to current regulations (Eurocodes), they are even expected to have about 4 times less seismic resistance. However, they often surprise one in a positive way.

Almost all heritage buildings, due to the lack of specific knowledge, available technologies and materials, and lack of verification for seismic actions, have inherent deficiencies:

- insufficient resistance of the wall structures (unfavourable overall structure, dominant walls in one plane),

- irregular layout of walls in floor plan and height,
- low tensile strength of load-bearing walls (stone or brick elements with weak mortar),
- absence of connecting walls,
- insufficient load-bearing capacity and stability of walls perpendicular to their plane,
- flexible floor structures with wooden beams do not transfer seismic actions to walls in all directions,
- poor connections of wooden beams and walls (bearings, support),
- inadequate roof construction,
- harmful staircase (cantilever) construction,
- deficiencies in the foundations and ground.

In larger public buildings, palaces, and sacral buildings, the shortcomings also include the behaviour of vaults and arches (thickness, materials, connecting means, tensions, supports), the behaviour of domes (tensions, supports), and the behaviour of towers and bell towers (heights, materials, connections to the structure, slenderness). The most concerning behaviour is due to unfavourable overall structures (large dimensions, materials: stone, brick and weak mortar). Residential and public buildings built from 1920 to 1965, with rigid ceilings, have surprisingly more favourable behaviour than the previous ones.

There are also secondarily acquired deficiencies in heritage buildings, such as:

- age and non-maintenance,
- uncontrolled walls and floor reconstruction,
- faulty upgrades,
- atmospheric action,
- dampness,
- underlayment of the foundation in disrepair,
- previous extraordinary actions (e.g. earthquake or fire).

As many as 2,400 heritage buildings were damaged during the Homeland War (1991–1995) and restored after.[190] Some experienced an earthquake in Zagreb (1880) and in Petrinja (1909), after which they were also restored (e.g. Church of St. Catherine in Zagreb).

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[190] Homeland War from 1991 to 1995 in which 2,423 (or 1,859,169 sqm) of cultural monuments were damaged or completely destroyed out of a total of 7,023 registered then. In SMŽ (Petrinja region), 243 out of 413 were damaged, and in the city of Zagreb 82 out of 493 individually protected buildings. All of them were renovated, but little attention was paid to their seismic resistance. They were restored mainly to their original condition in terms of vertical resistance and stability, and seismic resistance. However, there were some differences in approach. The earthquake in Petrinja revealed good examples of behaviour (the church of St. Lawrence in Petrinja) and bad ones (the church of St. Mary Magdalene).

## 6.2. Seismic risk

Seismic risk is critical for buildings. It is a result of a combination of four factors: seismic hazard of the region, local subsoil conditions, building vulnerability and exposure (i.e. concentration of buildings). In Croatia, the seismic risk is not ranked as the greatest risk compared to other natural disasters, but it is very significant due to the unpredictability of occurrence.

- **Seismic hazard**: in Europe, it occurs due to the mutual convergence of the African plate with the Eurasian plate. Croatia is located on the edge of this seismologically active area with moderate and high seismic hazards. According to the assessment[191] and the Mercalli scale, there is a high risk of earthquakes of magnitude VIII–IX on about 36% of the territory, while the danger of magnitude VII concerns about 56%. Seismic maps of individual areas indicating peak ground acceleration, which accounts for a particular probability of occurrence and return period (475 years), are based on seismic studies. The soil response spectra obtained from them are used to calculate the seismic action on the structure (Eurocode 8).
- **Local subsoil**: The effects of an earthquake depend on the depth and distance of the hypocentre of the earthquake as well as the local subsoil. The soft subsoil leads to shocks of up to ten times greater intensity than on the rock.
- **Building vulnerability:** It depends on the structural type of the building. Almost all buildings built in Croatia until the mid-20th century, including masonry heritage buildings without reinforced concrete elements, are highly sensitive to seismic effects, and they are rated in vulnerability class B according to the EMS scale (A to F, where A – most vulnerable).
- **Exposure**: High-density, highly developed areas like cities have a higher value concentration of risk than rural regions.[192]

[191] Atalic, Josip, Marta Savor Novak, Mario Uros, *Seismic risk for Croatia: overview of research activities and present assessments with guidelines for the future*, Građevinar, 71(10) 2019. DOI: 10.14256/JCE.2732.2019.

[192] For example, Zagreb has the highest risk, although its seismic hazard is not the highest.

# 6.3. Behaviour and damage of buildings in an earthquake

Heritage buildings are exposed to various actions and influences during their lifespan, which is significantly longer than the modern projected lifespan (50 years). Climate change and associated natural disasters, such as floods, storms and hurricanes, fires, avalanches, torrents, and earthquakes cause great material damage and take human lives due to inadequate building standards. Almost all natural disasters are predictable apart from an earthquake, which is predictable only by the strength, location, and return period, but not the time when the next event will happen.

Damage occurs mostly on the superstructure, especially chimneys, roofing, and gable walls. It could also be a separation of walls in two vertical directions due to the lack of connecting walls, damage to the joints of walls and/or floor structure (wooden beams intersecting a wall), damage to parapet walls, lintels, around openings and on ceiling structures. In addition, significant damage occurs on the staircases of large buildings (palaces, tenements) and on partition walls, which often take up a significant part of the seismic action. Damage may also occur on the load-bearing walls (vertical, diagonal, X cracks, crushing) – many buildings collapse due to the loss of mechanical resistance and stability. In palaces and sacral buildings, towers, domes, vaults, and arches may suffer too. Often the damage is not plainly visible from the outside of the building (on bearing walls), but the internal structures are damaged considerably.

## 6.4. Repair, recovery and reconstruction after the earthquake

The first thing to do after an earthquake is a quick inspection to protect human lives and property from possible aftershocks. Damaged buildings should be supported with the use of temporary structures to prevent the collapse of individual parts, and protected from weather events by being covered with plywood, wooden boards, etc. These are standard solutions that need to be applied before conservation and restoration. Failure to take these measures leads to further degradation of the capacity of the entire load-bearing structure, and a lack of stability in the individual parts of the building.

The second phase is preliminary research that includes collecting documentation and structural surveys, and selecting the right solutions for renovation. Both conservation and restoration potential should be analysed.

When choosing a solution for seismic reconstruction of the structure, the requirements of mechanical resistance and stability should be met. However, cultural heritage values must not be violated in the process.[193]

Renovation should be treated as an opportunity to 'Build Back Better (BBB)',[194] which may include energy retrofit and the improvement of other basic requirements (e.g. acoustics, user health, universal design, reuse and recycling of materials, and durability). It is an opportunity for the building to become more sustainable, but both objectives of preserving the value of cultural heritage and reaching satisfactory earthquake resistance are a must.

For the protection and preservation of cultural heritage, the approach to restoration is different for individually protected buildings or buildings within the cultural-historical area.[195]

Repair, recovery and reconstruction include three terms:

The **short-term** involves the urgent removal of seriously damaged and unstable structural elements (such as chimneys, turrets or architectural ornaments) and temporary securing of all elements to protect people and the building, as well as repairs to prevent further damage and enable the use of buildings with non-structural damage. These measures also include the protection or evacuation of movable cultural goods.

The **medium-term** includes the recovery of buildings and the conservation and restoration of damaged cultural heritage.

The **long-term** includes complete recovery of heritage buildings to decrease their vulnerability, while at the same time preserving their architectural and historical value. Special attention must be paid to the restitution of the façades of historic buildings, as they are usually vital to the historic cityscape.

Each heritage building must be repaired, reconstructed or rebuilt as an exact likeness.

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[193] Republic of Croatia, *Act on the Protection and Preservation of Cultural Heritage; Decision on the implementation of the inventory of damage to immovable cultural property caused by the earthquake in the City of Zagreb and its surroundings*, Official Gazette 69/99, 151/03, 157/03, 87/09, 88/10, 61/11, 25/12, 136/12, 157/13, 152/14, 44 / 17, 90/18, 32/20, 62/20); UNESCO, *Convention Concerning the Protection of World Cultural and Natural Heritage*. https://whc.unesco.org/en/conventiontext (June 2022).

[194] Hallegatte, Stephane, Maruyama Rentschler, Jun Erik Walsh, Brian James, *Building back better: achieving resilience through stronger, faster, and more inclusive post-disaster reconstruction* (English). World Bank Group, Washington, DC. http://documents.worldbank.org/curated/en/420321528985115831/Building-back-better-achieving-resilience-through-stronger-faster-and-more-inclusive-post-disaster-reconstruction (June 2022).

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## 6.5. Challenges

It is difficult to reconcile all the regulatory requirements for the safety of cultural monuments against seismic actions with the requirements for the protection and preservation of cultural values and climate renovation. An interdisciplinary approach and close cooperation of specialists and experts is needed to find optimal solutions in particular cases.

It must be considered that all cultural heritage buildings have low earthquake resistance, and those that have suffered an earthquake have it reduced further. Strategies should be adopted to strengthen these buildings, so that they survive the next earthquake. Seismic activity is growing because of climate change.

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# 7

# Algorithms

**Tomasz Jeleński**
· Cracow University of Technology

Various solutions to making buildings more resource-efficient and climate-friendly cannot be applied in every situation. Each building has a different history and specific conditions, therefore when designing a renovation or retrofit, the scope of works and choice of measures should be selected individually and with the use of conservation knowledge. However, such an approach slows down design and decision-making processes, as well as formal arrangements in the case of listed buildings.

The challenge is to find practical tools sympathetic to the protection of cultural heritage which respect the principle of minimum intervention, help improve the usability of historic buildings, reduce their environmental impact, and enhance their resilience to various threats.

In our interviews, various stakeholders of conservation and renovation processes admitted that the complexity of the problems causes misunderstandings and conflicts, and that decisions are often made intuitively. There is too little in terms of practical knowledge or guidelines that would facilitate and accelerate the cooperation of investors and designers with conservators and sufficient case analyses as the basis for making or issuing decisions. On the other hand, if universal guidelines appear, they are often too rigid and do not allow for individualised, tailor-made solutions.

Our proposal, which may facilitate progress through the complicated matter of conservation, renovation, or retrofit, is an algorithm, i.e. a tool that suggests the ways to proceed through the processes of analysis and design. An algorithm is a sequence of actions or a procedure leading to the performance of a specific task; facilitating the solution of the problem in a finite time. The algorithm must be given in the form of a specified set of activities to be performed, with an indication of their consequences. It aims to lead us from a certain initial state to the desired end state.

In complex tasks, algorithmic thinking makes it easier to capture multiple threads, with attention to important details and interconnections, and anticipate what might happen and where each step will lead us.

The tool we propose is primarily aimed at eliminating errors that are often made during renovation and retrofit. The algorithm will lead us along a specific reasoning path and indicate optimal solutions, taking into account the specific factors and individual conditions of the building.

The first step in the algorithm proposed here is the selection of insulation. As described in the previous chapters, we know that this often consists of covering the building with a thick layer of modern insulating material, which usually leads to certain problems and might be dangerous for the building and its users. The effect is not only the loss of architectural value but also progressive dampness, biological corrosion and degradation of a valuable substance.

If one cannot or does not want to insulate the walls due to their architectural qualities or physical properties, it is best to subject them only to conservation treatments. The walls of historical buildings, especially those built before World War I, are massive, having a high thermal capacity and, if properly maintained, good thermal properties. However, the possibility of interfering with other elements of the building should also be considered: conservation or renovation of the woodwork, elimination of thermal bridges, insulation of ceilings and/or the roof, greening the building and the site.

The next step, possibly difficult, but significant in reducing energy consumption and carbon footprint, might be to modernise the heating system and/or ventilation system to recover energy from the exhaust air. Efficient ventilation may, in turn, allow the building to be insulated from the inside although as a consequence it is only safe if the façade is protected against the effects of freezing.

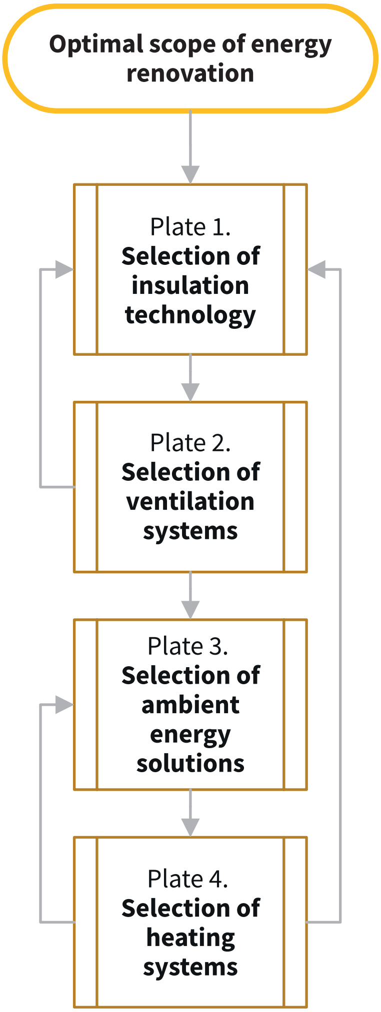
Each of the main elements of the algorithm is related to the others. Feedback is taken into account i.e. how a given decision affects other issues.

In our algorithm, we also pay attention to broader environmental and resilience criteria. Without taking them into account, our actions will not be sustainable. This becomes especially relevant in these times of climate crisis. The ecological criteria include, first of all, the carbon footprint of renovation, but then also its impact on the local climate, e.g. limiting the urban heat island effect, reducing dust pollution and surface runoff, and protecting the building against flash floods.

Apart from the environment, sustainable development is based on two other pillars: social and economic; therefore, it concerns the quality of life and the economy. We consider these factors, particularly regarding the protection of aesthetic and heritage values, the universal design criteria, the selection of renewable energy sources, and socio-economic externalities. Each of the proposed algorithms contains blocks relating to social and economic values.

This tool was tested and improved during the ClimBuild project workshops in Bielsko-Biała, Mysłowice, and Olsztyn (Poland), as well as in Koprivnica, Rijeka, and Zagreb (Croatia) (see Chapter 8).

Below we present the primary algorithm for selecting the optimal scope of energy renovation of any historical building. Detailed algorithms for the selection of insulation, ventilation, renewable energy sources and heating system are available on the Sendzimir Foundation website here.


Optimal scope of energy renovation
Plate 1. Selection of insulation technology
Plate 2. Selection of ventilation systems
Plate 3. Selection of ambient energy solutions
Plate 4. Selection of heating systems

# 8

# Case studies

**Tomasz Jeleński**
· Cracow University of Technology

# 8.1. Introduction

**Ewelina Pękała** · Sendzimir Foundation

This chapter presents a selection of works produced by the participants of a two-stage training project: "Renovation of historic buildings in times of climate crisis". The training was conducted by the Sendzimir Foundation and the Croatia Green Building Council as part of the "Climate Mitigation in Heritage Buildings" project.

The first stage of the training was based on an e-learning course in the autumn of 2021 which was provided in English and in Polish. A group of well over 100 of the most-engaged participants was selected and invited to take part in the second stage of the training – practical workshops organised in three Polish and three Croatian cities. Cooperation with a local partner was established in every city and the partners selected three buildings in each city that were destined for renovation or retrofit.

Teams of course participants and local stakeholders were composed to work on the case of each building. The aim was to develop recommendations and design guidelines for restoration, rehabilitation and retrofit. The second, educational objective of the workshop was to enable participants to work together in teams composed of people representing different sectors and professions. The multidisciplinarity of the workshop groups provided an opportunity for a multi-criteria analysis of conditions and a wide selection of possible solutions. This lead to the identification of optimal measures which could improve the energy performance of buildings and wellbeing of their users, while at the same time protecting heritage values.

Photo: Tomasz Jeleński

**Fig. 38.** An on-site visit of a working group in I High School in Olsztyn.

A working group would typically include:

- a conservator,
- an architect,
- an energy advisor,
- a civil engineer,
- a builder,
- a representative of an investor or administrator of the building,
- a representative of the local authority.

When conducting a real renovation process, the interests or priorities of such different stakeholders are often conflicting and collaborative analysis of a specific case from different perspectives is difficult or even impossible. This is why we considered it so important to create the best possible conditions for informed discussion in our project. The workshops confirmed that inter- or trans-disciplinary cooperation in the analysis and search for solutions can be very fruitful and that even under unfavourable conditions it is possible to reach agreement and propose solutions that are beneficial for the climate and take into account diverse and even seemingly contradictory objectives.

The notes presented here are abstracts of more elaborated studies and concepts produced during and after the workshops. The concepts were handed over to the local partners, who are to decide whether and to what extent the recommended solutions will be implemented.

# Buildings for which the workshops' participants developed recommendations for renovation or retrofitting

## Bielsko-Biała

LOCAL PARTNER: Municipal Department of Housing

Fig. 39. Villa at 3 Głowackiego St., built in the 1930s, listed on the Municipal Heritage Register. Photo: Ewelina Pękała

Fig. 40. Multi-family residential building at 67 Grażyńskiego St., built in 1914, listed on the Municipal Heritage Register. Photo: Agnieszka Czachowska

Fig. 41. Mixed-use building at 78/80/82 Słowackiego St., built at the beginning of the 20th century, listed on the Municipal Heritage Register. Photo: Tomasz Jeleński

## Koprivnica

LOCAL PARTNER: City Department for Spatial Planning

Fig. 42. Mixed-use Merić House at 1 Trg bana Jelačića, built in the late 18th century (after 1772), listed on Register of Cultural Goods of Croatia. Photo: Ana Šenhold

Fig. 43. Synagogue at 10 Svilarska St., built in 1875, listed on Register of Cultural Goods of Croatia. Photo: Ana Šenhold

Fig. 44. Mixed-use Malančec House, Koprivnica City Museum at 12 Đure Estera St., built in 1902, listed on the Register of Cultural Goods of Croatia. Photo: Ana Šenhold

## Mysłowice

LOCAL PARTNER: Mysłowice Municipality, Department of Architecture, Planning and Strategy

Fig. 45. Mysłowice City Hall at 1 Powstańców St., built in the years 1866–1868, listed on the National Heritage List for Poland. Photo: Ewelina Pękała

Fig. 46. Sports hall at 20 Piastów St., built in 1912, planned to be listed on the Municipal Heritage Register. Photo: Agnieszka Czachowska

Fig. 47. Multi-family residential building at 22 Grunwaldzka St., built in the years 1891–1892, listed on the National Heritage List for Poland. Photo: Krystian Kopka

## Olsztyn

LOCAL PARTNER: City of Olsztyn Municipal Monument Conservator Office


Fig. 48. Former Guardhouse in the Cavalry Barracks complex at 4a Dąbrowskiego St., built in 1885–1886, listed on the National Heritage List for Poland. Photo: Ewelina Pękała


Fig. 49. I High School at 6 Mickiewicza St., built in 1886–1887, listed on the National Heritage List for Poland. Photo: Tomasz Jeleński


Fig. 50. C. Hermenau Villa at 85 Niepodległości St., the seat of Arka, the Association for Aid to Children and Family, built in 1903, listed on the National Heritage List for Poland. Photo: Celina Łozowska

## Rijeka

LOCAL PARTNER: City of Rijeka Department of Culture

Fig. 51. Filodrammatica public building at 28 Korzo St., built in 1891, listed on the Register of Cultural Goods of Croatia. Photo: Ana Šenhold


Fig. 52. Administrative building at 3 Titov trg (Sq.), built between 1922 and 1974, listed on the Register of Cultural Goods of Croatia as a part of a cultural and historical complex. Photo: Jana Kačar


Fig. 53. Croatian House of Culture at 1 Strosmayerova St., built in 1938, listed on the Register of Cultural Goods of Croatia as a part of a cultural and historical complex. Photo: Dean Miculinić

## Zagreb

LOCAL PARTNER: City Office for Economy, Environmental Sustainability and Strategic Planning


Fig. 54. Gvozdanović Palace at 8 Visoka St., built at the turn of the 19th century, listed on the Register of Cultural Goods of Croatia. Photo: Aleksandar Jelovac


Fig. 55. Administrative building at 1 Stjepan Radić Sq., built between 1956 and 1958, listed on the Register of Cultural Goods of Croatia. Photo: Aleksandar Jelovac


Fig. 56. Kindergarten Vjeverica at 14 Ksaverska cesta St., built in 1975, listed on the Register of Cultural Goods of Croatia as a part of a cultural and historical complex. Photo: Ana Šenhold

# 8.2. Mixed-use building from the beginning of the 20th century

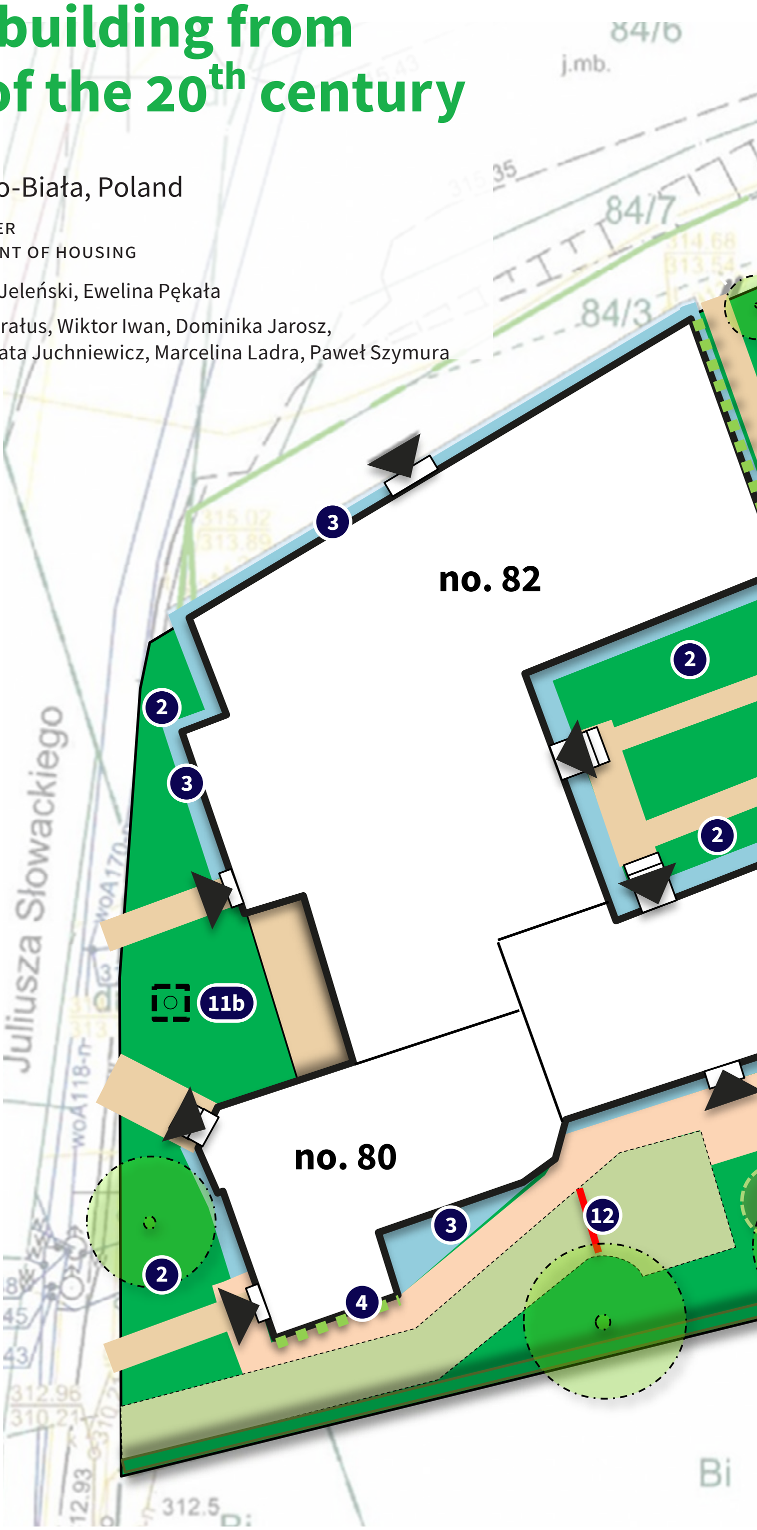
78/80/82 Słowackiego St., Bielsko-Biała, Poland

LISTED ON THE MUNICIPAL HERITAGE REGISTER
ADMINISTERED BY THE MUNICIPAL DEPARTMENT OF HOUSING

| | |
|---|---|
| SUMMARY OF THE DESIGN CONCEPT | Tomasz Jeleński, Ewelina Pękała |
| DESIGN WORKSHOP GROUP | Bogna Dralus, Wiktor Iwan, Dominika Jarosz, Małgorzata Juchniewicz, Marcelina Ladra, Paweł Szymura |

## SITE PLAN

1. Preserve trees (European ash, Norway spruce, bird cherry).
2. Plant subshrubs (e.g. dwarf periwinkle) and flowering shrubs (roses, panicle hydrangea, Meyer Lilac ‘Palibin’, rhododendrons, guelder rose).
3. Replace impervious ground and gravel along the plinth course to a minimum width of 60cm with façade gardens running around the building, including perennials, subshrubs, shrubs, grasses, and climbers.
4. Implement (on windowless walls) climbers that do not require trellis (Japanese creeper (Parthenocissus tricuspidata) and ivy (Hedera)).
5. Keep the two-car garage without the change of function and on its southeast wall add a pergola for climbers (clematis, silky wisteria or Chinese wisteria).
6. Build a recreational terrace.
7. Separate parking places with hedges; remove concrete and steel fences.



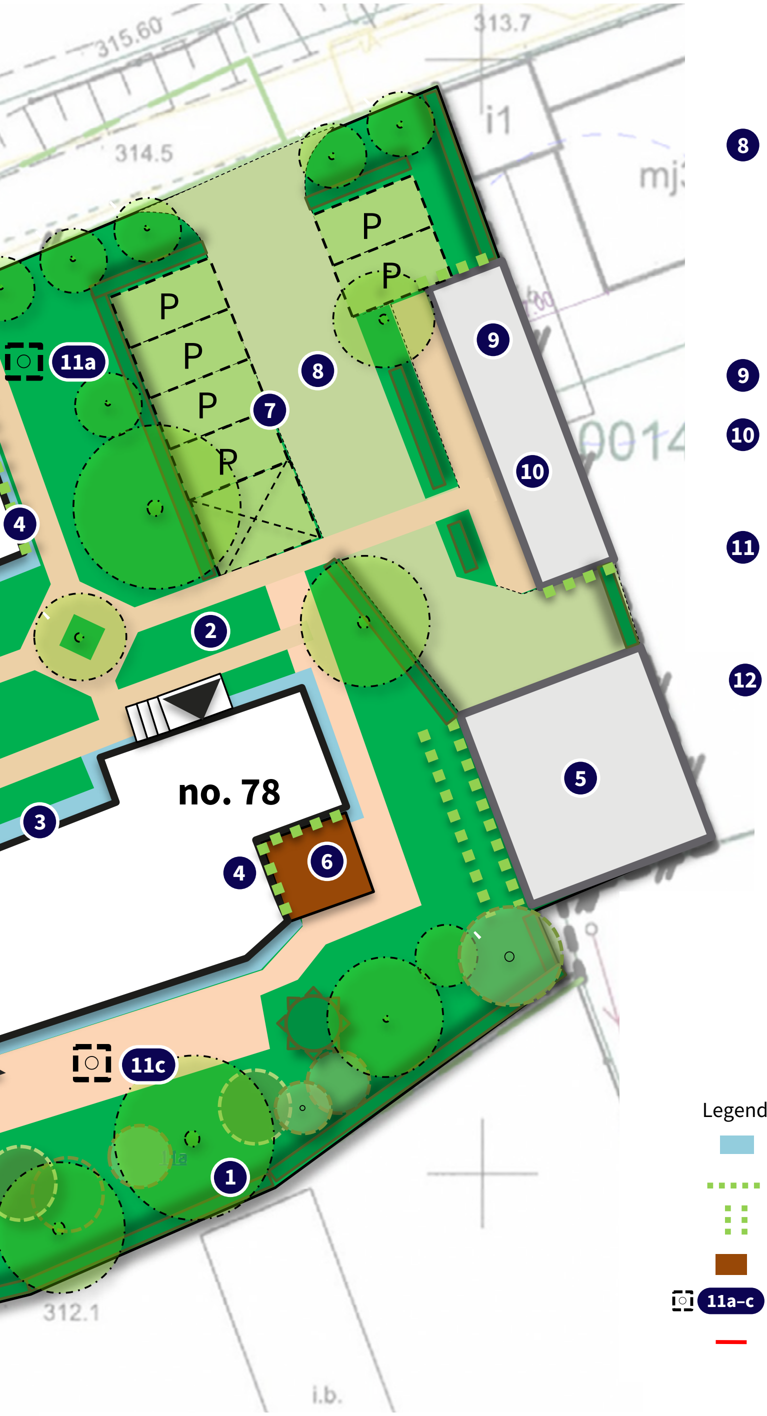


**Fig. 57.** Site development plan. Drawing: Tomasz Jeleński based on the workshop report.

8. Replace hard and impervious surfaces with three types of permeable ones:
   - 🟨 paving stones without chamfer on passages min. 1.2 m wide, for people with limited mobility
   - 🟩 permeable paving grids on other access and parking surfaces
   - 🟫 composite decking
9. Put the waste segregation containers into the existing utility building.
10. Arrange parts of the utility building as pushchair and bicycle rooms; on doorless walls plant climbers (ivy and three-lobed vine).
11. Collect the rainwater from the roofs; install 2–3 underground tanks to provide water for toilet flushing and watering plants; distribute excess rainwater on the premises, away from the buildings.
12. Build linear drainage connected to a sewer system via a separator.

Legend

🟦 façade garden surrounding the building

▪▪▪▪▪ climbers

⁞⁞ pergola

🟫 terrace

11a–c underground rainwater tanks

🟥 linear drainage

## Mixed-use building from the beginning of the 20th century

78/80/82 Słowackiego St., Bielsko-Biała, Poland

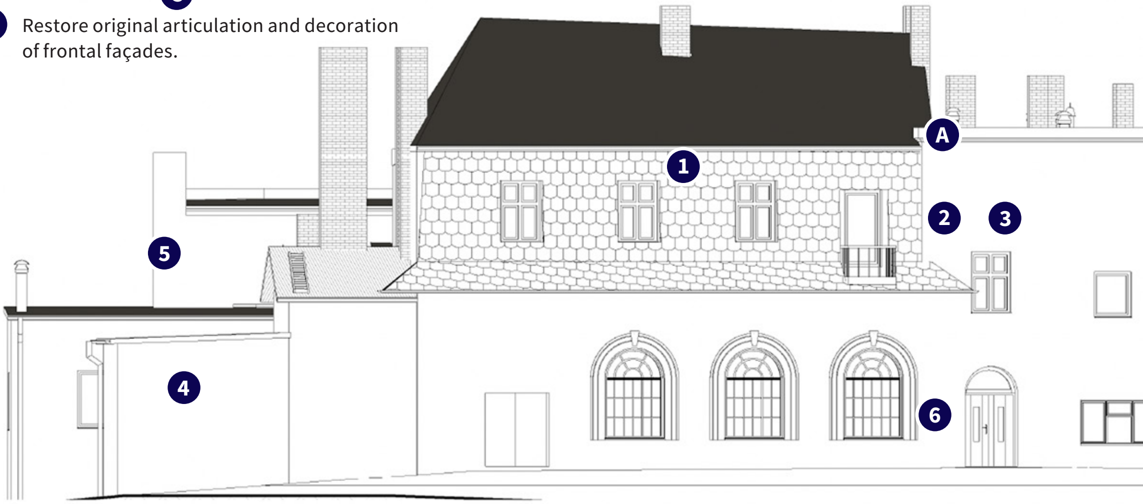
### BUILDING RENOVATION AND RETROFIT

① Restore the original form of 82 Słowackiego – remove the secondary roof Ⓐ, reconstruct the original shape Ⓑ and the tower entrance Ⓒ.

② Restore original articulation and decoration of frontal façades.

③ Use thermal insulation plasters on reconstructed elements and where the plastering needs replacement. Consider thermal insulation paints.

④ Remove annexes in the courtyard area; restore basic articulation of courtyard façades.



© Pracownia Projektowa ARCHIDOM Bernard Łopacz

**Fig. 58.** North-west elevation – current state and proposed points of intervention. The drawing comes from the "Project of reconstruction, renovation and energy-modernisation of residential and service buildings with the accompanying infrastructure and demolition of other buildings" by Pracownia Projektowa ARCHIDOM Bernard Łopacz. Drawing: Magdalena Zawojska.

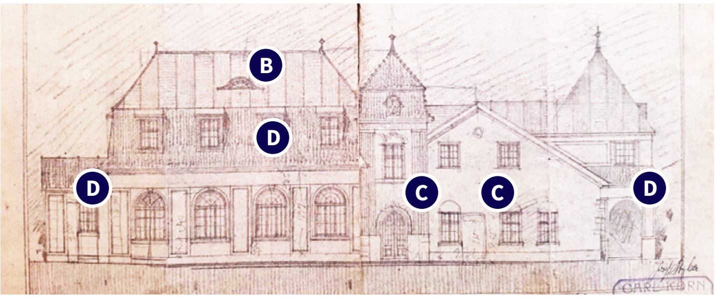


**Fig. 59.** North-west elevation – proposed points of intervention on the background of the original architecture project by Carl Korn. The drawing comes from the Archives of the Municipal Heritage Conservator in Bielsko-Biała.

**Basements**

→ Remove impermeable paints and chipped plasters; intensively ventilate for about two years, to dry naturally. Monitor dampness levels. Further actions should be based on the monitoring results.

**Roofs and attics**

→ While reconstructing the original shapes of roofs, restore damaged trusses or replace them where necessary; insulate roofs thermally with cellulose or woodwool.

→ Reinforce the roof structure in 78 Słowackiego St. for an additional load of photovoltaic panels.

→ Replace the roof covering on no. 78 and no. 80 for standing seam metal in the colour of natural grey (zinc) or light grey.

→ Restore the roof covering on 82 Słowackiego with plain ceramic tiles in the natural colour of burnt brick.

→ Insulate the floors above the residential units with cellulose wool.

→ Replace roof trusses in utility buildings by extending rafters outward by a min. 1.2m as a part of the pergola construction; protect the external elements with vapour-permeable (capillary active), water-repellent impregnation.

⑤ Insulate courtyard façades with woodwool or other natural material, or mineral wool as a last resort.

⑥ Renovation or restoration of the historical door and window woodwork with adaptation to current regulations. When renovating windows Ⓓ – consider introducing additional multi-paned window packages on the inside.

**Ceilings**

- → In 78 Słowackiego, replace the ceilings damaged due to the leaking and collapse of the roof; consider using RECTOLIGHT technology.
- → Maintain the remaining ceilings and provide additional floor joists and acoustic insulation.
- → In the attics, remove concrete screed from the boarding.
- → Insulate basement ceilings.

**Staircases**

- → In 78 Słowackiego, restore the wooden staircase.
- → In 80 Słowackiego, remove the OSB boards, assess the state of preservation and the possible need for restoration of structural elements; renovate the wooden treads while maintaining the original profiles; renovate metal elements and the wooden balustrade.
- → In 82 Słowackiego, renovate the terrazzo stairs.

**Other solutions**

- → Provide roof windows on the rear sides of the roofs, non-visible from the street, to adapt attics for residential use.
- → Remove impermeable paints and chipped plasters; repair and finish walls, ceilings and floors with water vapour permeable (capillary active) plasters, finishing coats and paints.
- → Remove gas installations and appliances; connect to the district heating network and provide suitable radiators and DHW installations.
- → Provide gravity ventilation ducts to all residential units. Mechanical ventilation with heat recovery may be considered, but emphasis should be placed on educating residents on its proper use.
- → Consider introducing mechanical ventilation with heat recovery in service units.
- → Photovoltaic panels may be introduced (for powering common areas) on the roofs of outbuildings and roof slopes of main buildings (especially No. 78), which are not visible from the street.
- → Comprehensively modernise the electrical installations.
- → Install LED lighting throughout entire premises.
- → Install motion sensor lighting in common areas.
- → Use rainwater from underground tanks for toilet flushing and garden maintenance. Consider recycling also grey water for toilet flushing.
- → Provide dwelling units on the ground floor with independent entrances.
- → Establish a dwelling unit on the ground floor for people with disabilities.
- → Provide separate kitchen, bathroom and rooms in each dwelling unit.
- → Involve residents in renovation works and landscaping.
- → Provide training for residents, after the renovation of the buildings, on proper use, achievable savings and possible losses caused by improper use of the amenities.

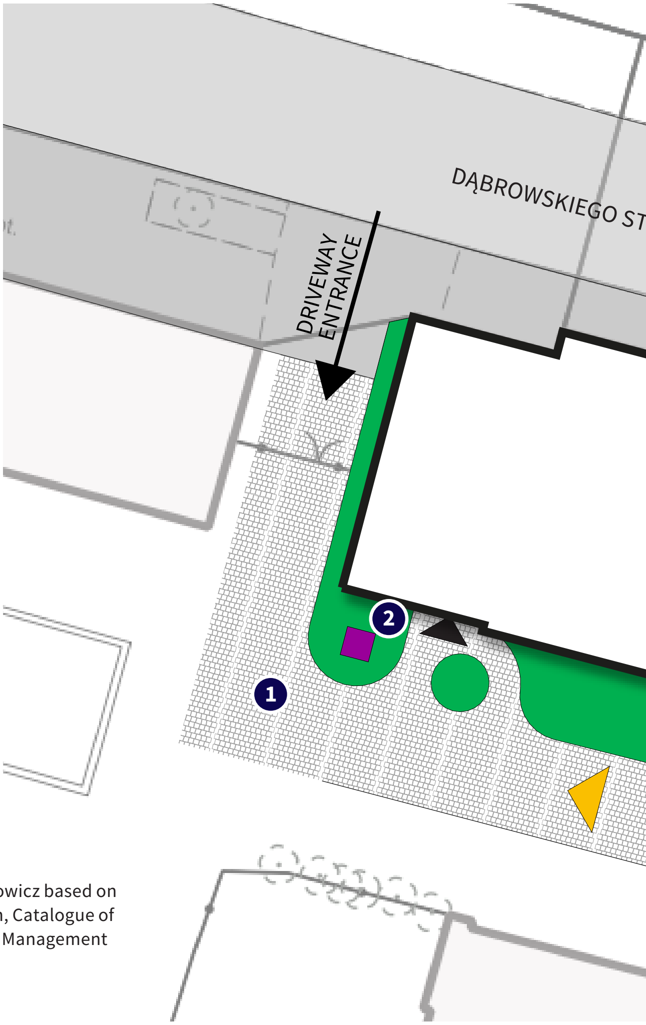
# 8.3. Former Guardhouse in the Cavalry Barracks complex, built in 1885–1886

4a Dąbrowskiego St., Olsztyn, Poland

LISTED ON THE NATIONAL HERITAGE LIST FOR POLAND
ADMINISTERED BY THE MUNICIPAL DEPARTMENT OF HOUSING

| | |
|---|---|
| SUMMARY OF THE DESIGN CONCEPT | Tomasz Jeleński, Ewelina Pękała |
| DESIGN WORKSHOP GROUP | Mirosława Aziukiewicz, Anna Bobko, Jakub Gołębiewski, Natalia Hasso-Agopsowicz, Bartosz Lewiński, Emanuel Okoń, Piotr Wiszowaty |

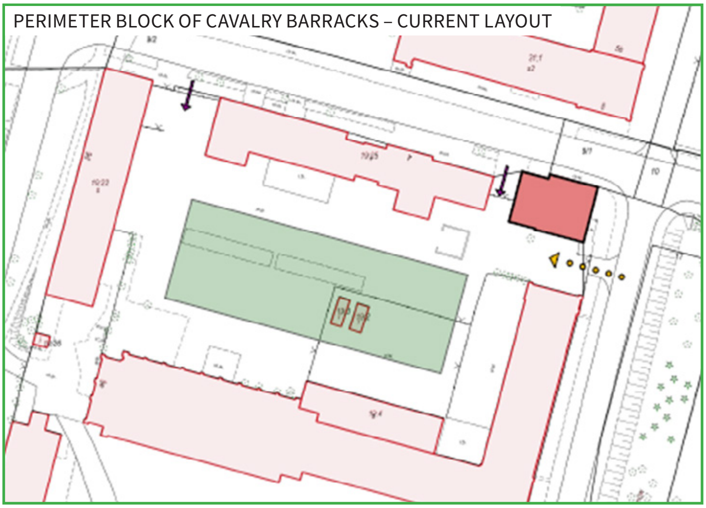
## SITE PLAN



① Passageways paved with recycled natural stone.
② Possible location of the heat pump. Modern casing covered with ivy.
③ The most exposed side of the building.
④ Porch reconstruction based on photographic documentation.
⑤ Proposed grass and low growing plants around the building. Evapotranspiration of excess moisture from the ground.
⑥ Main pedestrianised entrance to the historic barracks complex and emergency fire access.

→ It is recommended to collect rainwater from part of the roof in an underground tank (with an overflow to an absorbent well) and use it to water the greenery.

**Fig. 60.** Site development plan. Drawing: Natalia Hasso-Agopsowicz based on the workshop outcomes. Map source: WebEWID – City of Olsztyn, Catalogue of public e-services of the Department of Geodesy and Real Estate Management of Olsztyn Municipality.



PERIMETER BLOCK OF CAVALRY BARRACKS – CURRENT LAYOUT

## Former Guardhouse in the Cavalry Barracks complex

4a Dąbrowskiego St., Olsztyn, Poland

### BUILDING RESTORATION AND RETROFIT

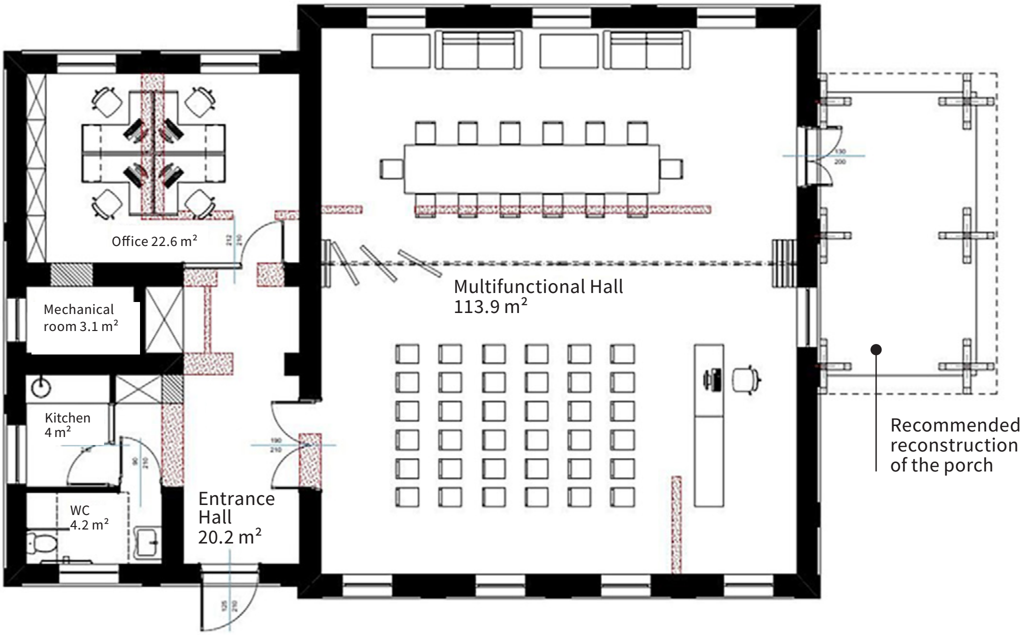


**Fig. 61.** Concept of the building adaptation – ground floor plan. Authors: Jakub Gołębiewski and Natalia Hasso-Agopsowicz. Drawing: Jakub Gołębiewski.

- The concept includes an adaptation of the building to a socio-cultural function.
- It is recommended to divide the building into two parts: a smaller one with an entrance hall, office and facilities, and a spacious multi-functional hall.

### BASEMENT

- It is necessary to perform architectural research to determine whether the building has a basement.

### FAÇADES

- The state of the original building fabric still allows for the restoration of the heritage values of the building.
- The original elements should be rehabilitated: the composition and articulation of the façades, including the rhythm of windows and doors in their original location and shape.

### WINDOW AND DOOR JOINERY

- It is recommended to reconstruct the joinery with the use of traditional materials and modern technology, restoring the original divisions and profiles based on iconography. A derogation is recommended for widening the active leaf of the entrance door to adapt it to the needs of people with disabilities.
- The colours should be based on the research carried out on the original joinery of the Barracks complex.

### ROOF

It is recommended to restore the original geometry of the roof and reconstruct the parapets, as well as:

- on two shaded slopes, introduce green roof thermally insulated with foamed glass,
- on the sunny slopes, apply PV panels above bituminous roofing with cellulose wool thermal insulation ventilated under the roofing,
- replace damaged rafters and trusses. A wooden structure is proposed, designed to bear a load of the green roof and the designed photovoltaic installation. In the multi-functional hall, trusses (and lower parts of rafters) should be exposed,
- insulation of a green inverted roof with foam glass. Under a bitumen roofing – cellulose wool insulation, ventilated,
- a new gutter system is needed with a discharge of rainwater from the green roof to an absorbing well and from the sunny slopes to the underground tank.

**Fig. 62.** Proposed reconstruction of the façades (provide a wheelchair ramp at the main entrance). Drawing: Jakub Gołębiewski.

## INTERIOR

→ The interiors do not have any original elements.

→ It is necessary to provide new electrical, multimedia, and alarm installations as well as new water and wastewater installations with connection to the municipal water and wastewater system.

It is recommended to thermally insulate:

→ the perimeter walls from the inside (e.g. with calcium silicate insulation boards or heat-insulating plasters),

→ the ceiling in the office and facilities area (with cellulose),

→ the floors (with foamed glass),

→ apply ceramic flooring on a low-temperature water heating system (wide expansion joints are necessary between the floor and the walls).

## VENTILATION SYSTEM

→ Mechanical ventilation with heat recovery is recommended, with two air handling units (NW1 and NW2) installed in the attic above the office and facilities, with a roof air exhaust (through the existing chimney) and an air intake integrated into the unused door in the west façade.

→ NW1 system to ventilate the office and facilities: air supply over the windows, exhaust in the toilet and the mechanical room;

→ NW2 system to ventilate the multifunctional hall: air supply above the windows, extraction in the centre of the hall.

## HEATING SYSTEM

→ An air-to-water heat pump combined with an underfloor heating system is recommended. Outdoor heat pump unit located at the south façade; condensate drained into the infiltration planter. An internal unit in the mechanical room together with a warm water buffer with a capacity of approx. 200–300 l, connected to four underfloor heating loops.

→ Electric flow heaters in kitchen and WC.

## RES

→ By using a heat pump, the building will harvest ambient energy to cover most of its heating energy demand, which will significantly reduce the final energy (FE) consumption.

→ The energy production from the rooftop PV system will significantly decrease the consumption of non-renewable primary energy (NRPE).

## SOCIAL PARTICIPATION

→ It is recommended that the administrator establish a dialogue with potential users (NGOs) to refine the optimal design solutions.

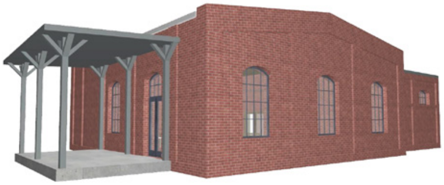


**Fig. 63.** Architectural restoration project – view from the north-east. Rendering: Jakub Gołębiewski.

**Fig. 64.** Architectural restoration project – view from the west. Rendering: Jakub Gołębiewski.

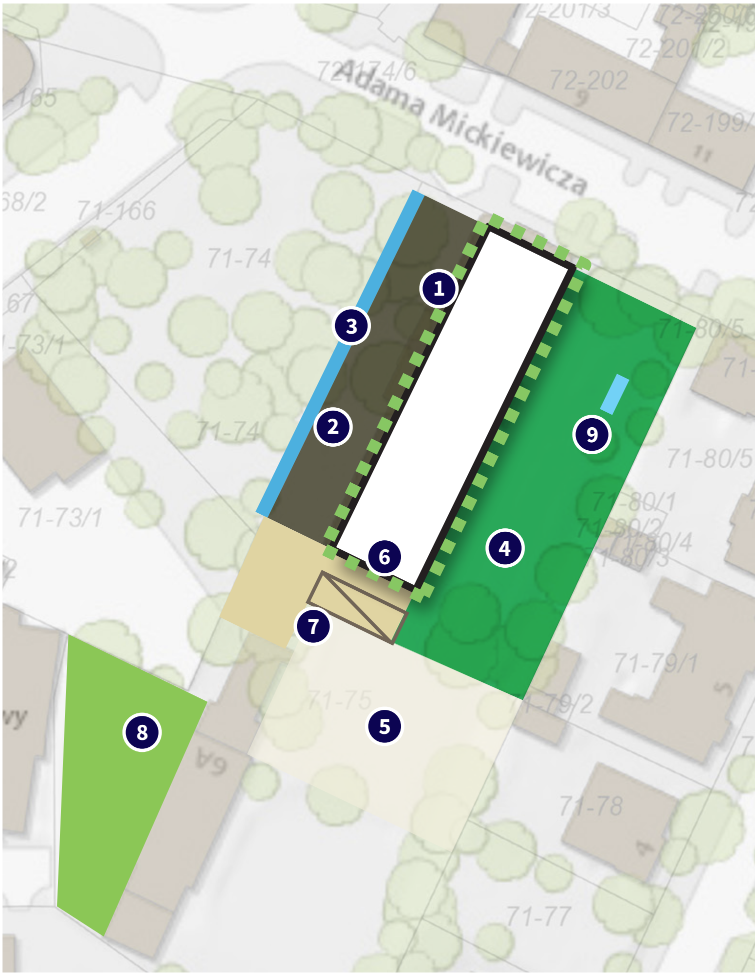
# 8.4. I High School built in 1886–1887

6 Mickiewicza St., Olsztyn, Poland

LISTED ON THE NATIONAL HERITAGE LIST FOR POLAND
ADMINISTERED BY THE OLSZTYN MUNICIPALITY

| | |
|---|---|
| SUMMARY OF THE DESIGN CONCEPT | Tomasz Jeleński, Agnieszka Czachowska |
| DESIGN WORKSHOP GROUP | Sylwia Brzezińska, Marcin Gregorowicz, Paweł Haczkowski, Agnieszka Kaczurba, Nina Kowiel-Zielińska, Piotr Popławski, Krzysztof Soszyński, Łukasz Szymański, Agata Zapart |

## SITEPLAN



① Remove concrete and asphalt alongside the plinth course, unseal the surface, create façade gardens, plant moisture-absorbing greenery.

② Remove the asphalt surface, profile a gentle slope to lead water away from the building down to the designed bioswale; install an underground rainwater tank (collecting water from the west side of the roof); apply semi-permeable substructure and surfaces; recycle cobblestones to pave parking space; on pedestrian paths, use paving stones without chamfer.

③ Build bioswale.

4. Develop vegetable and herb garden; install an underground rainwater tank (collecting water from the east side of the roof); use the rainwater for watering the garden and build a rain garden to be supplied with overflow water from the tank.
5. Replace the pitch hard surface with a semi-permeable, environment-friendly one, made of wood chips.
6. Adapt the entrance to the building to the needs of people with physical disabilities.
7. Build a solar shelter for bicycles and scooters, which charges bikes and mobility devices.
8. Create an additional educational space, e.g. an open biological laboratory, install an underground rainwater tank (collecting water from the gym roof); use the rainwater for watering the garden and build a rain garden to be supplied with overflow water from the tank.
9. Exemplary location of the air-to-water heat pump.

**Fig. 65.** Site development plan. Drawing: Agata Zapart based on the workshop outcomes. Map source: MSIPMO, Olsztyn City Municipal Spatial Information System.

## I High School built in 1886–1887

6 Mickiewicza St., Olsztyn, Poland

## BUILDING RENOVATION AND RETROFIT

### BASEMENT

→ Do not dig the ground against the foundation walls. There is no need for external insulation.

→ Repair damaged joints on the plinth; apply façade gardens, i.e. a green band along the plinth course that prevents water splashing and transpires excess water and moisture from the ground at the basement walls.

→ Inside: remove panelling, non-permeable paints and damaged plaster to enable evaporation/drying of the walls; expose a larger area of the walls in sanitary rooms by removing unnecessary tiles.

→ In places of damp – replace the damaged plaster with lime-sand or renovation plaster; always use paints with high vapour permeability.

### FAÇADES

→ Conservation works on the building façade are recommended: crack analysis; cleaning, desalination, filling cavities in bricks and joints; replacement of secondary grates of the basement windows with replicas of the preserved originals.

### VENTILATION SYSTEM

→ The present stack ventilation is insufficient. It is necessary to inventory the ventilation ducts and test/improve their patency and efficiency.

→ The solution recommended, due to the need to increase air exchange in the educational building, as well as possible high final energy savings, is the introduction of a mechanical ventilation system with heat recovery, for example, a cascade system (air supply into classrooms and exhaust from corridors and sanitary rooms) using the existing stack ventilation ducts and unused smoke ducts.

→ A necessary condition for ensuring proper airflow is the permanent opening of the transom windows between the classrooms and corridors or the installation of active flow fans.

→ The heat recovery unit would be located in the attic, in the part not adapted to teaching rooms.

### WINDOW AND DOOR JOINERY

The method of renovation of the windows will depend on the type of ventilation in the building:

→ if stack ventilation is left – in rooms where increased humidity is found, tight windows should be equipped with diffusers,

→ if mechanical ventilation is applied – sealing of all windows and doors would be necessary.

→ In newly adapted rooms in the attic – insulate windows by adding internal sashes with a double/triple glazing unit.

→ Stained glass windows – consider additional internal glazing as a heat shield.

### ROOF AND ATTIC

→ It is recommended to renovate the roofing, extend the ventilation chimneys above the roof, repair the flashing, add snow fences and leaf guard gutters.

→ When adapting parts of the attic as teaching rooms – insulation of their roof sections, external walls, and internal walls from the side of unheated attic spaces is necessary (see Fig. 66).

In the unheated part of the attic:

→ insulate the entire floor and the envelope of the assembly hall (ill. 67),

→ renovate the plank floor – use the original material to the maximum extent.

Use cellulose for all types of thermal insulation due to its negligible carbon footprint, favourable parameters and low cost.

### UNIVERSAL DESIGN

Adapt the building to the needs of people with disabilities:

→ install an elevator in a shaft separated from the classrooms adjacent to the staircase,

→ install a stairlift between the south entrance and the ground floor,

→ adapt toilets.

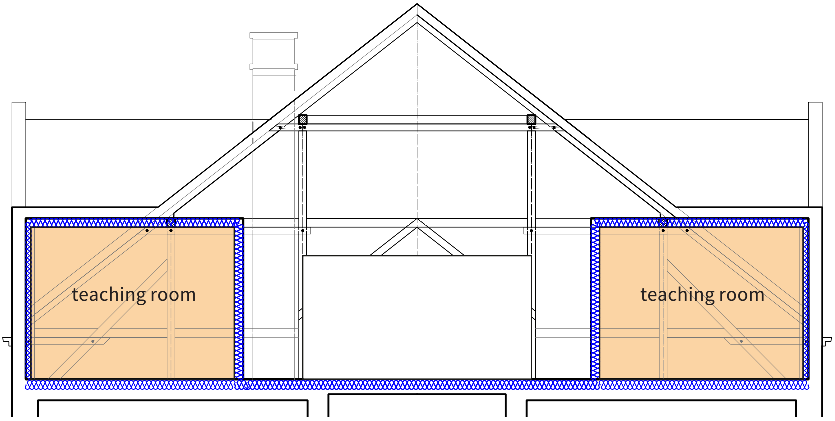


**Fig. 66.** Cross-section of the attic: thermal insulation of spaces adapted as teaching rooms. Drawing: Agata Zapart.

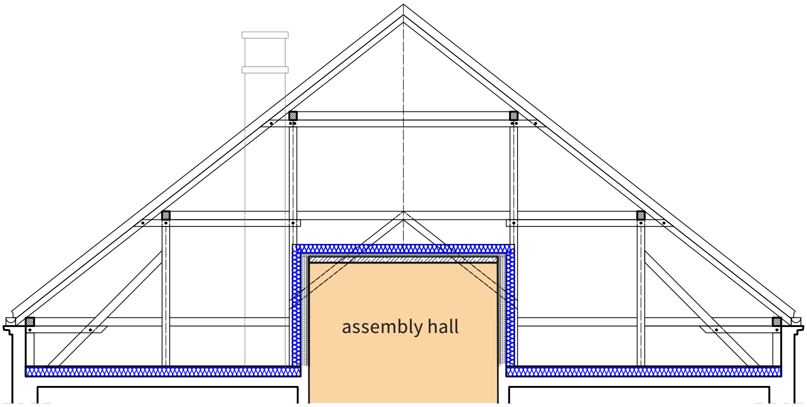


**Fig. 67.** Cross-section of the attic: thermal insulation of the floor and the Assembly Hall's envelope. Drawing: Agata Zapart.

### HEATING SYSTEM

- → Planned modernisation of the district heating substation may be supplemented by an air-to-water heat pump with an outdoor unit in the garden.
- → After installing the heat pump, the district heating would only be used at very low outdoor temperatures.

It is also recommended to:

- → install low-temperature radiators, remotely controlled; apply the algorithm for lowering the
- → temperature in rooms that are not currently used, also at night and on holidays,
- → separate metering and control of the heating system in gyms,
- → supply central heating to adapted attic rooms.

### WATER MANAGEMENT

- → Equip all taps with aerators. When replacing taps, install non-contact infrared taps.
- → When modernizing the water system – separate the toilet flush installation and supply it with rainwater from the underground tank located on the west side of the building.

### ELECTRICAL INSTALLATION

- → Inventory of lighting fixtures and replacement of fluorescent lamps with LEDs are necessary. Consider installation of an automatic light control.

# 8.5. Multi-family residential property built in the years 1891–1892

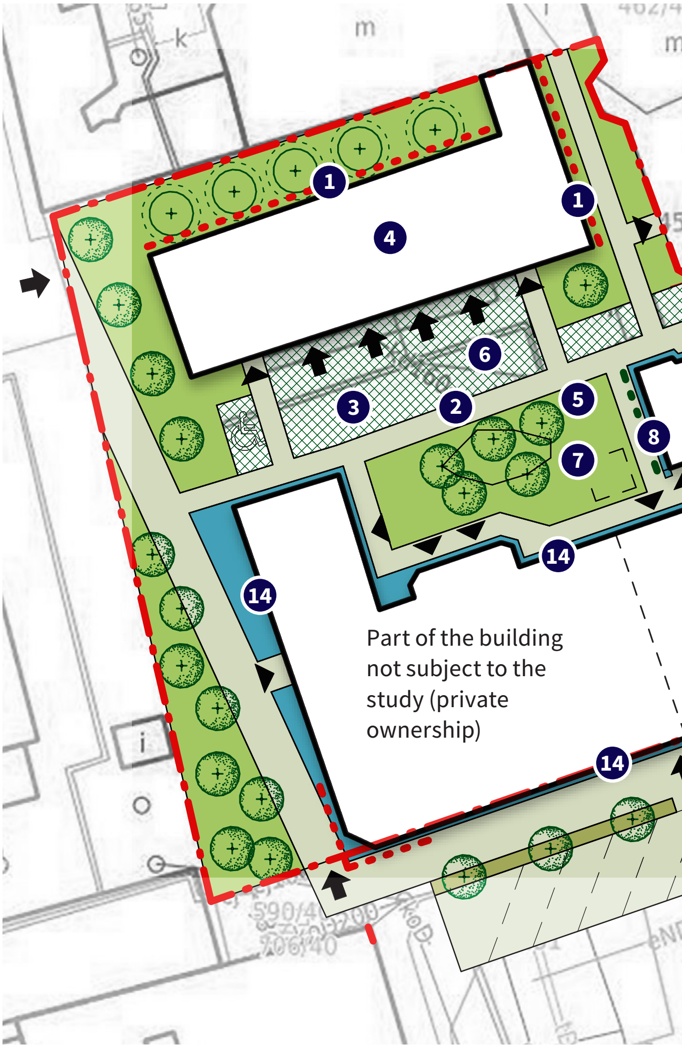
22 Grunwaldzka St., Mysłowice, Poland

LISTED ON THE NATIONAL HERITAGE LIST FOR POLAND
ADMINISTERED BY THE MUNICIPAL DEPARTMENT OF HOUSING

| | |
|---|---|
| SUMMARY OF THE DESIGN CONCEPT | Tomasz Jeleński, Ewelina Pękała |
| DESIGN WORKSHOP GROUP | Katarzyna Buda, Krystian Kopka, Ewa Krzysztoń, Dobrawa Skonieczna-Gawlik, Natalia Szablowska |

## SITE PLAN

1. **Close proximity to the neighbouring buildings. Fire protection expertise necessary.**
2. **Maintenance and paving of existing pedestrian path will improve the quality of the semi-private space expected by residents.**
3. **Restricting vehicle entry into the yard while maintaining parking spaces for people with disabilities.**
4. **Preserving the 'carriage house' and introducing a service function.**
   - → Maximising the potential of the place without increasing the carbon footprint.

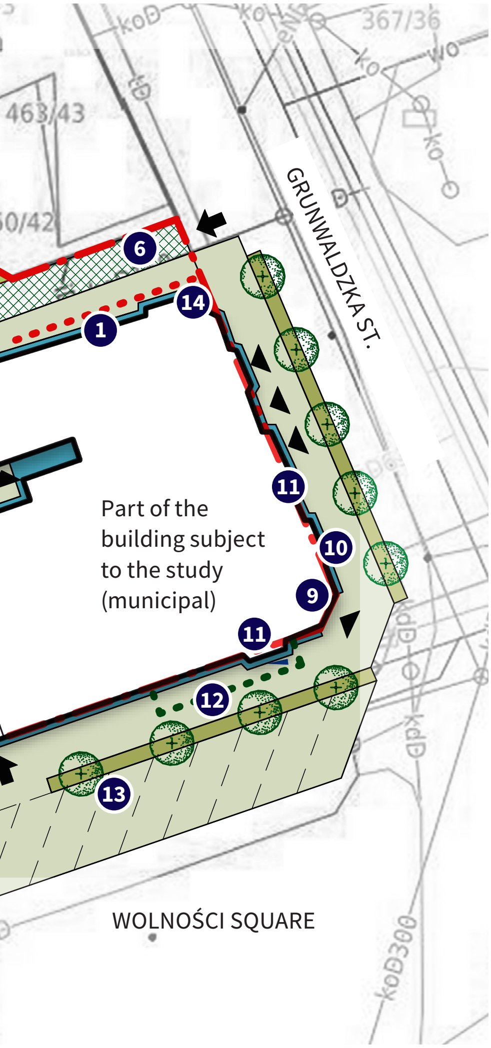


Site development – current state:

| | |
|---|---|
| → built area | 52% |
| → paved surface | 6% |
| → semi-permeable surface | 42% |
| → green area | 0% |

Site development – designed:

| | |
|---|---|
| → built area | 52% |
| → paved surface | 14% |
| → semi-permeable surface | 8% |
| → green area | 26% |



**5 Increasing recreational and green areas, introducing rain gardens.**

→ Bioretention, reduction of stormwater runoff.

→ Evapotranspiration – protection against the heat island and dampness in buildings.

→ Improving air quality.

→ Social functions.

**6 Semi-permeable paving.**

→ Reduction of stormwater runoff.

**7 Repair of drainpipes, collecting rainwater from the roof in an underground tank with an overflow to the rain garden.**

**8 Greening the blind wall with climbing plants, keeping the original architectural tectonics.**

→ Building protection against damp.

→ Improving air quality.

**9 Restoring a restaurant in the corner of the ground floor.**

→ Maximising the potential of the place.

**10 Construction of ramps.**

→ Accessibility for people with disabilities.

**11 Connection of drainpipes to the wastewater system.**

→ Protection against damp.

**12 Restoration of the sidewalk café.**

**13 Restoration of street trees (Hawthorn, Robinia Umbraculifera).**

→ Protection against the heat island effect.

→ Ecosystem services.

**14 The green band along the plinth course – removal of the concrete and introduction of façade gardens (where possible).**

→ Evapotranspiration to protect against damp plinth and basement.

**Fig. 68.** Site development plan. Drawing: Natalia Szablowska based on the workshop outcomes. Map source: Communal Property Administration in Mysłowice.

## Multi-family residential property

22 Grunwaldzka St., Mysłowice, Poland

### BUILDING RENOVATION AND RETROFIT

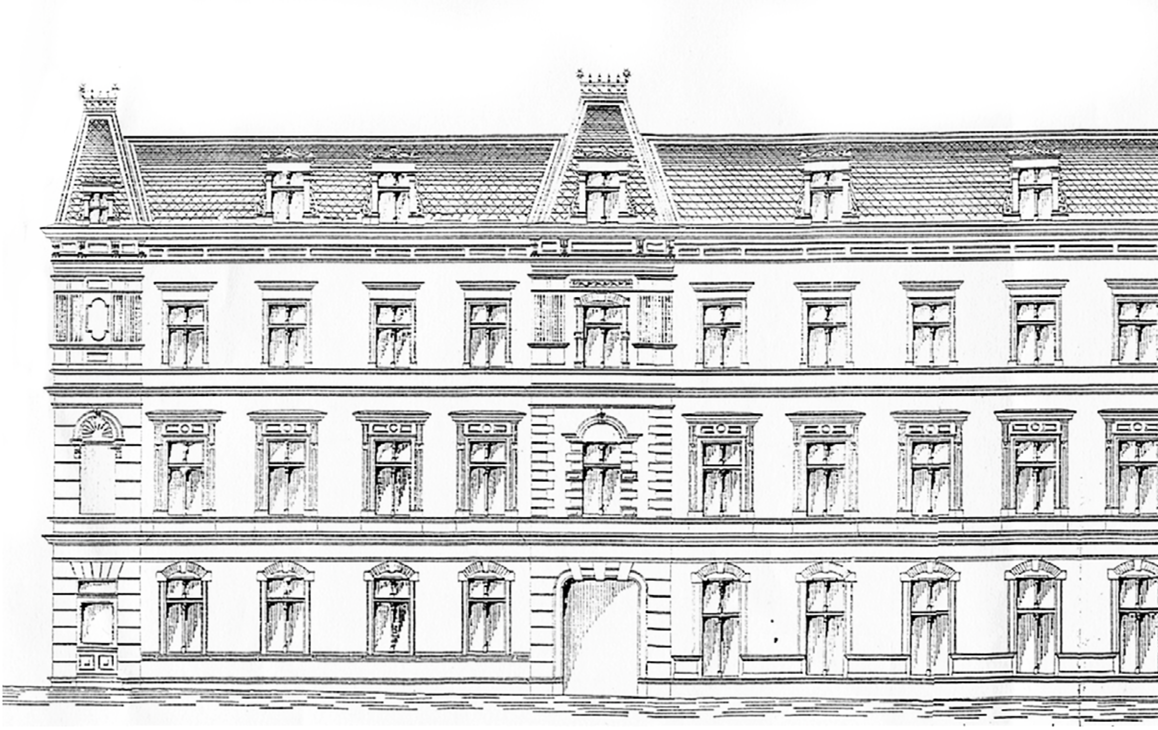


**Fig. 69.** South and east elevations combined – sketch by architect E. Knaut. Source: Files of the Construction Police in Mysłowice 1891–1902, Archives of the Mysłowice Municipality.

#### BASEMENT

→ It is proposed to use the basement as a wine bar or restaurant brewery.

→ Due to the microclimate and the original character of the basement, it is possible to partially restore the storage function (e.g. wine cellar). For this purpose, the existing chutes should be unblocked and secured.

#### FAÇADES

→ Restore the historical appearance of the façades: cleaning and supplementing brick surfaces, restoring stucco, supplementing the detail, removing secondary repainting, and restoring the original colours of the building in accordance with the study based on the original design, stratigraphy, and restoration program.

#### WINDOW AND DOOR JOINERY

→ Restore the historical appearance of the windows and external doors.

→ Installation of Quantum Glass (photovoltaic glazing of high transparency and thermal properties) to be considered.

#### ROOF

→ After a detailed analysis of the roof structure's load-bearing capacity, the roof truss's reinforcement or replacement should be considered, along with the replacement of the roofing of the yard-facing slopes, considering the need for thermal insulation of the roof and the possibility of installing photovoltaic panels on its non-visible slopes.

### ATTIC

- → Renovation and thermal insulation of the residential attic are necessary.

### VENTILATION SYSTEM

- → The effectiveness of different types of ventilation should be analyzed. Due to the dampness in the building, it is recommended to replace stack ventilation with mechanical ventilation with heat recovery. When designating routes for new ventilation ducts, one can use extant chimneys and the riser of auxiliary rooms at the staircase landings.

### HEATING SYSTEM

- → All apartments are to be connected to the district heating with separate metering for each of them.

### RES

- → The possibility of introducing photovoltaic panels (on non-visible roof slopes) or glazing in Q Glass technology to be considered.

### ENERGY EFFICIENCY

- → After connecting all apartments to the heating network, renovation or modernization of windows and doors, roof insulation, installation of photovoltaic panels and change of stack ventilation to heat exchange ventilation, the estimated energy savings will be at least 30%.

# 8.6. Kindergarten Vjeverica built in 1975

14 Ksaverska cesta, Zagreb, Croatia

LISTED ON THE MUNICIPAL REGISTER OF MONUMENTS

ADMINISTERED BY THE CITY OF ZAGREB

| | |
|---|---|
| SUMMARY OF THE DESIGN CONCEPT | Tomasz Jeleński, Hrvoje Bartulović, Agnieszka Czachowska, |
| DESIGN WORKSHOP GROUP | Hrvoje Bartulović, Kristina Spigl Uhrl, Marko Premec, Mirna Sabljak, Jasmina Smokvina |

## SITE PLAN

- → The building stretches in the direction from north to south under the hill of Medvednica that provides protection from strong wind. It is segmented to follow the inclination of the terrain.
- → Parking places located on the southwest of the building, near the main entrance, are well integrated with the surrounding greenery.
- → The driveway is located on the north of the building plot with easily reachable service and evacuation access. The accessibility for people with disabilities is ensured.
- → Trees and landscaping are integrated into the architecture; green areas are directly accessible from building facilities. The children's playground is shaded with surrounding trees.
- → Due to the years of constant use of the outdoor facilities, paving is partly damaged and needs replacement.
- → Regarding the retrofit solutions proposed below, the implementation of a heat pump would not interrupt the visual qualities of the site, and the lawn would be returned to its initial state.
- → The application of solar panels would respect existing greenery and would not cause a significant change in the landscape.

**Fig. 70.** Aerial view of the kindergarten site. Map Source: ZGGEOPORTAL, City of Zagreb Spatial Information System. Municipal Department for Economy, Sustainable Environment and Strategic Planning.

## BUILDING RENOVATION AND RETROFIT

- → The building is in average condition, with no dampness, mould, or other damage.
- → It is necessary to approach the renovation with maximum respect for the original design of individual elements and the whole, all in agreement with the conservator and architecture copyright holder.
- → The main drawbacks are the energy losses through ventilation, insufficient insulation and the condition of existing wooden carpentry.

### EARTHQUAKE RESISTANCE

- → The building has no major visible damage from recent earthquakes. It is necessary to inspect steel columns and their performance, in conjunction with reinforced concrete slabs, the roof structure, and the structural expansion joints if they exist. The steel columns have a high architectural value and need to be treated with special care. Any remedial actions depend on the test results.

### FIRE PROTECTION

- → No division of the building into fire sectors was observed, therefore a minimum separation of the facilities sector is proposed, which includes the boiler room, kitchen, and other service and technical rooms.
- → The possibility of dividing the kindergarten space into separate sectors should be considered.
- → It is necessary to examine the condition of the steel columns and treat them with coatings that provide the required REI 90.

Photo: Boris Magaš

**Fig. 71.** The Vjeverica kindergarten and nursery in the Mihaljevac park in Zagreb, designed in 1973–1975 by architect Boris Magaš. https://commons.wikimedia.org/wiki/File:Mihaljevac-Vjeverica-kindergarten-Boris-Magas.jpg (August 2022).

## Kindergarten Vjeverica

14 Ksaverska cesta, Zagreb, Croatia

- It is recommended to implement a fire alarm system as an already established standard for public buildings. Also, the implementation of an external and internal hydrant network should be considered.
- The site visit provided a clear insight into the fire access and operational zones on the west side of the building, which is mostly without openings, but not a clear insight into access from the east side. It is necessary to check the passability and remove any possible obstacles.

### EXTERNAL WALLS

- It is necessary to check the condition of reinforced concrete in places where it has been plastered. After repairing any damage, check how thick the thermal plaster could be applied, regarding the details of the connecting surfaces.
- When applying thermal plaster, it is necessary to maintain or renew the vertical groove pattern texture.
- If it is not possible to apply the thermal plaster, consider the possibility of implementing new technologies such as nano thermal insulation coating, which must be certified and have a statement of properties and other relevant documentation in accordance with the law.

### WINDOW AND DOOR JOINERY

- The carpentry should be inspected in detail. Wings and fittings should be repaired, if possible, or modernised, avoiding unnecessary dismantling of existing frames embedded in the reinforced concrete construction, and supplemented with automated control. Laminated wood should be considered the first choice of material when replacing damaged wings.
- The existing window shading needs to be renewed and the possibility of installing automatic control connected to the Central Control and Management System (CCMS) should be examined.

### ROOF

- The roof needs to be thermally insulated, on the top or bottom of the reinforced concrete panel. The decision will depend on consideration of the architectural and carpentry details. Environmentally friendly materials are preferred but energy performance calculation, fire resistance, the position of the fire sectors in the building, and fire classes of insulation products are among the factors that need to be considered. Vacuum insulating panels are suggested, ones that have the minimum thickness needed to achieve the desired energy performance, preserve architectural details and have a minimal effect on the appearance of the building overall.
- The lack of drip edges on exposed parts of concrete elements presents a big problem and it is necessary to install new ones which will prevent deterioration that leads to fungi and mould.
- It is not possible to implement a green roof over the entire building. The series of triangular roof slopes is a key architectural design element which together with the original material stands in contrast to the surrounding landscape.
- However, there are a few small parts of the building with flat roofs that possibly could be covered with green.

### STORMWATER MANAGEMENT

- The existing drainage system drains rainwater from the slopes of the roof into the surrounding terrain. It is necessary to examine the permeability of that system and examine its drainage capacity. If it is insufficient, it will be necessary to correct its dimensions, but in the spirit of the original design.
- It is necessary to examine the patency of drainage pipes and the hydro and thermal insulation of foundation walls. If these are inadequate, they should be repaired or replaced.

- The drainage could be upgraded to collect rainwater in a tank. Given the large roof surfaces, the collected water could be used for sanitary needs in the building and/or watering the garden.

### CENTRAL CONTROL AND MANAGEMENT SYSTEM

- A central monitoring system for heating, cooling and ventilation connected to room temperature and air quality sensors is proposed. The system would raise comfort levels and provide optimal use of energy for heating, ventilation, and air conditioning (HVAC).
- The entire lighting system is already equipped with LED lamps, but it is possible to optimize it further by integration with the Central Control and Management System (CCMS).

### VENTILATION

- It is recommended to use existing openings: windows, skylights, roof domes, etc. for natural ventilation and cooling during summer nights and also to provide a remote-control system with sensors to be connected to CCMS.
- Installing thermostatic and air quality sensors would allow automated control of natural ventilation through windows (e.g. VELUX ACTIVE with NETATMO smart sensor-based ventilation system).
- During the heating period, ventilation should be provided by a central unit that enables heat recovery. There are mechanical rooms where the unit may be placed.
- It is necessary to harmonize mechanical ventilation with other requirements e.g. fire safety, proper dimensioning of the distribution channels, noise silencing, etc.

### HEATING AND COOLING SYSTEM

- After increasing the thermal insulation of roofs, walls and floors, it is necessary to find the optimal solution for HVAC systems to ensure energy self-sufficiency so that the building is heated without the need for an external source of primary energy.
- Instead of the existing heating system with radiators, the implementation of both heating and cooling via fan coil units is proposed. Dividing the building into zones would allow for automatic regulation of temperatures by CCMS, providing additional savings by programming temperatures in all zones independently (e.g. 14 C when not in use, 22 C when children are inside).
- It is necessary to examine whether installing a Geothermal Heat Pump (GHP) with a horizontal collector loop or vertical boreholes would be possible and which would be more efficient. Some vertical GHPs can operate in passive cooling mode making use of groundwater temperature. They do not run the compressor during periods of low thermal load to provide additional energy savings.
- In 2017, the DHW system in the kitchen was modernised, with the introduction of solar collectors. Its connection to CCMS is proposed.
- Heat pumps need to be dimensioned so as to provide the optimal amount of hot water in combination with existing solar collectors.

### RES

- With the use of a heat pump, the building would harvest ambient energy to cover most of its heating energy demand, which will significantly reduce the final energy (FE) consumption.
- It is also necessary to examine the possibility of using PV panels to power the heat pump. PV cells might be installed on roof parts that would be suitable for installation integrated into the roof structure, in agreement with the architecture copyright holder and heritage conservation office.

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