REHVA

EUROPEAN GUIDEBOOK

Energy Efficient Renovation of Existing Buildings for HVAC professionals

NO. 32 - 2022

Federation of European Heating, Ventilation and Air Conditioning Associations

REHVA

Energy efficient renovation of existing buildings

for HVAC professionals

REHVA Task Force

DISCLAIMER
This Guidebook is the result of the efforts of REHVA volunteers. It has been written with care, using the best available information and the soundest judgment possible. REHVA and its volunteers, who contributed to this Guidebook, make no representation or warranty, expressed or implied, concerning the completeness, accuracy, or applicability of the information contained in the Guidebook. No liability of any kind shall be assumed by REHVA or the authors of this Guidebook as a result of reliance on any information contained in this document. The user shall assume the entire risk of the use of any and all information in this Guidebook.

REHVA is the Federation of European Heating, Ventilation and Air Conditioning Associations, www.rehva.eu

Requests for permission to make copies of any part of the work should be addressed to:
REHVA Office, 40 Rue Washington, 1050 Brussels – Belgium
e-mail: info@rehva.eu

ISBN 978-2-930521-31-2

Table of Contents

Preface

This Guidebook has been prepared by a REHVA Task Force that includes members from nine European countries, including Estonia, Finland, France, Greece, Italy, Poland, Romania, Serbia and Turkey. The modernisation of heating, ventilation and air conditioning (HVAC) systems can play a very important role during the deep renovation of existing buildings to achieve the calculated energy savings by properly operating existing installations. Therefore, the Guidebook aims to provide strategies and recommendations to support practising professionals in the field of energy renovation for existing buildings, with a focus on HVAC systems. The role of the building envelope is essential in initial efforts to reduce energy demand. Therefore, this topic is also covered within this Guidebook—albeit not in detail.

The Guidebook presents the fundamentals for specific energy efficiency and other renovation measures in existing buildings for which HVAC systems play an important role. Emphasis is placed on market-ready and technically mature solutions that have been proven in practice to increase building renovation rates and facilitate the energy renovation process of existing buildings. The Guidebook presents results from field studies with quantified energy savings that are complemented with payback time estimates to document the overall benefits resulting from different renovation measures that can be implemented by HVAC professionals and practitioners.

Focusing only on the energy renovation of the building envelope – instead of the building as a whole – will often limit potential energy savings and may significantly increase the payback time. Emphasis should also be placed on the renovation of HVAC systems and the energy education of building occupants to fully exploit the anticipated benefits of various implemented technologies. Additionally, the adaptation of HVAC systems to various building energy demands will further improve indoor environmental quality (IEQ) and overall occupant satisfaction.

For the transformation of existing buildings from high energy consumption and high carbon emissions to carbon-neutral buildings, professionals can use the general energy renovation concept proposed in this Guidebook. The information presented herein applies to different specific renovation concepts that can be adapted to various regional renovation projects. This holistic approach considers all primary factors that may affect energy consumption, IEQ, carbon footprint, costs and the future application of renewable energy sources (RESs) at all stages of the energy renovation process for existing buildings (i.e., from planning to construction, and finally monitoring).

The priority of improving IEQ and maintaining it at a desirable level should be complemented by technically and economically justified measures that increase the energy efficiency of existing buildings. A complete plan should consider the energy renovation of the building envelope and all HVAC installations with the use of low embodied energy (carbon) materials and user education. Reducing a building's energy demand and final energy consumption will also facilitate the selection of an appropriate RES and cost effectiveness in the use of appropriate technologies to cover the remaining low energy needs for a nearly zero energy building or carbon-neutral building.

The Guidebook presents the best available techniques and solutions that can be used as part of the energy modernisation process for HVAC systems, especially in residential buildings. They are usually characterised with a life cycle analysis to have a low carbon footprint, low payback time and short implementation time whilst minimising the disruption of building occupants and offering a high potential for repeatability to other buildings and widespread use. The information contained in this Guidebook should inspire and motivate professionals to achieve better project results, high-performance buildings and satisfied building owners and occupants.

Finally, the authors thank Mr. Jarkko Narvanne for the final layout and typesetting of the Guidebook.

Foreword

REHVA, founded in 1963, is a European professional federation that joins other national associations of building services engineers. Today, REHVA represents more than 120,000 HVAC designers, engineers, technicians and experts from 26 European countries. REHVA is dedicated to the improvement of health, comfort and energy efficiency in all buildings and communities. REHVA provides its members with a platform for international networking and knowledge exchange, contributes to technical and professional development, follows European Union policy developments and represents the interests of its members in Europe and the rest of the world. REHVA's mission is to promote energy-efficient, safe and healthy technologies for building mechanical services by disseminating knowledge among professionals and practitioners in Europe and beyond. The REHVA Guidebook series is amongst the most important tools used to diffuse knowledge on the latest developments and advanced technologies, providing practical guidance to practitioners. REHVA has published over 30 guidebooks. REHVA would like to express its sincere gratitude to the authors of this Guidebook for their invaluable work.

Member countries of REHVA

Belgium | Croatia | Czech Republic | Denmark | Estonia | Finland | France | Germany | Hungary | Italy | Latvia | Lithuania | Moldavia | Netherlands | Norway | Poland | Portugal | Romania | Serbia | Slovakia | Slovenia | Spain | Sweden | Switzerland | Turkey | United Kingdom

REHVA Task Force

This book was developed by a working group comprising the following experts:

Tomasz Cholewa (Chair), Lublin University of Technology, Poland

Constantinos A. Balaras, National Observatory of Athens, Greece

Jarek Kurnitski, Tallinn University of Technology, Estonia

Livio Mazzarella, Politecnico di Milano, Italy

Alicja Siuta-Olcha, Lublin University of Technology, Poland

Elena Dascalaki, National Observatory of Athens, Greece

Risto Kosonen, Aalto University, Finland

Catalin Lungu, Technical University of Civil Engineering of Bucharest, Romania

Marija Todorovic, Academy of Engineering Sciences of Serbia, Serbia

Ilinca Nastase, Technical University of Civil Engineering of Bucharest, Romania

Cécile Jolas, AICVF, France

Murat Çakan, Istanbul Technical University, Turkey

Reviewers

Julie Godefroy, CIBSE, United Kingdom

Zoltán Magyar, ETE, Hungary

Jorma Railio, FINVAC, Finland

List of abbreviations

AC	Air Conditioning
ACR	Air Change Rate
ACS	Air Conditioning System
AHU	Air Handling Unit
ASHP	Air Source Heat Pump
CEN	European Committee for Standardization
CDD	Cooling Degree Days
DH	District Heating
DHW	Domestic Hot Water
DPCV	Differential Pressure Control Valve
EAHP	Exhaust Air Heat Pump
EBP	Energy Building Performance
ECI	Embodied Carbon Intensity
EED	Energy Efficiency Directive
EEI	Embodied Energy Intensity
EP	Energy Performance Indicator
EPBD	Energy Performance of Buildings Directive
EUI	Energy Use Intensity
FES	Fossil Energy Source
F-gases	Fluorinated Gases
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HCA	Heat Cost Allocation
HDD	Heating Degree Days
HP	Heat Pump
HR	Heat Recovery
HRV	Heat Recovery Ventilation
HVAC	Heating, Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
ICT	Information and Communication Technologies
IEQ	Indoor Environmental Quality
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
ME	Mechanical Exhaust
MFH	Multi-Family House
MPC	Model Predictive Control
MV	Mechanical Ventilation
NZEB	Nearly Zero-Energy Building
nZEB	Net Zero-Energy Building
PCM	Phase Change Material
PEB	Positive Energy Building
PED	Positive Energy District
PIBRV	Pressure Independent Balancing Radiator Valve
PV	Photovoltaic
RES	Renewable Energy Source
RTS	Residential Thermal Station
SC	Space Cooling
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Ratio
SFH	Single-Family House
SFP	Specific Fan Power
SPBT	Simple Payback Time
SRVU	Single-Room Ventilation Unit
TCV	Temperature Control Valve
TRV	Thermostatic Radiator Valve
VIP	Vacuum Insulation Panel
VRF	Variable Refrigerant Flow
WSHP	Water Source Heat Pump
ZEB	Zero-Energy Building

1. Introduction

Buildings in the European Union (EU) use ~40% of the final energy consumption for their operation [82], which corresponds to ~23% of the total greenhouse gas (GHG) emissions stemming directly from the on-site combustion of fossil fuels and indirectly from the electricity and district heating used in buildings [118, 178]. Considering the long lifespan of buildings, it is estimated that 85–95% of the buildings that exist today will continue to be used in 2050 [160].

The building [83] sector is at the centre stage of European policies and national efforts to meet the energy and emissions targets in line with the Paris Agreement and the EU's commitment to climate neutrality by 2050 [70]. In the near term, the EU has set its 2030 targets, which commit to cutting GHG emissions by at least 55% by 2030 in comparison to 1990 levels [108], achieving at least a 32% share of renewable energy and at least a 32.5% improvement in energy efficiency [1]. Furthermore, the 'Fit for 55 package' [90] will include several new legislative proposals and policy initiatives to align EU legislation and policy initiatives to meet the 2030 targets and 2050 ambitions.

Efforts to decarbonise buildings and power generation through the use of renewables are among the main pillars of the EU's efforts to meet the 2030 targets. According to the framework of the Climate Target Plan 2030 [168], in order to achieve the 55% emission reduction by 2030 (compared to 1990 levels), it will be necessary to reduce the GHG emissions from buildings by at least 60%, the final energy consumption of the building sector by at least 14% and energy consumption for the heating and cooling of buildings by 18% by 2030 in comparison to 2015 levels [160].

Deep energy renovations can reduce primary energy consumption by at least 60% [37]. However, these are currently limited market activities that represent only ~0.2% of the existing building stock per year [160]. To change these trends, the EU Renovation Wave [159] aims to at least double the energy renovation rate and boost deep energy renovations. These renovations will enhance the quality of life for people living in and using buildings, tackle energy poverty and create thousands of new green jobs in the construction sector.

European directives such as 2018/844/EU [53], 2018/2001/EU [54] and the range of Energy Building Performance (EBP) Standards developed by both the CEN and ISO (e.g., EN ISO 52000- 1: 2017 [67], which is an overarching standard in which a holistic approach for assessing the energy performance of new and existing buildings is presented) are particularly helpful in the energy renovation process.

Activities in this area include not only ensuring the required thermal insulation of building partitions and air tightness, but also the high efficiency of building ventilation and energy systems. Reducing the demand for energy facilitates the use of renewable energy sources (RESs). Energy saving is also possible by introducing automatic regulation and control systems in a building, which, among other things, adjust the energy supply to current needs. Directive 2018/844/EU [53] introduced a requirement to assess the smart readiness of a building, which accounts for the use of ICT and electronic systems in buildings. By improving the energy performance of buildings, adequate indoor air quality (IAQ), as well as the thermal comfort and well-being of residents, are achieved. Users should be aware of the functioning of building technical systems, especially space heating, ventilation, cooling systems, domestic hot water (DHW) preparation and energy consumption reduction.

There are several strategies and reports on the energy renovation of buildings in the literature [39, 85, 102-104, 169]. However, these documents provide an overview of the key regulatory policies that require improvements to existing commercial and residential buildings during renovation, refurbishment or retrofit rather than clearly addressing the important role of heating, ventilation and air conditioning (HVAC) systems in this process. Other publications on similar topics are also available [41, 94, 98, 107, 142, 172]. However, these largely focus on building envelope modernisation. On the other hand, widely applicable modernisations in HVAC systems are not addressed in detail.

Numerous barriers continue to prevent higher renovation rates from being achieved, such as:

- low awareness of the current energy and resource profile of buildings and the benefits of renovation,
- lack of trust in the energy savings that renovation will achieve,
- energy performance not being fully reflected in real estate prices,
- burdensome procedures and split incentives between owners and tenants are among the strongest reasons behind low renovation rates [167].

Based on this context and the fact that the majority of energy in existing buildings is used by HVAC, it is crucial to have a guidebook that addresses these topics (e.g., minimising loads and focusing on the renovation of HVAC systems and increasing the energy efficiency of existing systems). The modernisation of HVAC systems can play a very important role during deep renovations to existing buildings in order to achieve the calculated energy savings in practice by operating existing HVAC systems.

The main objective of this Guidebook is to present the following:

1. Holistic and widely applicable concepts for the renovation of existing buildings that underline the critical role of HVAC professionals in the process.
2. Good practices that are widely applicable and have been validated and demonstrated by proven practices during field studies and document actual energy and cost savings and/or realistic estimates from life cycle analysis (LCA) that different renovations can achieve.
3. Practical guidelines applicable to different geographical locations and climate zones that have different priorities for heating/cooling during the renovation of existing buildings. The elaborated HVAC solutions will apply to different renovation concepts that may be specified by various renovation grants.

To comprehensively present the energy renovation process for individual HVAC systems (heating, cooling, ventilation, DHW) in existing buildings, the material in the Guidebook is organised into 11 chapters that address major HVAC systems, including heating, cooling, ventilation and DHW, as well as issues related to the energy education of users.

While the emphasis of this Guidebook is placed on existing residential buildings, the information contained herein may also be relevant to non-residential buildings that are equipped with similar HVAC systems. However, commercial and industrial buildings with very specific technical installations that serve distinct building types or functions are not explicitly covered in this Guidebook.

For the different technologies and cases under consideration, the presentations refer to representative buildings. The scope of the modernisation works carried out will document the impact of a given measure on a building's operational energy in the most unambiguous manner possible.

The technical, economic, climatic and cultural differences throughout Europe, which strongly affect the selection and applicability of measures aimed at energy savings, are also considered.

The main target audience of this Guidebook includes HVAC engineers and designers, energy auditors, public and private building investors, HVAC contractors, architects involved in renovations, technical building managers, academics, students, public authorities, and companies that offer products and services for the energy-efficient renovation of existing buildings.

The Guidebook is prepared by REHVA Task Force members, who have wide research and practical (as certified engineers) experience in the field of renovating existing buildings.

2. Deep renovation of existing buildings – a holistic approach

There are still too many ‘light’ renovations in the building market that are not well planned or coordinated and have little effect on building performance. To achieve energy performance and sustainability, adequate combinations of energy conservation measures leading to highly energy-efficient, resource-efficient and decarbonised buildings are required.

Whilst the evolving trend of renovation activities involves thermally upgrading the building envelope (e.g., insulating external walls and roofs, installing double glazing), it often overlooks the adequate adaptation of existing HVAC systems to lower energy demand. In many cases, this leads to lower actual energy savings in comparison to calculated ones (see **Chapter 5** for more detail).

Therefore, the primary aim of this renovation wave is to lead the deep renovation of the existing building stock while considering life cycle thinking and circularity to achieve highly energy-efficient and carbon-neutral buildings together with high indoor environmental quality (IEQ) by 2050. Additionally, when considering the existing building stock, the proposed solutions and detailed renovation concepts of existing buildings should be cost-optimal and suitable for large scale applications.

2.1. Moving towards net positive energy buildings

Over the past two decades, European policies and an evolving legislative framework, which includes the Energy Performance of Buildings Directive (EPBD) [51] and the Energy Efficiency Directive (EED) [52], have made significant progress towards establishing minimum energy requirements for new buildings, thereby making the nearly zero-energy building (NZEB) standard practice for new building construction in the EU. Moreover, these policies and frameworks have initiated efforts for renovating the existing building stock.

National cost-optimal studies have demonstrated the cost effectiveness of the NZEB concept for new buildings and the renovation of existing buildings [81]. All EU countries have set cost-optimal minimum energy performance requirements for new buildings, for existing buildings undergoing a major renovation, and for the replacement or retrofitting of building elements (e.g., heating and cooling systems, roofs and walls).

In the coming years, the evolution of the building construction industry will be towards (net) zero-energy buildings (ZEBs), positive energy buildings (PEBs), and a move towards a larger scale with the introduction of positive energy districts (PEDs). The main strategies of ultra-high-performance buildings continue to place the ‘energy efficiency first principle’ at centre stage by minimising energy demand and optimising energy supply via energy generation from renewables. Optimally, buildings will satisfy their very low energy demand from on-site renewables. On an annual basis, any periodically delivered energy will be balanced by the exported renewable energy for a ZEB – or even more energy exported by a PEB. The vision is that buildings will transform from being at the core of the energy problem to being part of the solution by complementing sustainability, climate neutrality and green growth efforts.

While the overarching principles are clear, differences are encountered when one starts considering the boundaries, the end-uses and other influencing parameters for defining ZEBs, PEBs and PEDs, among others. Relevant definitions available in the literature were elaborated for buildings by Moghaddasi et al. [140] and districts by Hedman et al. [101]. To provide a good understanding of the concepts involved in the renovation of existing buildings, the basic definitions of energy-efficient buildings that may be present in this process are discussed in **Chapter 2.2**.

2.2. Principles of near-zero energy buildings and definitions in Europe

According to EU Directive 2010/31/EU [51] on building energy performance, an NZEB is only defined in a general way as:

‘*a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on site or nearby*’.

This leaves the EU Member States a wide margin of discretion in operatively defining the meanings of ‘*very high energy performance*’, ‘*nearly zero or very low amount of energy required*’, ‘*very significant extent by energy from renewable sources*’ and ‘*nearby*’.

Furthermore, clause 3 of EPBD Article 9 [51] requires that Member States define their NZEB requirements in their national plans, including a numerical indicator of primary energy use expressed in kWh/m² per year. These may be varied for different building typologies within a country based on the climatic zone, heating system, building geometry and other factors. Accordingly, many Member States have defined a range of values for a given building type to set the minimum requirements to comply with to become an NZEB.

As a consequence of this discretion, a uniform approach for implementing NZEBs is not established in the EPBD.

Later, the European Commission attempted to clarify what a ‘nearly zero-energy’ building is in its 2016 NZEB Recommendations [36]. In these Recommendations, the Commission underlined that ‘*a very low level of energy need for heating and cooling is a vital precondition for nearly zero primary energy buildings*. *Very low energy needs are also a precondition to achieve a significant share of energy from renewable energy sources and nearly zero primary energy*’. That is, the NZEB concept first requires energy savings and only secondarily requires the use of renewable energy to cover such energy needs.