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RENOVERTY

Rural Energy Efficiency Roadmap (REER) for the energy renovation of family houses of households experiencing energy poverty in the area of Sveta Nedjelja and Žumberak, Croatia: A renovation guideline for households

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About RENOVERTY

RENOVERTY will foster energy efficiency building upgrades in the Central and Eastern Europe (CEE), South-eastern Europe (SEE) countries, as well as Southern European countries (SE), by setting the methodological and practical framework to build renovation roadmaps of vulnerable rural districts in a financially viable and socially just manner.

Specifically, the project aims to deliver tools and resources to support local and regional actors to build and execute operational single or multi-household roadmaps for rural areas. A scalable model will also be created to ensure the wide geographical replicability and implementation of the roadmaps by different actors at the EU level. Strategically, the project will contribute to minimising logistical, financial, administrative, and legal burdens caused by a complex and multi-stakeholder home renovation process. Additionally, RENOVERTY will ensure that building retrofits consider the social dimension by incorporating security, comfort, and improved accessibility in the roadmaps to further improve the quality of life of vulnerable populations.

Over the project's three years, seven pilots located in Sveta Nedelja (Croatia), Tartu (Estonia), Bükk-Mak & Somló-Marcalmente-Bakonyalja Leader (Hungary), Zasavje (Slovenia), Parma (Italy), Coimbra (Portugal), and Osona (Spain) will implement the roadmaps, while wider integration of rural and peri-urban development is foreseen in the long run.

CONTENT

List of abbreviations

CEC	Citizens' Energy Community
DHW	Domestic Hot Water
DREEM	Dynamic high-Resolution dEmand-sidE Management model
EEM	Energy Efficiency Measure
ESCO	Energy Service Company
EU	European Union
FZOEU	Environmental Protection and Energy Efficiency Fund
HVAC	Heating, Cooling and Air Conditioning
LAG	Local Action Group
LCSE	Levelised Cost of Saved Energy
NIAS	National Identification and Authentication System
NPV	Net Present Value
OG	The People's Newspaper (cro. *Narodne Novine, NN*)
PP	Payback Period
PVGIS	Photovoltaic Geographical Information System
SPP	Simple Payback Period
ZIS OSS	Joint Information System of Land Registers and Cadastre

SUMMARY

The Northwest Croatia Regional Energy and Climate Agency participates in the implementation of the EU-funded RENOVERTY project[1]. The project encourages improvements in the energy efficiency of buildings inhabited by those experiencing energy poverty through the development of roadmaps for energy renovation of family houses in rural areas, the guidelines of which have been adapted to the local characteristics of the pilot areas of Sveta Nedelja and Žumberak.

The main target groups of the Rural Energy Efficiency Roadmaps (hereinafter: REERs) are homeowners who want to implement energy renovation, as well as organisations that help guide households such as energy agencies, civil society organisations, local action groups (LAGs), decision-makers and implementers, and other organisations involved in energy renovation policies and processes.

Through the REERs, all involved stakeholders are introduced to the process of planning an energy renovation, as well as possible challenges and obstacles in the planning and implementation phase. An overview of key stakeholders that should be involved in the planning process and the implementation of energy renovation projects is given. The main focus of the REERs is placed on overcoming legal, financial and administrative obstacles, where LAGs operating in pilot areas play an extremely important role.

[1] Official website of the RENOVERTY project available on: https://ieecp.org/projects/renoverty/

1 Introduction

Sveta Nedelja and Žumberak are located in central Croatia, not far from the capital Zagreb. Sveta Nedelja is one of the Croatia's smaller towns, with a total of just over 18,000 inhabitants, where almost half of the 14 settlements meet the criteria for rural areas under Croatian legislation, as they are characterized by lower population density, predominantly natural or agricultural areas, and limited infrastructure and services. Sveta Nedelja is well developed with a growing population and standard of living. In contrast, the nearby municipality of Žumberak has 610 inhabitants spread over more than 100 square kilometers, with a continuous decrease in population, with some settlements having less than 5 inhabitants. Žumberak is also included among the areas of special state protection, based on its economic development, structural challenges and demographic characteristics[2].

These two areas, although being geographically close, are different in composition and challenges, and were therefore selected to help identify and better understand energy poverty in the rural areas of central Croatia, with a primary focus on single-family houses as the most common type of rural housing in the country. With the support of LAG[3] Sava[4] and LAG Vallis Colapis[5], which operate in the area of Sveta Nedelja and Žumberak and are familiar with the local context, households living in family houses potentially at risk of energy poverty were identified and selected. Energy audits were then conducted in these homes to assess the buildings' energy characteristics and determine the needs and priorities for implementing energy efficiency measures in similar households within the region.

'Energy poverty', for the purposes of this project and this document, refers to *a household does not have access to basic energy services, where such services ensure basic levels and a decent standard of living and health, including adequate heating, hot water, cooling, lighting and energy to power household appliances, in the relevant national context, existing national social policies and other relevant national policies, caused by a combination of factors, including at least affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes*, in accordance with Article 2, paragraph 52 of the Housing Act. Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast).[6]

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[2] Act on Areas of Special State Concern (OG 86/08, 75/11, 148/13, 76/14, 147/14, 18/15, 106/18)
[3] A Local Action Group (LAG) is a partnership of representatives of the public, economic and civil sector of a certain rural area, which was established with the intention of developing and implementing a local development strategy of that area, and whose members can be natural and legal persons.
[4] https://lagsava.hr/
[5] https://leader.vallis-colapis.hr/
[6] https://eur-lex.europa.eu/legal-content/HR/TXT/HTML/?uri=CELEX:32023L1791

Furthermore, 'vulnerable households' are *households experiencing energy poverty or households, including those with lower middle incomes, which are particularly exposed to high energy costs and do not have the means to renovate the building in which they live*, as defined in Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings[8].

In the period October and November of 2023, a total of 15 energy audits were carried out, of which 10 in the area of Sveta Nedelja and 5 in the area of Žumberak, which enabled an understanding of the specifics of residential buildings related to energy poverty in the pilot areas. In December 2023, homeowners were given energy certificates that remain in their permanent ownership.[7]

The new Directive (EU) 2024/1275 on the energy performance of buildings states[8]: *Inefficient buildings are often associated with energy poverty and social problems. Vulnerable households are particularly exposed to the increase in energy prices, as they spend most of their budget on energy products. Reducing excessive energy bills and building renovation can lift people out of energy poverty and prevent energy poverty. At the same time, building renovation is not free and it is crucial to ensure that the social impact of building renovation costs, especially on vulnerable households, is kept under control.*

In a conversation with the owners of family houses during the field visit, feedback was collected on the expectations for energy renovation of their houses, mostly due to the awareness of the numerous benefits that such renovation brings. However, the obstacles they face are often very complex, and are briefly described below.

The most common **expectations and advantages in the case of energy renovation** among owners of certified family houses:

1. Reducing Energy Costs: Homeowners expect energy renovation to lower their monthly energy bills via measures such as thermal insulation of building envelopes and replacement of windows or heating systems can significantly reduce energy consumption.
2. Improved Living Quality: Energy-efficient homes provide better living conditions, including more comfortable indoor temperatures, improved air quality, and reduced dampness and mould.

[7] Since possessing an energy certificate is a prerequisite for applying to existing tenders for co-financing energy renovation projects and renewable energy sources, all Energy Audit Reports and issued certificates are aligned with the Conditions and Criteria for Co-financing the Energy Renovation of Family Houses, published by the Environmental Protection and Energy Efficiency Fund (EPEEF) in late December 2023. https://www.fzoeu.hr/hr/objavljeni-uvjeti-za-sufinanciranje-energetske-obnove-obiteljskih-kuca-u-2024-godini-9647/9647

[8] https://eur-lex.europa.eu/legal-content/HR/TXT/HTML/?uri=OJ:L_202401275

3. Long-term Sustainability: Some homeowners recognise energy renovation as a safeguard against rising energy prices and the impacts of climate change.
4. Increased Property Value: Enhancing energy efficiency, lowering heating and cooling costs, and creating healthier living spaces contribute to higher property values.

The most common obstacles to the energy renovation of family houses include:

1. Financial Costs: High upfront costs remain the primary obstacle, as homeowners often lack the financial means to fund renovations. In rural areas, the costs of implementing energy efficiency measures or renewable energy solutions are often higher due to limited access and fewer available contractors.
2. Access to Information and Support: Homeowners experiencing energy poverty often lack information about renovation opportunities, subsidies, or incentives, even when available. The absence of advisory support further complicates the process.
3. Administrative Challenges: Application processes for existing programmes are often unclear and inaccessible to people experiencing energy poverty. The collection and submission of necessary permits and documentation can discourage homeowners from pursuing renovations.
4. Technical and Legal Constraints: Older houses may require significant structural improvements before energy renovations can proceed, increasing project complexity and cost. Additionally, proof of building legality is often required for national funding programmes, posing another barrier to securing financial support.

It can be concluded that implementing energy efficiency measures in rural areas is closely linked to broader financial, social, and geographical challenges.

Energy renovation, while challenging and costly, is crucial in addressing energy poverty. Energy audit results indicate that most single-family homes lack adequate thermal insulation, have outdated heating systems, and feature inefficient windows and doors, leading to higher energy bills, discomfort, and potential health risks for occupants.

When planning energy renovation measures, households experiencing energy often encounter numerous barriers. They typically lack the financial resources and awareness of co-financing mechanisms, face difficulties accessing contractors, and lack the necessary information to make informed decisions. Geographic isolation further increases service costs and logistical challenges. Additionally, these households may struggle to identify and prioritise the measures needed, balancing necessity with cost-effectiveness.

The aim of these REERs is therefore to provide support to the local community from the area of the Municipality of Žumberak and the City of Sveta Nedelja, in achieving easier, faster and better implementation of energy renovation measures with the aim of combating energy poverty.

2 Key steps in the energy renovation of family houses

To streamline the energy renovation process for family houses in the areas of Sveta Nedjelja and Žumberak, with a particular focus on households affected by energy poverty, a detailed overview of the key steps for identifying and implementing measures, including financing, is provided below. While this document primarily focuses on energy renovation as a means of combating energy poverty, it can also serve as a valuable resource for all other households in family homes seeking to implement energy renovation measures.

2.1 Building documentation and property relations

To apply for tenders for co-financing energy renovation with public funds, it is necessary to provide proof of building legality, ownership, and, in most cases, permanent residence. Therefore, it is essential to verify the status and collect the required documentation in a timely manner.

For this purpose, it is necessary to have existing building documentation, which includes:

- Building permit, occupancy permit, decision on as-built condition or other document that can determine the legality of the building;
    - It is possible to check the status of the building through the Physical Planning Information System at: https://ispu.mgipu.hr/#/
- Proof of ownership
    - The necessary documents can, if they exist, be obtained through the e-citizens service (Joint Information System of Land Registry and Cadastre - ZIS OSS, https://gov.hr/hr/katalog-usluga/10?katalog=1&podrucje=49);
    - If certain documents are missing or incomplete (e.g. the stamp of finality on the decision on the as-built condition is missing, etc.), they can be sought at the representative office of the competent local self-government unit

2.2 Energy audit and energy certification

Once the legality of the building is confirmed, the next step is to gain insight into the building's actual condition in terms of energy performance. This is a prerequisite for accessing national co-financing programmes in the Republic of Croatia, as well as a mandatory requirement for the sale of real estate. This step involves conducting an energy audit, also known as energy certification of the building.

Energy certification is a set of actions and procedures that are carried out for the purpose of issuing an energy certificate and includes an energy audit of a building, the necessary calculations for reference climate data to express the specific annual heat energy required for heating, the specific annual heat energy required for cooling, the specific annual energy supplied, the specific annual primary energy, the specific annual CO_2 emissions, the determination of the energy class of the building and the construction of the building.

Simply put, an energy audit evaluates the actual energy consumption of a family house and identifies measures to reduce this consumption while simultaneously improving living conditions.

An energy certificate is a document that details the building's energy performance. It is prepared by an energy certifier, a qualified professional authorised to conduct energy certification.[9]

Residential and non-residential buildings, including family houses, are classified into eight energy classes on a scale from **A+** (most energy efficient) to **G** (least energy efficient). An example of the energy class scale is shown in **Errore. L'origine riferimento non è stata trovata.**~~**Errore. L'origine riferimento non è stata trovata.**~~.

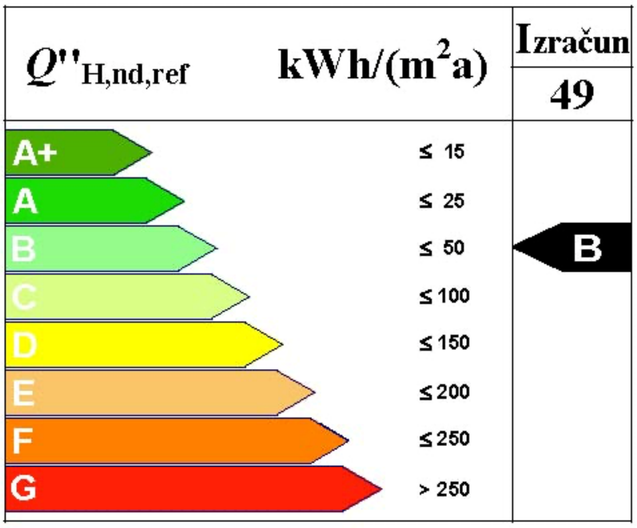


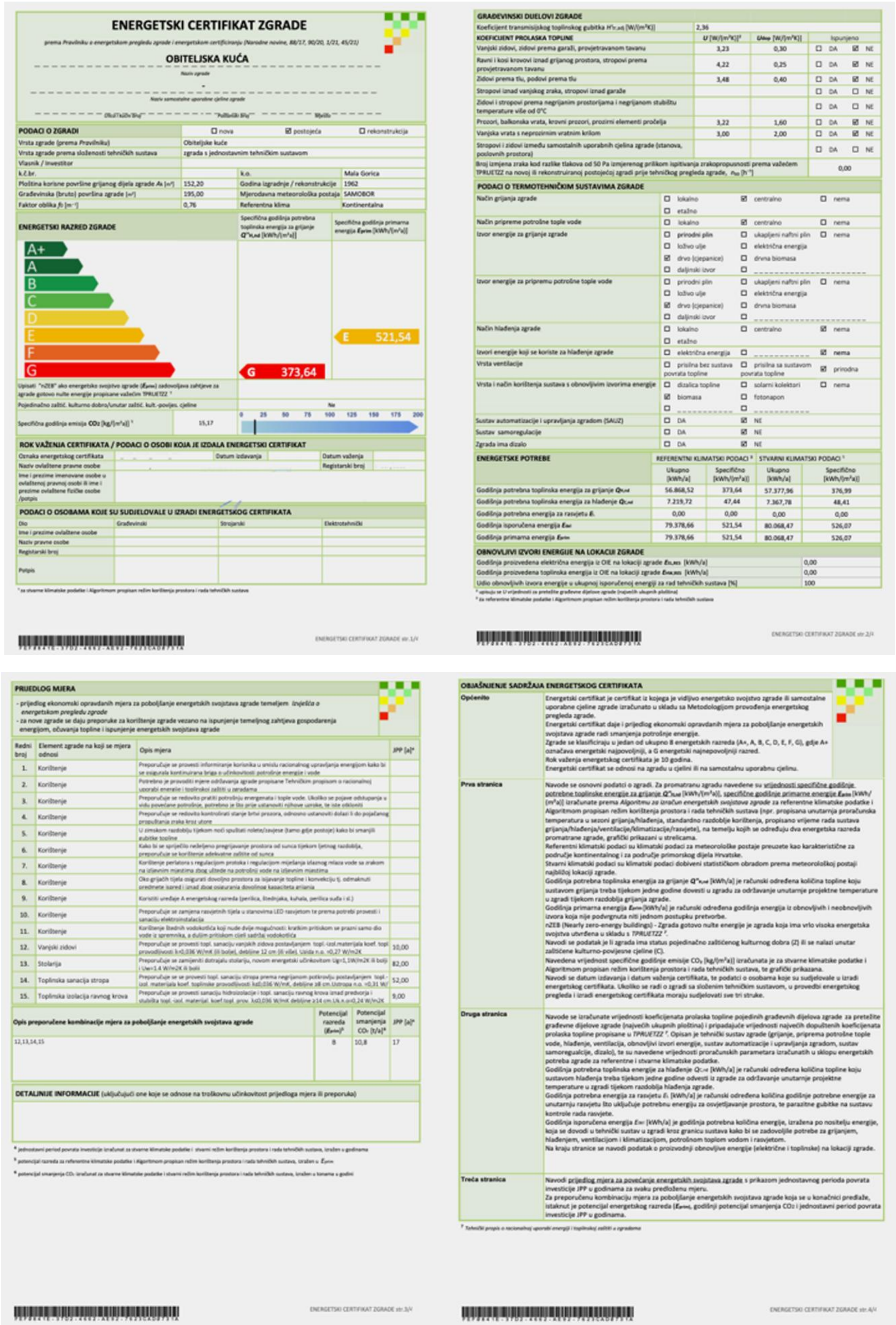
Figure 1 Overview of energy classes of buildings in the Republic of Croatia [10]

The energy audit provides detailed information on the energy performance of the building, its energy systems and energy sources, and provides a list of measures that identify the potential for improving overall energy efficiency. After the energy audit is carried out, the household will receive an energy certificate in permanent possession, which will clearly show all of the energy

[9] https://mpgi.gov.hr/o-ministarstvu/djelokrug/energetsko-certificiranje-zgrada-8304/8304

[10] Source: Ordinance on Energy Audit of Buildings and Energy Certification OG 88/17, 90/20, 01/21, 45/21, https://www.zakon.hr/cms.htm?id=45406

characteristics of the family house as an energy consumer, and also contains recommendations for the implementation of measures, as shown in the example Figure 1.


ENERGETSKI CERTIFIKAT ZGRADE

OBITELJSKA KUĆA

PODACI O ZGRADI

ENERGETSKI RAZRED ZGRADE

A+ A B C D E F G

E 521,54

G 373,64

ROK VAŽENJA CERTIFIKATA / PODACI O OSOBI KOJA JE IZDALA ENERGETSKI CERTIFIKAT

PODACI O OSOBAMA KOJE SU SUDJELOVALE U IZRADI ENERGETSKOG CERTIFIKATA

GRAĐEVINSKI DIJELOVI ZGRADE

PODACI O TERMOTEHNIČKIM SUSTAVIMA ZGRADE

ENERGETSKE POTREBE

OBNOVLJIVI IZVORI ENERGIJE NA LOKACIJI ZGRADE

PRIJEDLOG MJERA

DETALJNIJE INFORMACIJE

OBJAŠNJENJE SADRŽAJA ENERGETSKOG CERTIFIKATA

Picture 1 An example of an energy performance certificate

In addition to the energy certificate, the household will also receive a detailed report on the energy audit of the existing building for the purpose of creating an energy certificate. The report will list and detail the following segments:

1. Executive Summary – a brief overview of the main conclusions and recommendations
2. Snapshot of the existing state – description of the current state of the facility and its systems
    - 2.1. Basic information – ownership, location, parcel, etc.
    - 2.2. Construction and architectural elements – description of the current condition with photographs, including a description of the envelope of the house
    - 2.3. Heating, Cooling and Air Conditioning (HVAC) and Domestic Hot Water (DHW) systems – description of existing HVAC and DHW systems
    - 2.4. Electric lighting system — description of the existing lighting system
    - 2.5. Other electricity consumers – description of all other electricity consumers
    - 2.6. Water consumption systems — description of the existing DHW system
3. Energy analysis – assessment of energy consumption and energy efficiency of the building based on the existing condition
4. Budget to primary energy – current situation – detailed calculations of energy consumption and efficiency of technical systems
    - 4.1. Calculation of the annual heat energy required for heating/cooling – calculation of the amount of energy required to maintain a comfortable/designed temperature in the building throughout the year
    - 4.2. Calculation of annual delivered and primary energy to HVAC and DHW systems – calculation of energy consumed by heating, cooling and hot water systems (supplied), and total energy including heat losses (primary).
    - 4.3. Calculation of the total annual energy supplied to technical systems and primary energy – presentation of the overall picture of the energy consumption of the facility, taking into account all systems and their losses
    - 4.4. Energy classes – classification of the building according to energy consumption
5. Proposal of energy efficiency measures – recommendations for increasing the energy efficiency of the building
6. Conclusion – Overview of key observations and proposals for improving energy efficiency

The energy audit, including its cost and organisation, can be one of the initial obstacles to the energy renovation of a family house. Therefore, it is recommended that households regularly check the website of the Environmental Protection and Energy Efficiency Fund (FZOEU) at www.fzoeu.hr for announcements about upcoming tenders for co-financing the energy renovation of family houses.

In previous tenders, the cost of an energy audit for households experiencing energy poverty was considered an eligible expense, along with the cost of preparing tender applications, amounting to €250 (with co-financing covering 60% of the cost, or 80% for houses damaged by earthquakes).

Alternatively, households can seek assistance from local government representatives, including the City of Sveta Nedjelja and the Municipality of Žumberak, or from associations operating in their area, such as LAG Sava and LAG Vallis Colapis.

The cost of conducting an energy audit varies depending on the building's type, size, and system complexity. For an average family house in Croatia, the cost typically ranges between €200 and €350.

A list of authorised energy certifiers is available on the Energy Certificate Information System: https://eenergetskicertifikat.mpgi.hr/login.html. Through this link, it is also possible to view an existing building certificate, if available, by logging in via NIAS[11].

It is important to note that for certain national tenders, the EPEEF may define specific conditions, including exclusive lists of eligible certifiers. Therefore, households are strongly encouraged to regularly monitor announcements on their website: https://www.fzoeu.hr/energetska-obnova-obiteljskih-kuca-7679-7679.

2.3 Defining the scope of energy renovation

After the energy performance certificate has assessed the energy characteristics of the family house and provided a list of energy renovation measures, a decision must be made on which measures to implement and in what order. It is advisable to prioritise measures that offer the greatest energy and financial savings. However, depending on the household's financial capacity, several alternative approaches to implementing the measures can be considered.

One common approach is to select measures based on their cost-effectiveness, determined by the investment's payback period (PP). As outlined in the previous chapter, each energy performance certificate and its accompanying report provides an estimate of the simple payback period (SPP). The shorter the SPP, the more cost-effective the investment.

For example, **Errore. L'origine riferimento non è stata trovata.** illustrates simulation results based on the application of the Dynamic high-Resolution dEmand-sidE Management (DREEM)[12]

[11] https://nias.gov.hr

[12] https://www.sciencedirect.com/science/article/pii/S0196890419313469

model for prominent house typologies, heated with firewood via a wood stove, in the areas of Sveta Nedjelja and Žumberak. More information and discussion on the interpretation of the simulation results can be found in the *ANNEX 1 Overview of savings through the implementation of energy efficiency measures (Simulations* results from the DREEM model)*ANNEX 1 Overview of savings through the implementation of energy efficiency measures (Simulations* results from the DREEM model) of the document.

Simulation results, as indicated in Table 1, show that replacing lighting offers the highest cost-effectiveness due to its short payback period, though it achieves relatively small energy savings. Therefore, both cost-effectiveness and energy-saving potential must be considered when prioritising measures. The whole overview of the financial viability can be found in *ANNEX 1* Overview of savings through the implementation of energy efficiency measures (Simulations results from the DREEM model)*ANNEX 1* Overview of savings through the implementation of energy efficiency measures (Simulations results from the DREEM model)

It is also worth noting that although replacing windows and doors has a long payback period and may not be profitable when coupled with other actions that concern the upgrade of the entire building envelope (walls, roof, and windows), it achieves improved techno-economic performance. The latter is important, since replacing old windows reduces constant drafts and cold air infiltration, greatly enhancing the indoor environment and living comfort.

Table 1 Assessment of the feasibility of individual implementation of various energy renovation measures for family houses using firewood

	Investment Cost (€)	Lifespan (years)	Reduction of energy consumption (kWh/year)	Energy savings (%)	Payback period (year)
Exterior wall insulation	4,847	30	**5,814**	**10.1**	20.7
Double-glazed windows	3,584	30	**1,100**	**1.9**	>Lifespan
Roof insulation	4,788	30	**14,311**	**24.9**	6.4
Boiler upgrade to biomass	3,657	20	**9,724**	**16.9**	8.2
Boiler upgrade to heat pump	10,000	20	**43,280**	**75.3**	13.7
LED lighting	45	23	**579**	**1.0**	0.7

Table 1 presents a preliminary set of estimates on the impact of various energy efficiency measures in households located in the areas of Sveta Nedjelja and Žumberak. While this information provides valuable insights, it should be considered alongside the findings of each household's individual energy audit. Households are encouraged to make informed decisions based on the specific recommendations and results of their own audits to achieve the most effective energy savings.

Another approach that households, particularly those in isolated and dispersed areas like Žumberak, may consider is the consolidation of multiple energy renovation projects. Grouping several family house renovation projects together can lead to cost reductions and numerous other benefits, including:

- Lower costs: Contractors can offer reduced prices due to lower transport expenses, bulk procurement of materials, and more efficient organisation of works. For instance, placing larger orders for materials and equipment may secure better terms with suppliers, significantly decreasing the total cost per household—a particularly notable advantage in rural areas.
- Improved negotiation power: Larger projects increase the possibility of negotiating better contract terms with contractors, such as reduced costs and extended warranties on completed works.
- Reduced administrative costs: By planning and executing all works under a unified timeline, administrative expenses can be minimised, and the implementation process simplified.
- Enhanced access to funding: Consolidating projects makes it easier to meet eligibility criteria for funding programmes aimed at larger-scale initiatives.
- Increased awareness and community benefits: Broader project implementation raises awareness about energy renovation and the importance of energy efficiency. This improves living conditions for more households, reduces overall energy consumption at the community level, and contributes to the social and economic transformation of the entire area.

The consolidation of projects not only achieves financial savings but also enables more efficient, faster, and higher-quality implementation. Over time, this approach increases the sustainability and well-being of households while playing a vital role in combating energy poverty.

2.4 Preparation and creation of project documentation

Following the analysis of the existing condition of the building (energy certificate and the accompanying report, as described in *Chapter 2.2* *Energy audit and energy certification* ~~*Energy audit and energy certification*~~ and the conclusions derived from it, it is recommended to prepare a project assignment for the preparation of project and technical documentation for the energy and/or comprehensive renovation of the building.

Depending on the scope of the energy renovation, it is possible to contract and perform energy renovation in certain cases, using the energy certificate to obtain co-financing and carry out the work. For larger buildings, or in cases of consolidating procurement or joint planning of energy renovations for multiple family houses in a specific area, as further suggested in this document, it is recommended to prepare a main project. This ensures better planning of the works and helps avoid omissions or additional costs during the construction phase.

For the preparation of the project assignment, it is necessary to contract an expert based on the scope of the works (construction, electrical, and/or mechanical profession). The project assignment should be created according to the recommendations from the conducted reviews and analyses and should list all the measures, planned works, systems, and technologies to be implemented during the energy/comprehensive renovation.

The project assignment is part of the procurement documentation for preparing the project and technical documentation, based on which the selected designer will prepare the required documentation. The project assignment document provides a detailed overview of the input data, design guidelines, and the scope of the project and technical documentation.

After analysing and reviewing several alternative solutions, a renovation concept must be developed. The designer will present this concept as a description and graphic representation, proposing it to the investor. Once agreed upon with the investor, the most suitable solution is selected and further developed through the main project.

The renovation concept should contain solutions and proposals for measures to be applied to the building and its plot. When choosing a concept, it is important to ensure that, in addition to energy efficiency, it also addresses safety concerns, such as improving the mechanical resistance and stability of the building, increasing earthquake resistance, fire safety, ensuring healthy indoor climate conditions, accessibility for people with disabilities, and selecting an ecologically and economically optimal renovation concept that plays a key role in the building's future performance—both in terms of costs and its impact on the surrounding environment.

A final description and graphic representation of the project are also necessary for obtaining special conditions and conditions for the connection of public bodies. **For family houses that have the status of cultural heritage or are located within protected cultural and historical complexes**, it is advisable to send the proposal to the competent conservation department with a request for an expert opinion before obtaining special conditions. This will speed up the process and help find the best solution in compliance with conservation requirements. For protected buildings, it is essential to hire a designer authorised by the Ministry of Culture to work on such properties. The project and technical documentation for these buildings must be approved by the relevant conservation department.

The use of solar energy and other renewable energy sources located near the building is especially encouraged. Solar energy, optimal sunlight exposure, and seasonal characteristics are crucial for maximising heat gains during the building's heating period and meeting the hygienic conditions within the building.

Increasing energy efficiency—primarily by reducing the energy required for heating, cooling, lighting, and operating technical systems—is key to the energy renovation of the building. Connecting buildings to efficient centralised systems, utilising renewable energy sources, and producing energy from renewable sources on-site are all essential components of the energy renovation concept.

Recommended energy and comprehensive renovation measures include:

- Renovation of the building envelope:
    - thermal protection - façade, roofs, windows, doors, floors, ceilings (towards heated spaces), thermal bridges, etc.
- Mandatory checks and, if necessary, waterproofing of foundations and roofs, remediation of capillary moisture rise, and drainage around the foundation structure (especially in basements)
- installation of new or replacement of existing technical systems (HVAC and DHW)
- use of RES in heating and/or DHW systems (pellet/woodchip boiler, heat pumps, solar collectors, etc.)
- installation of solar power plants with the installation of electricity storage
- Replacing interior lighting with more efficient ones
- Introduction of building automation and management systems

Additional measures that are recommended to be carried out in accordance with the analysis of the current situation and recommendations (comprehensive renovation):

- Fire safety improvement measures
- measures to ensure healthy indoor climate conditions
- Improvement of the building’s mechanical resistance and stability, particularly increasing earthquake resistance.

If the main project is being prepared (which is usually NOT necessary for family houses), the energy/comprehensive renovation includes (depending on the designed measures and the scope of the project):

- an architectural project that includes an architectural snapshot of the existing state of the building with photo documentation
- *An overview of all applied fire protection measures* in Map 1 of the main project, made by an authorised person for the preparation of a fire protection study according to a special regulation, with the conclusion that the basic requirement of fire safety has been met in all parts of the main project
- project of rational use of energy and thermal protection of the building (according to the competence of the profession)

- construction design (proof of mechanical resistance and stability for measures applied in the main design with possibly necessary repairs/reinforcements of the structure, chimney repair project, design of hydraulic installations, project of increasing the earthquake resistance of the building and others according to the competence of the profession)
- electrical design (installation of high and low current, lighting, solar power plant, lightning protection system, fire alarm, automation and building management and other according to the competence of the profession)
- mechanical design (HVAC and DHW, building automation and management, chimney repair project and others according to the competence of the profession)
- project of landscaping of the building plot
- other projects in accordance with the applicable regulations and competencies of the profession

The main design is made in accordance with the Construction Act (Official Gazette 153/13, 20/17, 39/19, 125/19)[13] and the Ordinance on the Mandatory Content and Furnishing of Construction Projects (Official Gazette 118/19, 65/20)[14] and other related regulations. It should be well-prepared with implementation details to avoid unforeseen works that could create additional costs during execution.

It is essential to prepare a unified cost estimate for the equipment and works required for the energy/comprehensive renovation, which should cover all work groups based on the selected renovation concept, planned measures, and design. The cost estimate must align fully with the main design and include detailed descriptions of all items, general conditions, work groups, recapitulation, and detailed drawings for locksmith and carpentry work.

2.5 Securing financial resources

Consolidation of investments using the model of energy communities

In rural areas, the association of family house owners in a particular region can have a significant positive impact on the energy renovation process. By joining an energy community, households can optimise and reduce investment costs by consolidating procurement, both for the preparation of project documentation and for executing the works.

In rural areas, where there is often a large number of smaller family homes that are difficult to access and spread across a wide geographical area, designers and contractors are more likely to offer their services if procurement is consolidated. This approach also contributes to the development and transformation of the entire local community, influencing its social and

[13] https://www.zakon.hr/z/690/Zakon-o-gradnji
[14] https://www.zakon.hr/cms.htm?id=52330

economic growth. Furthermore, the energy community can engage in other activities related to energy, such as energy sharing and other forms of active participation in the energy transition.

It is recommended that owners of family homes who are part of the energy renovation community hire a project manager engineer to professionally oversee the entire process.

Application for calls for project proposals

It is essential to consistently monitor, inform, and simultaneously prepare documentation for applying to project proposal calls. To make the proposals as competitive as possible in tenders, it is highly recommended to prepare the investment in a way that maximises the projected savings and the measures applied in the renovation. This will help collect as many points as possible during the tender process, especially considering the high level of interest and the large number of applications.

If the application is successful, financing will be contracted with the competent implementing body.

The implementation of the identified measures will require the mobilisation of significant financial resources. The potential sources of financing for these measures are generally categorised into three main categories:

- Financial instruments and models available today in the Republic of Croatia;
- Financial instruments and models that are available to the EU today, but have not yet been used in Croatia;
- Innovative financial models that are being developed for the purpose of implementing individual measures.

In Errore. L'origine riferimento non è stata trovata.~~Errore. L'origine riferimento non è stata trovata.~~, an overview of possible sources of financing for the successful implementation of energy renovation measures is given.

Table 2 Overview of possible sources of funding for measures and activities

Source of funding	Kind	Maximum amount	Link
Budget of local self-government units	Grants	-	/
National funds (FZOEU)	Grants	Not specified	https://www.fzoeu.hr
Companies that offer a service according to the ESCO model (Energy Performance Contract)	Private equity/credit	-	/
Energy Communities	Public funds and private capital	-	https://energetske-zajednice.hr;

Source of funding	Kind	Maximum amount	Link
			https://www.hera.hr/hr/html/registar_EZG.html
LAG Sava	Grants	Specified within each call	https://lagsava.hr
LAG Vallis Colapis	Grants	Specified within each call	https://leader.vallis-colapis.hr

2.6 Implementation of measures

The first step after the selection of measures and implementation models (separately or consolidated) is the selection of the contractor. To choose a contractor, it is first necessary to find potential contractors on the market who are registered and specialised in the necessary types of work and to check the contractor in terms of experience, references, recommendations, and possession of certain permits. The next step is to collect bids, where it is necessary to collect bids and compare them according to the price, materials offered, the length of the warranty for the works performed and the installed materials and equipment, and the length or deadline for the execution of the works. After the selection of the contractor, the contract is signed, which contains information about the description of the works, deadlines, payment method and guarantees.

After selecting the contractor, the construction site should be reported (only if there is an obligation to apply), and then the execution of works begins. The investor is obliged to report the start of energy renovation works. In accordance with the scope of the work, the execution can be quite a complex process in which good coordination between the participants in the construction is essential, while the following are involved in this process:

- Investor's Representative
- Project Manager
- Designer in the role of design supervision
- A contractor with all of their co-workers
- Professional supervision in the necessary professions
- Other specialist experts (occupational safety coordinator, conservation supervision and others, if applicable).

It is important to carry out the work in accordance with the project assignment and project documentation, with quality, efficiency and within the agreed deadline, while taking into account that the usual activities in the building can take place as smoothly as possible during the execution of works. If the main design is not developed, the work must be carried out in according to the recommendations from EPC.

During energy renovation, the greatest attention should be **paid to details**. Not following the correct installation methods, using the wrong construction materials, or skipping certain steps can lead to problems and prevent achieving energy efficiency. This can result in issues such as poor window installation, façade detachment, thermal bridges, increased air leaks, or condensation on interior walls. It is very important that **professional supervision** is present during the execution of works to control the quality of the works performed and to be able to give a positive final report after the execution of all works with a written statement of the contractor on the performed works and the conditions of maintenance of the building.

Experience from practice shows that the **preparatory phase is very important**, i.e. a quality and detailed inspection of the building in the main design phase so that there are no additional costs during the execution of works.

It is best to entrust the preparation of the project, technical documentation and the execution of works to designers and contractors with experience and references in the energy renovation of existing buildings. It is advisable to compile quality procurement documentation, set criteria and score bidder references, and create extensive and clear contracts for all participants in the construction that are contracted, with defined responsibilities, deadlines, intermediate deadlines, payment methods, penalties for being late in the interim deadlines and deadline for completion of works, quality assurance of works and guarantees of the quality of works after the completion of works, and more.

2.6.1 Construction of a solar power plant

For households without experience or support in this field, it is recommended to contract a company offering a turnkey solution. However, to ensure the selection of a good contractor, the main steps and components of such a solution are outlined below.[15]

The first step in constructing a solar power plant is to analyse the building's energy consumption (e.g., the sum of annual electricity consumption in kWh from electricity supplier bills). The second step is to determine the capacity of the building's existing electrical connection in kW (this information can be obtained from HEP ODS or the local electricity distributor). The capacity of the solar power plant cannot exceed the power of the existing connection. The third step is to calculate the solar potential of the roof, i.e., the amount of electricity that can be produced. Solar

15 https://www.zgradonacelnik.hr/resources/files/zgradonacelnik.hr/documents/articles/upload/OSUNCAJMO/ePRIRUCNIK_ZA_OBNOVU_ZGRADA_JAVNOG_SEKTORA_A4_06092024.pdf

potential calculations can be done online using free tools such as PVGIS[16], SolarEdge Designer[17] and others. This check will provide information on what percentage of the building's existing consumption can be expected to be covered by the solar power plant throughout the year. The calculation will also simulate the reduction in electricity consumption based on different solar power plant capacities.

1. Preparation of quality project documentation

The process begins with the preparation of the solar power plant's project documentation, where it is recommended to adhere to the highest safety and fire protection standards. The main design of the solar power plant must be developed in accordance with the Ordinance on Simple and Other Buildings and Works[18] (a building permit is not necessary). The development of the main design for the installation of photovoltaic systems must include a certified electrical engineer (electrical engineering project). Additionally, it is recommended to hire a certified civil engineer (construction project) to verify the building's mechanical resistance and stability after the solar power plant is constructed. A certified fire protection specialist should also be engaged to assess the impact of the solar power plant on fire protection requirements and identify any additional work needed to ensure safety.

If the building is listed in the Register of Cultural Property of the Republic of Croatia, an architect must be engaged (the architect must have permission from the Ministry of Culture and Media to work on cultural property). It is also recommended to hire an architect if the project affects the building's appearance, design, or insulation layers (e.g., thermal insulation, waterproofing) to address details, potential breakthroughs, etc.

2. Choosing solar power plant equipment

The main components of a solar power plant are photovoltaic modules, inverters, substructures, cables, and protective equipment (e.g., distribution cabinets). When selecting equipment, it is important to consider the quality, manufacturer warranties, and the specific needs of the investor.

a) *Photovoltaic modules*

   Since a solar power plant is expected to last at least 20 years, it is recommended to select photovoltaic modules based on current technology (at least N-type solar panels) with a minimum efficiency of 22%, minimum fire class C, and those that have safety certificates related to fire, wind, hail, snow, salinity, etc. Additionally, the modules should have a warranty available in the EU.

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[16] https://pvgis.com

[17] https://www.solaredge.com/en/products/software-tools/designer

[18] https://narodne-novine.nn.hr/clanci/sluzbeni/2017_11_112_2625.html

b) *DC voltage-reducing devices, optimisers or microinverters*

A solar power plant can function without a rapid shutdown device, optimiser, or microinverter. These are additional components that enhance safety, increase productivity, reduce maintenance costs, or boost electricity generation. Technologies like optimisers or microinverters preventively monitor the operation of each individual photovoltaic module and the entire system, enabling continuous monitoring and real-time control through notifications on the application. This helps detect problems early and reduce maintenance costs. Furthermore, optimisers and microinverters increase energy production by eliminating the effects of shading on modules, such as shadows from chimneys, clouds, or accumulated dirt.

c) *Prefabricated substructures*

The type and design of the prefabricated substructure for a solar power plant depend on the roof type and cross-section. The most complex are substructures for flat roofs, which are fixed with concrete weights. In such cases, the impact of the new load on the building's mechanical resistance and stability must be calculated in accordance with Croatian building regulations. Substructures for pitched roofs are simpler but care must be taken not to compromise the waterproofing or mechanical properties of the existing building.

d) *Installation Material*

Often overlooked, the installation material is crucial because electricity constantly flows through it. This includes connectors, cables, switches, etc., which must have current certificates, fire protection certificates, multi-year weather resistance, and a long warranty.

3. Installation of equipment

A solar power plant must be built by a certified installer of photovoltaic systems with experience in working with the technology to be installed (e.g. optimiser, i.e. microinverter) and who provides a warranty for the work performed. A list of certified installers is available on the website of the Ministry of Physical Planning, Construction and State Assets of the Republic of Croatia.

2.6.2 Energy renovation of the entire envelope

Energy renovation of the entire envelope of a family house is a key step in achieving greater energy efficiency, reducing energy consumption and increasing living comfort. The outer envelope includes walls, roofs, windows, doors, floors and ceilings and has a significant impact on the heat loss of the house and the total cost of heating and cooling. Through careful planning of energy renovation measures on the outer surface of the envelope of a family house, it is possible to achieve significant savings, reduce greenhouse gas emissions and increase the value of the property. Moreover, the renovation of the building's envelope will result in increased indoor temperatures during winter and decreased temperatures during summer, ensuring that the indoor temperature. This will not only reduce energy consumption, and lower costs for heating and cooling, but also improve living conditions by increasing air quality and thermal comfort. These indicators will help provide a clearer understanding of the expected outcomes of insulation measures

Below are the key steps for a quality renovation of the exterior envelope of a family house.

1. Preparation of quality project documentation

The first step is preparing the project documentation, which includes a detailed overview of the existing condition of the family house and the definition of necessary measures for the outer shell renovation. The project documentation should contain an estimate of heat losses through external walls, roofs, windows and doors, floors, and ceilings. It also defines the optimal materials and technologies for insulation and renovation of the outer surface of the envelope (e.g., type of insulation material, required technical specifications for windows, etc.). The project documentation must comply with the applicable regulations.

2. Thermal protection of external walls

Exterior walls make up the largest part of the outer shell of a family house and play a crucial role in reducing heat loss. Once the optimal insulation material for thermal protection of external walls (e.g., mineral wool) is defined in the project documentation, the insulation and the final façade layer are installed on the outer walls of the family house, following the manufacturer's instructions for the façade system.

3. Replacement of existing windows and doors

This step involves replacing the existing windows and doors on the outer surface of the envelope of the family house with energy-efficient windows and doors to reduce heat loss.

4. Thermal protection of roofs

This measure includes thermal protection for sloping and flat roofs. In cases where the family house has an unheated attic space, it also includes insulation of the attic floor. Insulation materials for the roofs (e.g., mineral wool and waterproofing materials) are defined in the project documentation.

5. Insulation of floors and ceilings

This measure refers to the insulation of floors that are in contact with the ground or unheated spaces, as well as ceilings above unheated spaces, to improve energy efficiency and comfort within the home.

6. Connecting the outer envelope to renewable energy sources

Consideration should be given to installing a solar power plant or solar collectors for the preparation of DHW on the roof of the family house. More information about the installation of a solar power plant is provided in Chapter 2.6.1.

7. Selection of certified contractors and materials

For all works, it is crucial to choose contractors with experience in energy renovation projects who use certified materials. To assist family house owners in finding contractors, the Croatian Chamber of Economy published a list of contractors who expressed interest in participating in the energy renovation of family houses as part of the Public Call for Co-financing Energy Renovation in 2020. The list is available on the website of the Croatian Chamber of Economy.

2.6.3 Replacing the heating system

Ensuring healthy indoor conditions is essential for achieving a satisfactory standard of living in any building. In addition to interventions in the building envelope and planning the construction of a solar power plant, mechanical systems, particularly heating systems, are of critical importance.

- *Legislative Framework for Heating System Replacement*

When planning measures to replace any existing heating system, it is essential to adhere to the current legislative framework, specifically the Building Act and the Regulations on Simple Buildings and Works, which, for the sake of simplifying the process, introduce a threshold of 30 kW capacity for HVAC systems. This threshold is significant because all technical systems, in this case primarily heating and DHW preparation systems, in single-family houses very rarely exceed this limit.

Furthermore, for such systems (below 30 kW capacity), whether they are standalone measures or part of energy renovation efforts, it is not necessary to prepare comprehensive project-technical documentation (e.g., the main mechanical installation project). Instead, it suffices to obtain a 'turnkey' solution or a detailed cost estimate from contractors available in the area where the building/house is located.

- *Approaches Based on the Existing Heating System and Future Technology*

When replacing the existing heating system in a single-family house, i.e., a system below 30 kW capacity, the approach varies depending on the type of the current system, its purpose, and the selection of future heating technology.

- Replacement of Individual Wood Stoves

If the heating system relies on an individual wood stove used only in one room, the replacement measure must include a decision on whether the new heat source will also heat only that room or whether the heating system will be expanded to other rooms. Based on this decision, the replacement measure includes:

  - Dismantling the existing wood stove.
  - Installing a new heat source, such as a heat pump or a biomass boiler.

- Extending the heating distribution system to one or more rooms to be heated in the future.
- Installing heating elements, such as underfloor heating, fan coil units, or radiators.
- Installing a thermal buffer tank
- Installing additional mechanical equipment, such as pumps, balancing valves, etc.

The newly installed heat source prepares the heating medium (water) and stores it in a hot water tank, from which the medium is distributed to the heating elements. The thermal energy is then transferred to the space. Additionally, if the heating system replacement measure includes DHW preparation, the mentioned hot water tank must be increased in size based on the engineer's assessment or calculations, and an additional distribution system for DHW must be introduced to supply the kitchen, shower, and other fixtures.

- Replacement of Existing Gas Boilers

If the current heating system is a gas boiler, the approach differs regarding the heating distribution system and heating elements, as these already exist in the building/house. Therefore, the replacement measure includes:

- Dismantling the existing gas boiler
- adequately sealing the gas connection.
- Installing a new heat source, such as a heat pump or a biomass boiler.
- Installing a thermal buffer tank or replacing the existing one if needed
- connecting of new heat source to the existing heating distribution system and heating elements.

If necessary, the heating distribution system can be extended to other rooms by installing additional heating elements. On the other hand, if the existing distribution system and heating elements are worn out, they can also be replaced as part of this measure, which would enable the implementation of a low-temperature heating system.

It is important to note that existing natural gas systems (gas boilers) are classified as high-temperature systems. Therefore, when installing a heat pump (unless the existing distribution system is replaced, i.e., a low-temperature heating system is introduced), it is necessary to install an additional device—an electric heater in the hot water tank with a capacity of 3–5 kW. This will ensure the medium (water) is heated to an adequate temperature, as heat pumps using electricity can only heat the medium (water) to 50–55°C, and sometimes lower during winter months when the outside air temperature is significantly lower. In the case of biomass boilers, this intervention is not required as biomass boilers can meet all the needs of high-temperature systems.

- *Conclusions*

Regardless of the existing heating system (and DHW preparation), the process of replacing the heating system is the same from the perspective of the building/house owner. It is necessary to contact potential contractors to obtain a 'turnkey' offer for replacing the existing system with a new system, such as a heat pump or a biomass boiler. Contractors will then, following a site inspection of the building/house, internally prepare project documentation needed for selecting appropriate equipment (primarily a hydraulic system diagram). However, this documentation is not submitted to the investor nor considered official but serves as a basis for preparing the offer and detailed cost estimate.

2.7 Use of the building after renovation

After the completion of the renovation, the investor or user must get acquainted with the way the building is used, undergo certain education and learn how to use the renovated building in the best and most efficient way, i.e. all technical systems that have been installed or modernised. This is necessary in order to actually achieve the projected savings, but also to realize the full potential of renovation in the context of indoor climatic conditions and the comfort of living in the renovated building. Designers and contractors are obliged to provide support in this regard to the investor or user and to present him with instructions for the use of the building and technical systems, i.e. to educate him about it.

The investor or user is also expected to monitor the actual consumption of energy and water, notice any anomalies and act promptly if they occur.

3 Conclusion

REERs serve as the foundation for providing support to households experiencing energy poverty in Croatia, particularly those in single-family homes located in peri-urban and rural areas. Their goal is to provide these households with access to more energy-efficient, healthier, and more sustainable homes, establishing a framework to address energy poverty through specific measures tailored to the needs of the most vulnerable. The success of these REERs depends on their effective implementation and adaptation at the national, regional, and local levels, as well as their potential to be adjusted to local specificities and further disseminated among local and regional self-government units within Croatia and beyond.

While the REERs are standardised, they are flexible enough to be adapted to the specific needs of different regions in Croatia. The primary objective of the REERs is to offer general recommendations that can be applied across various communities, with the possibility of customisation based on local conditions and characteristics. For effective implementation at the local level, collaboration with local stakeholders (such as local authorities, LAGs, civil society organisations, and experts) is essential to ensure that the REERs meet the genuine needs of the community.

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ANNEX

ANNEX 1 Overview of savings through the implementation of energy efficiency measures (Simulations results from the DREEM model)

As part of the RENOVERTY project and based on the results of energy audits as well as nationally available data, simulations on the impact of the energy performances of different energy efficiency measures we conducted by employing the *Dynamic high-Resolution dE-mand-sidE Management* (DREEM)[19] model. DREEM is used to define the implementation of the most cost-effective energy efficiency measures, based on their energy-saving potential and techno-economic viability.

The energy efficiency measures (EEM) that were selected and analysed through the DREEM model for all 7 pilot countries are as follows:

- **EEM_1 - Insulation of exterior walls**: Insulation of the exterior walls of a building.
- **EEM_2 - Double-glazed windows**: Replacing single-glazed windows with more energy-efficient windows (double-glazed IZO windows) to reduce heat loss.
- **EEM_3 – Thermal insulation of the roof**: Insulation between and under the rafters of the roof itself, reducing the overall heat transfer coefficient by adding materials with low thermal conductivity.
- **EEM_4 - Energy Efficient Heating System (Boiler Upgrade - Gas):** In this case, the existing heating system is replaced by a more efficient gas boiler with a higher efficiency rate. The gas heating system was analysed solely for financial indicators, but given its negative impact on the environment and contribution to climate change, it is recommended to switch to sustainable heating systems that use renewable energy sources, such as heat pumps and biomass.
- **EEM_5 - Energy Efficient Heating System (Boiler Upgrade - Biomass):** In this case, the existing heating system is replaced by a more efficient biomass boiler with a higher efficiency rate.
- **EEM_6 - Energy Efficient Heating System (Heat Pump):** In this case, the outdated heating system is replaced by a heat pump with a higher degree of operation.

[19]More information available within the RENOVERTY project report *Home Renovation Roadmaps to Address Energy Poverty in Vulnerable Rural Districts: https://ieecp.org/wp-content/uploads/2024/07/RENOVERTY-Deliverable-4.1_final-version_layout-website.pdf (August 2024.)*

- **EEM$_7$ – LED lighting**: In this case, fluorescent and incandescent bulbs are replaced by high-efficiency LED lamps.

The modelling results provide detailed information on the energy-saving potential, environmental impacts, cost-effectiveness, and profitability of households resulting from the implementation of various measures, demonstrating different outcomes in different case studies. The energy-saving potential of EEM is highly dependent on the initial condition of the building and the heating system, underscoring the critical role of the baseline situation in determining the effectiveness of interventions aimed at reducing energy consumption and environmental impact. Implementing EEM in areas where they are most needed, considering the current inefficiency and high energy consumption will ultimately lead to significant improvements in energy efficiency, living conditions, and environmental protection.

Furthermore, variations in the applicability and techno-economic sustainability of different measures highlight the benefits and the subsequent need to ensure co-financing for individual measures. Funding mechanisms must be adapted to the specific needs of rural areas, with strategies and plans designed to encourage regional and local development in a tailored way, ensuring targeted allocation and addressing the specific needs of vulnerable households.

Additionally, one of the key factors affecting the profitability of certain investments, leading to a long payback period, is the low regulation of electricity and natural gas prices. Removing price regulation and redirecting these funds to encourage the use of renewable energy sources and energy renovation, particularly in rural and vulnerable areas, can help reduce energy poverty while optimising the use of public funds.

The prices used in assessing the cost-effectiveness of individual EEM are shown in Table (Annex) 1.

Table (Annex) 1. Energy prices used in techno-economic analysis

Average electricity price - household (€/kWh)	Average gas price – household (€/kWh)	Average biomass price (€/kWh)
0.06[20]	0.04[21]	0.06[22]

In the pilot areas of Sveta Nedelja and Žumberak, two typologies of family houses were identified that were considered in the analysis:

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[20] https://www.hep.hr/elektra/kucanstvo/tarifne-stavke-cijene/1547

[21] https://www.hep.hr/plin/UserDocsImages/cjenici_HEP_Plin/20240325/Odluka%20o%20iznosu%20tarifnih%20stavki%20za%20javnu%20uslugu%20opskrbe%20plinom%20-%20HEP-Plin%20d.o.o..pdf

[22] https://www.drvnipelet.hr/o-drvnom-peletu/

- family houses that use a wood stove as their primary heating system, and
- family houses that use a gas boiler as their primary heating system.

Estimates of annual energy savings (kWh) and reduction of CO_2 emissions by implementing each of EEM for both types of typologies are given below.

1. Family houses that use a wood stove

When it comes to the implementation of EEM_6 related to the installation of a heat pump, the highest energy savings in the amount of 43,280.4 kWh per year can be achieved, reducing consumption by 75.3% compared to the baseline scenario. In the case of the implementation of the EEM_4 measure, when it comes to replacing the wood stove with a gas boiler, savings of 15,017.00 kWh per year would be achieved, i.e. by 26.1% compared to the baseline scenario, and in the case of the implementation of the EEM_5 measure, when it comes to replacing the wood stove with a biomass boiler, savings of 9,724.8 kWh per year would be achieved, by 16.9% compared to the baseline scenario.

Given the negative impact on the environment, the gas heating system contributes to climate change and should be avoided. On the other hand, sustainable and green heating systems, such as heat pumps and biomass, use renewable energy sources, reduce greenhouse gas emissions and are more environmentally friendly in the long run. The transition to these systems is key to reducing dependence on fossil fuels and preserving the environment.

Table (Annex) 2. Annual savings achieved by implementing EEM related to family houses using wood stoves

	Reduction of energy consumption (kWh/year)	Energy savings (%)
EEM_1: Insulation of exterior walls	5,814.1	10.1
EEM_2: Double-glazed windows	1,100.1	1.9
EEM_3: Roof insulation	14,311.2	24.9
EEM_4: Heating system upgrade - Gas	15,017.0	26.1
EEM_5: Heating system upgrade - Biomass	9,724.8	16.9
EEM_6: Heat pump	43,280.4	75.3
EEM7: LED Lighting	579.7	1.0

Table (Annex) 3 shows the reduction of CO_2 emissions through the implementation of individual EEM in family houses equipped with wood stoves. The most significant reduction will be achieved by the implementation of the EEM_5 measure, which will lead to a reduction in CO_2 emissions by 16,757.5 kg of CO_2 per year compared to the baseline scenario, followed by the EEM_6 and EEM_4 measures with an annual reduction of 12,771.4 and 9,025.6 kg of CO_2.

Table (Annex) 3. Annual reduction of CO2 emissions through the implementation of EEM related to family houses using a wood stove

	Reduction of emissions (kg CO_2)	Emission savings (%)
EEM_1: Insulation of exterior walls	1,814.0	9.6
EEM_2: Double-glazed windows	343.2	1.8
EEM_3: Roof insulation	4,465.1	23.5
EEM_4: Heating System Upgrade - Gas	9,052.6	47.7
EEM_5: Heating System Upgrade - Biomass	16,757.5	88.3
EEM_6: Heat Pump	12,771.4	67.3
EEM_7: LED Lighting	218.0	1.1

Table (Annex) 4 shows the results of the techno-economic analysis of different EEM. According to the analysis, measure EEM_4 (Boiler upgrade – gas) and measure EEM_3 (Roof insulation) show the best results in terms of net present value (NPV) that show profitability of project investment, with NPVs of €18,583.90 and €10,060.60, respectively. Also, given the negative impact of gas on the environment and its contribution to climate change, it is recommended to switch to sustainable heating systems that use renewable energy sources, such as heat pumps and biomass.

The measure EEM_7 (LED lighting) and EEM_6 (heat pump) result in the lowest levelized cost of saved energy (LCSE), at €0.005/kWh and €0.018/kWh respectively. Furthermore, the implementation of measures EEM_7 and EEM_4 will achieve the best results in terms of the required payback period, with 0.7 and 2.4 years, respectively. The implementation of the EEM_2 (Double Windows) measure proved to be less attractive investment since it shows a negative amount of NPV.

The significant economic benefits provided by all EEM highlight the poor state of the current situation of residential buildings and highlight the urgent need to implement EEM in the buildings of rural households in Sveta Nedelja and Žumberak. In addition, the replacement of existing heating systems will bring numerous benefits to households in the area of Sveta Nedelja and Žumberak, as switching to a more efficient heating system will reduce heating costs, but also significantly improve the comfort of living and air quality in the house.

Table (Annex) 4. Techno-economic analysis of the implementation of various EEM related to family houses using wood stoves

	Investment Cost (€)	Lifespan (years)	Discount rate (%)	NPV (€)	PP (year)	LCSE (€/kWh)
EEM_1	4,847	30	4.00%	1,185.1	20.7	0.048
EEM_2	3,584	30	4.00%	-2,687.0	>Lifespan	0.240
EEM_3	4,788	30	4.00%	10,060.6	6.4	0.019
EEM_4	3,468	20	4.00%	18,583.9	2.4	0.019
EEM_5	3,657	20	4.00%	3,593.3	8.2	0.033
EEM_6	10,000	20	4.00%	3,108.6	13.7	0.018
EEM_7	45	23	4.00%	962.7	0.7	0.005

Obtaining co-financing for the implementation of energy renovation of family houses in rural and peri-urban areas is crucial for citizens, especially for those experiencing energy poverty, because it allows them to renovate their family houses with a lower financial burden. This is especially important when considering the long payback period and the often high amount of own funds required to launch such projects. Households experiencing energy poverty often do not have enough resources to finance energy renovation on their own, so co-financing allows them to access renovation without the need for large initial investments. In addition, co-financing reduces the total amount of the investment, which accelerates the return on investment through savings on energy bills. With financial support, citizens can afford more comprehensive energy renovation measures, such as heat pumps or solar panels, which contribute to long-term sustainability, reduced greenhouse gas emissions and a better quality of life. It is necessary to reiterate here the fact that the long periods of return on investment in energy renovation measures are currently significantly influenced by subsidised electricity and natural gas prices. In order to ensure the dual benefit, increase the profitability of investments in energy renovation and reduce dependence on fossil fuels, it is necessary to remove price regulation mechanisms and redirect funds to increasing energy efficiency and applying renewable energy measures, especially for vulnerable groups.

Table (Annex) 5 presents the results of the techno-economic analysis taking into account the co-financing in the amount of 50%, and with a higher percentage of co-financing, it is possible to achieve even greater economic benefits for households experiencing energy poverty in terms of net present value and energy price savings. From the above values, it is evident that co-financing will significantly improve the financial sustainability of the implementation of measures, especially those with higher initial costs and longer return on investment.

Table (Annex) 5. Techno-economic analysis of the implementation of various EEM related to family houses using wood stoves (50% co-financing)

	Investment Costs (€)	Co-financing	Lifespan (years)	Discount rate (%)	NPV (€)	PP (year)	LCSE (€/kWh)
EEM_1	4,847	50%	30	4.00%	3,608.7	8.3	0.024
EEM_2	3,584		30	4.00%	-895.0	>Lifespan	0.120
EEM_3	4,788		30	4.00%	12,454.4	3.0	0.010
EEM_4	3,468		20	4.00%	20,317.9	1.2	0.011
EEM_5	3,657		20	4.00%	5,421.8	3.8	0.019
EEM_6	10,000		20	4.00%	8,108.7	5.9	0.010
EEM_7	45		23	4.00%	985.2	0.3	0.003

2. Family houses equipped with a gas boiler

From Table (Annex) 6, which refers to the replacement of the existing gas boiler, it is evident that the implementation of EEM_6, which refers to the installation of a heat pump, will lead to the highest energy savings, i.e. 27,996.8 kWh per year, i.e. consumption will be reduced by 71.3% compared to the baseline scenario. In the case of the implementation of the EEM_3 measure, when it comes to the roof installation, savings of 10,618.00 kWh per year would be achieved, i.e. by 27% compared to the baseline scenario.

Table (Annex) 6. Annual savings achieved by implementing EEM related to family houses equipped with a gas boiler

Annual energy savings (kWh)		
	Reduction of consumption (kWh)	**Energy savings (%)**
EEM_1: Insulation of exterior walls	4,322.0	11.0
EEM_2: Double-glazed windows	857.5	2.2
EEM_3: Roof insulation	10,618.0	27.0
EEM_4: Heating System Upgrade - Gas	4,520.4	11.5

EEM_5: Heating System Upgrade - Biomass	1,154.0	2.9
EEM_6: Heat Pump	27,996.8	71.3
EEM_7: LED Lighting	597.7	1.5

Table (Annex) 7 shows the reduction of CO_2 emissions through the implementation of individual EEM in family houses equipped with gas boilers. The most significant reduction will be achieved through the implementation of the EEM_5 measure, which will lead to a reduction in CO_2 emissions by 7,130.6 kg of CO_2 per year compared to the baseline scenario, followed by EEM_6 and EEM_3 measures with an annual reduction of 4,171.3 and 2,144.8 kg of CO_2, respectively.

Table (Annex) 7. Annual reduction of CO2 emissions through the implementation of EEM related to family houses equipped with a gas boiler

Annual reduction of CO_2 emissions		
	Reduction of emissions (kg CO_2)	**Emission savings (%)**
EEM_1: Insulation of exterior walls	873.0	10.4
EEM_2: Double-glazed windows	173.2	2.1
EEM_3: Roof insulation	2,144.8	25.5
EEM_4: Heating System Upgrade - Gas	913.1	10.8
EEM_5: Heating System Upgrade - Biomass	7,130.6	84.7
EEM_6: Heat Pump	4,171.3	49.6
EEM_7: Energy Efficient Lighting	218.0	2.6

Table (Annex) 8 presents the results of the techno-economic analysis of different energy efficiency (EEM) measures. According to the analysis, the EEM_3 measure (Roof insulation) and the EEM_7 measure (LED lighting) show the best results in terms of profitability of the project investment (NPV), with NPVs of €3,107.60 and €957.7, respectively. Other measures have proven to be less attractive if financial support is not received for their implementation, since they show a negative amount of NPV.

The EEM_7 and EEM_4 measures result in the LCSE, at €0.006/kWh and €0.026/kWh respectively. Furthermore, the implementation of EEM_7 and EEM_3 measures will achieve the best results in terms of the required time of return on investment (PP), with 0.8 and 13.9 years, respectively. The implementation of the EEM_1, EEM_2, EEM_4, EEM_5 and EEM_6 measures indicates a less attractive investment due to negative NPV.

The significant economic benefits provided by all EEM highlight the poor state of the current situation of residential buildings and emphasise the urgent need to implement EEM in family houses of rural households in Sveta Nedelja and Žumberak. In addition, the profitability of measures (EEM) related to the replacement of existing heating systems in family houses shows that there is an urgent need to switch the housing stock of Sveta Nedelja and Žumberak to more efficient heating systems.

Table (Annex) 8. Techno-economic analysis of the implementation of various EEM related to family houses equipped with a gas boiler

	Investment Costs (€)	Lifespan (years)	Discount rate (%)	NPV(€)	PP (year)	LCSE (€/kWh)
EEM_1	4,847	30	4.00%	-1,633.5	>Lifespan	0.065
EEM_2	3,584	30	4.00%	-3,082.9	>Lifespan	0.308
EEM_3	4,788	30	4.00%	3,107,6	13.9	0.026
EEM_4	3,468	20	4.00%	-1,381.6	>Lifespan	0.064
EEM_5	3,657	20	4.00%	-11,834.3	-	0.277
EEM_6	10,000	20	4.00%	-2,896.4	>Lifespan	0.028
EEM_7	45	23	4.00%	957.7	0.8	0.006

Table (Annex) 9 presents the results of the techno-economic analysis taking into account co-financing in the amount of 50%, and with a higher percentage of co-financing, it is possible to achieve even greater economic benefits for households experiencing energy poverty in terms of net present value and energy price savings. From the above values, it is evident that co-financing will significantly improve the financial sustainability of the implementation of measures, especially those with higher initial costs and longer returns on investment.

Table (Annex) 9. Techno-economic analysis of the implementation of various EEMs related to family houses equipped with a gas boiler (50% co-financing).

	Investment Costs (€)	Co-financing	Lifespan (years)	Discount rate (%)	NPV (€)	PP (year)	LCSE (€/kWh)
EEM_1	4,847	50%	30	4.00%	790.1	18.8	0.032
EEM_2	3,584		30	4.00%	-1,290.9	>Lifespan	0.154
EEM_3	4,788		30	4.00%	5,5501.4	6.0	0.013
EEM_4	3,468		20	4.00%	352.4	12.0	0.038
EEM_5	3,657		20	4.00%	-10,005.8	-	0.160
EEM_6	10,000		20	4.00%	2,103.8	12.3	0.015
EEM_7	45		23	4.00%	982.7	0.4	0.003

Although the techno-economic analysis shows that the implementation of the EEM_2 (Double Glazed Windows) measure results in a negative NPV, this does not mean that this measure should be avoided. Despite the negative economic indicator, the implementation of this measure will significantly contribute to increasing the comfort of staying in the space through improved thermal insulation and reduced energy losses. In order to make this measure more economically viable, it is recommended to increase the level of co-financing to an amount that would ensure that the NPV is neutral (0).

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