ANNEX 75

EBC
Energy in Building and Communities Programme

International Energy Agency

Good practices and lessons learned to transform existing districts into low-energy and low-emission districts

Energy in Buildings and Communities Technology Collaboration Programme

April 2023

Technology Collaboration Programme by iea

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Good practices and lessons learned to transform existing districts into low-energy and low-emission districts

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April 2023

Author

David Venus, AEE – Institute for Sustainable Technologies, Austria (office@aee.at)

Contributing Authors

Silvia Domingo-Irigoyen, INDP - Institute for Sustainability and Democracy Policy, Switzerland (silvia.domingo@indp.ch)

Toivo Säwén, StruSoft AB, Sweden (sawen@chalmers.se)

Johnny Kronvall, StruSoft AB, Sweden (johnny.kronvall@strusoft.com)

Henrik Davidsson, Lund University, Sweden (henrik.davidsson@ebd.lth.se)

Erik Johansson, Lund University, Sweden (erik.johansson@hdm.lth.se)

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Additional copies of this report may be obtained from: EBC Executive Committee Support Services Unit (ESSU), C/o AECOM Ltd, The Colmore Building, Colmore Circus Queensway, Birmingham B4 6AT, United Kingdom
www.iea-ebc.org
essu@iea-ebc.org

Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA coordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy-efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high-priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of 'low tech', robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimisation in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities (*)
Working Group - Building Energy Codes
(*) – completed working groups

Table of contents

Definitions[1]

Various IEA EBC Annex 75 reports use a common language for communication between local authorities, professionals, researchers, inhabitants and, in general, all stakeholders and international partners.

Each term is defined in the context and scope of IEA EBC Annex 75, namely building renovations at the district level, and combines definitions from the European legal framework, common definitions of English dictionaries, related projects, research papers, and other professional publications. The concepts are sorted alphabetically.

Actors: The persons and entities active during the planning and implementation of energy renovation processes in buildings and districts.

Anyway renovation: Renovation measures necessary to restore a building's functionality without improving its energy performance. The anyway measures may be hypothetical if the renovations without improving energy efficiency are legally not allowed or are not practically reasonable.

Assembly of homeowners/ homeowner association: An organisation managed by the persons and entities that own parts of a building or district that aims at building maintenance and/or improving the overall conditions and livelihood of the building and its environment.

Building manager: A person or company that manages buildings, keeping owners, landlords and tenants informed about the current situation of the building, calculating the future needs and assisting during the decision-making process. They are also known as property managers, real estate managers or facility managers, when respectively properties, real estate or facilities are managed.

Building renovation: An improvement of the building envelope or the energy system of a building, at least to restore its functionality, and usually to improve its energy performance. Within IEA EBC Annex 75, building renovation is understood to refer to energy efficiency measures in buildings, particularly on building envelopes, as well as renewable energy measures in buildings, in particular for heating or cooling purposes, whether through a decentralised energy system of a building or a connection to a centralised district heating/cooling system.

Building services or Energy performance of buildings (EPB) services: Services, such as heating, cooling, ventilation, domestic hot water, lighting and others, for which the energy use is considered in the energy performance of buildings (European Commission, 2021).

Carbon emissions: Shorthand expression used by IEA EBC to represent all greenhouse gas emissions to the atmosphere (this means carbon dioxide, methane, certain refrigerants, and so on) from the combustion of fossil fuels and non-combustion sources such as refrigerant leakage. It should be quantified in terms of 'CO_2 equivalent emissions'.

Centralised or decentralised thermal energy system: Centralised systems can either refer to a connection to an external district heating or district cooling system, covering a larger area, or to a local thermal energy production system covering only the district in question. A decentralised system refers to a single-building heating or cooling system.

[1] A comprehensive list of all IEA EBC Annex 75 definitions can be found here: (Hidalgo-Betanzos et al., 2023) - https://annex75.iea-ebc.org/publications

Cost-optimal level: The energy performance level which leads to the lowest cost during the estimated economic life cycle of a building (European Commission, 2010).

Deep renovation: A renovation which transforms a building or building unit into a nearly zero-energy building (until 2030) or a zero-emission building (after 2030), according to the latest European Commission proposal (European Commission, 2021). The previous EU legal framework didn't define deep renovations in detail, but they were typical of more than 60% energy savings. (European Commission, DG Energy, 2014) (BPIE – Deep renovation, 2021).

District: A group of buildings in an area of a town or city that has limited borders chosen for purposes of, for example, building renovation projects, energy system planning, or others. This area can be defined by building owners, local government, urban planners, or project developers, e.g. along realities of social interactions, the proximity of buildings or infrastructural preconditions in certain territorial units within a municipality. IEA EBC Annex 75 focuses on residential buildings, both single and multi-family houses, but districts with other buildings with similar characteristics, such as schools or simple office buildings without complex HVAC systems, can also be included in the district.

District heating or District cooling: A centralised system with the distribution of thermal energy in the form of steam, hot water, or chilled liquids, from a central production source through a network to multiple buildings or sites, for use in space heating or cooling, domestic hot water, or other services.

Embodied Energy: The total energy inputs consumed throughout a product's life cycle. Initial embodied energy represents the energy used to extract raw materials, transportation to the factory, processing and manufacturing, transportation to the site, and construction. Once the material is installed, recurring embodied energy represents the energy used to maintain, replace, and recycle materials and components of a building throughout its life. One fundamental purpose for measuring this quantity is to compare the amount of energy produced or saved by the product in question to the amount of energy consumed in making it.

Energy carrier: A substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes. An energy carrier is a transmitter of energy that includes electricity and heat, as well as solid, liquid, and gaseous fuels. The energy carriers occupy intermediate steps in the energy-supply chain between primary sources and end-user applications (IPCC, 2007).

Energy performance of a building: The calculated or measured amount of energy needed to meet the energy need associated with the typical or standard use of the building services.

Energy source: Source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.

Energy Service Company (ESCO): A company that offers long-term services to cater to all the building renovation project needs using Energy Performance Contracts (EPCs) as a financing mechanism based on ongoing energy performance guarantees. These EPCs are based on a long-term relationship with the customer, which can include renovation project design, retrofitting works, energy systems and renewable energy systems monitoring, operation and maintenance, fuel supplies, security management, savings justifications, and utility bills management. ESCOs might offer all the project services in-house or outsource some of them (Brown et al., 2019).

Energy use: The energy input to a technical building system providing an energy performance of buildings service intended to satisfy an energy need (European Commission, 2021).

Funding: The money provided, especially by an organisation or government, for purposes related to building renovations, such as energy-efficient measures or renewable energy implementations (European Commission, DG Energy, 2015).

Housing association: An association that owns, lets and manages rented housing, usually under special conditions, for people that cannot reach the market or rented housing due to vulnerability or other socio-economic situations.

Intermediaries: Stakeholders that act as a third party and interact or connect between supply and demand, for example, between demanding actors and energy and renovation solution providers. Intermediaries may have more experience and expertise compared to the homeowner, therefore being able to deliver a more comprehensively/thoroughly researched solution.

Investors: Stakeholders that act as clients or beneficiaries of building renovation or renewable energy projects. There is a wide range of demand organisations which can be private or social, public, semi-public, or mixed, depending on the situation. For instance, private owners or assemblies of homeowners are typically in this category, as well as investment funds, housing associations, housing cooperatives and housing companies, as they may be owners of buildings to be renovated.

One-Stop-Shop (OSS): An office that offers a single point of contact catering to all building renovation project needs, not only as an intermediate agent but aiming to provide energy efficiency or renewable energy with an integrated solution. A typical set of services offered by the OSS includes preliminary evaluation, energy audit and scenario analysis, design, arrangement of third-party financing, procurement, outsourced manufacturing and installation, and performance testing to verify the system in operation (Haavik et al., 2012; Styczynska and Zubel, 2019).

Policymakers: All kinds of actors and stakeholders who define, develop, and implement policy instruments regarding building renovation or renewable energy projects. That includes all political levels: local, regional, national, and international, as well as all administrative levels and to a certain extent also administrative decision-makers.

Primary energy: Energy that has not been subjected to any conversion or transformation process. Primary energy includes both non-renewable and renewable energy. For a building, it is the energy used to produce the energy delivered to the building. It is calculated from the delivered and exported amounts of energy carriers using conversion factors. Upstream processes and related losses are considered.

Renewable energy: Energy from sources that are not depleted by extraction, such as wind power, solar power, hydroelectric power, ocean energy, geothermal energy, heat from the ambient air, surface water or the ground, or biomass and biofuels. These alternatives to fossil fuels contribute to reducing greenhouse gas emissions, diversifying the energy supply and reducing dependence on unreliable and volatile fossil fuel markets, particularly oil and gas.

Renovation: Construction activities related to interventions onto existing buildings or connected infrastructure. These interventions range from simple repairs and maintenance to adaptive conversion, transformation, and reuse. In the framework of IEA EBC Annex 75, renovation can refer to both renewal/retrofit of building envelopes and energy system changes.

Stakeholders: The persons, homeowners, companies, public institutions and in general every agent with an interest or concern in an ongoing or future project. The stakeholders in renovation projects can be a wide and diverse list of agents, including decision-making actors and also other involved participants that can influence the success or failure of the renovation process.

Stakeholder dialogue: The process whereby a lead actor, usually a local administration, facilitates communication and interaction with stakeholders, particularly also building owners, in a certain community area/neighbourhood/district to get them going in the direction that is politically favoured i.e., climate neutrality, energy efficiency, enhanced use of renewables. This dialogue can be implemented through various formats of information and communication and can be based either on regulations (if applicable) or on persuasion and commitment.

Trust: A firm belief of customers and stakeholders in the reliability and truth of the building renovation project, in authorities, in other building owners for developing joint projects, or in the ability of the service providers such as the suppliers, intermediate agents, One-Stop-Shops, ESCOs, etc.

Zero-emission building: A building with a remarkably high energy performance, where the very low amount of energy still required is fully covered by energy from renewable sources at the building or district or community level where technically feasible (notably those generated on-site, from a renewable energy community or renewable energy or waste heat from a district heating and cooling system) (European Commission, 2021).

1. Introduction

1.1 About IEA EBC Annex 75

Buildings are a major source of carbon emissions and cost-effectively reducing their energy use and associated emissions are particularly challenging for the existing building stock, mainly because of the existence of many architectural and technical hurdles. Transforming existing buildings into low-emission and low-energy buildings is particularly challenging in cities, where many buildings continue to rely too much on fossil fuels. However, at the same time, there are specific opportunities to develop and take advantage of district-level solutions at the urban scale. In this context, the project aims to clarify the cost-effectiveness of various approaches combining energy efficiency and renewable energy measures at the district level. At this level, finding the balance between renewable energy measures and energy efficiency measures for the existing building stock is a complex task and many research questions still need to be answered, including:

- What are the cost-effective combinations between renewable energy measures and energy efficiency measures to achieve far-reaching reductions in carbon emissions and primary energy use in urban districts?
- What are the cost-effective strategies to combine district-level heating or cooling based on available environmental heat, solar energy, waste heat, or natural heat sinks, with energy efficiency measures applied to building envelopes?
- How do related strategies compare in terms of cost-effectiveness and impact with strategies that combine a decentralised switching of energy carriers to renewable energy sources with energy efficiency measures applied to building envelopes?
- Under which circumstances is it more appropriate to use available renewable energy potentials in cities at a district level, and under which circumstances are decentralised renewable energy solutions more advantageous, combined with energy efficiency measures applied to building envelopes?

1.2 Objectives of IEA EBC Annex 75

The project aims to investigate cost-effective strategies for reducing carbon emissions and energy use in city buildings at the district level combining energy efficiency and renewable energy measures. The objective is to guide policymakers, companies working in the field of the energy transition, as well as building owners to transform the city's energy use in the existing building stock cost-effectively towards low-emission and low-energy solutions.

Given the limitations due to available financial resources and the large number of investments needed to transform the cities' energy use in buildings, identifying cost-effective strategies is important for accelerating the transition towards low-emission and low-energy districts.

The project focuses on the following objectives:

- To give an overview of various technology options, taking into account existing and emerging efficient technologies with the potential to be successfully applied within that context and how challenges specifically occurring in an urban context can be overcome.
- To develop a methodology that can be applied to urban districts to identify such cost-effective strategies, supporting decision-makers in the evaluation of the efficiency, impacts, cost-effectiveness, and acceptance of various strategies for renovating urban districts.

- To illustrate the development of such strategies in selected case studies and gather related best-practice examples.
- To give recommendations to policymakers and energy-related companies on how they can influence the uptake of cost-effective combinations of energy efficiency and renewable energy measures in building renovation at the district level and to guide building owners/investors on related cost-effective renovation strategies.
- To provide accurate and understandable information, guidelines, tools, and recommendations to support decision-makers from the public and private sectors in making better decisions and choosing the best options that apply to their needs.

1.3 Objectives of this report

The objective of this report is to illustrate, in selected case studies, cost-effective strategies combining energy efficiency measures and renewable energy use in building renovation at the district level, to investigate factors influencing the choice of these strategies, and to gather related best-practice examples (the so-called "success stories").

In a first step, success stories involving district-based solutions for renewable energy use and energy efficiency measures were gathered and characterised. This included transforming previously existing district heating systems and creating district heating systems based on renewable energies in districts previously heated with decentralised installations. In addition, it included success stories for the massive thermal renovation of envelopes in a specific district. It was documented to what extent the combination of energy efficiency measures in building envelopes with renewable energy was taken into account in the selected cases and to what extent grid-based solutions are advantageous when compared to individual heating or cooling solutions in the district.

In a second step, the necessary data was gathered for selected case studies to carry out parametric assessments, applying and testing the methodology developed within this Annex. It was, in particular, investigated to what extent there were synergies and to what extent there were trade-offs for combining energy efficiency measures and renewable energy measures. It was envisaged to determine cost-effective renovation strategies for the investigated districts considering energy efficiency and renewable energy measures.

The last step included the identification of barriers that hinder energy-efficient measures and drivers which enable the implementation of cost-effective building renovation at the district level. For this purpose, the collected success stories were analysed.

Additionally, different stakeholders, which have been involved in energy building renovations at the district level, were interviewed about their experiences to identify barriers and drivers. The stakeholders included policymakers, renovation solution suppliers, energy solution suppliers, clients and beneficiaries, financing intermediaries and other intermediaries. In total, 38 in-depth interviews from eight countries (Austria, Belgium, Germany, the Netherlands, Portugal, Spain, Sweden and Switzerland) were carried out.

It must be noted that the analysis carried out in this report was mainly based on case studies and success stories provided by the countries participating in this project. These cases focused primarily on district heating solutions, which, in some situations, conditioned the analysis carried out. Nevertheless, the methodology developed in the IEA EBC Annex 75 project (Bolliger et al., 2023), is valid for both district heating and district cooling situations.

This report also aims to bring together the work carried out with the analysis of case studies and success stories of the participating countries with the conclusions obtained from the analysis of the calculations carried out with the generic districts. These generic districts pretend to be representative of urban districts in the participating countries, and the calculations were performed similarly to the case study calculations.

The present report includes the following parts:

- Conclusions from the analysis of the success stories.
- Conclusions from the investigations of the case studies as well as of the investigations of the generic district calculations.
- Conclusions from the identification of barriers that hinder energy-efficient measures and of drivers that enable the implementation of cost-effective building renovation at the district level.

Based on this work, the present report can be seen as good practice guidance for transforming existing districts into low-energy and low-emission districts.

2. Conclusions from the Success Stories

The success stories present good practice examples of different strategies for reducing carbon emissions of the existing building stock by improving energy efficiency and implementing renewable energies at the district level. The investigated district renovations have been mainly carried out between 2008 and 2021. The success stories include transforming previously existing district heating systems and creating district heating systems based on renewable energies in districts previously heated with decentralised installations. Furthermore, this includes success stories related to the massive thermal renovation of envelopes in a specific district. Fifteen success stories from seven European countries were collected and analysed. The success stories are spread throughout Europe, especially in three core areas: Central Europe (Northern Italy, Switzerland, and Austria), Northern Europe (Sweden and Denmark), and Southern Europe (Spain and Portugal). Based on the analysis of these success stories, the following conclusions can be drawn.

District renovation is a complex activity due to the large number of stakeholders involved, the broad knowledge, and the large financial resources needed. The success stories have shown that achieving a high energy and emissions reduction by combining energy efficiency measures at the building or energy system level and renewable energies is possible. In those interventions that have striven to reach this goal, the energy efficiency levels and renewables implemented largely exceed the minimum requirements set in the national regulations. In most cases, the balance between energy efficiency measures and renewable energy use is so far based on expert estimations and not on calculations. This is also cited as the main challenge or bottleneck during the design phase. Therefore, there is potential for improvement, and the methodology developed in the IEA EBC Annex 75 can help decision-making and contribute to further emissions reductions in district renovation.

An important goal of most interventions is the improvement of comfort and adaptation of the buildings to a contemporary standard of living as well as the improvement of the quality of open space, the attractiveness, and the image of the district. Improving the quality and increasing the value of the building stock to ensure profitability, maintaining affordability (with or without a reasonable increase in rent or low investment costs for the owners) and improving the social diversity and cohesion in the neighbourhood were also drivers in several interventions.

Renovation measures at the district scale vary from one success story to another. However, most of those investigated have a centralised energy supply system. Either centralised systems were newly installed, or an existing one was renovated to improve efficiency or incorporate renewable energy sources. There is only one success story in which geothermal heat pumps replaced a centralised system to reduce operational costs and become more environmentally friendly. In most cases, renewable energy is used for heating through a district heating system. Solar thermal was installed in six success stories, and in four of them, PV panels. The reduction in heating energy use ranges from 20% to 77%, with an average reduction of around 50%.

District renovation is mainly initiated by the willingness and support of the municipality, a housing association or a residents' association, or the inhabitants' wishes. Therefore, these are key actors during the whole process. Investors and tenants/residents are also key actors in the implementation of the renovation. Usually, the investors are a building association that owns the buildings or individual building owners, a public body, an Energy Conservation Service Company (ESCO), or a real estate development company in one of the districts. It is important to note that many district renovations described in the success stories are partly financed (in some cases to a large extent) through public money, either as direct financing or via subsidies. Lack of financial resources is the most frequently cited challenge in the analysed cases, and, in many cases, the intervention would not have been possible without public funds. The vital role of public institutions and public funding in the analysed district-level renovations is not just because the renovations carried out were particularly innovative or complex but because public support is essential for most projects to be successful.

Citizens' engagement and communication with tenants from the early stages of the project led to a higher overall satisfaction rate. They were considered to be key for the entire renovation process. Communicating why a renovation is needed, what measures will be performed, and what are the expected results, is essential. Including tenants by asking for opinions and approval of the proposed changes is advantageous. Success is determined in many cases by the existence of a coordination facilitator. This can be one person or a steering group with more people involved. Including the district renovation in a European program greatly facilitates this task since a clear goal and economic resources are available for coordinating all agents. Usually, this is done by using a One-Stop-Shop, which aggregates the relevant information and services in one place. This experience is interesting and could, in principle, be taken up in any district renovation project, even without public support.

In the investigated success stories, the main barrier to the district renovation was the funding. However, many challenges can hinder or make the process challenging. The main challenges are the coordination of all stakeholders, the difficulty in finding the optimal renovation measures, the need to relocate the tenants during the renovation works as well as other technical aspects such as unforeseen problems, the location of the energy production systems and the pipe lying of a district heating system in a built area. Some of these challenges can be overcome with an appropriate business model, such as a market intermediation model, a One-Stop-Shop, and an ESCO.

The main take-away messages from the lessons learned in the presented success stories are the following.

- Energy-efficient measures for district renovation can be combined with renewable energy measures and beyond that with social or other improvements at the urban scale or in the infrastructure to bring more value to the intervention and make more efficient use of the financial resources available.
- There are no big technological barriers to the renovation of districts. On the contrary, there are technological opportunities, such as accessing a renewable source like a lake which could not be done through individual heating solutions, or by providing the opportunity to make use of innovative heat pumps with high efficiency and low carbon emissions. However, there is a lack of technical knowledge and protocols to simplify such a complex process and a lack of resources to carry out related coordination work. Furthermore, flexibility is required because such complex projects can hardly ever be developed exactly as planned and project phases are required to overlap to shorten otherwise long project timelines.
- The availability of financial resources is essential. European funding via European research projects or funding on national or lower levels can be key in the process as they not only cover part of the investment costs but also bring knowledge and experience in the field in such consortia. An ESCO can also finance the intervention, but they tend to invest in projects that are only linked to energy production systems.
- Good coordination between all stakeholders is needed to guarantee a successful renovation and timing. For that reason, the support of regional and local authorities, building associations, or management teams that act as facilitators of the processes (coordination of all the agents involved, definition of proposals, funding, agreement, information, and dissemination) is key. Such services could be covered through a one-stop shop.
- Citizen and tenant engagement is necessary for the process to run smoothly. This is achieved through clear communication from before the start of the intervention and throughout the project, incorporating the feedback received by the citizens. This task is time-consuming and could be supported by neighbour's associations or other social stakeholders from the district supporting the project.
- Overall, public support is crucial to facilitate funding of district projects and enable sufficient stakeholder dialogue and coordination work for successfully carrying out district renovation projects, particularly if they combine both energy efficiency and renewable energy measures.

More information about the success stories can be found in the success stories summarising report (Domingo-Irigoyen et al., 2023).

3. Conclusions from the Case Studies and Generic Districts calculations

For selected case studies, the necessary data was gathered to carry out parametric assessments, applying and testing the methodology developed in the IEA EBC Annex 75. It was intended to select, as case studies, existing urban districts with renovation needs, where the results of the case studies could guide in choosing an appropriate renovation strategy for the respective district. It was, in particular, investigated to what extent there are synergies and to what extent there are trade-offs for combining energy efficiency measures and renewable energy measures. It was envisaged to determine cost-effective renovation strategies for the investigated districts, considering both energy efficiency and renewable energy measures.

Apart from the case studies, assessments were also carried out for generic districts. Whereas case studies refer to real districts, generic districts were defined based on typical building typologies and district sizes in the participating countries.

Within the IEA EBC Annex 75 project, nine case study assessments in eight countries and seven generic district assessments were performed. The participating countries were:
Case Studies: Austria, Italy, Norway, Portugal, Spain, Sweden, Switzerland, and the Netherlands.
Generic Districts: Austria, Denmark, Italy, Portugal, Spain, Sweden, and Switzerland.

The following sections 3.1 and 3.2 summarise the main conclusions from the assessments and investigations.

3.1 Generic Districts

In this parametric study, seven generic districts were defined in seven different countries to study combinations of alternative energy efficiency measures and energy system options. Each participating country defined the districts based on their relevant starting situations. The cost-effectiveness and environmental impact of the various renovation scenarios were investigated to develop recommendations for action.

Of the hypotheses stated, only one could be conclusively confirmed (hypothesis 1): it was shown in five out of seven studies that the cost-effective level of energy efficiency measures did not differ when comparing centralised and decentralised approaches. This indicates that optimisation of energy efficiency measures can be implemented regardless of future potential choices for energy systems. This means that, regardless of the energy supply system used, it is advisable to renovate building envelopes. No general conclusion could be drawn about the cost-effective level of energy efficiency measures. In some cases, no measures were cost-effective, while in others, any measure was cost-effective. The situation needs to be considered based on the starting level of thermal insulation and climate conditions.

The environmental impact was also different in different cases. In most cases, the measures applied led to reduced carbon emissions and reduced use of primary energy. However, in some cases, reductions were very small or nonexistent due to the significant impact of considering the energy embodied in the materials used in the renovation.

Regarding renewable energies, there were also conflicting results. One case found that emissions and primary energy use were reduced by the use of renewables, with higher savings, while one case suggested that the embodied impact of, e.g., photovoltaics, negatively impacted the emissions.

There was some disagreement on the choice between centralised and decentralised systems. In some cases, implementing or keeping a district heating system was the most environmentally suitable choice for emissions and primary energy use. In another case, based on the investigated solutions and assumed framework conditions, decentralised solutions have less environmental impact due to higher efficiency.

In countries where district heating is widespread, the LCC assessments suggested that, if not already existing in the starting position, district heating solutions were more cost-effective than decentralised options. However, when a country has limited extension of district heating networks, the results were conflicting, with one country suggesting that the high investment cost of a new district heating network made this solution infeasible, while another suggested a centralised solution to be cost-effective despite not being a common practice. In one case, it was found that switching to renewable-based energy systems caused a significant reduction in carbon emissions and a smaller reduction in primary energy use. This is because the conversion factors of renewable-based energy systems (compared to fossil fuels) are much lower when looking at the carbon emissions than the primary energy use.

There was a great variety of results when considering the most cost-effective combination of renovation measures and energy systems. In two cases, a switch to centralised heat pumps was preferred. One case suggested the switch from district heating to decentralised renewables. One study showed no advantage in implementing building renovation measures, while one found that keeping a fossil gas system was the most cost-effective. One highlighted difference due to different climates. For example, energy efficiency measures applied to building envelopes combined with decentralised air source heat pumps and PV were the most cost-effective in Milan. In Rome, the anyway renovation of the envelope combined with a high-temperature air source heat pump, decentralised heating system and PV panels was the most cost-effective combination. None of the studied measures was cost-effective in the Palermo case.

The results of this report need to be considered based on many assumptions regarding construction and equipment life cycle costs, future energy prices, and energy-related emissions. The definition of cost-effectiveness in this study only considers economic parameters, disregarding factors such as nature preservation.

Table 1: Overview of the hypotheses of all countries as a result of the generic district assessments.

Hypotheses	AUT	DEN	ITA	POR	ESP	SWE	SUI
1. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when these measures are associated either with a district heating system based on renewable energy or with decentralised individual heating systems based on renewable energy.»	✓	✓	✓	–	✓	–	✓
2. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when an existing district heating system based (fully or to a large extent) on fossil fuels is switched to a centralised heating system based on renewable energy.»	–	✓	–	–	–	–	–

Hypotheses	AUT	DEN	ITA	POR	ESP	SWE	SUI
3. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when an existing district heating system based (fully or to a large extent) on fossil fuels is replaced by decentralised heating systems based on renewable energy.»	✗	✓	–	–	✗	–	–
4. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when existing decentralised heating systems based on fossil fuels are replaced by a centralised heating system based on renewable energies.»	✓	–	–	✗	✗	–	✓
5. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when existing decentralised heating systems based on fossil fuels are replaced by a low-temperature renewable energy-based district heating system associated with decentralised heat pumps.»	–	–	–	–	✓	–	✓
6. «The cost-optimal level of the energy efficiency measures on building envelopes involves a lower level of insulation when an existing district heating system is switched centrally to renewables than when switched to a newly installed centralised heating system based on renewable energy. This is due to a lower potential for synergies between renewable energy measures and energy efficiency measures in the former case.»	✓	–	–	–	–	–	–
7. «In case the starting situation is a district with a low level of thermal insulation in the building envelopes, every optimal solution includes, to some extent, the implementation of energy efficiency measures on the building envelopes.»	✓	✓	✓	✓	✗	–	✓
8. «In case the starting situation is a district with a high level of thermal insulation in the building envelopes with a fossil fuel-based heating system, every optimal solution includes at least a switch to a renewable energy-based heating system.»	–	–	✓	–	–	–	–

✓ Confirmed

– Not investigated

✗ Not confirmed

More information on the generic districts' calculations can be found in the respective report (Säwén et al. 2023).

3.2 Case Studies

Based on the results of the case studies some general conclusions can be drawn.

The renovation of the thermal envelope is generally recommended, although the cost-effectiveness of the renovation can vary. Sometimes it is only one measure, e.g., window replacement, and sometimes the renovation of the complete envelope. Sometimes, however, it can be in between. Which measures are cost-effective depends on several factors. Influencing factors are, for example, the initial situation (building already insulated or not), the climatic conditions (how much heating is required), and the prices (ratio of investment to energy costs).

Concerning the energy supply systems analysed, no clear recommendation can be derived about the heat generation system. Both decentralised, on the building level, heat pumps (air-water and geothermal) and district heating lead to good results and savings. These were mostly not recommendable in the case studies where a supply on the apartment level was investigated.

Results may differ if district heating systems are particularly large and benefit from substantial economies of scale. In such a case, district heating systems to use renewable energies may have clearer economic advantages. In a large district heating system, however, it would be more challenging to benefit from energy efficiency measures on building envelopes by reducing the temperature in the grid, as it becomes more challenging that the energy performance of all buildings in the district is increased.

A common finding supported by the results of most, though not all, case studies is that the cost-optimal level of energy efficiency measures in building envelopes does not differ significantly when comparing a combination of such measures with a district heating system based on renewable energy with a combination of these measures with decentralised individual heating systems based on renewable energy. This is an important finding as it indicates that energy efficiency measures are equally attractive for renewable energy use at the district level and the level of individual buildings.

There are indications in various countries that energy systems based on heat pumps benefit from energy efficiency measures on building envelopes more strongly than fossil fuel-based systems. Concerning the balance between energy efficiency and renewable energy measures, there are synergies between the use of renewable energy measures and energy efficiency measures, and not trade-offs, at the district level.

Energy efficiency measures on building envelopes may yield powerful synergies with renewable energy measures if these are carried out for all buildings in a district, allowing, accordingly, to reduce the temperature of the grid. This has benefits for increasing the efficiency of a centralised heat pump and reducing thermal losses in the grid. Furthermore, in the case of using the ground as a heat source at the district level in connection with heat pumps, energy efficiency measures on building envelopes reduce the need to regenerate heat in the ground, which is another reason for synergies between energy efficiency measures and renewable energy measures.

A finding supported by most case studies is that in a district with a low level of thermal insulation in the building envelopes, every optimal solution includes, to some extent, implementing energy efficiency measures on the buildings' envelopes.

In the case studies examined, photovoltaics was largely investigated as a renewable energy source on site. It has been shown that installing a PV system makes sense from an energy point of view (and thus also carbon emissions). Still, economic viability is not always immediately assured.

Renovation measures on the building envelope, measures to replace the energy supply systems, and measures to use renewable energy sources can lead to carbon and primary energy savings but are not always cost-effective or cost-optimal. This is where the conflicting priorities become apparent - savings to protect the environment vs. cost-effectiveness.

Since the cost-effectiveness is determined by comparing the investigated scenarios with the reference case, the definition of the reference case plays a special role. The reference cases differ from country to country, but even within a country, districts can have different initial situations and, thus, different reference variants.

Many assumptions must be made for the calculation of different scenarios. This concerns assumptions about costs, such as investment costs for the renovation of the building envelope, energy supply and renewable energy sources, maintenance and repair costs, and energy costs. But assumptions must also be made about user behaviour: what room temperature is used for calculations, what hot water consumption is assumed, and is active cooling also used? All these assumptions can influence the calculation results and, if individual parameters are changed, can also lead to different results or recommendations. Therefore, it is important to investigate not only different technical renovation measures but also the influence of such parameters. Also, the choice of calculation software can influence the results. This must be considered as well.

In addition to cost, carbon and primary energy savings, measures on the building envelope and the energy supply system also have other effects that were not taken into account in the analysis of the case studies but must be, in any case, considered. These are the so-called "co-benefits" relevant to the decision-making process. For example, the thermal renovation of the exterior walls and the replacement of the windows positively affect indoor thermal comfort, which is an additional benefit that has to be considered. Likewise, using a PV system, for example, can reduce energy dependency.

Table 2 gives an overview of all investigated hypotheses and the findings from all countries. It can be seen that in the investigations, the main focus was on hypotheses 1, 4, and 7. The other hypothesis could not be investigated due to the given starting situations or applicability of scenarios in the respective country.

In hypothesis 1, the focus is on the cost-optimal level of energy efficiency measures on the building envelope in combination with different energy supply systems. Based on the calculation results this hypothesis can be confirmed in five of the eight countries. Only in the Netherlands was this hypothesis not confirmed.

In hypothesis 4, the starting situation is a decentralised heated district based on fossil fuels. It was investigated if the cost-optimal level of renovation measures on the envelope changes if the district is connected to renewable energy-based district heating. This is the case in Austria and Switzerland, where the cost-optimal renovation measures on the building envelope change if the energy supply system is changed to district heating. In five other countries, this hypothesis cannot be confirmed, which means that the switch from decentralised fossil fuel-based heating to renewable energy-based district heating doesn't change the cost-optimum level of renovation measures on the building envelope.

In hypothesis 7, it was investigated if the implementation of energy efficiency measures on the buildings' envelopes automatically leads to cost-optimal solutions. This can be confirmed in five of the eight countries. In two countries, this hypothesis was not investigated. In Sweden, it cannot be confirmed.

All other hypotheses cannot be confirmed or were not investigated.

Table 2: Overview of the hypotheses of all countries of the case study assessments.

Hypotheses	AUT	ITA	NOR	POR	SPA	SUI1	SUI2	SWE	NED
1. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when these measures are associated either with a district heating system based on renewable energy or with decentralised heating systems based on renewable energy.»	✓	–	✓	–	✓	✓	✓	✓	✗
2. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when an existing district heating system based (fully or to a large extent) on fossil fuels is switched to a centralised heating system based on renewable energy.»	–	–	–	–	–	–	–	✗	–
3. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when an existing district heating system based (fully or to a large extent) on fossil fuels is replaced by a decentralised heating systems based on renewable energy.»	–	–	–	–	–	–	–	✗	–
4. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when existing decentralised heating systems based on fossil fuels are replaced by a centralised heating system based on renewable energies.»	✓	✗	–	✗	✗	✓	✓	✗	✗
5. «The cost-optimal level of the energy efficiency measures on building envelopes does not differ significantly when existing decentralised heating systems based on fossil fuels are replaced by a low-temperature renewable energy-based district heating system associated with decentralised heat pumps.»	–	–	–	–	✗	✓	✓	✗	✗
6. «The cost-optimal level of the energy efficiency measures on building envelopes involves a lower level of insulation when an existing district heating system is switched centrally to renewables than when switched to a newly installed centralised heating system based on renewable energy. This is due to a lower potential for synergies between renewable energy measures and energy efficiency measures in the former case.»	–	–	–	–	–	–	–	✗	–
7. «In case the starting situation is a district with a low level of thermal insulation in the building envelopes, every optimal solution includes, to some extent, the implementation of energy efficiency measures on the building envelopes.»	✓	✓	–	✓	✗	✓	✓	✓	–

Hypotheses	AUT	ITA	NOR	POR	SPA	SUI1	SUI2	SWE	NED
8. «In case the starting situation is a district with a high level of thermal insulation in the building envelopes with a fossil fuel-based heating system, every optimal solution includes at least a switch to renewable energy-based heating systems.»	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated	Not investigated	Not confirmed	Not investigated

- ✓ Confirmed
- − Not investigated
- ✗ Not confirmed

More information on the case studies calculations can be found in the respective report (Venus et al., 2023).

4. Recommendations for energy-efficient renovation strategies at the district level from the investigation of the success stories and from stakeholders interviews

4.1 Policy and legal measures

It is recommended to apply a holistic approach to energy renovation, including upgrading the whole district, as this will create more acceptance among the public. This could include, e.g., providing improved social infrastructure such as greener space around the buildings, providing playgrounds and a barrier-free modernisation to facilitate for old adults.

Municipalities should collaborate and learn from each other, possibly involving regional and/or national authorities. Renovation instruments that have been developed by one municipality can be shared with others to save costs. Similarly, municipalities and provinces could spread risks by collaborating on financing initiatives.

Municipalities could also organise support for unburdening residents, providing bank guarantees and exercising clear communication.

Public municipal companies, e.g. housing associations, can play an important role in energy renovation at the district level, especially if the companies are big and the municipality has ambitious goals regarding energy efficiency and the use of renewable energy. This enables the associations to act as drivers in the renovation process and implement a holistic view of renovation at the district level. Another advantage of public companies is that citizens may have more confidence in such non-profit companies since they are more objective than private companies.

It is recommended that national, regional and local authorities use economic incentives to encourage a shift from the use of fossil fuels, such as natural gas, towards cleaner, carbon-free energy. Incentives could include a lower tax on fossil-free electricity and a higher tax on gas and oil to make installing heat pumps, solar thermal heating, PV panels etc., more profitable.

Policymakers should explore suitable policy initiatives that support customer journeys, i.e., making actors go from awareness to interest, to desire and finally to action.

Best practice examples constitute an excellent way to encourage the spread of renovation at the district level, either starting with single buildings and upscaling them to districts or spreading good district examples to other districts.

The municipality can select/award the tender with the most attractive project from an energy/environmental perspective for publicly owned buildings.

In the interviews, the interviewees recommended that local authorities support homeowners and homeowners associations in different ways. This could be organisational support, economic support, awareness campaigns, or advice (free of charge). Since many steps are needed to convince a homeowner association, there might be a need to consider non-energy wishes, such as the neighbourhood environment.

It is recommended that local authorities take up a leading role in coordinating entire district renovation processes also among private building owners. This may include connecting building owners, identifying appropriate solutions for a given district, supporting the creation of appropriate legal structures among building owners to implement a district solution, and supporting the tendering process for implementing a district solution.

Energy-efficient renovation at the district level is complicated, but it has several advantages, justifying a proactive role of local authorities:

- District projects may encourage building owners to carry out energy renovation measures which they otherwise would not do when acting alone.
- District solutions can accelerate the energy transition in big steps.
- District solutions allow transforming entire parts of a city to sustainable energy use within each project.

The interviewees recommended developing specific regulations for renovation. These should emphasise energy efficiency both in construction and operation to ensure low energy use over time. Furthermore, it is recommended to include regulations regarding renewable energy use. However, regulations should not be too strict but have realistic and reasonable targets and should not be too complicated to apply.

For the development of new district heating projects, it is recommended to combine regulations regarding energy efficiency and renewable energy measures.

As the availability of large renewable energy sources is a key driver for building renovation projects at the district level, it is recommended that local authorities identify such potentials, make them known, and develop strategies to access them.

Moreover, building permit legislation should be elaborated at the municipal level to simplify the project approval process. In addition, it is recommended that regulations are put into place which allow homeowner associations to decide on energy-related decisions with a simple majority of homeowners.

It is recommended to introduce and promote "green" certification at the district level, similar to the building level.

4.2 Economic measures

Bank guarantees, particularly for housing associations and energy supply companies, are a suitable financial solution to encourage energy-efficient renovation at the district level. According to the interviewees, such guarantees can be given on municipal, regional or national levels. It can be given as guarantee funds from banks to private companies or municipalities to municipal housing associations.

Other recommended financial instruments include:

- Funding schemes from the national and/or regional level.
- Additional funding at the local level combined with monitoring of renovation activities.

- Fit-for-purpose financing products, which are based on the households' disposable income. This could be combined with individual renovation plans, especially in districts where the need for renovation varies greatly between buildings.
- The use of energy performance contracts to achieve renovations also in case of a longer payback period and to reduce public funding.
- To offer financing arrangements and insights into cash flow which provide a high percentage of energy saving to secure a maximum level of energy costs after the renovation.
- One-stop-shop companies which offer financial calculation models which allow that households can pay or lend according to their financial capabilities.
- To develop and manage revolving loan funds, which can be used both to support municipal housing associations and homeowner associations. Revolving funds could also aim at specific target groups such as young starters, old adults, vulnerable households, and small homeowner associations.
- Use cross-financing options where, e.g., public housing associations take over the parking management and use this income to fund the renovation scheme.

It is also recommended that the European Union stimulates renovation at the district level by either project funding or subsidies, especially in those countries within the Union that are in most need of fuel transition and/or developing energy-efficient buildings. Recommended incentives include tax incentives to encourage investments in the renovation and installation of renewable energy solutions.

At the research level, the European Union supports initiatives via different research funding programmes, such as the Horizon Europe programme (https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en).

To promote through subsidies a combination of renewable energy measures and energy efficiency measures, it is recommended to determine the extent of subsidies for energy systems or connections to district heating systems based on the gross floor area and not the capacity of the heating system, in order to provide an incentive to reduce energy needs in combination with the installation of a new heating system or the connection to a district heating system.

Other recommended incentives include adding storeys to existing buildings – in return for compliance with improved energy standards – which would be attractive for housing associations and private housing companies as well as individual tariffs on heating, domestic hot water etc.

It is recommended that municipalities provide different types of economic support to encourage energy renovation at the district level:
- Use of available funds to provide different types of subsidies.
- Give bank guarantees, particularly to their municipal housing associations, or help housing associations borrow by offering low-interest loans.
- Create their own funding framework to support both individual homeowners' and housing associations' investment measures.
- Enable investment in solar energy by providing bank guarantees or funding the preparation of roofs for PV panels.
- Support to homeowner associations, small and medium-sized enterprises and societal organisations.
- Use their municipal housing associations to provide financial help for renovation to low-income groups e.g., through special credit schemes.
- Support homeowners financially, either individually or in homeowner associations, through a special fund for the transition from fossil to renewable energy.

Furthermore, it is recommended to make building owners shift the focus of attention from investment costs to life cycle costs.

4.3 Social aspects

Renovation at the district level means a lot of disturbance for residents and homeowners: increased costs and inconveniences during the renovation phase. Furthermore, bringing various building owners together for common district renovation projects is a challenge.

It is important that the cost of living of households is not affected too much by the energy renovation. It is recommended:

- To be transparent when communicating the renovation costs to the residents and how the rents will be affected. It is important to minimise the rent increase or minimise the monthly cost in the case of ownership. However, cost-effectiveness is less important if increased living standard, such as improved thermal comfort, is understood. Then, even a slight increase in the rent can be accepted.
- To unburden homeowners, e.g., by providing smooth financial solutions and fast renovation processes.

User involvement is likely to raise the acceptance of the energy renovation. If the tenants can influence some things, it will make them more favourable to the whole renovation project. Therefore, it is recommended to encourage citizen involvement and user participation, e.g., through co-creation of the renovation concept together with residents. This approach may lead to a higher degree of acceptance, even for unpopular actions.

Similarly, it is recommended to support bottom-up initiatives, e.g., by providing coaches for citizen groups, arranging inspirational meetings for the citizens in the district and person-to-person communication.

It is recommended to conduct networking meetings for district citizens to support inspiration and trust for possible joint district renovation projects. Citizen involvement could also be in thematic workshops or consultations where many different district renovation issues are treated, even the design of open spaces, and where all tenants participate. Furthermore, it is recommended to provide a framework which encourages initiatives by residents and individual building owners in the district that can result in improved district solutions.

Another way could be to stimulate bottom-up citizen initiatives such as local ownership of renewable energy production (solar and/or wind) or jointly developing a district heating grid. Furthermore, residents could be given a say in choosing energy sources for district heating systems.

Having to move may have negative social consequences. If emptying the buildings to be renovated is unavoidable, it is recommended to assist residents in finding alternative housing, preferably in the same area and offer them to move back to the same area after renovation (to have priority).

As mentioned above, improving the outdoor environment in the district being renovated is recommended. Public spaces, such as parks and playgrounds, constitute important parts of the social infrastructure of housing areas. By improving them, social acceptance will likely be higher, the feeling of belonging to the neighbourhood will improve and facilitate the closeness between families and social groups, and the area's status will rise.

Moreover, it is important that the actors involved in energy renovation at the district level are well-known to the citizens, which helps create societal trust.

4.4 Communication

It is recommended to ensure that advice and guidance are available free of charge to all interested building owners or energy professionals intending to develop district renovation projects, from initiating such projects to all phases of implementing such solutions. The guidance includes general information, advice on energy saving, providing contact points, showing best practice examples, offers for consultancy, opportunities for funding and assistance with funding applications. Both initial advice, including advice on funding, and advice during the whole renovation process are needed. It is recommended to showcase solutions with concrete and visual examples, e.g., visualisation through 3D.

It is important how residents in the district subjected to energy renovation are approached. They need to be informed in good time about the different steps in the renovation project. Moreover, residents should receive adequate information continuously throughout the project, and the communication should be friendly and fact-oriented. Information to residents must come at the right moment, but only when relevant information exists. During a step-by-step implementation, residents must be continuously informed about noise, dust, what happens when, etc.

Municipalities and other stakeholders should inform about good practice examples. Neighbourhoods and municipalities in the region can learn from each other, and good results from one project can be used to convince other potential renovation areas. Communicating and spreading information about good practices and pilot areas is important to accelerate the renovation process.

One way to reach residents is door-to-door actions using smart communication such as webinars and virtual visits to demonstration houses.

Good stakeholder dialogue is crucial for a successful energy-efficient renovation at the district level. Municipalities have an important role in communicating with different stakeholders. It is recommended that the municipalities:

- Establish a steering group for each district renovation project.
- Connect various building owners and help them implement a district heating solution.
- Take the role of both moderator and central actor to reach a large number of stakeholders.
- Provide a framework allowing individual building owners to influence district renovation projects.

Thematic workshops could be organised, including all district renovation issues and addressing all types of tenants. It is recommended that the renovation project group consists of district management, citizens representation, public administration, public companies, neighbourhood institutions etc. and that they meet regularly, also after the completion of the renovation.

It is recommended to deploy energy plans or other map-based information showing each building owner's available options for renewable energies, including possible connections to district heating systems and energy efficiency measures.

As pointed out earlier, homeowners can be difficult to reach. Consequently, communication with this group is important. Meetings can bring building owners together. Individual building owners may play a key role in motivating others to join district projects. Therefore, it is recommended to support such individuals in particular.

4.5 Technical aspects

It is recommended that authorities ensure that high-quality advice is provided by renovation consultants offering renovation concept development. E.g., experts might assess the available renewable energy options and the available efficiency measures, ideally in combination, and develop appropriate renovation strategies for districts.

District projects may allow using large renewable energy sources or particularly innovative energy solutions due to the large scale at which they are implemented. It is recommended that authorities ensure that the related knowledge is spread.

Housing associations should provide involved and experienced staff to guide beneficiaries and supervise interventions.

To convince building owners, it is necessary to perform calculations to demonstrate the effect of improving energy efficiency.

Other recommendations for good project management include:

- Develop a platform to coordinate the renovation coaching system to ensure a certain quality.
- Hire specialised staff in municipal companies to guide the total renovation process.
- Include the contractor early in the renovation process to get their knowledge and involvement throughout the process.

Already implemented projects can lead to certain standardisation and more efficient construction. Analysing past projects in greater depth is recommended to achieve synergy effects and standardisation. It is also recommended to develop prefab solutions and standardisation of processes since such an approach can decrease costs and reduce the time of renovation, reducing the disturbance for the residents.

In areas with existing district heating networks, the district heating supplier can install new pipes that are more energy efficient. It is recommended to connect the residual heat from industrial areas to the district heating if possible.

4.6 Knowledge and training

It is important to increase the knowledge and experience among different stakeholders involved in different parts of the renovation at the district level.

Examples of such knowledge include accumulated experience among the staff of a regional authority, training of building managers to influence decision-making and making residents (homeowners) understand their own houses (e.g., by using smart meters and the display of the energy consumption and production online or on the phone).

4.7 Concluding remarks

The recommendations presented here are general and based on a limited number of success stories and interview answers. The field of energy renovation at the district level, considering both energy efficiency and renewable energy measures, is still quite new. Future studies should look more into adequate solutions for different contexts in various countries, regions and cities. Emphasis must be put on efficient energy supply solutions such as district heating and cooling, which are key for decarbonisation. At the district level, several stakeholders must cooperate in carrying out such solutions. The stakeholder dialogue is thus very important and must be prioritised.

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