ANNEX 75

EBC
Energy in Building and Communities Programme

International Energy Agency

# Strategies 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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April 2023

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# 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 co-ordinates 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 CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 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 (*)
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Annex 74: Competition and Living Lab Platform
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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

# Executive Summary

## Introduction

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 many architectural, socio-economical, 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 heat supplied by fossil fuels. However, 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 both energy efficiency measures and renewable energy measures at the district level.

## Objective

This report aims to describe various strategies to transform existing districts into low-energy and low-emission districts in different country contexts and the opportunities and risks of such strategies. These strategies are based on the results of other work packages and subtasks associated with this Annex.

The strategies described in this report are based on the assessments of case studies and generic district analyses. This necessarily means there are some limitations, such as taking a pure techno-economic evaluation and focusing on residential-only districts. This report emphasises which properties are essential to consider when developing neighbourhood renovation strategies. Given the limitations, it can neither be claimed that identifying these properties is complete nor that the same set of properties applies to all districts. Furthermore, while this report focuses on techno-economic aspects, it is important to point out that other aspects play a key role in building renovation projects at the district level. For example, social aspects, aspects related to the economic development of a district overall, and financial aspects. The present report does not address these latter aspects. Therefore, before applying any of the suggestions in this report, the readers are recommended to consider the specific situation of the district they are working with. Social, economic, policy and financial contexts must be considered, including the district's physical characteristics and the key actors involved in the process, such as policymakers, building owners and district heating system operators.

## Strategy development

This report has used the results from the calculations performed in IEA EBC Annex 75 and highlighted the most relevant strategies for district renovation. The report focuses on 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 developed strategies were derived from the starting conditions defined in the IEA EBC Annex 75 methodology (Bolliger et al., 2023) and the calculations performed on generic districts (Säwén et al., 2023) and specific case studies (Venus et al., 2023). The strategies are further distinguished into two levels:

- Thermal energy production and distribution concept: Centralised approaches are distinguished from decentralised approaches. A centralised approach refers to one production unit distributing thermal energy to several buildings, while a decentralised approach refers to one production unit per building;
- Heating and cooling production technology.

The level of energy efficiency measures and the installation of local energy systems based on renewable energy sources (RES) are considered ambition levels within each strategy, not separate strategies.

In general, it is challenging to draw concrete conclusions and recommendations for specific strategies based on the limited amount of case studies and generic district calculations performed in IEA EBC Annex 75, especially given the enormous variance observed in the investigated cases (district size, geographical location, initial state of the buildings etc.). Even with a more extensive set of calculation results, it would be impossible to give definitive answers due to the many specific characteristics of individual districts. Therefore, applying the IEA EBC Annex 75 methodology individually in each case is recommended.

However, some general trends can be identified from the results as follows:

- The difference in cost-effectiveness between centralised and decentralised solutions from a life cycle perspective is often small. Centralised solutions do benefit from economies of scale. However, they are associated with losses due to distribution, and they bring the cost of the distribution network. Furthermore, the temperature in the district heating system must be higher than in individual heating systems because of the distribution losses and because the district system has to take into account the building with the highest temperature need. This, in turn, limits the efficiency of centralised approaches. These effects, to some extent, cancel each other out, leading to similar results in the cost-effectiveness of decentralised and centralised solutions.
- The scale of centralised solutions brings the need for more planning and coordination efforts and dependencies on end users. This carries both costs and risks.
- There is often no clear economic case for choosing centralised approaches unless there is already an existing thermal network in good condition in the district. In this case, it is usually more cost-effective to continue utilizing it.
- However, there may be other good reasons for preferring centralised approaches, which may be:
  - to make use of a large heat source or a seasonal thermal storage
  - to have more flexibility concerning the choice of energy carriers
  - to reduce the burden on the electricity grid
  - to provide non-fossil heating to buildings where decentralised solutions are challenging for practical reasons
- If policymakers want district projects to be implemented to harness those additional benefits, policy measures are necessary because the market all by itself is unlikely to provide district solutions to a large extent.
- Nevertheless, decentralised solutions continue to be attractive options with the following advantages:
  - less need for planning and coordination efforts as well as dependencies on end-users
  - open up the possibility of customizing energy efficiency at the building level
- For decentralised solutions, heat pumps are usually the most cost-effective solution. Local constraints and availability mainly decide the choice of heat pump technology.
- Synergies between energy efficiency measures and renewable energy-based heating systems occur for all types of heating systems. There are even indications that such synergies are higher for district heating systems than for individual heating systems. An important factor concerning synergies between energy efficiency measures on building envelopes and renewable energy systems is the possibility of lowering the temperature of the grid due to energy efficiency measures on the building envelopes.This requires a solution to generate hot water while maintaining its safety from a health perspective, even at lower temperatures. Such solutions exist yet require careful examination. The lowering of the temperature can be supported by measures related to the radiators supplying heat.
- Significant energy efficiency measures are usually cost-effective for building envelopes in poor condition. If renovations are needed for some or all of the buildings in a district, it is important to consider the impact of these energy efficiency measures on heat demand before selecting a solution.

In general, the results of the IEA EBC Annex 75 calculations further demonstrate the attractiveness of the decarbonisation trend in the upcoming energy transition, mostly through electrification. The calculations also show that a switch to renewable energy-based heating systems is a cost-effective way forward, including options at the district level. However, for buildings to aid and not hamper the energy transition, it is important to also keep a focus on energy efficiency measures. Results of this Annex show that a significant number of synergies exist between energy efficiency measures switching to renewable energy sources, yet those synergies may not be utilized easily.

There is a risk that various advantages of district solutions, such as fuel-switch possibilities, are overlooked when focusing on cost-effectiveness at the district level. Therefore, it makes sense to develop city-wide, regional, and country strategies within the framework of which district strategies can be positioned and developed.

Further factors and issues like policy and planning instruments, stakeholder dialogue and mobilization activities, and their impact on strategies are discussed in the IEA EBC Annex 75 Guidebook (Meyer et al., 2023).

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# Abbreviations

| Abbreviations | Meaning |
|---|---|
| **ASHP** | Air source heat pump |
| **COP** | Coefficient of performance |
| **DH** | District heating |
| **DHW** | Domestic hot water |
| **EE** | Energy efficiency |
| **GSHP** | Ground source heat pump |
| **PEF** | Primary energy factor |
| **PV** | PV panels |
| **RES** | Renewable energy sources |
| **WSHP** | Water source heat pump |

# 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.

**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.

**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.

**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'.

**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).

**Delivered energy:** Energy, expressed per energy carrier, supplied to the technical building systems through the system boundary to satisfy the users, taking into account heating, cooling, ventilation, domestic hot water, lighting, appliances, etc.

**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.

[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

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

**Linear heat density:** Annual heat delivered per meter of piping for a district heating system.

**Non-renewable energy**: Energy taken from a source depleted by extraction (e.g., fossil fuels).

**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.

# 1. Introduction

## 1.1 General Context

Buildings are a major source of carbon emissions, and cost-effectively reducing their energy use and associated emissions is particularly challenging for the existing building stock, mainly because 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 heat supplied by fossil fuels. However, 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 both energy efficiency measures 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 the following:

What are the cost-effective combinations between renewable energy 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 energy transition, as well as building owners to cost-effectively transform the city's energy use in the existing building stock 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 necessary transition towards low-emission and low-energy districts.

This project focuses on the following objectives:

- To give an overview of various technology options with the potential to be successfully applied within the urban context, taking into account existing and emerging efficient technologies
- To identify specific challenges that occur in an urban context and describe how they can be overcome

- To develop a methodology that can be applied to urban districts to identify 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 strategies in selected case studies and gather related best-practice examples
- To inform 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
- To provide guidance to building owners/investors on cost-effective renovation strategies.

## 1.3 Objectives and Development of the strategy report

This report describes strategies that could transform existing districts into low-energy and low-emission districts in different country contexts. Furthermore, which properties are essential when developing neighbourhood renovation strategies is emphasised.

The strategies are based on the results of the overall work carried out within this Annex.

In subtask A, a review of potential technologies for district renovation was performed (Mørk et al., 2020). This analysis was used to explore the technical and economic characteristics of the most appropriate technology options for different situations. This includes information on their efficiency, cost elements, such as investment costs and operational costs, considering economies of scale. The interdependencies, obstacles, and success factors for combining the technology options are also described. The technology options are put into context with available potentials, and an outlook is made on their future developments.

In subtask B, the methodology report (Bolliger et al., 2023) developed and described a methodology for assessing the cost-effectiveness of strategies to achieve far-reaching carbon emission reductions in a life cycle perspective. This report considers various combinations of energy efficiency measures and a switch to renewable energy sources. With this background, case studies (Venus et al., 2023) and generic districts (Säwén et al., 2023) were assessed in different countries, and the calculation results were deeply discussed at the biannual expert meetings throughout the project.

To gain further insight from the calculations, participants performing the calculations were asked to complete a template for each case study and generic district calculations, weighing different parameters and characteristics regarding their influence on the results. Factors were weighted from 1 to 5, where “5” means “important” and “1” means “not important”. In section 2, the results obtained with this template are shown in boxplots and discussed for each category of strategy development. A total of 11 templates have been received, covering case studies from Austria, Italy, the Netherlands, Norway, Portugal and Sweden and generic district calculations from Austria, Denmark, Italy, Portugal, Sweden and Switzerland. The full template can be found in Appendix A. The coloured areas in the boxplot represent the interquartile range (IQR), the line in the middle is the median, and the cross is the mean. The height of the IQR and whiskers show the spread in the answers. The factors with small ranges are considered to be most important on a general level. More details on how to read the boxplot can be found in (The Microsoft 365 Marketing Team, 2015).

## 1.4 Limitations

The strategy development described in this report is mainly based on the assessments of case studies and generic districts, and thereby it also has the same limitations as those studies. Important examples of these limitations are:

- The IEA EBC Annex 75 calculations are limited to residential districts. Purely residential districts will have a homogenous consumption pattern. This is especially true in the case of simulations, as the same standardised consumption profiles are usually assumed for all buildings of the same category. The very high coincidence factor limits the benefits of central systems, as the possibility of reducing the total installed capacity is not significant. Also, residential buildings have limited cooling demand.
- The effects of user behaviour, such as the rebound effect, are not considered in the simulations.
- The IEA EBC Annex 75 methodology focuses on renovations at the district level. This is a broader scope than the individual building level, but there is still a risk that solutions are suboptimal at a larger scale. Therefore, it is important to carefully consider what overarching strategies and parameters could influence the choice of the strategy.
- The IEA EBC Annex 75 methodology is purely techno-economic. Other social factors, such as user acceptance, ownership/tenants, etc., are not included but will determine the driving actors behind the strategy and influence the choice of strategy.

Also, creating solutions at a district level usually takes place within a complex economic, social and financial context, with a positive and negative impact on technical possibilities, costs and benefits which are not included in the methodology.

This report emphasises which properties are essential when developing neighbourhood renovation strategies. However, given the limitations, it can neither be claimed that identifying these properties is complete nor that the same set of properties applies to all districts.

Given this report's limitations, before applying any of the presented suggestions, the readers are recommended to consider the specific situation of the district they are working with. Social, economic, policy and financial contexts must be considered, including the district's physical characteristics and the key actors involved in the process, such as policymakers, building owners and district heating system operators.

# 2. Strategy development

## 2.1 Approach to strategy development

The process of strategy development is illustrated in Figure 1. The developed strategies are derived from the three starting conditions defined in the IEA EBC Annex 75 methodology, the review of available technologies for district renovation (Subtask A), and the calculations performed on generic districts (Subtask B) and specific case studies (Subtask C). From the starting conditions, the strategies are further distinguished into two levels:

- Thermal energy production and distribution concept (central or decentralised)
- Heating and cooling production technology

The energy efficiency measures and installation of local energy production from renewable energy sources (RES) are considered ambition levels within each strategy.

The lines between the boxes show the possible strategy pathways. The dotted lines are feasible options but are not considered relevant strategies in this work or represented in any of the calculations. The same is for individual solutions (dashed boxes).

As shown, the strategies are distinguished sequentially from the highest abstraction level. However, the evaluation should not be done in this order. As described in the IEA EBC Annex 75 methodology report (Bolliger & Terés-Zubiaga et al., 2023), the different levels of energy efficiency measures (renovation packages) are considered first so that the size and performance of the energy production and distribution system can take this into account.

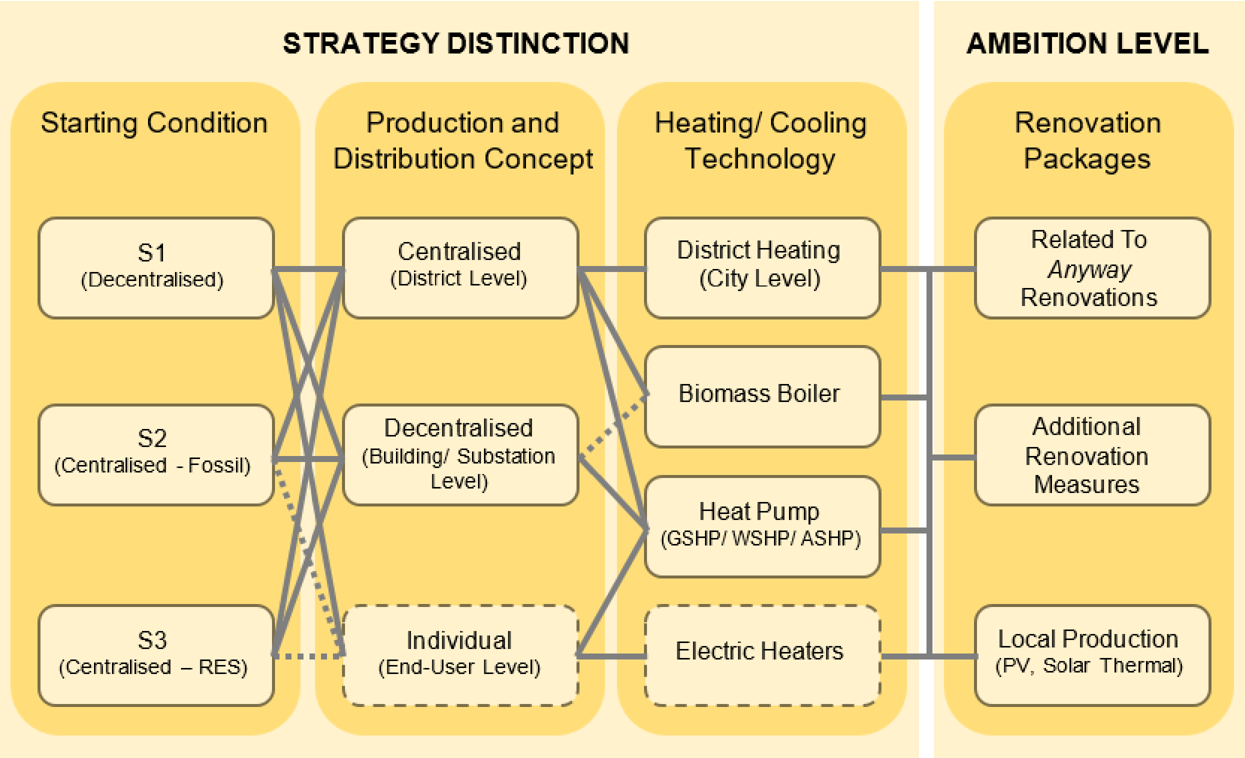


Figure 1. Strategy definition diagram (by the authors).

## 2.2 Production and distribution concept

The following two main production and distribution concepts are distinguished:

**Centralised thermal energy system**: one production unit distributing thermal energy to each building through a piping network. This can either refer to a connection to an external district heating system, covering a larger area, or to a local thermal energy production system covering only the district in question.

**Decentralised thermal energy system**: one production unit per building. Energy is transferred to the building with an energy carrier (i.e. electricity or gas) and converted locally to thermal energy, i.e. with a heat pump.

One of the most significant differences between district renovations and individual building renovations is the possibility of developing common centralised thermal energy systems.

### 2.2.1 Key results from calculations

In general, the calculations show that in cases where there is already a centralised thermal energy supply network in the neighbourhood, the most cost-effective solution is to utilize the existing network. However, the calculations have shown that there are some exceptions. For example, if the distribution system's condition is very poor, significant renovation costs are expected. Renovating underground piping systems can be costly and outweigh the cost-benefit of having a centralised production system or being connected to a district heating grid. Another exception can be considered when the temperature of the heat distribution network, operated by a centralised heat pump, has to be very high to satisfy the needs of a single building. Under these circumstances, the heat losses associated with the heat distribution network are also high and the system is inefficient. In this case, using decentralised individual heating systems makes it possible to significantly reduce distribution temperatures and, consequently, heat losses in the network and achieve greater efficiency of heat pumps.

If there is no existing infrastructure, the results are not so clear. The following section discusses important factors for choosing between centralised and decentralised systems.

### 2.2.2 Important factors

Figure 2 shows the results from the evaluation of which factors are most important in the choice between centralised and decentralised energy production and distribution concepts according to the filled-out templates. In general, one can see that the results are quite dispersed for most factors. The exception is mainly the linear heat density and the existence of infrastructure. However, all are found important by some.

The linear heat density indicates how much piping is needed per energy use. This directly impacts on the investment cost of installing a new distribution system and the operational costs due to the pipes' heat losses. In general, the higher the energy density, the better the district is suited for a centralised system. However, if energy efficiency measures allow for reducing energy consumption, this is usually, to a large extent, cost-effective, even though this lowers the energy density.

The importance of energy prices for fuel and electricity shows a significant variance. Still, the median is high, which means that most respondents find it very important. In some cases, one can experience considerable differences in the energy prices and tariffs paid by a large consumer for operating a district heating system compared to decentralised consumers. This could have a significant impact on the results.

For the rest of the factors, the weighting is quite different between the cases due to other local or case-specific factors. But in general, all the mentioned factors could influence the optimal result.

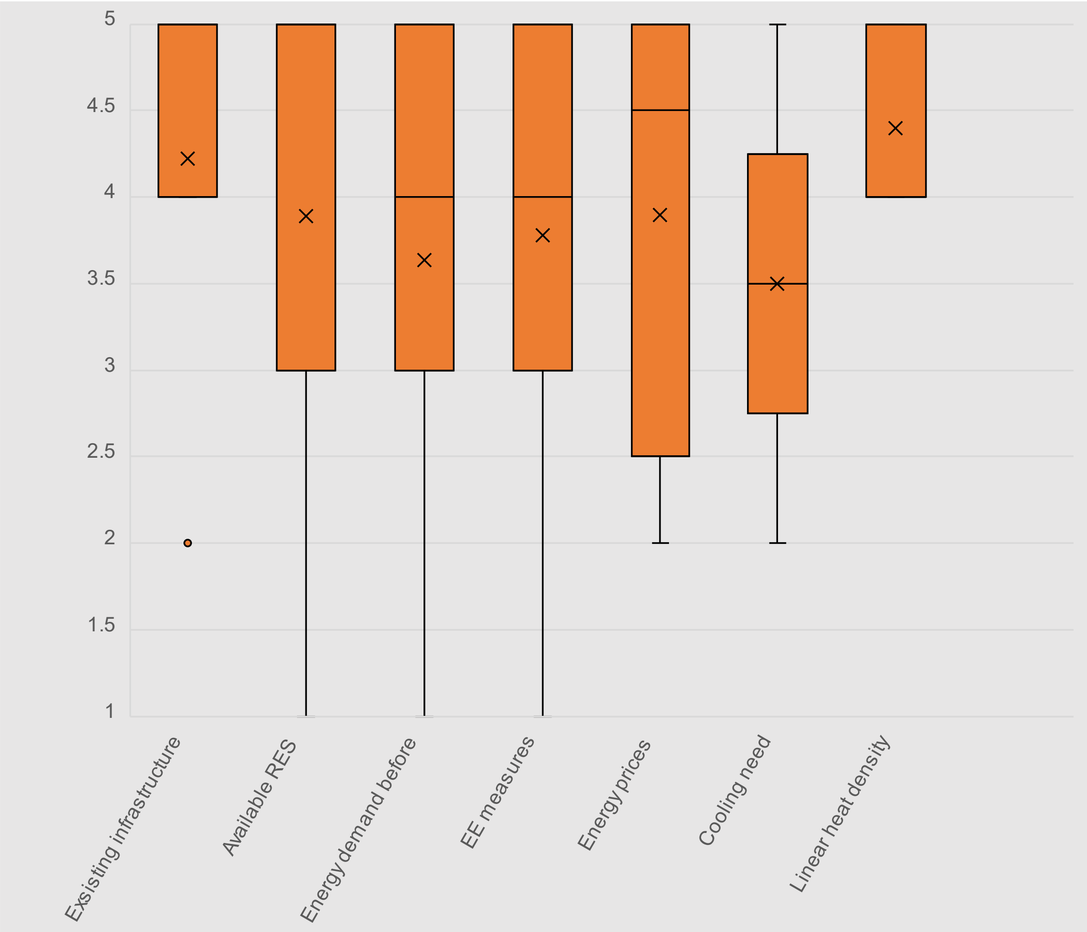


**Figure 2.** Important factor for the choice between centralised or decentralised thermal energy production and distribution (11 respondents).

### 2.2.3 Risks and opportunities

The choice between a centralised or a decentralised solution is a choice that could have important impacts beyond what is considered in the methodology. In general, a centralised solution is considered more flexible regarding energy sources and the possibility of switching between them. On the other hand, a decentralised solution is more flexible regarding individual adoption. It is also easier to perform a step-by-step renovation of a district for decentralised systems, as they do not depend on each other in the same way.

Installing one single thermal production system brings an economy of scale effect compared to multiple smaller systems. However, if a new distribution network is needed, this brings additional initial costs and complexity regarding planning and coordination needs as well as dependencies on end user investment choices to the project.

The distribution of heat in thermal networks typically has higher losses than in decentralised solutions. In addition, a centralised heat pump which is forced to supply higher temperatures, is less efficient than decentralised heat pumps. A centralised heat pump is required to supply higher temperatures because of the already mentioned heat losses in the heat grid and because in a district heating system, the temperature to be provided must be adapted to the building connected to the system with the highest temperature needs. Furthermore, losses in heat grids are higher than for electricity distribution. Therefore, centralised solutions for thermal energy production must compensate for these disadvantages with lower investment costs or more efficient operations to be cost-effective.

A centralised solution typically needs a separate building for its thermal energy generation system. This brings additional costs, but also space requirements. On the other hand, decentralised solutions typically require more space at the individual building level.

Some factors could make it interesting to consider centralised solutions even if they are not the most cost-effective solution based on the IEA EBC Annex 75 methodology. For example, if there are readily available energy resources, such as heat sources suitable for heat pumps (lakes, rivers, aquifers) or waste heat, which could make sense to utilize to reduce greenhouse gas emissions or primary energy use, but are not necessarily cost-effective with respect to decentralised solutions. While such solutions may not be cost-effective when assessed for a specific small district, this does not mean that they could not be more cost-effective when implemented at a larger scale. The same could be the case in situations where seasonal thermal storage solutions are an alternative. Developing districts with decentralised systems or small-scale centralised solutions might accordingly lead to suboptimal solutions. Also, in areas where district heating systems utilise waste incineration for electricity and heat production, there is a risk that available heat will remain unused if too few costumers are connected.

There are also situations where decentralised solutions are challenging for practical reasons, such as space limitations, sound challenges or local pollution problems. For central systems, it is easier to finance a more professional operation and maintenance team with large-scale systems. General calculations often assume that systems are working as intended. However, this requires good service and maintenance. It is also an advantage to have a professional operator who has the economic benefit of running the system as efficiently as possible.

There are also some risks associated with centralised systems compared to decentralised systems. For example, if many customers refuse to connect, the system's cost-effectiveness is reduced. The cost-effectiveness may also be low if a district consists of only single-family buildings. Furthermore, the operation of centralised systems is usually based on profit, which can lead to non-optimal operation from a climate protection perspective, for example, using non-renewable energy sources for peak heating or resorting to less efficient energy use.

The customer with the highest temperature needs determines the supply temperature of the centralised systems. A few customers requiring high-temperature heating may have a negative impact on the efficiency of the entire system or require special local solutions. Extensive energy efficiency (EE) measures can potentially reduce the necessary supply temperature. However, it requires measures on all connected buildings. The supply temperature could also be constrained by the temperature needed for domestic hot water (DHW) production. Usually, national regulations to prevent bacterial growth (legionella) can limit the possibility of lowering the temperature. The regulations differ significantly from country to country, making it difficult to make general recommendations (Van Kenhove et al., 2019). The large variation in regulations, indicates that the risks of legionella growth are not fully understood, and it should be considered that regulations could also be changed, if the safety of consumers is guaranteed. There are concepts and technologies for solving this locally, either with boosters or sterilization methods (Yang et al., 2016) or instantaneous heat exchangers with tankless DHW preparation (Toffanin et al., 2021)). Instantaneous heat exchangers offer an attractive solution for reducing temperatures in the grid in combination with energy efficiency measures on building envelopes. They benefit from the fact that temperatures required for comfort are usually significantly lower than those required to prevent legionella growth in storage tanks. For example, in Germany, such solutions are allowed if the water volume in the DHW piping system after the heat exchanger is less than 3 litres (DVGW, 2004). This concept is challenging because it usually requires multiple substations, e.g. at the apartment level, to reduce the water volume. The lowering of the temperature can be supported by measures related to the radiators supplying heat.

## 2.3 Heating and cooling technology

Heating and cooling technologies convert an energy source or carrier into useful thermal energy for heating and cooling purposes. The potential technologies largely depend on the chosen production and distribution concept (centralised or decentralised). For decentralised systems, the choice is mainly narrowed down to electricity-based solutions, e.g., heat pumps.

### 2.3.1 Key results from calculations

Generally, for all case studies and generic district calculations, where a decentralised solution is the most cost-effective solution, a heat pump is the most cost-effective technology. Some assessments only took into account heat pumps as decentralised solutions. Mainly ground source heat pumps (GSHP) and air source heat pumps (ASHP) are considered heat pump options, and in most cases, GSHP are more cost-effective than ASHP. For centralised systems, heat pumps in connection to existing district heating systems yet also in connection with newly installed district heating systems are found to be cost-effective solutions. One study considers solar thermal systems for domestic hot water production, but it is not cost-effective compared to heat pumps and PV.

### 2.3.2 Important factors

Figure 3 shows the results from the evaluation of which factors are most important in choosing technology for thermal energy supply.

In addition to existing infrastructure, energy efficiency measures are consistently the most important. The exception is the cases where the buildings are already at a reasonably high energy efficiency level. In these cases, the improvement of the envelope has a much smaller effect on the total thermal energy needs. There are indications that energy efficiency measures benefit centralised solutions more strongly than individual energy systems if the energy efficiency measures can decrease the temperature of the heat distribution system. This may astonish at first sight because it might be expected that centralised systems have a large share of fixed costs which do not vary strongly with changes in the required heating capacity due to efficiency measures. However, it must be kept in mind that centralised solutions are often a bit less efficient than individual solutions because of the need to operate with a high temperature in the heat distribution system and the associated losses in the grid.

The cooling needs are not considered a significant factor. This is partly due to the IEA EBC Annex 75 case studies that focus on residential areas. In many countries, cooling is not necessary in private houses and apartments. In the case where cooling is needed, the most cost-effective solution is a central heat pump for heat production and individual cooling units. In a district with more commercial buildings and higher cooling needs, it might be more cost-effective to benefit from the synergies between heating and cooling needs, i.e., with a heat pump producing both heating and cooling. The assessments have been performed based on the current climate. With climate change, cooling might play a more important role in the future.

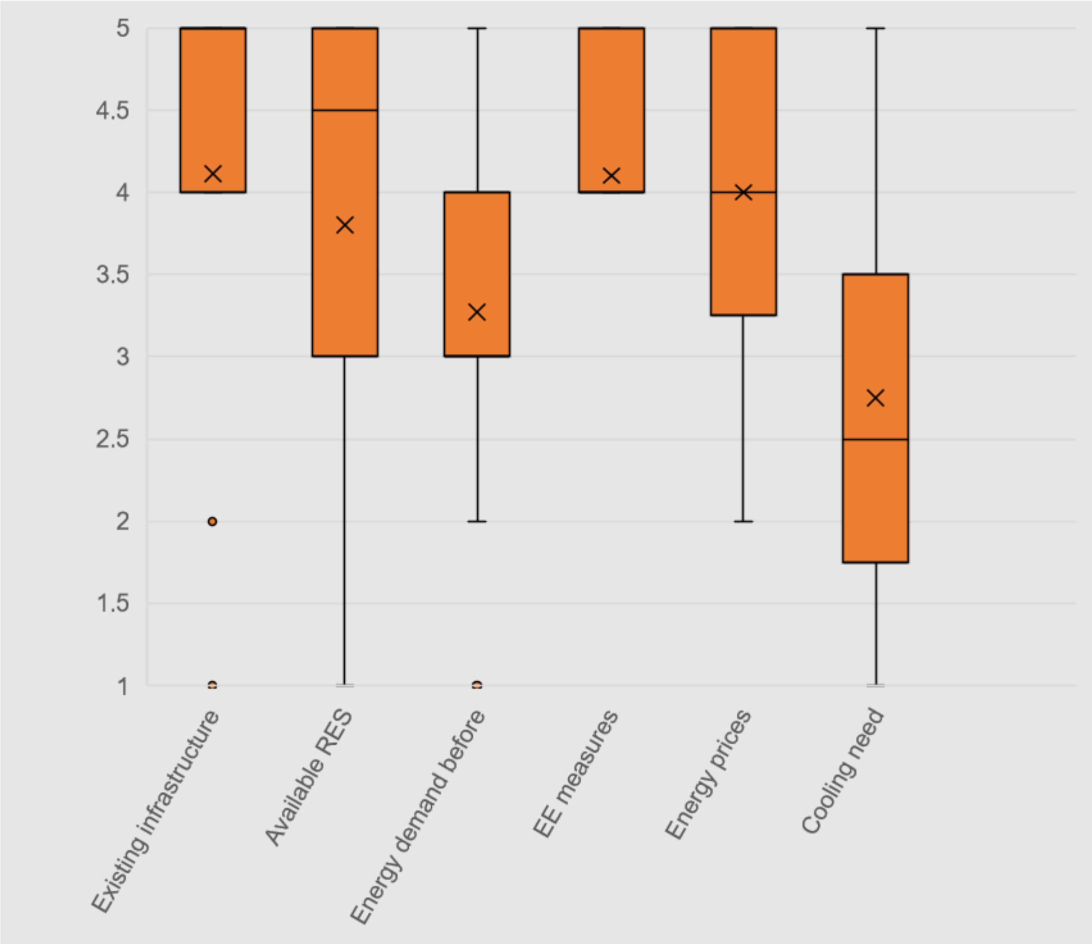


**Figure 3.** Important factors for the choice of technology for thermal energy supply (11 respondents).

### 2.3.3 Risks and opportunities

In many cases, heat pumps are the most cost-effective solution. Heat pumps are a technology that can be applied at most locations, as the heat can come from any source, whether from the ground, surface water or simply the surrounding air. Heat pumps need electricity to increase the temperature of the heat source to the required supply temperature in the building. It is essential to consider the implications of large-scale electrification of the heating supply to buildings, particularly with other sectors also seeing growth in electricity demand, such as mobility or industry. The IEA EBC Annex 75 methodology does not consider grid reinforcement needs outside the district due to increased electricity use inside the district. However, it is likely that increased use of heat pumps at large scale does require grid reinforcement to address risks to the grid's stability.

A GSHP is, in many cases, the most cost-effective solution. However, finding space for boreholes in central areas is often challenging. Therefore, they can be found not applicable in many cases.

As discussed, energy efficiency measures significantly impact the cost-optimal technology choice. In a district renovation process, it is a risk that investment decisions for thermal heat supply and energy efficiency measures are not made by the same (group of) actors. Because of the missing synchronisation of investment cycles and renovation decisions, not all buildings might participate in the renovation, and measures might not lead to the estimated effect. This might influence the cost optimality of the technologies used.

## 2.4 Energy efficiency measures

Energy efficiency measures are measures on the building envelope to reduce the thermal energy needs and usually consist of adding insulation, new windows or installing heat recovery ventilation. The main goal is to reduce the net energy needed to heat or cool the building.

### 2.4.1 Key results from calculations

In general, there are wide variations in which energy efficiency measures are cost-effective. In most cases, energy efficiency measures are cost-effective. Adding insulation to the façade and roof is usually cost-effective if the current energy efficiency level is low, and energy efficiency measures are typically cost-effective when compared to anyway renovations. It has also been found in calculations that the cost-optimal level of efficiency measures does not strongly depend on the type of heating system chosen.

### 2.4.2 Important factors

Figure 4 shows the factors most important in determining which energy efficiency measures are more cost-effective. The most important factor is the energy need of the buildings before renovation. This is linked to the building envelope's current status and the potential for energy savings.

Carrying out energy renovations when some renovation would have to be done anyway on a building element to restore its functionality, is an important factor that can increase the cost-effectiveness of renovations. In these cases, the additional costs of the energy efficiency measures are absorbed by their efficiency, which reduces overall energy costs and leads to overall costs lower than those of an anyway renovation.

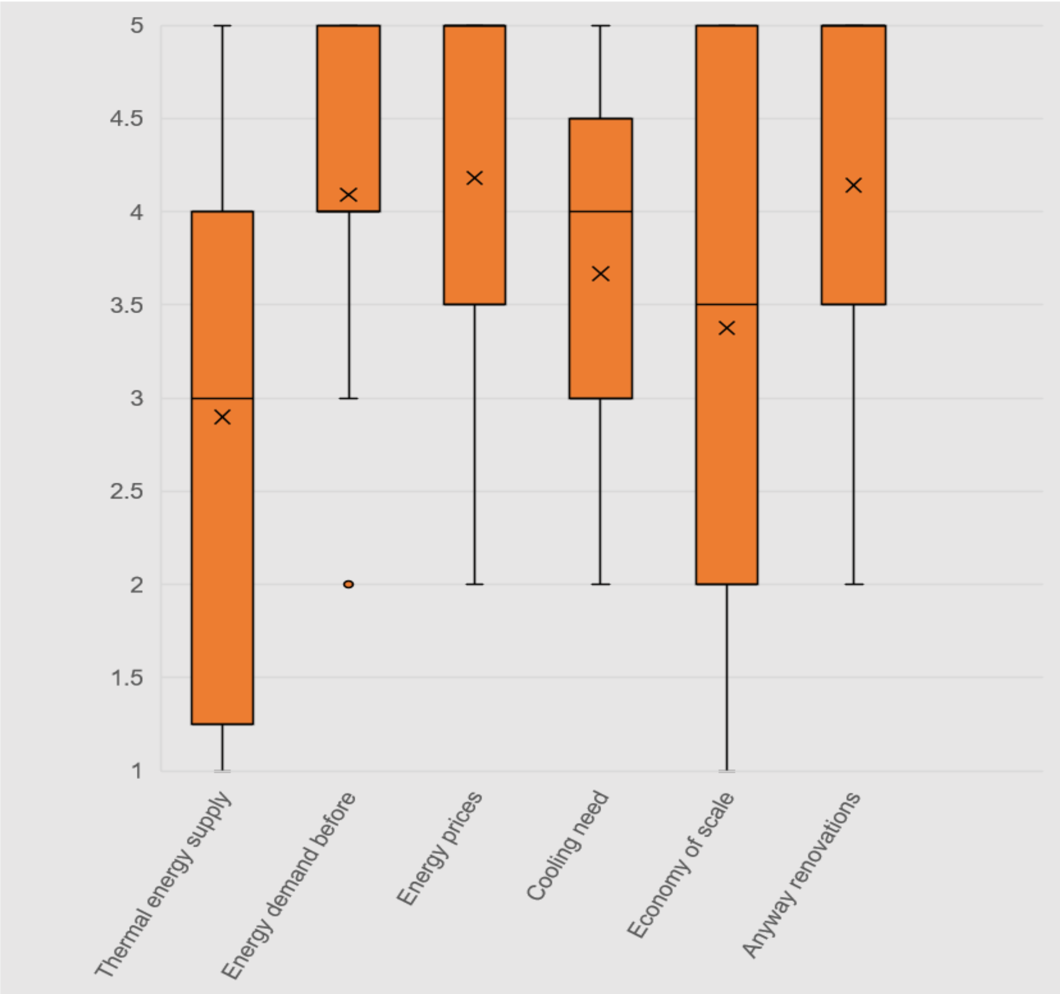


Figure 4. Important factors for cost-effective energy efficiency measures (11 respondents).

### 2.4.3 Risks and opportunities

The assessment of energy efficiency measures in IEA EBC Annex 75 is based on energy simulations. Energy simulations are known to overestimate the effect of energy efficiency measures. This is partly because user behaviour changes due to energy efficiency measures. When the energy cost is reduced, consumption will increase. This is also known as the rebound effect (Greening et al., 2000). This would again overestimate the cost-effectiveness of energy efficiency measures. However, it could mean an increase in user comfort.

In some districts, urban design or monumental/heritage protection could limit the possibilities for energy efficiency (EE) measures. This is important to take into account, as it could have an important impact on the choice of energy technologies and distribution concepts.

The results from IEA EBC Annex 75 show that even though energy efficiency measures are not cost-effective separately, they are cost-effective when compared with a reference case which includes anyway renovations (e.g., adding insulation when replacing or repainting the façade). Therefore, it is a critical opportunity for buildings needing renovation or maintenance to investigate the possibility of applying EE measures. If buildings perform renovations without EE measures, it is a considerable risk that they will not perform EE measures on the same building element in the near future. Carrying out EE measures when some measures are necessary anyway will also reduce the negative impact of embodied energy and emissions.

Energy efficiency measures also improve thermal comfort and possibly also indoor air quality. These are values that are not included in the techno-economic assessment of the IEA EBC Annex 75 methodology but are usually attractive to the occupants.

Energy efficiency measures can increase the risk of overheating, resulting in cooling needs. Therefore, considering the need for other measures, such as shading or ventilation, is important.

## 2.5 Local electricity production

The main option for local electricity production is usually solar PV panels. Electricity can also be produced locally through CHP from wood energy. However, in most such cases, wood is transported to the building for that purpose, and it is accordingly not a form of electricity production from a local energy source. In assessments performed in IEA EBC Annex 75, only PV has been investigated as a local electricity production technology.

### 2.5.1 Key results from calculations

In most cases, the installation of PV is cost-effective, and the cost-effective capacity is mainly constrained by available space. However, in some cases, PV has a negative emission impact due to the very low emission factor for electricity. Important factors for the cost-effectiveness of PV are described below.

### 2.5.2 Important factors

Figure 5 shows the results for which factors are most important in determining the cost-effectiveness of local electricity production.

Climate comes out as the consistently most important factor. The solar conditions directly impact produced electricity per installed capacity of PV, and thereby also the profitability. The tariff system, and energy prices, are also directly influencing profitability. Tariff structures are either designed at the national or regional level through political actors or by energy companies directly themselves. In most cases, they differ significantly from country to country, sometimes also from city to city. The feed-in tariff is only important when not all the produced electricity is self-consumed. However, this is the most frequent case.

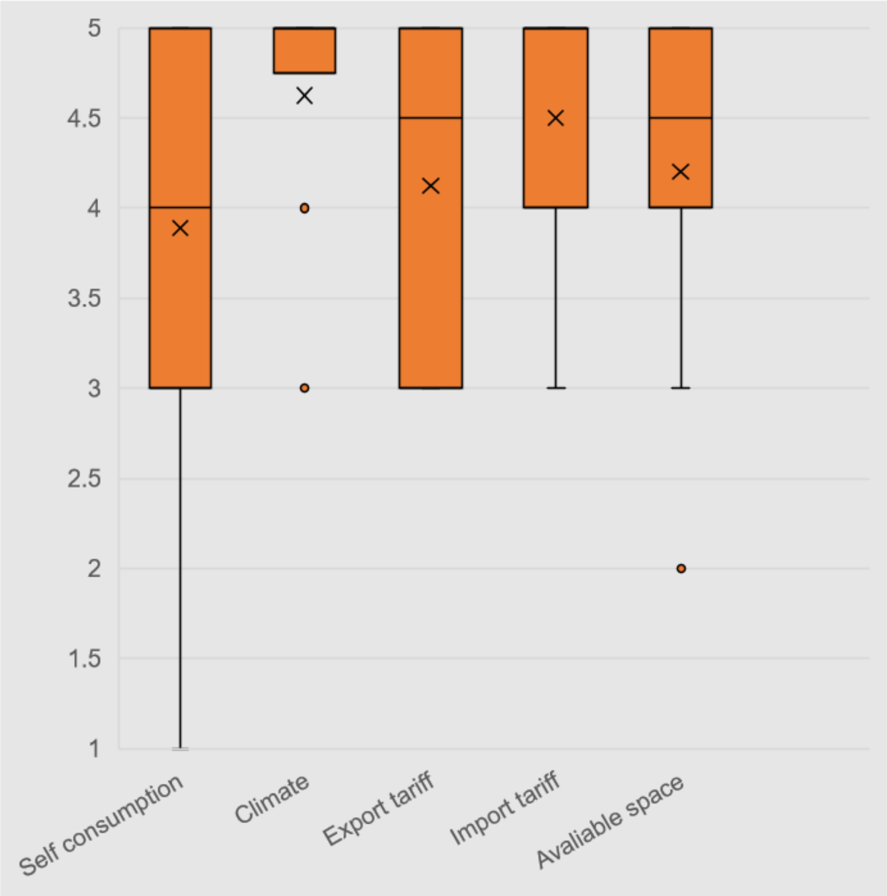


**Figure 5.** Important factors for the cost-effectiveness of local energy production (PV) (10 respondents).

### 2.5.3 Risks and opportunities

For some countries with very low emissions from the electricity system, the calculations show a negative effect on the carbon emissions when including local electricity production from PV. This is due to the negative effect of embodied emissions and the lifetime of the PV systems compared to the positive effect of the produced electricity. This issue is further discussed in section 3.2.3.

Installing PV panels on a district level could benefit both due to the economy of scale and risk-sharing possibilities. However, it is important to consider how the local tariff system influences cost-effectiveness. There is no system for sharing locally produced electricity within a community in many locations. This means that, in principle, the produced electricity must be sold to the energy supplier and bought back by the individual end-users, who then also pay taxes on that electricity. These regulations are expected to improve in the coming years (at least in Europe) i.e., due to the new EU directive on electricity markets (European Commission, 2019).

Space occupied by PV panels could conflict with solar thermal energy. Using solar energy for producing electricity is often advantageous compared to thermal use, as all the electricity produced can be used, if necessary, by injecting it into the grid. In contrast, a large part of thermal energy collected through solar thermal collectors is often lost as heat production exceeds the need on sunny days. However, solar thermal collectors have a higher overall efficiency and may involve fewer installation costs. Solar thermal collectors are particularly interesting for seasonal solar energy storage.

Space occupied by PV panels could conflict with other uses, such as roof terraces or green roofs. This could be important for user acceptance and social sustainability, especially in urban areas with limited access to parks and private outdoor spaces.

# 3. Application of the strategies

The strategies described in this report are developed based on results from calculations on a set of case studies and generic districts. The results and strategies will not be directly transferable to other cases but can be used as inspiration and guidance. Before deciding which strategies are most suited for a specific case, some basic knowledge is necessary.

## 3.1 Necessary knowledge about the case

This section lists some important properties that need to be understood before evaluating which strategies are most relevant for the neighbourhood.

### 3.1.1 Starting conditions for the energy system

The developed strategies are based on the given starting conditions for the existing thermal energy supply system. Therefore, the first step is to investigate which of the predefined starting conditions best matches the starting conditions of the district. Following the IEA EBC Annex 75 methodology (Bolliger, Terés-Zubiaga et al., 2023), three starting conditions have been distinguished concerning the heating system in place:

S1. Urban districts previously heated decentrally by natural gas, oil or electricity, or cooled decentrally through individual cooling devices

S2. Urban districts previously connected to district heating systems with a high share of fossil fuel

S3. Urban districts previously connected to district heating systems with a substantial share of renewable energy carriers

The starting conditions listed above are those found relevant within IEA EBC Annex 75 for investigating district renovation projects. Other starting conditions and different combinations could influence the choice of strategies.

The starting condition is highly important for the choice of strategies. In particular, two fundamental properties are highlighted:

- Is a central thermal energy supply with a district heating network already available that supplies thermal energy to the buildings in the neighbourhood? If such a centralised system is already available, this facilitates the implementation of district heating-based solutions.
- What are the emissions and primary energy use related to the current thermal energy supply system? If the current system is mainly based on fossil fuels, there is a high probability that all relevant strategies will include some sort of modification or switch of thermal energy production to renewable energy.

Furthermore, for the evaluation of the cost-effectiveness of energy efficiency measures on building envelopes, the thermal characteristics of the building envelopes are important.

### 3.1.2 Available energy sources and constraints

When evaluating which energy sources make sense to apply in the neighbourhood, it is necessary to first investigate which sources are available.

**District heating**

If a district heating system is available for the neighbourhood, either already connected or through a nearby connection point, this could be a relevant energy source. It is then necessary to gather important information, such as: which energy sources are currently used in the district heating system? to what extent is there a potential to increase their use to also cover the district in question?

**Environmental heat**

Typical energy sources are the following.

- Surface water from lake/sea/river or groundwater. If such energy sources are available near the neighbourhood, they are often highly attractive for water source heat pumps (WSHP). However, there are significant constraints to consider. Often, there are restrictions on how much energy can be extracted without disturbing the local ecosystem. Local regulations or authorities usually define this. Water-based heat pumps may either operate with cold water district heating systems, where heat pumps are installed decentrally at each building, or based on a centralised heat pump from which water is transported at high temperature to each building connected.
- Ground. Ground source heat pumps (GSHP) usually use closed energy wells extracting heat from the bedrock with boreholes. It is necessary to determine the properties of the ground and the available space for drilling boreholes. In a densely populated area, underground infrastructure might limit the possibilities of GSHPs. IEA EBC Annex 75 focuses on residential districts with limited cooling demand. In the case of a borehole heat exchanger, this could require large borehole fields, as there is no heat from cooling demand that can charge the boreholes during summer, or specific measures to regenerate the heat in the ground.
- Air. Air as a heat source for air source heat pumps (ASHP) is always available, but there are often challenges in finding space for the outdoor unit and sound/noise constraints.

Heat pumps need electricity, and when replacing a non-electric heat source (e.g., gas boiler) with such a system, it is necessary to make sure that there is available capacity in the electric grid. Additional costs must be considered if the local electric grid needs to be reinforced.

**Biomass**

If biomass, such as wood energy, is available, it is a heat source that often comes with low carbon emissions and primary energy factor (PEF). However, mapping other issues, such as transport logistics, is important. In densely populated areas, local pollution is often a factor that disallows biomass-based heat sources. The sustainability of the biomass source is also an important factor that requires consideration. Furthermore, the potential of biomass is limited, and only a relatively small fraction of all buildings could be supplied with biomass energy. In addition, there are competing uses of biomass, for example, to generate electricity, which can only be achieved at competitive costs when carried out in relatively large systems.

**Solar energy**

In most locations, there is abundant heat available from solar energy in summer, while there is a lack of it in wintertime. Seasonal storage of solar energy is, accordingly, potentially an interesting option. The challenge is how to minimize energy losses. Ideally, storage occurs either within buildings, therefore making use of losses, as all energy that escapes the water tank heats the building, or, alternatively, in large facilities, which benefit from the fact that in large systems, the ratio of the surface compared to the volume is small, which favours the minimization of losses. Seasonal storage of solar energy has the advantage that it relies on an energy source which is, in principle, available everywhere and avoids using electricity.

**Decentralised vs. Centralised approaches**

To assess whether centralised or decentralised approaches make most sense, it is suitable to determine cost curves for various approaches of heating systems as a function of installed capacity. For centralised approaches, it is suitable to consider costs for heat intake, centralised heat generation, the thermal grid and individual substations to connect to the district heating system.

For centralised approaches, it is also important to consider specifically the need for a suitable location for centralised heat generation.

In the case of wood energy, one factor is that larger systems can install more advanced filters, thus contributing to clean air.

### 3.1.3 Current status of the buildings and neighbourhood

Before any strategies on both energy efficiency measures and the energy supply concept can be selected, it is crucial to determine the energy characteristics of the buildings in the district. There are several important aspects:

- Current energy efficiency level. The current energy efficiency level of the buildings gives important information on the potential for reducing energy consumption. The poorer the energy condition, the more likely it is cost-effective to implement energy efficiency measures.
- Need for renovation. Investments in measures on the building envelopes make mostly sense when some renovation activities are required anyway. It is, therefore, important to determine which building elements are in need of renovation anyway. “Anyway renovation” is an important concept in the IEA EBC Annex 75 methodology (Bolliger et al., 2023). When comparing the cost-effectiveness of energy efficiency measures, it is important that the reference includes the cost of the renovation measures that are necessary anyway.
- Options for renovation measures. It is suitable to make estimates on costs and expected impacts on the energy performance of the building of renovation measures at various efficiency levels for different components of building envelopes, as a basis to choose which building elements are renovated and the optimum energy efficiency levels when renovating.

  In addition, it might be necessary to investigate the status of the electric grid. This could be important when switching from fuel-based heating technology to electricity-based district heating, such as heat pumps. Who must cover potential reinforcement costs can differ from country to country.

## 3.2 General risks

The performed calculations are based on the IEA EBC Annex 75 methodology, which is a purely techno-economical assessment methodology. Strategies developed based on this kind of calculation are to be used as decision support and guidance together with other important assessments and factors (e.g., social factors, user acceptance, practical constraints etc.).

There are several risks in using results based on these types of assessments, which are typically performed at a general level or in an early phase of planning, where a limited number of details and practical implications are known. The following subchapters discuss some general risks in addition to the strategic-specific risks discussed in section 2.

### 3.2.1 Country-specific boundary conditions

The strategies presented in this document are generalized across several countries. Country-specific or local boundary conditions can influence the cost-effectiveness of different strategies and limit possible options. These could be energy prices, tariff structures, climate, emission factors, subsidies, carbon taxes etc..

Country-specific boundary conditions are further discussed in section 5.

### 3.2.2 Uncertainty in cost estimates

The calculations performed in IEA EBC Annex 75 are based on generic cost data from available sources in each country. Especially when it comes to renovation costs, there are large uncertainties. Renovation costs depend highly on case-specific conditions, such as building construction and condition, accessibility, and logistics. Cost increase due to risk factors is not considered in cost calculations. This could significantly impact the cost-effectiveness of energy efficiency measures and infrastructure development.

Energy costs are also uncertain when considering renovation strategies. Investments in thermal energy supply systems, energy efficiency measures and local renewable electricity production are all long-term investments with cost-effectiveness highly dependent on energy prices. The calculations performed in IEA EBC Annex 75 apply a "best-guess" approach for prices in 2030. However, the values were defined before the energy crises in 2022.

Data on investment costs for district heating systems and their components are scarce. Often, such data is confidential to energy companies. Estimating the costs of district heating systems is accordingly challenging.

### 3.2.3 Emission and primary energy factors

The emission factors and primary energy factors for the energy sources and carriers can significantly impact what solution looks most environmentally friendly. Especially for electricity, setting the emission factors and primary energy factors can be challenging.

Like estimating future energy costs, estimating the future emission and primary energy factors for electricity is challenging. Both factors are expected to reduce with the implementation of more renewable energy solutions in the future.

In IEA EBC Annex 75, national emission factors and primary energy factors are applied. Especially for electricity, the differences can be significant between countries, thereby favouring different solutions in different countries. On the other hand, the electricity market is interconnected in Europe through transmission lines. Therefore, even though some energy savings measures might not reduce emissions based on national emission factors in countries with high share of renewables in the electricity mix, the reduced consumption would result in increased export, which again reduces the emission factor in other countries. Such effects are not shown in the calculations.

## 3.3 General opportunities

Strategies investigated here focus on finding cost-effective strategies for achieving far-reaching reductions in carbon emissions and primary energy use in districts. Such strategies mainly offer to contribute to climate protection. However, it has also become evident that the continued use of fossil fuels is used to fund conflicts in the world. Switching to renewable energy sources may, therefore, not only be a measure that saves costs and protects the climate, but it also has tremendous benefits in contributing to peace in the world.

When comparing various renewable energy solutions, all associated with only a small amount of carbon emissions, a suitable decision criterion is not only costs but also which solution causes the smallest amount of electricity consumption. Any solution that minimizes electricity consumption also minimizes related impacts on the landscape or the natural environment more generally. When comparing various renewable energy options, which all have low carbon emissions, it is, therefore, suitable to compare, in particular, also their impact on primary energy use.

It is important to consider that energy efficiency measures usually also come with increased thermal comfort and indoor air quality. These are non-economic benefits (co-benefits) for the end-user that are usually not considered in calculations.

## 3.4 Overarching strategies

Broadening the scope from individual buildings to districts helps avoid sub-optimal solutions. However, looking at a district level, choosing suboptimal strategies at the city, national, or even globally is still a risk. Therefore, it is important to keep in mind what overarching strategies are considered on a higher level. The overarching strategies are strongly linked to country-specific risks and opportunities.

This section considers some possible overarching strategies and how the district strategies relate to them. The list of overarching strategies considered here is not complete, and other strategies might be relevant to also take into account.

### 3.4.1 Electrification of the energy system

The electrification of the energy system plays a major role in the clean energy transition and is expected to increase drastically in the coming years (IEA, 2019). Electrification of heating and cooling in buildings will also play an important role in this transition, especially with heat pumps. However, the electrification of heating and cooling in buildings, together with the electrification of the transport sector, will bring a significant need for reinforcement of the electric grid. According to Heat Roadmap Europe (Paardekooper et al., 2018), district energy is cost-effective in reducing costs for the electric grid in most urban areas. Large-scale district solutions are better suited for thermal storage solutions (both short-term and long-term), which can be utilized as sources of flexibility by the electric system. Also, larger thermal systems are better suited to use other energy sources, such as industrial waste heat, solar thermal and biomass.

It is, therefore, important to consider implications on the surrounding energy system when evaluating strategies for district renovation. Applying a decentralised electric solution is often not a problem for a single district. Still, at a large-scale implementation, centralised solutions have advantages for reducing electricity grid costs, which makes sense to consider.

It is also important to remember the critical role of energy efficiency measures combined with electrification to avoid a massive increase in electricity use (IRENA, 2022). Assuming that the electric system will be based on 100% renewables soon, it might lead to situations where it is most attractive (and cost-effective on a local level) to just switch to electricity-based thermal energy sources without applying energy efficiency measures. However, this would imply that much more electricity has to be produced from renewable sources than up to now. While PV energy production continues to have great growth potential in suitable locations and with virtually no negative impact, the reality is different for other technologies. For example, wind energy production significantly affects the landscape, and there are increasingly fewer ideal locations for producing renewable electricity. Therefore, from an overarching perspective, applying energy efficiency measures may still make sense, even if they are beyond the most cost-effective solution at the district level.

### 3.4.2 Utilization of existing district heating system

Multiple studies in IEA EBC Annex 75 have shown that it is cost-effective (for the end-user) to disconnect from district heating and instead develop new systems based on heat pumps. This development yields challenges on a larger scale, as described in the previous section. In addition, many of these large-scale district heating systems are based on waste incineration or industrial waste heat, which is non-flexible, and the heat will be wasted if not utilized. To minimise electricity consumption in the transition of districts to renewable energy, it is advisable to make sure that the heat from waste incineration or industrial processes is used.

Also, in the case of district heating systems fully or partially fuelled by fossil fuels, it could be a better solution that the buildings stay connected and that fuel sources are switched at a central level. This would then have a positive impact beyond the renovated district. However, the district heating operator must be willing or forced to perform this switch.

### 3.4.3 Large-scale systems to enable the use of seasonal storage solutions and alternative sources

As mentioned in 3.4.1, large-scale district energy systems are better suited for thermal energy storage systems. Both the specific costs (€/kWh) and specific losses ($kWh_{loss}/kWh_{stored}$) increase with reduced storage size (Walnum & Fredriksen, 2018). Seasonal storage is especially interesting in combination with energy sources that do not match the seasonal variation of heating demand, such as solar thermal or waste incineration. If such systems are suitable for a city, it could be suboptimal if local districts start creating their own solutions.

### 3.4.4 Time constraints for carrying out the transition

Even though district heating systems may be cost-effective or have other advantages, it must be kept in mind that it may be challenging to implement them to achieve the necessary transition. Complying with the 1.5 °C climate protection target requires immediate action. However, putting district heating systems into place requires relatively long development processes. As the years go by, building owners who are required to replace their heating systems in part will likely switch to decentralised renewable energy systems, even if district approaches could be advantageous. This makes the case more complex and harder for district heating systems. In areas where district solutions are attractive, steps can be taken to ensure that building owners undertaking renovations prior to the installation of central systems install systems compatible with the switch to a district heating system at a later stage.

## 3.5 Combination of strategies

In many cases, there might be limitations, practical or social, that make it impossible to apply a common strategy to all buildings within a neighbourhood.

In some buildings, renovating might not be feasible (historic buildings, recently renovated buildings, etc.). This could be constraining the temperature level of the central system. If these buildings represent a minor portion of the district's thermal energy need, it might be cost-effective to have a separate system or a local booster for these buildings to allow the central system to operate more efficiently.

# 4. Strategies

In this chapter, various renovation strategies are categorized. The strategies presented are those identified as cost-optimal in the case studies and generic districts calculations. Advantages and disadvantages, risks and opportunities are discussed from a general perspective, and recommendations are formulated at a general level based on the results from the calculations.

The strategies are distinguished based on the predefined starting conditions and the choice of a centralised or decentralised solution. The level of energy efficiency measures is not directly part of the strategy, but rather the synergies with energy efficiency measures are discussed. The thermal energy system will influence the cost-optimal level of energy efficiency measures, and conversely, the thermal energy system will be influenced by the level of energy efficiency. However, these are not the only factors that will determine the best approach to take. These concepts are discussed in more detail in section 2.4.

In general, the IEA EBC Annex 75 methodology and the developed strategies are based on the concept that energy efficiency measures are performed first, so that the thermal energy supply system can be sized and designed based on the expected future demand. This is important since the demand (both in amount and temperature level) influences the design and cost of the energy supply system.

## 4.1 Starting condition S1

| |
|---|
| **Starting condition 1**: Urban districts previously heated decentrally by natural gas, oil, or electricity, or cooled decentrally through individual cooling devices |

In starting condition 1 there is no central heating system or installed infrastructure.
The main strategic choice regarding the energy supply systems is whether a central heating system is installed or if the decentralised systems are only replaced with new decentralised systems based on renewable energy.

This starting condition is by far the most common in the case studies and generic district assessment within IEA EBC Annex 75 (13 of a total of 19 cases).

### 4.1.1 Strategy S1.1 New central system based on biomass or heat pumps

Reasons for choosing this strategy may be the availability of a large heat source that could otherwise not be used unless through district heating or if the linear heat density and the system's overall efficiency are high enough to make an energy distribution network attractive purely for economic reasons. Regarding the choice between biomass or heat pumps, one of the factors may be cost-effectiveness, but often also practical limitations and constraints. Biomass systems require logistics for fuel transport, and local pollution could be an issue in urban areas. Heat pumps require an energy source (water, ground or air) which comes with different challenges. See section 3.1.2. for further details.

**Synergies with energy efficiency measures**

Energy efficiency measures on the building envelope will reduce the buildings' energy needs, thereby also the linear heat density. This could have a negative impact on the cost-effectiveness of a central system. However, energy efficiency measures reduce the required peak capacity and might also allow for lower supply and return temperature for the central system, resulting in higher production efficiency and lower distribution losses. However, it requires that all buildings can lower the necessary supply temperature. Heat pumps benefit significantly from lower temperatures, but also condensing biomass boilers benefit from lower (return) temperatures. IEA EBC Annex 75 results suggest that the latter effects dominate the former: synergies with energy efficiency measures are higher for district heating systems than individual heating systems.

**Strategy advantages and disadvantages**

Some advantages of this strategy are the following.

- The approach allows the heating system to tap into large-scale heat sources that could be efficiently used at a district level but could not be accessed through decentralised systems. Examples are waste heat from plants for incineration of municipal solid waste, or heat from surface water or groundwater, which can be used efficiently but cannot be used at a decentralised level.
- District approaches may allow using stored thermal energy, such as seasonal waste heat storage or seasonal solar thermal storage.
- Central systems allow the heating system to provide heat to buildings also, if for space restrictions or noise restrictions, the installation of an individual heating system at each building would be challenging.
- Using biomass at the district level has the advantage of achieving a higher level of filtration to reach a high air quality.
- There are economies of scale in the heating system.
- As the energy efficiency of building envelopes is increased through renovation measures, potentially the area covered by the district heating system can be expanded to use capacity that is otherwise no longer needed.
- As a large costumer, district heating operators could benefit from lower energy tariffs.

Some disadvantages of this strategy are the following.

- Has more energy losses than decentralised systems.
- Must operate at a higher temperature than individual systems because of the losses and because the temperature in the system is dependent on the building with the highest temperature requirement in the grid, which results in a high temperature which in turn is not favourable for the efficiency of a centralised heat pump.
- Supply temperature could be constrained for hygienic reasons (section 2.2).
- If significant energy efficiency measures are implemented on the buildings within the district, the efficiency of the distribution system will be reduced due to higher relative heat losses. Reduced energy consumption is not a disadvantage, but the increased relative losses could increase the energy price for the end-user. This can be counteracted if the energy efficiency measures mean that the distribution temperature can be reduced. Not only does this reduce losses; a lower target temperature also implies a higher efficiency of a centralised heat pump.

**Strategy risks and opportunities**

Some risks connected with this strategy are the following.

- Developing a new infrastructure for thermal energy supply in an urban area is complex, and estimating costs is difficult. It is a significant risk that early-stage cost estimates underpredict the real costs.
- This solution could be the socio-economic most cost-effective solution, but it might not be the most cost-effective for the end user, depending on the pricing scheme. This might make it difficult to get them involved.
- If the strategy and the cost-effectiveness are based on minor energy efficiency measures, there is a risk that future energy efficiency measures can reduce the cost effectiveness of the system, as the energy need, and the linear heat density is reduced.
- The cost-effectiveness of developing a new central system depends on enough customers connecting to the system. If a large portion of the building owners is not willing to connect, the project might fail.
- Developing a district heating system takes time. Given the current pressure to decarbonise, many building owners might switch to a decentralised system while a district heating system is being developed. In

such cases, it could be advisable to apply measures to ensure that the installed solutions comply with a later switch to district heating.

Some opportunities related to this strategy are the following.

- The operation of centralised systems allows for a more advanced professional service for such systems.
- Possibilities for expansion of the grid to neighbouring districts.
- If significant energy efficiency measures are performed on the building envelopes, it might be possible to reduce the distribution temperature, which reduces the heat losses and can improve the efficiency of the heat production. However, this might be constrained by the temperature needed for domestic hot water production or buildings that still need higher temperatures (inside or outside the neighbourhood). However, there are several possibilities with the potential to overcome this hurdle. This is further discussed in section 2.2.

**Strategy recommendations**

This strategy is suited for areas with the following properties:

- Available large heat sources that could otherwise not be used.
- High linear heat density.
- Space or noise restrictions that make installing individual heating systems based on renewable energy challenging.
- Feasible to develop new infrastructure without significant practical limitations.
- Available space and sources to develop a central thermal energy system

### 4.1.2 Strategy S1.2: Switching to decentralised heat pumps

In this strategy, the existing decentralised heat production system based on fossil fuels is replaced locally by heat pumps. For systems with no existing hydronic system, it could be either installed a new one or used individual air-to-air heat pumps. For hydronic systems, heat pump technology (ground source or air source) will depend on climate, energy demand and local constraints. Typical local constraints are related to available space and acceptable sound levels. For example, decentralised solutions may also be applied with a cold district heating system based on lake water.

**Synergies with energy efficiency measures**

Energy efficiency measures on the building envelope will reduce the energy need of the buildings, and thereby also the sizing of the heat pump. Energy efficiency measures might also allow for lower supply and return temperature for the hydronic system, which results in higher heat pump COP and lower distribution losses. Since heat pumps are installed at a distributed level, synergies with energy efficiency measures at each building occur directly and do not depend on energy efficiency measures in other buildings or a group of buildings.

**Strategy advantages and disadvantages**

Some advantages of this strategy are the following.

- There is no need to develop an external infrastructure for district heating.
- Compared to centralised systems, decentralised heat pumps can more easily deliver different temperatures for DHW and space heating, which improves efficiency.
- Compared to centralised systems, the temperature to be reached through the operation of a heat pump can be lower, as there are fewer losses in the distribution. Furthermore, this system is not dependent on the specific temperature needs of some buildings, as in the case of a district heating system. This situation has benefits for the efficiency of the heat pump.
- There are fewer distribution losses.
- Decentralised heat pumps are also easier to combine with cooling demand, either using reversible heat pumps or connecting to the cold side for water-to-water heat pumps.

Some disadvantages are the following.
- GSHP systems require space for the borehole field. This could be challenging in dense areas, while the outdoor unit of ASHP systems could have noise-related challenges.
- Decentralised systems do not enable energy exchange between buildings and exploitation of non-coincident demand. This typically means that the sum of installed capacity for decentralised heat pumps will be larger than the necessary installed capacity for a central system.

**Risks and opportunities**
Some risks connected with this strategy are the following.
- Switching to electric systems will increase the electricity demand. Extra expenses may incur if there is limited expansion capacity in the local grid.
- If this strategy is widely implemented, it could result in bottlenecks in the electric transmission or distribution grid (on cold winter days).
- Focusing on decentralised systems only could make it more challenging to switch all buildings to renewable energy, as for some buildings. This might be particularly challenging to achieve and for those buildings it could be highly beneficial if there was a district approach.
- Efficient large-scale heat sources might not be used. Electricity consumption associated with the decarbonisation of the building stock might accordingly be higher than if those large-scale heat sources are used.
- An all-electric solution, such as heat pumps, has no fuel source flexibility. This means that backup solutions (not part of the cost calculation) might be necessary for areas with a risk of longer power cuts.

Some opportunities related to this strategy:
- This solution can efficiently be combined with free cooling for ground or water-based heat sources. For buildings which do not have cooling already, this can be an extra comfort that improves user acceptance.
- Combining an electric heating/cooling system and PV is a good solution as it increases self-consumption and reduces grid issues due to high export power.
- Two or three neighbouring buildings could be connected to microgrids, allowing them to benefit from some advantages of a district approach without creating much dependency.

**Strategy recommendations**
This strategy is recommended for neighbourhoods with the following main characteristics:
- No existing thermal network.
- Low linear heat density
- Few challenges for drilling boreholes for ground source heat pumps or few challenges for conforming with noise restrictions for air source heat pumps
- Lack of availability of a large-scale heat source that could be used efficiently

## 4.2 Starting condition S2

**Starting condition 2**: Urban districts previously connected to district heating systems with a high share of fossil fuel

For this starting condition, the main strategic choice is to increase the share of renewable energy in the district heating system or disconnect the district and use renewable energy sources locally.

### 4.2.1 Strategy S2.1: Increasing the renewable share in the existing DH system

For this strategy, the main goal is to increase the share of renewable energy sources in the existing DH heating system and continue to utilize the existing infrastructure. If the existing infrastructure is in good shape, this is usually a more cost-effective solution than disconnecting from the grid. However, it is not straightforward to modify the existing DH system. The choice of renewable energy source for heat production will depend on local properties. Still, a large-scale system often increases the number of possible solutions and the cost-effectiveness of combining solutions. E.g., systems such as solar thermal combined with seasonal storage and top-up heaters are only reasonable for large-scale systems.

**Synergies with energy efficiency measures**

Energy efficiency measures on the building envelope will reduce the buildings' energy needs and, thereby, the linear heat density. This could have a negative impact on the cost-effectiveness of the distribution system. However, energy efficiency measures reduce the required peak capacity. They might also allow for lower supply and return temperature for the central system, resulting in higher production efficiency and lower distribution losses. However, compared to a centralised system designed for the district alone, this benefit is limited in the short term if not the rest of the district heating system can lower the temperature.

Furthermore, synergies with energy efficiency measures are smaller for a district heating system already in place than for a district heating system installed newly. Some system components, such as the distribution pipes, will likely remain in place without benefitting from energy efficiency measures. However, another benefit of the energy efficiency measures is that the reduced demand in the district can free up capacity for the connection of new buildings and thereby have a positive impact beyond the renovated district itself. Alternatively, the reduced demand can reduce the need for installing new renewable energy sources in the existing DH system.

**Strategy advantages and disadvantages**

Some advantages of this strategy are the following.

- Minimum work is necessary on the thermal energy systems of the buildings, as the system, in principle, remains unchanged.
- The inhabitants will not be influenced by the changes (if the energy price will not need to be increased), and user acceptance might be easier. This is particularly valuable concerning the space required for installing a heating system. If buildings are already connected to a district heating system, they are likely not to have any space readily available to install a heating system in each building.
- The approach allows the heating system to tap into large-scale heat sources that could be efficiently used at a district level but could not be accessed through decentralised systems.
- The approach also allows the heating system to provide heat to the buildings if installing an individual heating system in each building is challenging due to space or noise restrictions.
- There are economies of scale in the heating system.
- As the energy efficiency of building envelopes is increased through renovation measures, potentially the area covered by the district heating system can be expanded to use capacity that is otherwise no longer needed.
- As large customers, district heating operators could benefit from lower energy tariffs.

Some disadvantages are the following.

- Has more energy losses than decentralised systems.
- Has to operate at a higher temperature than individual systems because the temperature in the system is dependent on the building with the highest temperature requirement in the grid, which results in a high temperature which, in turn, is not favourable for the efficiency of a centralised heat pump.
- With an existing district heating system, energy efficiency measures on building envelopes create fewer synergies with the district heating system, as pipes are not likely to be replaced soon.
- If significant energy efficiency measures are implemented on the buildings within the district, the efficiency of the distribution system will be reduced due to higher relative heat losses. This can be counteracted if the energy efficiency measures mean that the distribution temperature can be reduced. Reduced energy consumption is not a disadvantage, but the increased relative losses could increase the energy price for the end-user.

**Risks and opportunities**

Some risks connected with this strategy are the following.

- The DH system and production plant owner needs to be a part of the project. If not, it might not be possible to change the energy sources. If the modifications are not in the interest of the DH owner, they must be enforced through policy measures.
- Many renewable energy sources require more space or local circumstances (e.g. access to heat sources for heat pumps), which might not be available.
- This solution could be the socio-economic most cost-effective solution, but it might not be most cost-effective for the end user, depending on the pricing scheme. This might make it difficult to get them involved.
- Significant energy efficiency measures might create a cooling demand. Local solutions could then be necessary, and exploiting the synergies between heating and cooling production is challenging. In many cases, this could be compensated with passive measures, such as shading.

Some opportunities related to this strategy are the following.

- If the DH system delivers heat beyond the district under renovation, the switch to renewable energy will have an effect beyond the district.
- If significant energy efficiency measures are performed on the building envelopes, it might be possible to reduce the distribution temperature, which reduces the heat losses and can improve the heat production efficiency. However, this might be constrained by the temperature needed for DHW production or buildings that still need higher temperatures (inside or outside the neighbourhood). However, there are several possibilities with the potential to overcome this hurdle. This is further discussed in section 2.2.

**Strategy recommendations**

This strategy is recommended for neighbourhoods with the following main characteristics:

- Districts already connected to a DH system.
- The existing DH infrastructure is in good shape.
- Possibilities to influence the investments in the central DH system.
- Large heat sources that could otherwise not be used.
- Space or noise restrictions making the installation of individual heating systems based on renewable energy challenging.

### 4.2.2 Strategy S2.2: Switching to decentralised heat pumps

An alternative strategy to changing centralised thermal energy production is disconnecting from the grid and installing decentralised renewable energy sources. Heat pumps are the most appropriate solution for this.

**Synergies with energy efficiency measures**

Energy efficiency measures on the building envelope will reduce the buildings' energy needs, thereby also the heat pump sizing. Energy efficiency measures might also allow for lower supply and return temperature for the hydronic system, which results in higher heat pump COP and lower distribution losses. Since heat pumps are installed at a distributed level, it allows for different energy efficiency measures for each building or group of buildings. Synergies with energy efficiency measures at each building occur directly and do not depend on energy efficiency measures in other buildings or a group of buildings.

**Strategy advantages and disadvantages**

Some advantages of this strategy are the following.

- Compared to centralised systems, decentralised heat pumps can deliver different temperatures for DHW and space heating, which improves efficiency.
- Decentralised heat pumps are easier to combine with cooling demand, either using reversible heat pumps or connecting to the cold side for water-to-water heat pumps.
- Decentralised solutions have reduced heat losses in distribution.

Some disadvantages are the following.

- GSHP systems require space for the borehole field. This could be challenging in dense areas, while the outdoor unit of ASHP systems could have challenges regarding noise.
- Decentralised systems do not enable an exchange of energy between buildings and exploitation of non-coincident demand. This typically means that the sum of installed capacity for decentralised heat pumps will be larger than the necessary installed capacity for a central system

**Risks and opportunities**

Some risks connected with this strategy are the following.

- Depending on district heating pricing, this might be the most cost-effective solution for the end-users, but not the socio-economic best solution.
- Switching to electric systems will increase electric demand. Extra expenses may incur if there is limited expansion capacity in the local grid.
- If this strategy is widely implemented, it could result in bottlenecks in the electric transmission or distribution grid (on cold winter days).
- Focusing on decentralised systems only could make it more challenging to switch all buildings to renewable energy, as for some buildings, this might be particularly challenging to achieve, and for those buildings, it could be highly beneficial if there was a district approach
- Efficient large-scale heat sources might not be used. Electricity consumption associated with the decarbonisation of the building stock might be higher than if those large-scale heat sources are used.
- An all-electric solution, such as heat pumps, has no fuel source flexibility. This means that backup solutions (not part of the cost calculation) might be necessary for areas with a risk of longer power cuts.

Some opportunities related to this strategy are the following.

- This solution can efficiently be combined with free cooling for ground or water-based heat sources. For buildings which do not have cooling already, this can be an extra comfort that improves user acceptance.
- Combining an electric heating/cooling system and PV is a good solution as it increases self-consumption and reduces the risk of grid issues due to high export power.
- Two or three neighbouring buildings could be connected to microgrids, allowing them to benefit from some advantages of a district approach without creating much dependency.

**Strategy recommendations**

This strategy is recommended for neighbourhoods with the following main characteristics:

- The existing thermal energy network is in poor shape.
- Overall low linear heat density.
- Few challenges for drilling boreholes for ground source heat pumps or few challenges for conforming with noise restrictions for air source heat pumps.
- Lack of availability of a large-scale heat source that could be used particularly efficiently

## 4.3 Starting condition S3

**Starting condition 3**: Urban districts connected to district heating systems with a substantial share of renewable energy carriers.

This starting condition is most typical for the European Nordic countries, where DH infrastructure is well developed, and the heat is usually based on biomass boilers, waste incineration or heat pumps. For this starting condition, the main question is whether to keep the connection to the district heating system or disconnect and install decentralised heat pumps. Intuitively, staying connected and performing energy efficiency measures on the building envelope may sound reasonable. However, experience shows that due to the pricing of the DH for the end-user, disconnecting and installing decentralised heat pumps might be more cost-effective. Intermediary forms may also occur, i.e., it may be attractive to disconnect from a large district heating system and create a new smaller district heating system for a specific area. Furthermore, microgrids could be a possibility for connecting only two or three buildings at a time.

### 4.3.1 Strategy S3.1: Keep a connection to the district heating system

In principle, this strategy does not significantly change the thermal energy system. However, there might be improvements on a central level to increase the share of renewable energy sources (if not already 100 %). If the existing infrastructure is in good shape, this is usually a more cost-effective solution than disconnecting from the grid and installing new systems.

**Synergies with energy efficiency measures**

Energy efficiency measures on the building envelope will reduce the buildings' energy needs and, thereby, the linear heat density. This could have a negative impact on the cost-effectiveness of the distribution system. However, energy efficiency measures reduce the required peak capacity and might also allow for lower supply and return temperature for the central system, resulting in higher production efficiency and lower distribution losses. Nevertheless, compared to a centralised system designed for the district alone, this benefit is limited in the short term if the rest of the district heating system cannot lower the temperature. Furthermore, synergies with energy efficiency measures are lower for an already implemented district heating system than for a newly installed one. Some system components, such as distribution pipes, are likely to remain in place without benefiting from energy efficiency measures. Another benefit of the energy efficiency measures is that the reduced demand in the district can free up capacity for the connection of new buildings and thereby have a positive impact beyond the renovated district itself. The reduced demand can reduce the need for installing new renewable energy sources in the existing DH system.

**Strategy advantages and disadvantages**

Some advantages of this strategy are the following.

- Less work is needed on the buildings' thermal energy systems as the system, in principle, remains unchanged.
- The approach allows the operator to tap into large-scale heat sources that could be efficiently used at a district level.
- The approach allows the operator to provide heat to buildings even if there are space or noise restrictions that would prevent the installation of an individual heating system at each building.
- There are economies of scale in the heating system.
- As the energy efficiency of building envelopes is increased through renovation measures, potentially the area covered by the district heating system can be expanded to use capacity that is otherwise no longer needed.
- As large customers, district heating operators could benefit from lower energy tariffs.

Some disadvantages are the following.

- A district heating system has more energy losses than decentralised systems.
- A district heating system has to operate at a higher temperature than individual systems on average because the system's temperature depends on the building with the highest temperature requirement in the grid, which is not favourable for the efficiency of a centralised heat pump.
- With an existing district heating system, energy efficiency measures on building envelopes create fewer synergies with the district heating system, as pipes are not likely to be replaced soon.
- If significant energy efficiency measures are applied to the buildings within the district, the efficiency of the distribution system will be reduced due to higher relative heat losses. This can be counteracted if the energy efficiency measures mean that the distribution temperature can be reduced. Reduced energy consumption is not a disadvantage, but the increased relative losses could increase the energy price for the end-user.

**Risks and opportunities**

Some risks connected with this strategy are the following.

- Depending on the pricing scheme, this solution could be the most cost-effective socio-economic solution, but it might not be most cost-effective for the end user. This might make it difficult to get them involved.
- Significant energy efficiency measures might create a cooling demand. Local solutions could then be necessary, and exploiting the synergies between heating and cooling production is challenging if there is no cooling network.

Some opportunities related to this strategy are the following.

- If significant energy efficiency measures are applied to the building envelopes, it might be possible to reduce the distribution temperature, and consequently the heat losses, and improve the heat production efficiency. However, this might be constrained by the temperature needed for DHW production or single buildings that still need higher temperatures. However, there are several possibilities with the potential to overcome this hurdle. This is further discussed in section 2.2.

**Strategy recommendations**

This strategy is recommended for neighbourhoods with the following main characteristics:

- Districts already connected to a DH system.
- The existing DH infrastructure is in good shape.
- Large heat sources that could otherwise not be used.
- Space or noise restrictions making the installation of individual heating systems based on renewable energy challenging.

### 4.3.2 Strategy S3.2: Switching to decentralised heat pumps

An alternative strategy to changing centralised thermal energy production is disconnecting and installing decentralised renewable energy sources. Heat pumps are the most appropriate solution for this. This might be an alternative solution if the existing network is in poor shape.

**Synergies with energy efficiency measures**

Energy efficiency measures on the building envelope will reduce the buildings' energy needs and, therefore, the heat pump sizing. Energy efficiency measures might also allow for lower supply and return temperature for the hydronic system, which results in higher heat pump COP and lower distribution losses. Since the heat pumps are installed on a distributed basis, this allows applying different energy efficiency measures for each building or group of buildings. Synergies with energy efficiency measures in each building occur directly and do not depend on energy efficiency measures in other buildings or a group of buildings.

**Strategy advantages and disadvantages**

Some advantages of this strategy are the following.

- Compared to centralised systems, decentralised heat pumps can deliver different temperatures for DHW and space heating, which improves efficiency.
- Decentralised heat pumps are easier to combine with cooling demand, either using reversible heat pumps or connecting to the cold side for water-to-water heat pumps.
- Decentralised solutions have reduced heat losses in distribution.

Some disadvantages are the following.

- GSHP systems require space for the borehole field. This could be challenging in dense areas, while the outdoor unit of ASHP systems could cause noise-related problems.

- Decentralised systems do not enable an exchange of energy between buildings and exploitation of non-coincident demand. This typically means that the sum of installed capacity for decentralised heat pumps will be larger than the necessary installed capacity for a central system

**Risks and opportunities**

Some risks connected with this strategy are the following.

- Depending on district heating pricing, this might be the most cost-effective solution for the end-users, but not the socio-economic best solution.
- Switching to electric systems will increase electric demand. Extra expenses may incur if there is limited expansion capacity in the local grid.
- If this strategy is widely implemented, it could result in bottlenecks in the electric transmission or distribution grid (on cold winter days).
- Focusing on decentralised systems only could make it more challenging to switch all buildings to renewable energy, as for some buildings, this might be particularly challenging to achieve, and for those buildings, it could be highly beneficial if there was a district approach.
- Efficient large-scale heat sources might not be used. Electricity consumption associated with the decarbonisation of the building stock might accordingly be higher than if those large-scale heat sources are used.
- An all-electric solution, such as heat pumps, has no fuel source flexibility. This means that backup solutions (not part of the cost calculation) might be necessary for areas with a risk of longer power cuts.

Some opportunities related to this strategy are the following.

- This solution can efficiently be combined with free cooling for ground or water-based heat sources. For buildings which do not have cooling already, this can be an extra comfort that improves user acceptance.
- Combining an electric heating/cooling system and PV is a good solution as it increases self-consumption and reduces grid issues due to high export power.
- Two or three neighbouring buildings could be connected to microgrids, allowing them to benefit from some advantages of a district approach without creating much dependency.

**Strategy recommendations**

This strategy is recommended for neighbourhoods with the following main characteristics:

- The existing thermal energy network is in poor shape.
- Overall low linear heat density.
- There are few challenges for drilling boreholes for ground source heat pumps or for conforming with noise restrictions for air source heat pumps.
- Lack of availability of a large-scale heat source that could be used particularly efficiently.

# 5. Country-specific risks and opportunities

This chapter discusses country-specific risks and opportunities of various strategies in separate subchapters. This includes estimates and/or discussions, for example, about the potential of replication of specific strategies within a given country, also depending on existing renewable energy potentials and settlement structures. Recommendations are made regarding the most promising strategies for each country.

## 5.1 Austria

### 5.1.1 Important boundary conditions

**Climate conditions**

According to the descriptive classification, the climate in Austria can be assigned to the humid-cool temperate zone. A more oceanic climate, often characterized by humid westerly winds, prevails in the west and north of Austria. Conversely, a more Pannonian-continental, low-precipitation climate with hot summers and cold winters predominates in the east. Especially in the Southern Alps, low-pressure areas with high precipitation from the Mediterranean region are noticeable.

**Energy system**

Historically, Austria has had two main renewable energy sources: hydropower and biogenic fuels. These two renewable energy sources account for the largest share of domestic primary energy production, with the share of hydropower trending slightly downward and the share of biomass rising.
Other renewable energy sources, particularly the use of ambient heat in heat pumps and primary energy production from wind and photovoltaics, are also increasing continuously and significantly.
The household energy sources show that electricity accounts for the largest share, followed by wood, gas, district heating, and heating oil.

**Building stock**

Most buildings in Austria – nine out of ten – are mainly used for residential purposes. Currently, the renovation rate in Austria is 1.5%, which is half of the 3% target in the current government program.

**Legislation and regulations**

There is a staged plan to phase out fossil heat generation: Since 2020, oil heating systems may no longer be installed in new buildings in Austria, and since 2021 they have also been prohibited when heating systems are replaced. From 2025, oil boilers older than 25 years must be compellingly replaced. At the latest, from 2035, all boilers will have to be replaced.
Analogous to the phased plan for oil in space heating, the government also wants to create a legal basis for replacing gas heating systems. Accordingly, no more gas boilers or new connections are to be allowed in new construction from 2025. As for coal, almost no new heating systems have been installed in recent years.

### 5.1.2 Most promising strategies

**System and technologies**

If district heating based on renewables is available, connecting to it is always beneficial. The calculation results show that switching to district heating can reduce carbon emissions and life cycle costs compared to decentralised heat pumps. Heat pumps can be an option if district heating is unavailable or pellet heating is not allowed.

Heat pump systems, especially air-source heat pumps, have advantages when energy efficiency measures on the building envelope are also carried out. By improving the insulation level of the thermal envelope of the buildings, the heating supply temperature can be reduced, which leads to a more efficient operation of the heat pump. For heat pumps, furthermore, a combination with PV is advisable.

**Energy efficiency measures**
The calculations within the IEA EBC Annex 75 showed that the roof and the façade insulation are always cost-effective compared to the reference case. In combination with a heat pump system, installing new windows is also cost-effective. Besides the positive effect on the life cycle costs, the investigated energy efficiency measures also reduce the building's primary and final energy consumption.
Other positive effects of the insulation measures are the reduction of thermal bridges and the improvement of thermal comfort. Such positive effects, also called co-benefits, have also been investigated in the IEA EBC Annex 56 project for Austrian building renovations.

**Local renewable electricity production**
Photovoltaic is the most popular technology to produce renewable energy on-site. Especially with the newly created possibility of energy communities, PV is also becoming economically more attractive for individual building owners.
Solar thermal installations for heat production have also been very popular in the past years, with the peak around 2010. Since then, the yearly newly installed solar thermal collector power has decreased.

## 5.2 Denmark

### 5.2.1 Important boundary conditions

**Climate conditions**
Denmark has a temperate climate (Marine West Coast Climate or Cfb, according to the Koppen-Geiger classification). In residential buildings, the thermal energy demand is purely heat-driven; traditionally, only non-residential buildings apply active cooling.

Due to the northern European location, available solar energy is limited during the heating season, increasing the seasonal mismatch between demand and potential renewable energy production.

**Energy system**
Denmark's electricity consumption is covered by approximately 80% (127 g $CO_2$/kWh) of renewable energy production (4% photovoltaic and 76% wind turbines) (Green Power Denmark, 2020). For imported electricity, 86% is based on renewable energy (Green Power Denmark, 2020). Denmark is connected to the European electricity grid, and e.g., the COBRA-cable connecting Holland and Denmark has saved Holland one million tons of carbon emissions in a little over a year (Green Power Denmark, 2020).

District heating primarily provides heating (55%) (Statistics Denmark, n.d.). The district heating is 72% based on renewable energy sources (solar, wind, biomass, biogas and geothermal) (Danish District Heating Association, 2022). The remaining buildings are heated by fossil fuels, e.g., natural gas (18%) and oil (10%), electric panels (6%), heat pumps (5%) and other forms (6%) (Statistics Denmark, n.d.). Heat pump and district heating coverage have increased dramatically as oil and natural gas have been phased out in recent years.

The total electricity consumption was 35 TWh in 2019 (Statistics Denmark, n.d.) and is expected to increase to 70 TWh by 2030, if the overall goal of a 70% reduction in carbon emissions is to be achieved (electrification).

**Building stock**

The Danish building stock consists of (numbers from 2022) 1,128,851 single-family houses, 268,017 detached houses, 99,916 blocks of flats and 7,787 other types of dwellings. Buildings not used as dwellings constitute 315,926 farm buildings, 50,103 factories/workshops, 101,361 office buildings, 17,625 educational buildings and 230,597 summer cottages (Statistics Denmark, n.d.).

The energy efficiency level of the Danish building stock is very varied, but when the recent goals regarding carbon emissions were set, an investigation showed that an average of 50% should reduce energy consumption to achieve these goals.

**Legislation and regulations**

Denmark will reduce carbon emissions by 70% (compared to a 1990 baseline) by 2030. By 2050 Denmark will be 100% fossil-free (Danish Energy Agency, n.d.). As mentioned previously, 500,000 dwellings are still heated by fossil fuels, but Denmark has been reducing this number dramatically over the last years and continue to do so.

In Denmark, there is a free choice of electricity supplier, which means that in e.g., a block of flats, tenants do not necessarily have the same supplier. Therefore, local renewable energy production can only be used for common electricity, not private use. For e.g., in single-family houses, local renewable energy production makes sense to an extent where the production covers the electricity use (based on hourly measurements), and any surplus production can be sold to the grid at a low price.

### 5.2.2 Most promising strategies

**System and technologies**

Denmark will continue to develop the district heating infrastructure for densely populated areas, and for more sparsely populated areas, the development is shifting towards electrification using heat pumps. It is foreseen that by 2030 the vast majority of the 500,000 existing fossil fuel-heated houses will either have been connected to district heating or have individual heat pumps. By 2050 the electricity network and district heating systems should be 100% fossil-free.

**Energy efficiency measures**

Previous studies indicate that some standalone energy efficiency measures are still cost-effective in Denmark, depending on the starting situation (Kragh & Aggerholm, 2021). This is also confirmed by the calculations performed within IEA EBC Annex 75 for a generic Danish district. The IEA EBC Annex 75 analysis points out that the most cost-effective measures regarding the building envelope are related to exterior walls, roofs, and windows.

It is important to note that increasing the energy efficiency of buildings is much more relevant in connection with renovations in general, i.e., taking advantage of situations where the building is undergoing general maintenance. It is also important to note that increasing the energy efficiency of buildings will usually positively affect indoor climate and comfort and may also significantly reduce problems related to thermal bridges, etc.

**Local renewable electricity production**
Large installations with electricity production via PV panels or hot water production via solar thermal panels with seasonal storage are the most relevant technologies in Denmark. Regarding PV, a challenge is that the present and expected future development in capacity challenges the distribution network, which needs to be updated, particularly if installation placement is not planned centrally.

## 5.3 Italy

### 5.3.1 Important boundary conditions

**Climate conditions**
Italy's Climate classification is highly variable from a humid subtropical climate to a hot-summer Mediterranean climate (Cfa to Csa according to the Koppen-Geiger classification) and from Oceanic climate (Cfb) to a warm humid continental climate (Dfb) and to a warm-summer Mediterranean climate (Csb).

**Energy system**
Primary energy demand in Italy in 2019 amounted to 1807 TWh, down by 1% compared to 2018. The data confirms the decreasing trend recorded from 2006 (-1.5% average annually in 2006-2019). Final energy consumption amounted to 1398 TWh of energy.

Renewable energy production amounted to 315 TWh in 2019 and satisfied 19% of the primary energy demand: 28.9% came from solid biofuels, 18.3% from geothermal energy and 14.8% from wind and sun and 14.7% from hydropower. Gas is the main energy source for electricity production through thermoelectric generation, covering 64.6 % of the production.

In 2019, Italy's per capita primary energy consumption was about 30 000 kWh / inhabitant and 362 TWh in total for the residential sector. Natural gas is the main source of energy, with a share of over 50% of the overall consumption of the sector, followed by solid biofuels with almost 20% of the sector's energy demand and electricity with 18% (ENEA, 2021).

**Building stock**
The analysis done by ISTAT (Istituto Nazionale di Statistica) regarding the building typology at the national level shows that 84% are residential buildings. Among them, about 52% correspond to single-family houses. In North Italy, about 48% of the buildings are single-family houses, 24% are terrace houses, 25% are multi-family buildings, and only 3% correspond to large apartment blocks.

**Legislation and regulations**
National legislation on energy for the buildings sector was published in Italy following the requirements of the EU Directives. In the case of building refurbishment, a subsidized tax regime and public financing actions were proposed.
The last Legislative Decree nr 48 published in June 2021 is the implementation of the UE Directive 2018/844. The Decrees published in June 2015 propose requirements for Energy Certification of Buildings, the calculation methodology for energy use in buildings and the compilation of the technical report that the public authorities require when a refurbishment or a new building is built.
Concerning renewable energy, Legislative Decree nr 28/ 2011 was published as European Directive 28/2009 implementation, updated by recent decree D. Lgs. 199/2021.

### 5.3.2 Most promising strategies

**System and technologies**

Heating purposes represent 67% of Italy's energy requirements for residential buildings. The heating systems for buildings are mainly characterized by gas boilers and water distribution (radiators): 17,5 million homes and apartments in Italy use this typology. The use of (air-water) heat pumps is promoted by National policy action (Ecobonus), also considering utilising this equipment for cooling. The use of district heating is concentrated in the Alps Regions.

For cooling, the market of HVAC systems for residential buildings is still growing (multisplit systems) and the improving efficiencies due to the use of more sophisticated control systems favour such technologies application.

**Energy efficiency measures**

Italian legislation promotes improving thermal efficiency for heating systems (condensation boilers, heat pumps) and cooling systems.
U-value for each building envelope component shall be improved before/ during the refurbishment or design operation. During the last year, the most adopted measures for residential buildings are the windows and thermal system improvements.

**Local renewable electricity production**

Concerning the percentage of renewable energy produced, the overall 2020 target indicated by EU Commission (Directive 2009/28/CE) for Italy was 17%.
For electricity, renewable energy production accounts for 41% from hydropower (highly dependent on water availability during the year), 20 % from PV and 17% from wind power (GSE Report on Renewable 2020). The PV systems installation has been growing since 2008, and the energy produced in 2020 is equal to 24.942 GWh (GSE, 2021a, 2021b).

## 5.4 Norway

### 5.4.1 Important boundary conditions

**Climate conditions**

According to the Koppen-Geiger classification, Norway is dominated by sub-artic and continental climates (Dfb and Dfc). Thermal energy demand is, therefore, mainly heat-driven. Traditionally, only non-residential buildings apply active cooling.

Due to the northern location, limited solar energy is available during the heating season, increasing the seasonal mismatch between demand and potential renewable energy production.

**Energy system**

Norway's electricity demand is almost 100% covered by hydropower, which gives a very low national emission factor. The grid is connected to the European electricity grid, which influences the Norwegian energy market and the global benefit of reducing electricity consumption in Norway.

Electricity is the most common source for space heating and domestic hot water. It is estimated that about 70-80% of energy for space heating in apartment blocks is covered by electricity (Sartori et al., 2021). The rest is mainly covered by district heating. Most DH systems are located in cities with waste incineration as the base load and additional sources on top. On average, 95.5 % of heat production is covered by non-fossil energy sources.

The electricity demand from other sectors is expected to increase due to the electrification of the transport sector and the power-intensive industry (Gogia et al., 2019). This makes it interesting to reduce the demand in the building sector, to reduce necessary investment in the electric grid.

**Building stock**

About 57 % of the Norwegian building stock consists of small houses (single-family houses or row houses), 12 % are multi-family houses, and 31 % are service buildings.
It is estimated that 38% of existing multi-family houses have hydronic heating systems. Electric resistance heaters mainly heat the rest. For commercial buildings, the corresponding number is estimated to 58% (Sartori et al., 2021). The energy efficiency level of the residential building stock is very varied, but a study on the current status in 2010 estimated that 70-85 % of the apartment blocks built before 1980 have undergone energy efficiency-related renovation (Mjønes et al., 2012). This is often not deep renovations but minor improvements. This makes it less cost-effective to improve the building envelope further.

**Legislation and regulations**

Legislation against fossil fuels for heating purposes in buildings (space heating and domestic hot water) came into force in 2020, also covering existing systems. This means that no buildings should currently be heated with fossil fuels.

There is a regulation for prosumers (below 100 kW production) for local renewable energy production, ensuring they can feed energy into the system. However, this is for individual units, not for neighbourhoods. For central systems at the neighbourhood level, produced energy must be sold to the energy company and bought back from the individual end-users. This reduces the possibility of self-consumption and cost-effectiveness of neighbourhood PV systems.

### 5.4.2 Most promising strategies

**System and technologies**

Due to the legislation against fossil fuels for heating, Norway's most relevant starting conditions are S1, with decentralised (individual or building level) electric heating, and S3, with nearly 100% renewable district heating. For buildings with individual electric heating (panel ovens) only, it is very challenging to do anything with the heating system, as introducing a hydronic heating system is a comprehensive, intrusive and expensive measure.

**Energy efficiency measures**

Earlier studies (Mjønes et al., 2012) have shown that few standalone energy efficiency measures are cost-effective in Norway. This is also confirmed by the calculations performed within IEA EBC Annex 75. Also, with the very low emissions from the heat sources typically applied in Norway (electricity and district heating), the embodied emissions from added materials in energy efficiency measures can often exceed the reduced emissions due to reduced energy consumption from a life cycle perspective.
Therefore, focusing on energy efficiency measures in relation to anyway measures is important. This could typically be adding insulation when the façade needs to be renovated or selecting more efficient windows when the windows need to be changed.

**Local renewable electricity production**

Electricity production with PV panels is the most relevant technology in Norway. However, in many cases, the technology is not cost-effective with the current energy prices (before 2021). With the Norwegian climate and the low national emission factor for electricity, calculations will often give a negative emission impact from a life cycle perspective for PV panels. The real effect is more complex, as increased PV production in Norway would lead to higher export of electricity to Europe, leading to more renewables in the European energy mix. Anyway, the effect highlights the importance of applying PV panels with as low as possible embodied emissions.

# 5.5 Portugal

## 5.5.1 Important boundary conditions

**Climate conditions**

The Portuguese mainland has, according to the Koppen-Geiger classification, a predominantly temperate continental climate, which can be divided into two types: Csa, Mediterranean with warm and dry summer, and Csb, Mediterranean with dry and mild summer (in most of northern Portugal, above the Montejunto-Estrela mountain range). Madeira's climate is of the Csa type, while Azores ranges between Csb and Cfb climate, temperate oceanic climate.

**Energy system**

In 2020, oil represented the largest consumption of primary energy (41%), followed by natural gas (25%). Renewables represented a share of around 30% and coal 5,6% (Energy Observatory, 2022b). Coal-fired electricity production, however, was halted in November 2021, two years earlier than the original forecast. Natural gas relevance is expected to be gradually reduced over time, and its use is foreseen mainly as a backup for the electricity generation system in the decarbonisation process.

The highest share of electricity consumption in Portugal comes from wind power (33%), followed by thermal electricity from non-renewable sources (30%), hydropower (13%), biomass (6%) and photovoltaics (3.5%). Imported electricity corresponds to around 13% (Energy Observatory, 2022a).

In the Domestic Sector (INE, 2021), electricity is the main energy source (46,4%), followed by natural gas (28,0%) and biomass (18,4%). The use of solar thermal systems, although representing only 2,1% of energy consumption, has almost tripled in the last decade, resulting from the encouragement of national policies. Notably, from 2014 onwards, the introduction of heat pumps increased electricity consumption by 1,6%.

Space heating corresponds to only 19,1% of total energy consumption, DHW corresponds to 22,0% and space cooling to 1,0%. This represents the specific Portuguese context, where the population is either accustomed to living in thermal discomfort or is in an energy poverty condition. Space heating was covered in 2020 mainly by biomass (67,1%), followed by heating oil (12,4%) and electricity (10,0%). DHW supply is based on gas boilers (76,5%), solar thermal systems (7,7%), and electricity (2,7%). Space cooling, when assured, is provided exclusively by air conditioning. Individual heating is the general rule in Portugal, where district heating is essentially non-existent (just a single example was implemented in Lisbon in 1998).

**Building stock**

The building stock in Portugal is mainly residential (99%), with only 1% of non-residential buildings (PORDATA (Contemporary Portugal Database), 2021). Except for multifamily buildings built from 2016 onwards, the building stock presents some level of thermal discomfort in more than 95% of the hours of the year (ELPRE, Long-Term Building Renovation Strategy by 2050, 2021). Thermal discomfort is aggravated during winter, when, without active heating, indoor temperatures can often reach 10ºC. Only about 20% of the Portuguese residential building stock is leased, while about 70% is owner-occupied (INE & LNEC, 2013).

**Legislation and regulations**

Portugal committed in 2016 to achieving carbon neutrality by 2050. To date, several official documents have been published to help reach the decarbonisation goal, such as the Roadmap for Carbon Neutrality 2050 (RNC2050), the 2030 National Energy and Climate Plan (PNEC2030), and the Long-term Building Renovation Strategy by 2050 (ELPRE). A Long-term National Strategy against Energy Poverty is under development.

Implementing district energy systems is not foreseen in the country and is not even considered in ELPRE's recommendations. Only at the local renewable energy production level, the Decree-Law 162/2019 regulates renewable energy production for self-consumption with the possibility of exporting to the grid and creating Energy Communities.

The buildings' thermal performance is regulated by Decrees-Law 101-D/2020 and 102/2021. The regulation now makes the approval of financial incentives (loans) conditional on improving the energy efficiency of the building. Despite these advances, the regulations still focus on the building level rather than the district/ neighbourhood scale, missing the opportunity for more cost-effective renovations, especially when on-site renewable energy integration is an option.

Portugal has identified opportunities and set targets in compliance with the EU policies aiming for complete decarbonisation by 2050**,** but implementing a massive building renovation at the district level is still highly challenging since the necessary conditions are not yet met.

### 5.5.2 Most promising strategies

**System and technologies**
Currently, Portugal's space heating and DHW supply are decentralised (starting condition S1). In 2011, almost 50% of the space heating in residential buildings was provided by electric heaters, while fireplaces and fireplaces with heat recovery represented a share of 26,6%. Central heating (per residential unit) was responsible for only 10,7% of total heating, while 14,0% of the residential units had no heating system (INE & LNEC, 2013, p. 86).

No change is expected in this scenario since no centralised systems are foreseen, even in the long-term renovation strategies. In the simulations conducted in the IEA EBC Annex 75 for social housing typologies, the energy performance was tested for highly efficient decentralised systems and different options of centralised systems. The results indicate that both were cost-effective compared to the anyway measures (related to the necessary maintenance of the buildings). Furthermore, centralised systems associated with renewable energy sources showed better environmental performance and lower energy consumption than the decentralised package. Heat pumps associated with PV seem to be the most promising system in terms of cost-effectiveness.

**Energy efficiency measures**
The Portuguese building stock urgently needs to implement energy efficiency measures on the building envelope (walls, roof, and windows), which is mostly uninsulated and with high air infiltration rates. Passive measures are essential in the Portuguese context, not only to reduce the building energy needs but also to bring several co-benefits, such as reducing building pathologies (especially those related to mould) and improving indoor air quality (IAQ). The installation and/or replacement of highly efficient heating and DHW systems is also a priority. For cooling, other passive strategies are equally important, such as solar shading, natural ventilation, and high thermal inertia of the building.

Within IEA EBC Annex 75, in the calculations, all the renovation packages included energy efficiency measures on the building envelope as the renovation strategy to be implemented first. The results demonstrated that all the renovation packages were cost-effective compared with the anyway measures (reference case) associated with all the proposed energy supply systems (including the conventional decentralised system).

**Local renewable electricity production**

By 2030, Portugal aims to achieve a renewable energy share of 47% of the total energy production, with renewable energy contributing to 80% of electricity generation, mainly comprising wind energy 31%, hydro-electricity 22%, and solar energy 27% (the latter with the highest expected growth).

Considering the expected increase in the electrification of all the economic sectors, renewable energy, currently responsible for around 60% of the total electricity produced in Portugal, must have its production enhanced. This must be done in association with new technologies such as battery storage and/or connection to the grid, allowing progress in the decarbonisation process. Hydropower has been impacted in recent years by sequential and severe drought periods due to climate change. On the other hand, onshore wind energy and photovoltaic energy are the most promising sources due to the favourable Portuguese geographic position. The Roadmap for Carbon Neutrality 2050 forecasts that together, they can potentially and cost-effectively supply 50% of the electricity by 2030 and 70% by 2050 (RNC 2050, Roadmap for Carbon Neutrality 2050, 2019, p. 31).

## 5.6 Sweden

### 5.6.1 Important boundary conditions

**Climate conditions**

Sub-arctic and continental climates dominate Sweden. The energy needs are dominated by heating, and cooling is less common. The Koppen-Geiger classifications are: Dfb in the south and Dfc in the north.

Solar energy is not used to a high degree. This is partly due to low solar irradiation during the winter period. Also, the relatively low electricity prices made solar energy installations not profitable. However, this is changing as PV technology has reduced in price.

**Energy system**

Swedish electricity production is covered by 39% from hydropower, 39% from nuclear power, about 12% wind energy and 10% electricity from heat and power plants. Electricity and district heating covers about 80% of the energy needs of the building sector. The remaining energy is mainly covered with bio energy and fossil fuels. 2020 Sweden exported about 25 TWh electricity. This was mainly exported to Finland. But also, Lithuania, Denmark and Poland imported electricity from Sweden.

**Building stock**

In total, there are approximately 8 million buildings in Sweden. About 37% of these are dwellings. Buildings that are older than 40 years have a large renovation need. Only 15% to 25% of these buildings have been renovated (Boverket och Energimyndigheten, 2019). In the building sector, 3% of the buildings are directly heated by gas and oil. The remainder is heated by district heating (57%), electricity (including heat pumps) (26%) and biomass (14%) (Energimyndigheten, 2019). Around 90% of multifamily buildings and around 17% of single-family buildings are heated by district heating. Of the fuels used to produce district heating, 6% are fossil (Boverket och Energimyndigheten, 2019). Electricity is 99 % non-fossil (produced from hydropower and nuclear power). Consequently, the carbon emissions from the building sector are fairly low, around 10% of the total Swedish emissions (Byman, 2020).
However, the building stock accounts for a large part of Sweden's total energy use. In 2017, the housing and service sector accounted for 39 % of the total energy use in Sweden. Heating and production of hot water in buildings accounted for 60 % of the final energy use of the energy use in the buildings (Boverket och Energimyndigheten, 2019).

**Legislation and regulations**

New regulations regarding individual measurement and charging of bought heat for multifamily houses with primary energy above 200 kWh/m². Exceptions can be made in exceptional cases if, for instance, the owner can show that such installation will not be profitable.

Green technology tax reduction can give 15% reduction for investment in PV installation and 50% for installation of storage capacity (Skatteverket, n.d.-b). A tax reduction of 0,60 SEK/kWh sold electricity from a PV installation is rewarded for up to 30 000 kWh/year (Skatteverket, n.d.-a).

### 5.6.2 Most promising strategies

**System and technologies**

As the energy mix differs between different municipalities for electricity production and district heating, it is often challenging to determine a "one strategy fits all".

**Energy efficiency measures**

The performed simulations in IEA EBC Annex 75 show that profitability is difficult regarding energy-efficient renovation strategies in Sweden. The relatively low electricity prices make renovation measures less profitable (Energimyndigheten, 2019). The starting condition is important for the final profitability.

**Local renewable electricity production**

Sweden's solar energy production is very limited today, with only 411 MW by the end of 2018. However, the growth rate of new installations is large and solar energy is expected to keep increasing in Sweden (Energimyndigheten, 2020).

## 5.7 Switzerland

### 5.7.1 Important boundary conditions

**Climate conditions**

The Alps strongly influence the climate in Switzerland. To the North of the Alps, the climate is mainly influenced by the Atlantic Ocean. To the South of the Alps, the climate is mostly influenced by the Mediterranean Sea. Western winds in combination with the Alps, frequently bring rainfall. Winters are generally relatively mild, yet buildings generally require heating for thermal comfort. In the Alps, the high altitudes lead to arctic temperatures in winter. Usually, only non-residential buildings apply active cooling in summer.

**Energy system**

Switzerland's electricity production sources are mainly hydropower and nuclear energy. The amount of solar electricity produced by PV panels has gradually increased in recent years, whereas the amount of electricity produced from wind power has not increased for several years. Other sources of electricity production are waste incineration, biogas plants, or wood-based combined heat and power. For the transition to an electricity system based 100% on renewable energy, either storage of solar electricity from summer months to winter months or an increase in electricity imports in winter are necessary.

Energy for heating purposes continues to be mainly based on fossil fuels. In new buildings, however, heat pumps are usually installed.

**Building stock**

Buildings are the source of approximately a third of $CO_2$ emissions in Switzerland.

There are currently approximately 1.8 million heated buildings with a total heated floor area of 800 million m². About 83% of the buildings are residential buildings, with a share of the total heated floor area of 64%.

The building envelopes are usually of good quality, leading to a long service life of building envelopes. Consequently, a relatively large share of Swiss buildings continues to have a relatively low energy performance, as building envelopes are often already relatively old. This increases the attractiveness of energy efficiency measures on the building envelopes.

**Legislation and regulations**
Like most other countries, Switzerland is a signatory of the Paris Agreement and thus aims to limit climate change to the extent that average global warming is kept within 1.5 °C compared to pre-industrial times. The government has explicitly communicated that it supports this target. However, national plans for reducing carbon emissions are not yet sufficient to contribute to that target in a way as required on average by countries around the world to achieve that.

In Switzerland, regulations on buildings are primarily the responsibility of cantons, according to the Constitution. Attempts were made to introduce nationally binding $CO_2$ emission limits for buildings. The related $CO_2$ law, which would have introduced such limits, was rejected by the population in a referendum voted in June 2021. The law was rejected mostly for reasons other than those related to $CO_2$ limits in buildings. So, there is the possibility of soon having an agreement at the national level to introduce $CO_2$ limits differently. Nevertheless, for now, there are no $CO_2$ emission limits in buildings, and regulations on reducing energy use in buildings or switching to renewable energy-based heating systems exist only at the cantonal level.

The regulatory framework on buildings differs from canton to canton. Some cantons require building owners to switch to renewable energy when replacing their heating systems unless some exception clauses apply.

A national $CO_2$ levy on fossil heating fuels is about CHF 120 per ton of $CO_2$ emissions. All cantons participate in a common subsidy programme funded by a third of the revenues of the $CO_2$ levy. Subsidies are provided for energy efficiency measures on the building envelopes and the switch to renewable energy-based heating systems. Two-thirds of the revenues of the national $CO_2$ levy are reimbursed to the population and companies.

### 5.7.2 Most promising strategies

**System and technologies**
Currently, most buildings relying on fossil fuels for heating purposes have their own heating system in Switzerland. Accordingly, starting condition S1 is prevalent. Therefore, the main choice among the strategies described in this report is between strategies S1.1 and S1.2.

The question is to understand which strategy is the most favourable in a specific case. In some cases, a replacement of the heating systems with a centralised switch to a renewable energy-based system, as described by strategy S.1.1, is favourable. In others, a switch to decentralised renewable energy systems is the most appropriate, as described by strategy S1.2.

In terms of cost-effectiveness, an advantage of a switch to a centralised renewable energy system is that such systems benefit from lower electricity prices due to another tariff that applies to large electricity customers.

In terms of minimizing carbon emissions and primary energy use, it is attractive to use waste heat or stored solar heat or heat from lakes, rivers, or groundwater. These energy sources can only be accessed when taking a district approach. It is advisable to favour decentralised solutions for ground-source heat pumps or air-source heat pumps.

Considering the boundary conditions and the existing situation in Switzerland, the following specific risks present themselves in connection with district renovation strategies:

- There is a risk that a separate fossil fuel-based heating system covers the peak load in district heating systems. It is financially more attractive to install such a secondary heating system at a district level than at the level of an individual building. This is especially true as many energy companies active in cities also provide natural gas.
- There is a risk that district heating systems are not implemented because of a lack of financial attractiveness, even though such systems may make sense for using heat that is otherwise wasted.

Taking into account the boundary conditions and the existing situation in Switzerland, the following specific opportunities present themselves in connection with district renovation strategies:

- Waste heat from waste incineration is a highly useful, yet limited, energy source for heating purposes; energy efficiency measures on building envelopes allow to cover a larger territory with this energy source. It only makes sense to use this energy source in district heating projects.
- There is a significant potential to use rivers, lakes or groundwater as a heat source and also as a cooling source through district heating projects.
- Waste heat from waste incineration, which occurs in the summertime, is, so far, hardly utilized, as there is no energy needs for heating purposes in summer. There is only an energy need for hot water during summer. It could therefore be an attractive option to store energy produced in waste incineration plants from summer to winter. District heating projects allow tapping into this energy source.
- Solar energy is abundant in summer, and solar thermal energy collected during that time of the year may be sufficient to cover the buildings’ heating needs. It is, in that case, attractive to use a district-wide storage system for that purpose. However, solar energy storage systems implemented at the individual buildings level allow inherent energy losses to be easily used for space heating, provided the storage tank is located within the building envelope. Such a solution is only possible by definition in the case of decentralised systems. In such situations, minimising the energy required for heating is of great interest, as it allows sizing the storage tank to a smaller size. In this case, this is highly advantageous as it frees up useful space through energy efficiency measures.

Overall, the following is concluded for promising strategies concerning the heating system.

When waste heat is available from waste incineration plants, other industrial plants, or commercial facilities, it is advisable to use that energy through district heating projects to reduce carbon emissions and primary energy use. Furthermore, accessing this energy source through district projects makes sense when surface or groundwater is available. If there is an option to use seasonal solar thermal energy storage, this can be an attractive solution, as it greatly reduces primary energy consumption. Solar energy is abundant in summer, and its use in winter does not depend on using electricity to the extent required for a heat pump. When drilling boreholes is possible and geothermal heat pumps are the chosen solution, using this energy through decentralised systems usually makes sense, as heat generation in a centralised heat pump and the distribution grid have large energy losses. Air source heat pumps use a slightly less efficient energy source than ground energy through geothermal heat pumps. Biomass can be better utilized in large district heating systems with the best filter technologies to ensure high air quality. It could be used to cover peak demand. From the point of view of cost-effectiveness, any of the mentioned renewable sources can be the most attractive, depending on the situation of the specific case.

**Energy efficiency measures**

Energy efficiency measures on building envelopes are beneficial economically and ecologically when considering that in the absence of such measures, other measures would have to be implemented anyway at some point just to restore building envelopes' functionality.

An exception is the installation of new windows. Often, such a measure is not cost-effective. Furthermore, due to the embodied energy and embodied emissions involved, such a measure may also not be environmentally beneficial. Accordingly, installing new windows often requires a justification other than cost savings or environmental benefits. Increased thermal comfort or reduced impact by noise may be such a justification.

Energy efficiency measures are particularly also useful in combination with ground-source heat pumps, in case many buildings use that technology close to each other, as it is often suitable in Switzerland. In such cases, energy efficiency measures may allow avoiding measures to regenerate heat in the ground extracted by heat pumps.

However, a key prerequisite to harness benefits of efficiency measures at the district level is that a solution is found for providing hot water, even if temperatures within the district heating system are lowered.

Taking into account the boundary conditions and the existing situation in Switzerland, the following specific risk presents itself in connection with district renovation strategies:
Buildings in districts are often owned by various building owners. The share of entire districts owned by single building owners or building owner associations is small. This makes it challenging to combine energy efficiency measures with energy efficiency measures at the district level. This leads to a risk that district heating projects impede energy efficiency measures on building envelopes, as this makes it challenging to coordinate energy efficiency measures with the point in time when the district heating system is put in place.

**Local renewable electricity production**
The generation of electricity from solar energy makes sense ecologically. Yet, given the current tariffs in Switzerland, it is attractive financially only in case of a high share of self-consumption of the electricity produced.

# 6. Concluding remarks

This report has used the results from the calculations in IEA EBC Annex 75 and highlighted the most relevant strategies for district renovation. The report focuses on cost-effective strategies for reducing carbon emissions and energy use in city buildings at the district level, combining energy efficiency and renewable energy measures.

In general, it is challenging to draw concrete conclusions and recommendations for specific strategies based on the limited amount of case studies and generic district calculations performed in IEA EBC Annex 75, especially given the enormous variance observed in the investigated cases (district size, geographical location, initial state of the buildings, etc.). Even with a more extensive set of calculation results, it would be impossible to give definitive answers due to the many specific characteristics of individual districts. Therefore, applying the IEA EBC Annex 75 methodology individually in each case is recommended.

However, some general trends can be identified from the results:

- The difference in cost-effectiveness between centralised and decentralised solutions from a lifecycle perspective is often small. Centralised solutions do benefit from economies of scale. However, they are associated with losses due to distribution and bring the distribution network's costs. Furthermore, the temperature in the district heating system must be higher than in individual heating systems because of the distribution losses and because the district system must consider the building with the highest temperature need. This, in turn, limits the efficiency of the centralised approaches. These effects, to some extent, cancel each other out, leading to similar results in the cost-effectiveness of decentralised and centralised solutions.
- The scale of centralised solutions brings the need for more planning, coordination efforts, and dependencies on end users. This carries costs and risks.
- There is often no clear economic case for choosing centralised approaches. If an existing thermal network is in good condition in the district, it is usually most cost-effective to continue utilizing it.
- However, there may be other good reasons for preferring centralised approaches. Such reasons may be:
    - to make use of a large heat source or seasonal thermal storage;
    - to have more flexibility concerning the choice of energy carriers or to access cost-effective short-term thermal storage solutions;
    - to reduce the burden on the electricity grid;
    - to provide non-fossil heating solutions to buildings for which switching to a decentralised renewable energy system is challenging. It may be worth giving preference to district solutions, even if only for a part of the buildings concerned such challenges exist.
- If policymakers would like to see district projects be implemented to harness those additional benefits, policy measures are necessary, because the market all by itself is unlikely to deliver district solutions to a large extent.
- Nevertheless, decentralised solutions continue to be attractive options. Advantages they have are:
    - Less need for planning and coordination efforts as well as dependencies on end-users;
    - Open up the possibility of customizing energy efficiency at the building level.
- For decentralised solutions, heat pumps are usually the most cost-effective solution. Local constraints and availability mainly decide the choice of heat pump technology.
- Synergies between energy efficiency measures and renewable energy-based heating systems occur for all types of heating systems. There are even indications that such synergies are higher for district heating systems than for individual heating systems.
- An important factor concerning synergies between energy efficiency measures on building envelopes and renewable energy systems is the possibility of lowering the temperature of the grid due to energy

efficiency measures on the building envelopes. This requires a solution to generate hot water while maintaining its safety from a health perspective, even at lower temperatures. Such solutions exist yet require careful examination. The lowering of the temperature can be supported by measures related to the radiators supplying heat.
- Significant energy efficiency measures are usually particularly cost-effective for building envelopes in poor condition (from an energy efficiency perspective). For buildings that have previously undergone energy efficiency measures, reaching cost-effectiveness in these measures is more challenging. It is important to utilize the opportunity for energy efficiency measures on building envelopes when renovations are needed anyway.

There are some important limitations to the studies performed in IEA EBC Annex 75:
- The IEA EBC Annex 75 calculations are limited to residential districts. This has some important implications. Purely residential districts will have a homogenous consumption pattern. This is especially true in the case of simulations, as the same standardised consumption profiles are usually assumed for all buildings of the same category. The very high coincidence factor limits the benefits of central systems, as the possibility of reducing the total installed capacity is not significant. This can, to some extent, be handled by utilizing statistical modelling of individual profiles. However, this has not been performed in any of the IEA EBC Annex 75 calculations. Also, residential buildings have limited cooling demand. Only the studies performed in southern Europe (Italy and Portugal) include cooling.
- The districts investigated are fairly homogenous.
- The IEA EBC Annex 75 methodology focuses on renovations at the district level. This is a broader scope than the individual building level, but there is still a risk that solutions are suboptimal at a larger scale. Therefore, it is important to carefully consider what overarching strategies and parameters could influence the choice of the strategy.
- The IEA EBC Annex 75 methodology is purely techno-economic. Other social factors, such as user acceptance, ownership/tenants, etc., are not included but will influence the choice of strategy.

In general, the results from the IEA EBC Annex 75 calculations further demonstrate the attractiveness of the decarbonisation trend in the upcoming energy transition, mostly through electrification. The results show that changing to renewable energy-based heating systems, including district-level options, is a cost-effective way forward. However, for buildings to help and not hinder the energy transition, it is also important to keep a focus on energy efficiency measures. Results of this Annex show that many synergies exist between the two, yet those synergies may not be utilized easily.

As pointed out above, there is a risk that various advantages of district solutions are overlooked when focusing on cost-effectiveness at the district level. The electrification of the energy system requires flexible end-users. Individual buildings can be flexible themselves. However, further flexibility could be added with larger-scale thermal systems, with more cost-effective thermal storage (short-term and long-term) and fuel-switch possibilities. District-level solutions can also be key to accessing certain renewable energy sources or providing heating to buildings where this would be challenging to achieve at the level of individual buildings. Therefore, it makes sense to develop city-wide, regional, and country strategies within the framework of which district strategies can be positioned and developed.

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# Appendix

## Appendix A – strategy development template

## Questions for input to the strategy development

***General comments to this part of the template***
*In the B4 strategy report a more qualitative assessment of the results will be done to try to extract recommended strategies from the calculation results. To get the best possible foundation for this, It is important that you try to answer the questions in this section as elaborative as possible. All multiple choice/tick-off questions have a possibility for comments, please use them. In all tables with alternatives, you are free to add extra lines.*

In context of the results from the calculations please try to answer the following questions:

## IEA EBC Annex 75 Research questions

1 What are 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 meeting the pre-set targets?

Answer:

2 In particular: What are 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 on the buildings' envelopes?

Answer:

3 How do related strategies compare in terms of cost-effectiveness and impacts with strategies that combine a decentralised switching of energy carriers to renewable energy with energy efficiency measures on the buildings' envelopes?

Answer:

4 In particular: Under which circumstances does it make sense to use available renewable energy potentials in cities at a district level, and under which circumstances are decentralised renewable energy solutions, in combination with energy efficiency measures on the buildings' envelopes, more advantageous?

Answer:

5 Which approaches, taking into account various possibilities for energy efficiency measures and renewable energy measures, allow to achieve districts supplied entirely with renewable energy at least costs?

Answer:

6 Which factors determine the cost-effective balance between efficiency measures on the building envelopes and measures to use renewable energy, if far-reaching reductions in carbon emissions and primary energy use in urban districts are the target?

Answer:

7 To what extent does the cost-effectiveness of renovation measures on the building envelopes in the case of a local district heating system based on renewable energy differ from the cost-effectiveness of such measures in case of a decentralised use of renewable energy sources for heating in each individual building?

Answer:

## Further elaboration:

**General:**

*Below you are asked to rate different factors according do importance. Please consider the following scale:*

| *Not important* | *Rather not important* | *Neutral* | *Rather important* | *Important* | *Not part of investigation* |
|---|---|---|---|---|---|
| *1* | *2* | *3* | *4* | *5* | *0* |

**In relation to the choice between central or decentral solution:** How important do you consider various factors to be in your case studies/generic districts in influencing the comparison of the cost-effectiveness between the two approaches? Mark the right alternative for each row.

| | 1 | 2 | 3 | 4 | 5 | 0 | Comment |
|---|---|---|---|---|---|---|---|
| Existing infrastructure for district heating | | | | | | | |
| Available renewable energy sources | | | | | | | |
| Energy need of the buildings for heating before renovation | | | | | | | |
| Synergies with measures on the building envelope | | | | | | | |
| Energy prices | | | | | | | |
| Cooling needs of the buildings | | | | | | | |
| Linear energy density (distribution pipelines per kWh delivered heat) | | | | | | | |
| Others | | | | | | | |

Are there factors not included in the calculation method and results that are important in the choice between central or decentral solutions (both practical and social)?

Answer:

**In relation to the technology for thermal energy supply:** How important do you consider various factors to be in your case studies/generic districts in influencing the comparison of the cost-effectiveness? Mark the right alternative for each row.

| | 1 | 2 | 3 | 4 | 5 | 0 | Comment |
|---|---|---|---|---|---|---|---|
| Existing infrastructure for district heating | | | | | | | |
| Available renewable energy sources | | | | | | | |
| Energy need of the buildings for heating before renovation | | | | | | | |
| Synergies with measures on the building envelope | | | | | | | |
| Energy prices | | | | | | | |
| Cooling needs of the buildings | | | | | | | |
| Others | | | | | | | |

Are there factors not included in the calculation method and results that are important in the choice of thermal energy supply solution (both practical and social)?
Answer:

**In relation to the most cost-effective level of energy efficiency measures on the building envelopes:** How important do you consider various factors in your case studies/generic districts to be in influencing the most cost-effective level of energy efficiency measures on the building envelopes? Mark the right alternative for each row.

| | 1 | 2 | 3 | 4 | 5 | 0 | Comment |
|---|---|---|---|---|---|---|---|
| Thermal energy supply system | | | | | | | |
| Energy need of the buildings for heating before renovation | | | | | | | |
| Energy prices | | | | | | | |
| Cooling needs of the buildings | | | | | | | |
| Economies of scale for renovation costs in districts | | | | | | | |
| Others | | | | | | | |

To what extent is the cost effectiveness of the energy efficiency measures with respect to the reference case dependent on anyway renovations included in the reference case? Select the most accurate alternative.

| | 1 | 2 | 3 | 4 | 5 | 0 | Comment |
|---|---|---|---|---|---|---|---|
| Significance of anyway renovation measures in reference case for cost-effectiveness with reference case | | | | | | | |

**In relation to local renewable electricity production:**
How important do you consider various factors to be in your case studies/generic districts in influencing the cost effectiveness of local renewable electricity production?

| | 1 | 2 | 3 | 4 | 5 | 0 | Comment |
|---|---|---|---|---|---|---|---|
| Share of self consumption vs export to the grid | | | | | | | |
| Climate | | | | | | | |
| Tariff for electricity fed into the grid | | | | | | | |

Tariff of electricity provided by the grid
Available space, size of the installation
Others

**General:**

Do you see the most cost-effective solution to be the best overall solution for the district? If not, Why? E.g density of population; structure of building types/ownership / tenants (esp. age); structure of current energy supply system/ suppliers; perspective of the housing market/ etc....)
Answer:

Are there other important cost factors not included in the calculation boundary? Eg. a switch from a fuel or district heating-based system to an electric system (Heat pump) could require an upgrade of the electricity infrastructure outside the district.
Answer:

Are there practical implications/limitations not included in the analysis that might disqualify some of the solutions?
Answer:

Any other comments you think are relevant?
Answer:

ANNEX 75

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