Final report

1. Project details

Project title	Cost-effective strategies to combine energy efficiency measures and renewable energy use in building renovation at district level – Danish participation in IEA EBC Annex 75
File no.	64017-0586 and 134-21014 (which is an extension of the Annex 75 project)
Name of the funding scheme	EUDP
Project managing company / institution	BUILD, AAU
CVR number (central business register)	29102384
Project partners	Ove Mørck and Ole Balslev-Olesen, Kuben Management; Jørgen Rose and Kirsten Engelund Thomsen, Department of the Built Environment (former SBi), AAU
Submission date	23 April 2024

2. Summary

In English:

The project aimed to investigate cost-effective strategies for reducing greenhouse gas emissions and energy use in buildings in cities at district level, combining both energy efficiency measures and renewable energy measures. The objective was to provide guidance to policy makers, companies working in the field of the energy transition, as well as building owners for transforming cost-effectively 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, the identification of cost-effective strategies is important for accelerating the necessary transition towards low-emission and low-energy districts in cities. The Annex focused mainly on residential buildings, both single and multifamily houses.

Several reports, guidelines, tools, and papers for international journals have been produced to support decision-makers from public and private sectors in making better decisions. The Danish team was responsible for writing a Technology Overview Report including the following main parts: Overview on state-of-the-art tech-

nology, Techno-economic characterization of technology options, Identification of interdependencies, obstacles, and success factors for combining energy efficiency measures with renewable integration and outlook to potentials and future developments.

The Danish team was deeply involved in the Methodology Report on cost-efficient building renovation at district level to assess the optimal balance between energy efficiency measures and renewable energy measures at district level. Furthermore, a Danish success story (Kildeparken, Denmark) was included, and for this district generic parameters studies were performed. Dissemination of project news and results are carried out on the project website (annex75.iea-ebc.org) and through social media.

In Danish:

Formålet med projektet er at undersøge omkostningseffektive strategier til at reducere udledningen af drivhusgasser og energiforbrug i bygninger i byerne på bydelsniveau, der kombinerer både energieffektivitet og foranstaltninger for vedvarende energi. Det overordnede formål er at udvikle retningslinjer og vejledninger for den nødvendige transformering af byens energiforbrug i den eksisterende bygningsmasse mod lavenergi og lavemissions løsninger på en kosteffektiv måde. Målgrupperne er politikere, offentlige beslutningstagere, firmaer der arbejder med strategier for en ændret energiforsyning samt bygningsejere. Annex 75 fokuserede hovedsageligt på beboelsesejendomme, både en- og flerfamiliehuse.

Adskillige rapporter, retningslinjer, værktøjer og papers til internationale tidsskrifter er blevet udarbejdet for at støtte beslutningstagere fra offentlige og private sektorer i at træffe bedre beslutninger. Det danske team har været ansvarlig for at skrive en teknologioversigtsrapport, der indeholder følgende dele: Oversigt over den nyeste teknologi, Teknoøkonomisk karakterisering af teknologimuligheder, Identifikation af indbyrdes afhængigheder, forhindringer og succes faktorer for at kombinere energieffektivitet med integration af vedvarende energi samt oversigt over potentialer og fremtidig udvikling.

Det danske team var dybt involveret i udarbejdelsen af en Methodology report om omkostningseffektiv bygningsrenovering på bydelsniveau for at vurdere den optimale balance mellem energieffektiviseringstiltag og vedvarende energitiltag. Endvidere blev en dansk succeshistorie (Kildeparken, Danmark) inkluderet, og for denne bydel blev der udført generiske parameteranalyser og udarbejdet omkostningskurver for de foranstaltninger og scenarier, der blev undersøgt mht. energi- og livscyklus analyser.

Formidling af projektnyheder og resultater meddeles på projektets hjemmeside (annex75.iea-ebc.org) og gennem de sociale medier.

3. Project objectives

Buildings are a major source of greenhouse gas emissions and cost-effectively reducing their energy consumption and associated emissions is particularly challenging for the existing building stock mainly because of the existence of many architectural and technical hurdles.

The transformation of existing buildings into low-emission and low-energy buildings is particularly challenging in cities, where many buildings continue to rely too much on heat supply by fossil fuels. However, at the same time, there are specific opportunities to develop and take advantage of district-level solutions at urban scale. In this context, the project aimed at clarifying the cost-effectiveness of various approaches combining both energy efficiency measures and renewable energy measures at district level.

The objective was to provide guidance to policy makers, companies working in the field of the energy transition, as well as building owners for transforming cost-effectively 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, the identification of cost-effective strategies is important for accelerating the necessary transition towards low-emission and low-energy districts in cities.

The Annex focused mainly on residential buildings, both single and multifamily houses.

Accurate understandable information, guidelines, tools, and recommendations are provided to support decision-makers from public and private sectors in making better decisions.

To summarize, the project focused on the following objectives:

- To give an overview on various technology options, taking into account existing and emerging efficient technologies with potential to be successfully applied within that context, and how challenges specifically occurring in an urban context can be overcome;
- To develop a methodology which can be applied to urban districts in order to identify such cost-effective strategies, supporting decision makers in the evaluation of the efficiency, impacts, cost-effectiveness and acceptance of various strategies for renovating urban districts;
- To illustrate the development of such strategies in selected case studies and gather related best-practice examples;
- To give recommendations to policy makers and energy related companies on how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures in building renovation at district level, and to give guidance to building owners/investors on related cost-effective renovation strategies.

The Annex 75 is structured in four major subtasks.

Subtask A: Technology Overview

The aim of this subtask was to provide an overview on the available technology options for renovating building envelopes and for switching heating and cooling systems, as well as domestic hot water systems, into renewable energy-based systems in districts.

Subtask B: Optimization Methodology and Strategy Development

The objective of this subtask was to develop the methodology to define cost-effective strategies for renovating urban districts towards far-reaching reductions of carbon emissions and energy use. This methodology will build on the methodology previously developed for individual buildings in Annex 56 extending it to the level of groups of buildings.

Subtask C: Case Studies

The objective of this subtask was to illustrate in selected case studies the development of cost-effective strategies to combine energy efficiency measures and renewable energy use in building renovation at district level. It also aims to investigate factors influencing the choice for a cost-effective strategy, and to gather related best-practice examples.

Subtask D: Policy Instruments, Stakeholder Dialogue, and Dissemination

The objective of this subtask was to give recommendations, in form of guidelines, to policy makers and local energy related companies on how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures for the transformation of existing districts into low- energy and low-emission districts. The subtask also aims to provide guidance to building owners, as they are the main decision-makers and investors for building renovation.

4. Project implementation

Annex 75 was approved in November 2016 and its Preparation Phase was from November 2016 until November 2017. The Danish participation of Annex 75 started November 2017 until the end of June 2022. Originally, Annex 75 should have been completed by the end of December 2021, but due to Covid-19 there has been a half year extension of the project.

At the meeting in June 2022, it was announced that the IEA Annex 75 project had been postponed until November 2022. BUILD will end the Danish project at the end of June 2022 but will continue for the rest of the year to help complete the final reports.

Figure 1. Meeting and networking in Bilbao, March 2019.

Meetings (Preparation Phase):

Meeting no. 1: Online meeting - July 2017 - 20 participants from 9 countries

Meeting no. 2: Guimarães, Portugal - October 2017 - 15 participants from 8 countries

Meetings (Working Phase):

Meeting no. 3: Madrid, Spain – March 2018 - 28 participants from 10 countries

Meeting no. 4: Graz, Austria – October 2018 - 30 participants from 10 countries

Meeting no. 5: Bilbao, Spain – March 2019 - 29 participants from 11 countries

Meeting no. 6: Delft, Netherlands – September 2019 - 27 participants from 13 countries

Meeting no. 7: Online meeting – March 2020 - 33 participants from 12 countries

Meeting no. 8: Online meeting – September 2020 - 27 participants from 11 countries

Meeting no. 9: Online meeting – March 2021 - 29 participants from 10 countries

Meeting no. 10: Online meeting – September 2021 - 30 participants from 10 countries

Meeting no. 11: Vienna, Austria – June 2022

Figure 2. Meeting and networking in Delft, September 2019.

Some of the meetings were held in connection with workshops, unfortunately this could not be done in connection with all the on-line meetings.

- Workshop on district renovation towards nZEB, Vitoria-Gasteiz, Spain, 27 March 2019
- Upscaling energy renovation to the district level, TU Delft, the Netherlands, 25 September 2019
- Workshop with the results from Annex 75, Austrian Institute of Technology, Vienna, Austria, 28 June 2022.

Annex 75 Webinar

- Roman Bolliger and Silvia Domingo Irigoyen from INDP organized the Annex 75 Webinar "Combining the heating and cooling potential of lakes and rivers with energy efficiency measures in buildings at district level" on September 23rd, 2020. Experts were invited to discuss the potential that lakes and rivers offer for providing heating and cooling energy to buildings, also in combination with energy efficiency measures on the building envelopes. In this webinar, related strategies and experiences were presented and discussed by several experts.

5. Project results

The project was organized in four Subtasks as follows:

- Subtask A: Technology Overview
- Subtask B: Optimization Methodology and Strategy Development
- Subtask C: Case Studies
- Subtask D: Policy Instruments, Stakeholder Dialogue, and Dissemination

5.1 Subtask A: Technology Overview

Leader: **Ove Mørck/Jørgen Rose** (Kuben Management/Aalborg University)
Co-leader: **Tomas Matuska** (CVUT, Czechia)

The aim of this subtask was to provide an overview on the available technology options for renovating building envelopes and for switching heating and cooling systems as well as domestic hot water systems into renewable energy-based systems in districts.

Starting from a characterization of measures in single buildings (information readily available as already investigated in depth by other studies), a focus was put on identifying options for carrying out such measures at district level. Concerning energy efficiency measures on building envelopes, such options refer to the cost-effective renovation of groups of buildings with a similar structure.

Concerning renewable energy measures, a distinction is made based on the question whether a district heating system is available in each district, or whether heating and cooling is carried out decentrally. For existing district heating systems, measures are described for transforming them into renewable energy-based district heating systems. For districts with decentralized heating and cooling, options are described for new high-temperature or low-temperature renewable energy-based district heating systems.

A focus is thereby put on the large untapped potential for renewable energy use based on low-grade renewable energy from the ground or from hydrothermal resources such as rivers, lakes, groundwater, aquifers, or the sewage system as well as on the use of solar energy. Large, related energy potentials are available in most cities; however, so far, only few cities have made use of these opportunities. Novel technologies are characterized such as cascading heat pumps or high temperature heat pumps that can upgrade heat from low temperatures to high supply temperatures, which are often necessary in existing buildings and particularly in existing district heating systems. Furthermore, technology options are described including the use of new types of "cool" district heating systems, where the working fluid is distributed to buildings without any upgrading of the heat source (making use of decentralized heat pumps in buildings for upgrading the heat source to the temperature required in each building). Also, technology options using solar energy at district level, in combination with storage capacities, are investigated. Within the framework of this work, information on various options previously identified in specific IEA projects and other research projects is brought together and characterized in a common format.

A typology of technology options to be investigated is developed. The technical, economic, and ecologic characteristics of the technology options are determined. This includes information on their efficiency, cost elements such as investment costs and operational costs considering economies of scale, as well as the embodied energy and the embodied emissions associated with these options. 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.

Subtask A (STA) was organized in the following work packages (WP)

- WP A1: Identification of existing and emerging technology options (both envelope and systems and at both building and urban scale)
- WP A2: Characterization of technology options (cooperation with WP B1)
- WP A3: Interdependencies, obstacles, and success factors for combining energy efficiency measures with renewable integration
- WP A4: Potentials and future developments

Main products

A Technology Overview Report was written including the following main parts:

- Overview on state-of-the-art technology
- Techno-economic and ecologic characterization of technology options
- Identification of interdependencies, obstacles, and success factors for combining energy efficiency measures with renewable integration
- Outlook to potentials and future developments.

Technology Overview Report, May 2020

Author(s): Ove C. Mørck, Jørgen Rose, Kirsten Engelund Thomsen, Tomas Matuska, Sergio Vega Sanchez.

This report is the first of the deliverables from the IEA Annex 75 project. It documents the work of Subtask A – Technology Overview. As the title of the subtask indicates, the idea of this subtask was to create an overview of the available technologies for energy renovation and renewable energy supply at the district level. The technical and economic characteristics of the technology options are also determined. 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.

The work has been carried out in several steps. In the first step, candidate technologies were identified among the project participants and briefly documented in a standard (mini-) template. The 25 technologies identified and described were compiled in a short report ("Technology overview – Subtask A Work Package A1"), which is available at the project website.

In the second step, based on their individual relevance regarding the scope of the project, technologies were selected and combined into 14 main technologies. The technologies are documented in this report using a (maxi-) template providing also technical as well as financial and environmental information. The 14 technologies have been subdivided into three overarching categories:

- Demand reduction - energy saving technologies (5 technologies)
- Energy distribution and supply systems (7 technologies)
- Energy storage systems (2 technologies)

It should be noted that the list of technologies documented in no way is to be considered exhaustive. The idea has been to document the technologies with a potential for cost reductions when implemented for a series of buildings at the urban scale, as well as technologies with a clear potential to be implemented at an urban scale for energy supply and storage.

In a third step, data for the identified technologies on their technical performance and costs were identified, collected, and documented. This was done via a survey to the countries participating in Annex 75. An excel sheet template was developed for each of the technologies and distributed amongst the participants. Data was received for eight of the participating countries. Data on measures for individual buildings are readily available. Data on renewable energy sources, PV, and solar thermal applications, together with heat pumps, are covered quite well, while data on cooling units, PVT collectors (still quite new on the market) or biomass combined heat and power are covered to a lesser extent. The consistency of the data for PV systems, solar thermal and heat pumps were checked by comparing the received data from the different countries. Quite large absolute differences in costs were observed, but the trends showing reduced costs with size (economy of scale) were consistent between different national contexts.

The fourth step was an analysis of the interdependencies, obstacles factors and success factors for implementing individual technologies and furthermore identifying cost-effective combination of technologies and strategies. To fulfil the objective of intervening in buildings and districts in such a way that a renovated Net Zero Energy Districts is achieved, this work started from a holistic approach. This allowed to create a map of processes and a flow diagram of all the phases of the process, agents and stakeholders involved - the main key drivers that must support a successful renovation of Net Zero Energy Districts. In this report, however, the work presented is limited to the technical aspects of the reported technologies and documented in a fact sheet for each of the technologies covering the interdependencies, obstacles, and success factors. None of the technologies and strategies analysed are applicable to different climatic conditions and uses, and it is the analysis of the interdependencies between combinations of technologies and strategies and the identification of what their efficiency depends on that allows their cost-effectiveness to be optimized.

In the fifth and final step, the technology options were put into context with available potentials, and an outlook is made on their future developments. Possible and foreseen future developments are described for individual technologies to foresee possibilities for further improvements to efficiencies, reductions of price or major breakthroughs in technologies. Again, the primary intention has been to describe technologies most relevant to the Annex 75 work.

Summing up, the work carried out in subtask A has established an overview of a technology base that can be utilized in the calculations that will be carried out in subtask B regarding generic districts and for case studies in subtask C.

5.2 Subtask B: Optimization Methodology and Strategy Development

Leader: **Roman Bolliger** (INDP, Switzerland)
Co-leaders: **Jon Terés Zubiaga** (University of Basque Country, Spain)
Andreas Rudena/Toivo Säwèn (StruSoft, Sweden)
Harald Walnum (SINTEF, Norway)

The objective of this subtask was to develop the methodology to define cost-effective strategies for renovating urban districts towards far-reaching objectives regarding the reduction of greenhouse gas emissions and energy use. The Annex was built on the methodology previously developed for individual buildings in Annex 56 extending it to the level of groups of buildings. The idea was to identify cost-effective strategies, as facilitated by the methodology to be developed, that will support decision makers in the evaluation of the efficiency, impacts, cost-effectiveness, and acceptance of various strategies for renovating urban districts.

A typology of districts is established. The type of districts to be investigated is defined, indicating the scope regarding the number of buildings to be considered as well as the mix of urban functions in these districts, such as residential and businesses. A flexible approach was chosen, which can be applied both to small groups of buildings, as well as to larger groups of buildings amounting to districts. It is also considered that there are neighbourhoods where heat consumption is lower than what could be expected from the energy performance of the corresponding building envelopes due to energy poverty situations.

Furthermore, national framework conditions are defined, including expectations regarding their future development. A life-cycle cost approach is applied, putting energy efficiency measures and renewable energy measures into perspective with each other and allowing to assess combinations of the two types of measures in a comprehensive framework.

The methodology addresses the challenge that in districts, buildings have different starting situations, as well as the challenge that renovation cycles of the buildings' envelopes in a district are usually not synchronized. Furthermore, the methodology provide guidance on how and up to what level of detail the energy needs of the district's buildings must be determined for developing cost-effective strategies.

The resulting tool is intended to serve as a support tool for preliminary decisions, which does not just consider fixed types of building typologies yet can be adapted to fit the reality.

The methodology is applied and tested in generic calculations in Subtask B and in parametric calculations based on case studies in Subtask C. Through the application of the methodology in such a way, it is possible to identify and characterize factors, such as energy density in each area, affecting cost-effectiveness of renovation strategies for urban districts. In addition, it is possible to investigate synergies as well as trade-offs between renewable energy measures and energy efficiency measures, and between individual and collective solutions.

Based on the results obtained, and considering results from other Subtasks, various strategies are described to transform existing districts into low-energy and low-emission districts in different country contexts, as well as the opportunities and risks of such strategies.

Subtask B (STB) was organized in four work packages (WP):

- WP B1: Methodological guidelines and framework conditions
- WP B2: Adaption or development of optimization tools
- WP B3: Cost optimization with respect to varying energy and GHG reduction targets for generic reference districts
- WP B4: Strategy development

Main products

- Methodology Report on cost-efficient building renovation at district level: A methodology in conformity with the methodology previously developed in Annex 56 at building level and extended, to assess the optimal balance between energy efficiency measures and renewable energy measures at district level.
- Assessment tools: identification and adaptation of one or more existing tools to support the application of the methodology in generic and case-specific assessments.
- Report on the application of the methodology in generic districts
- Report on strategy development

In **WP B1** – Methodological guidelines and framework conditions, an interim version of the report on the Annex 75 methodology was submitted to the EBC ExCo for review in June 2020. At the Experts Meeting in March 2022, it was proposed to reformulate part of the wording in the report concerning the hypotheses to further facilitate understanding by readers, while keeping all its content. The final version of this report is planned to be completed in June 2022 to accommodate these additional changes. The final data on primary energy factors and energy prices used in the calculations will also be included in this version.

The hypotheses focus mainly on comparing the cost-optimal level of energy efficiency measures on building envelopes in different scenarios. The following hypotheses are investigated:

Hypothesis 1: Comparing centralized and decentralized renewable energy systems

When comparing centralized and decentralized renewable energy systems, the hypothesis is as follows:

«The **cost-optimal level of energy efficiency measures** on building envelopes **does not differ significantly** when comparing on the one hand a combination of such measures with a **district heating system based on renewable energies** and on the other hand a combination of such measures with **decentralized individual heating systems based on renewable energies**. »

Hypothesis 2: Comparing a fossil fuel-based district heating system with a centralized switch to renewable energies

When comparing a fossil fuel-based district heating system with a centralized switch to renewable energies, the hypothesis is as follows:

«In case the starting situation is an existing district heating system based fully or to a large extent on fossil fuels, **a centralized switch of that heating system to renewable energies does not lead to a significant change in the cost-optimal level of energy efficiency measures on the envelopes** of buildings connected to that system in comparison with the reference case based on the starting situation. »

Hypothesis 3: Comparing a fossil fuel-based district heating system with a decentralized switch to renewable energies

When comparing a fossil fuel-based district heating system with a decentralized switch to renewable energies, the hypothesis is as follows:

«In case the starting situation is an existing district heating system based fully or to a large extent on fossil fuels, **a switch to decentralized renewable energy systems does not lead to a significant change in the**

cost-optimal level of energy efficiency measures on the envelopes of the related buildings in comparison to the reference case based on the starting situation. »

Hypothesis 4: Comparing decentralized fossil fuel systems with a centralized switch to renewable energies

When comparing decentralized fossil fuel systems with a centralized switch to renewable energies, the hypothesis is as follows:

«In case the starting situation is a district with decentralized fossil fuel heating systems, a switch to **a centralized renewable energy based district heating system does not lead to a significant change in the cost-optimal level of energy efficiency measures on the envelopes** of the related buildings in comparison to the reference case based on the starting situation. »

Hypothesis 5: Comparing decentralized fossil fuel systems with a cold renewable energy-based district heating system

When comparing decentralized fossil fuel systems with a cold renewable energy-based district heating system, the hypothesis is as follows:

«In case the starting situation is a district with decentralized fossil fuel heating systems, a switch to **a cold renewable energy-based district heating system linked to decentralized heat pumps does not lead to a significant change in the cost-optimal level of energy efficiency measures on the envelopes** of the related buildings in comparison to the reference case based on the starting situation. »

Hypothesis 6: Comparing a new renewable energy-based district heating system with a switch of an existing district heating system to renewable energies

When comparing a new renewable energy-based district heating system with a switch of an existing district heating system to renewable energies, the hypothesis is as follows:

«**Compared to a district where a centralized renewable energy-based district heating system is newly installed, in the case of an existing district heating system switching centrally to renewables, the cost-optimal level of energy efficiency measures is less ambitious,** due to a lower potential of synergies between renewable energy measures and energy efficiency measures. »

Hypothesis 7: Districts with initial low level of thermal insulation

Regarding districts with initial low level of thermal insulation, the hypothesis is as follows:

«**In case the starting situation is a district with a low level of thermal insulation in the building envelopes, every optimal solution includes, to some extent, the implementation of energy efficiency measures on the buildings' envelopes**. »

Hypothesis 8: Districts with initial high level of thermal insulation

Regarding districts with initial high level of thermal insulation, the hypothesis is as follows:

«**In case the starting situation is a district with a high level of thermal insulation in the building envelopes with a fossil fuel-based heating system, every optimal solution includes at least a switch to renewable energy-based heating systems**»

Within **WP B2** – Adaptation or development of optimisation tools. The tool was developed as a web app, consisting of various parts, which define general information about the case to be assessed, characteristics of the building types in the district to be studied, cost curves and other parameters of measures to be implemented, as well as the renovation scenarios to be investigated. The tool calculates results and allows their visualisation. In parallel, and facilitated by the work on a common tool, project partners have been adapting their own tools to carry out assessments. The common IEA EBC Annex 75 tool ensured that all project partners could test the methodology developed in this project, applying it to investigate renovation strategies of selected generic or real-world districts and contributing to further harmonising project partners' own tools. Before the end of the Annex, a manual, a documentation of the calculation method will be written and a webinar to present the tool to interested people outside the project will be performed. In the future, beyond the framework of IEA EBC Annex 75, the possibility of including national databases and energy needs calculations is considered. The tool is open source and can be further developed in the future by anyone interested in doing this.

In the scope of **WP B3** – Cost optimisation concerning varying energy and GHG reduction targets for generic reference districts, participants completed the assessments of generic districts using their own tools or the common IEA EBC Annex 75 tool. Generic districts are virtual districts with characteristics that can be commonly found in the respective countries. The parametric studies performed in the generic districts are being used to demonstrate the feasibility of the IEA EBC Annex 75 methodology, investigate cost-effective packages of renovation measures, and investigate the synergies and trade-offs between energy efficiency measures and renewable energy measures. The report is currently being edited for completion in June 2022.

For **WP B4** – Strategy development, information was gathered from the generic assessments and case studies carried out within the Annex. Project partners completed a related template by providing feedback on factors influencing the cost-effectiveness of various combinations between renewable energy and energy efficiency measures and other aspects that may affect the development of suitable strategies. Questions included aspects on the following points: the choice between centralised and decentralised solutions, which technologies are seen as most relevant, how energy efficiency measures relate to technology choices, to what extent energy efficiency measures beyond anyway renovations are cost-effective, which local renewable energy production systems are often part of an optimal solution, as well as what other factors may influence strategy development. In addition, country-specific inputs on strategy development were prepared, considering national boundary conditions, national legislation, and national goals, as well as the main challenges and opportunities. The report is currently being edited for completion in June 2022.

5.3 Subtask C: Case-Studies

Leader: **David Venus** (AEE INTEC, Austria)
Co-leader: **Silvia Domingo Irigoyen** (INDP, Switzerland)

The objective of this subtask is to illustrate in selected case studies the development of cost-effective strategies to combine energy efficiency measures and renewable energy use in building renovation at district level, to investigate factors influencing the choice for a cost-effective strategy, and to gather related best-practice examples. It is also intended to obtain information regarding necessary framework conditions or policy instruments for facilitating the uptake of cost effective strategies for far-reaching renovations of districts. Furthermore, the role of co-benefits is also investigated.

In a first step, success stories involving district-based solutions for renewable energy use and energy efficiency measures are gathered and characterized. This includes both the transformation of previously existing district heating systems, as well as the creation of district heating systems based on renewable energies in districts previously heated with decentralized installations. Furthermore, this includes success stories for the mass-renovation of thermal envelopes in a specific district. It is documented to what extent the combination with energy efficiency measures on the building envelopes has been considered in the selected cases investigated, and to what extent grid-based solutions were advantageous with respect to individual heating or cooling solutions in the district.

In a second step, for selected case studies, the necessary data is gathered to carry out parametric assessments, applying and testing the methodology to be developed by the Annex. It is intended to select as case studies existing urban districts with renovation needs where the results of the case studies can provide guidance in choosing an appropriate renovation strategy for the respective district. It is investigated to what extent there are synergies and to what extent there are trade-offs for combining energy efficiency measures and renewable energy measures. It is envisaged to determine cost-effective renovation strategies for the investigated districts considering both energy efficiency measures and renewable energy measures.

Enabling factors and obstacles for the implementation and replication of successful case studies for transforming existing districts into low-energy and low-emission districts are assessed in various country contexts, considering also co-benefits as well as results on investigations on user acceptance from previous studies.

Results obtained and lessons learned are used to prepare a good practice guidance for low-energy and low-emission districts.

Subtask C (STC) was organized in four work packages (WP)

- WP C1: Success stories
- WP C2: Parametric assessment of selected case studies
- WP C3: Enabling factors and obstacles for replicating successful case studies
- WP C4: Good practice guidance for transforming existing districts into low-energy and low-emission districts

Main products

- Report on parametric assessments of case studies: case studies on cost-effective combinations of energy efficiency measures and renewable energy measures in building renovation at district level
- Online documentation of good practice examples: a collection of good examples for successful implementation of strategies on transforming existing urban districts to low-energy and low-emission districts, combining energy efficiency measures and renewable energy measures or waste heat, including aspects relating to stakeholder dialogue and acceptance by building owners
- Report on enabling factors and obstacles to replicate successful case studies
- Good practice guidance: Guidance for transforming existing districts into low-energy and low-emission districts

In WP C1 – Success Stories, 15 success stories have been prepared and are available in an interactive map on the IEA EBC Annex 75 website (http://annex75.iea-ebc.org/success-stories). A summarising report has been prepared and is now under internal review. It includes in one document all success stories and additional tables which summarise the main outcomes of all success stories. The report also includes, as an attachment, the collection of existing databases of best practice examples, which were gathered in the IEA EBC Annex 75. This task aims to give a broader overview of best practice examples, which were collected in other research projects. The report will be submitted for the EBC ExCo review in June 2022.

In WP C2 - Parametric assessment of selected case studies is planned to be finished by the end of June 2022. Results of the case study investigations will be included in the WP C4 report and in the guidelines that are being prepared by STD, besides being presented at the final Workshop to be held in June 2022 in Vienna.

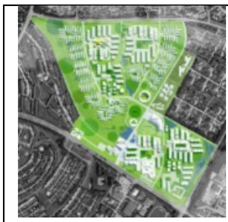
The main objective of WP C3 - Enabling factors and obstacles for replicating successful case studies, is to assess enabling factors and obstacles for the implementation and replication of successful case studies for transforming existing districts into low-energy and low-emission districts. The report on WP C3 has been prepared and discussed and the work is based on the data collection from the 15 success stories (see also WP C1) as well as on 31 interviews with different stakeholders, which were carried out and analysed together with STD. The report will be finalised by June 2022.

The report of WP C4 - Good practice guidance for transforming existing districts into low-energy and low-emission districts, has been postponed several times because this good practice guidance totally depends on the results of the work packages C1, C2, and C3. Additionally, the aim is also to have a link to the technologies, which were analysed in STA and to the generic districts' calculations analysed in STB (B3). The draft version of the report is sent out by the end of May 2022 for internal review and sent to the ExCo in June 2022.

A list of 9 success stories are shown below.

A cross-section analysis of the case studies has helped identify similarities, differences and general findings that can feed into the ongoing work. The analysis covered: goals of the interventions, the balance between energy efficiency and renewable energy sources, drivers, e.g., decisive aspects for the successful implementation of interventions, the main barriers and influencing factors, policy instruments, business models examples and the most important lessons learned. Those are the topics described in the data collection template (IEA Annex 56 Webpage), which was based on previous Annexes' experiences (Bolliger & Terés-Zubiaga, 2020), as explained in the methodology section. The topics are considered to cover the different phases and stakeholders of the case studies. As such they contribute to the replicability of the findings in different context of district renovation. The analysis was conducted by comparing the individual parts of the case study descriptions, e.g., regarding stakeholder involvement or the goal of the intervention and then categorizing and cataloguing each case study for each parameter analysed. This way, case studies that have similarities were grouped and a cross-sectional analysis was conducted to withdraw as much information as possible. The following table summarizes the case-study analysis results, according to the identified topics.

Strubergasse, Austria (before/after: 623/636 dwellings)				***AT***
	Areas [m²]	Energy use [kWh/m²y]	before	after
	District	Heating	93-150	27-35
	45 000	DHW	≈ 30	≈ 20
	Heated floor (before/after)	Cooling	0	0
	15 500/36 000	Renewable energy (ST m²)	0	2 048
	The renovation of 286 apartments, the demolition of 337 apartments and new construction of another 350 apartments were combined with the connection to an existing district heating network of the Salzburg AG. The intervention included the implementation of a new, high-quality open space and shows a possible way for improving the housing quality for other existing city districts.			
Kildeparken, Denmark (before/after: 942/1 228 dwellings)				***DK***



Areas [m²]	Energy use [kWh/m²y]	before	after
District	Heating	≈ 134	≈ 68
540 000	DHW	≈ 53	≈ 23
Heated floor (before/after)	Cooling	0	0
96 446/119 886	Renewable energy (m²)	0	0

The buildings in this project have undergone a transformation: building envelopes have been insulated, windows replaced, and the district heating network has been refurbished. New buildings have been added and the overall purpose of the refurbishment has been to lift the neighbourhood and make it more attractive to both existing and possible new tenants. The project has succeeded in transforming Kildeparken to a much more interesting community for its inhabitants.

Quartiere Sangallo, Italy (235 dwellings) — ***IT***

Areas [m²]	Energy use [kWh/m²y]	before	after
District	Heating	219	50
7 542	DHW	54	22
Heated floor	Cooling	0	0
23 258	Renewable energy (PV m²)	0	49

The intervention consists of the renovation of the district heating system, replacing the heat generators, improving control and distribution efficiencies of the heating system as well as the thermal renovation of three of the buildings (enclosed in a square in both figures) having 48 dwellings). In these buildings, a grid-connected photovoltaic system was installed on each building roof along with an air-to-water heat pump per building for producing DHW in the summer period.

Rainha Dona Leonor, Portugal (before/after: 150/90 dwellings) — ***PT1***

Areas [m²]	Energy use [kWh/m²y]	before	after
District	Heating	119	69
19 700	DHW	37	27
Heated floor	Cooling	6.4	7.8
5 000	Renewable energy (ST m²)	0.0	540

In this renovation project, heating needs were reduced by 43%. The new cooling system improved indoor living conditions during hot seasons. Renovation measures led to an increase in rent, but it was offset by energy savings. Energy use was reduced by almost 70%, which also enabled users to heat indoor spaces and keep the interior environment within healthy and comfortable temperatures.

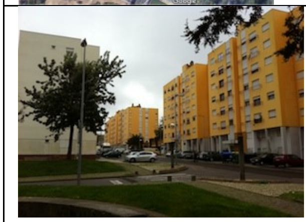
Vila D´Este Housing, Portugal (2 085 dwellings) — ***PT2***

Areas [m²]	Energy use [kWh/m²y]	before	after
District	Heating	84	57
170 000	DHW	30	30
Heated floor	Cooling	0	0
126 000	Renewable energy (ST m²)	0	500

This renovation project led to the improvement of the energy performance of the buildings, allowing a potential annual saving of 3 800 ton CO_2-eq. and an estimated annual saving of 837 434 €. The intervention consists of an extensive renovation of all the residential buildings, as well as the implementation of solar energy in the common swimming pools complex.

Boavista neighbourhood, Portugal (1 559 dwellings) — ***PT3***

Areas [m^2]	Energy use [kWh/m^2y]	before	after
District	Heating	60.5	48.2
55 000	DHW	30	20
Heated floor	Cooling	0	0
80 000	Renewable energy (ST m^2)	0	118



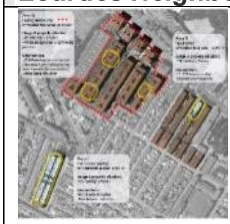
This project is an interesting intervention, because it is the first phase of a project with a significant intervention area of 20 hectares, where approximately 6 000 people live. The intervention was made taking into consideration not only energy efficiency, but also health and thermal comfort concerns. Energy efficiency measures combines with the implementation of renewable energy sources.

Coronación district, Spain (320 dwellings + 5 tertiary buildings) — ***ES1***

Areas [m^2]	Energy use [kWh/m^2y]	before	after
District	Heating	151	70
89 100	DHW	Included in heating	
Heated floor	Cooling	0	0
49 187	Renewable energy (m^2)	0	0

This project is part of SmartEnCity, a project funded under the European Union's Horizon 2020 in which Vitoria-Gasteiz is one of the three lighthouse demonstrator cities. The intervention consisted of the thermal renovation of 320 dwellings and the installation of a new district heating system based on biomass boilers (wood chips). An integrated energy management system will optimise efficiency at dwelling, building and district level. The project was partly financed (up to 54%) by different public institutions; in some cases (households with low incomes), the regional government cover up to 100% of the cost.

Lourdes Neighbourhood, Spain (486 dwellings) — ***ES2***



Areas [m^2]	Energy use [kWh/m^2y]	before	after
District	Heating	90	46*/24**
22 500	DHW	Included in heating	
Heated floor	Cooling	0	0
40 448	Renewable energy (m^2)	0	0

* Non-renovated buildings

** Renovated buildings

	This project responds to the need to promote the integral renovation of this deprived social housing area and the upgrade of the inefficient district heating system (80% renewables with biomass) as well as the improvement of thermal envelopes of only three blocks. The project was framed within a CONCERTO Programme and subsidies and the favourable financing opportunities played an important role in the successful implementation of the intervention. This success is moving other neighbours into action and a second redevelopment project in the district is currently under development, promoting the renovation of thermal envelopes of the rest of the blocks.			
Linero, Sweden (379 dwellings)				***SE***
	Areas [m^2]	Energy use [kWh/m^2y]	before	after
	District	Heating	98-182	66-107
	90 300	DHW	12-30	21
	Heated floor	Cooling	0	0
	40 400	Renewable energy (PV m^2)	0	500
	This project was initiated and mainly financed by the municipal housing association LKF and partly funded by EU as one of CITyFiED demo-site district retrofit projects. The intervention included the renovation of the buildings as well as the renovation of the existing district heating network and addition of PV panels, to reach 100 % renewable energy sourcing. The project was initiated to maintain the affordability of the apartments by reducing current and future energy costs. A pilot study carried out on just 4 apartments was performed to ensure the successful implementation of the project.			

Figure 3. Nine success stories.

Some general conclusions can be drawn:

- The renovation of the thermal envelope is generally recommended, although cost-effective renovation can vary. Sometimes it is only one measure, e.g., window replacement, sometimes the refurbishment of the complete envelope. Sometimes, however, it can be in between. Which measures are cost-effective depends on several factors. Influencing factors are, for example, the initial situation (building already insulated or not), the climatic conditions (how much heating is required), and the prices (ratio of investment to energy costs).
- Concerning the energy supply systems studied, no clear recommendation can be derived about the energy generation system. Both decentralized, on the building level, heat pumps (air-water as well as geothermal) and district heating lead to good results and savings. In the case studies in which a supply on apartment level was investigated, these were mostly not recommendable.
- In the case studies examined, photovoltaics was largely investigated as a renewable energy source on site. It has been shown that the installation of a PV system makes sense from an energy point of view (and thus also CO_2 emissions), but that the economic viability is not always immediately given.
- Renovation measures on the building envelope, measures to replace the energy supply systems, and measures to use renewable energy sources can lead to CO_2 and primary energy savings but are not always cost-efficient or cost optimal. This is where the conflicting priorities become apparent. Savings to protect the environment vs. cost efficiency.
- Since the cost-efficiency is determined by comparing the investigated scenarios with the reference case, the definition of the reference case plays a special role. The reference cases differ from country to country, but even within a country, districts can have different initial situations and thus different reference variants.

- Many assumptions must be made for the calculation of different scenarios. This concerns assumptions about costs, such as investment costs for the refurbishment of the building envelope, energy supply and renewable energy sources, maintenance and repair costs, and energy costs. But assumptions must also be made about user behavior: what room temperature is used for calculations, what hot water consumption is assumed, and is active cooling also used? All these assumptions can influence the calculation results and, if individual parameters are changed, can also lead to different results or recommendations. Therefore, it is important not only to investigate different technical renovation measures but also the influence of such parameters. Also, the choice of the calculation program can influence the results. This must be considered as well.
- In addition to cost, CO_2, and primary energy savings, measures on the building envelope and the energy supply system also have other effects that were not part of the case studies but must nevertheless be taken into account (so-called "co-benefits"). For example, the thermal renovation of the exterior wall and the replacement of windows have a positive effect on the thermal comfort in the interior. Likewise, the use of a PV system, for example, can reduce energy dependency.

5.4 Subtask D: Policy Instruments, Stakeholder Dialogue, and Dissemination

Leader: **Erwin Mlecnik** (TU Delft - Faculty of Architecture and The Built Environment)
Co-leader: **Hauke Meyer** (German Association for Housing Urban and Spatial Development)

The objective of this subtask was to give recommendations to policy makers and local energy related companies about how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures in building renovation at district level. The subtask also aims to provide guidance to building owners, as they are the main decision-makers and investors for building renovation.

This will on the one hand be reached through the identification of suitable policy instruments. This will include recommendations regarding subsidy programs, mandates or obligations for energy companies or contractors, structures of energy tariffs, links to energy planning and contests for encouraging market up-take of cost-effective strategies for the renovation of urban districts. On the other hand, this will be reached through the development of business models for the renovation of districts and for putting them into perspective with individual solutions. Expert interviews are planned to take place with policy makers and stakeholders to identify such policy instruments and business models. A cooperation is thereby in particular sought with local authorities from cities in which case studies are carried out within the framework of the Annex.

Based on the results of the Annex, guidelines are prepared for policy makers, municipalities, and energy related companies on how to encourage the market take-up of cost-effective strategies combining energy efficiency measures and renewable energy measures for the transformation of existing districts into low-energy and low-emission districts. The guidelines also include aspects on stakeholder dialogue. Furthermore, guidelines are also prepared for building owners.

For the dissemination of the project, an Annex website are created as the main information point for various target groups and interested persons in general. Furthermore, Annex Newsletters are prepared and sent out regularly. Results from the research carried out, apart from their presentation in reports, are also published in scientific journals. Preference is given to open-access publications. The project is furthermore presented at international conferences. In several of the countries participating in the Annex, regional workshops are carried out for disseminating the results of the Annex. These workshops involved policy makers and stakeholders, to present and disseminate the guidelines and other results of the project.

Subtask D (STD) was organized in four work packages (WP)

- WP D1: Policy instruments
- WP D2: Business models and models for stakeholder dialogue (including user acceptance)
- WP D3: Guidelines
- WP D4: Dissemination

Main products

- Report on policy instruments, including recommendations for subsidy programmes and for encouraging market take-up through contests

- Report on business models and models for stakeholder dialogue

- Guidebooks: Guidelines for policy makers and energy related companies on how to encourage the market take-up of cost-effective strategies combining energy efficiency measures and renewable energy measures or waste heat for the transformation of existing districts to low-energy and low-emission districts; guidelines for building owners/investors about cost-effective renovation strategies, including district-based solutions

- Annex Website and Annex Newsletters

- Scientific publications, presentations at international conferences

- Carrying out of regional policy conferences with participation of international guests

- Regular communication through social media.

Subtask D was organised in four interrelated work packages and focuses on the preparation of supporting reports on policy instruments and business models with resulting recommendations. It further proceeds into guidelines to policymakers and building owners on how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures in districts. The Subtask aims to provide international input and guidance for exploring and developing policy instruments (report D1), for understanding and developing related business models (report D2) and guidance to policymakers and WP D4 supports the dissemination of results.

During the last months in spring 2022, Subtask D collected and analysed questionnaire results, guided by an analysis template for Annex members, to gather quantitative and qualitative information from representative stakeholders in Annex member countries. In this framework, WP D1, WP D2 and WP C3 used collective results that fit the topics and purposes of multiple deliverables. The compilation of the interview data collection progressed until November 2021, leading to a further increase in results (38 in-depth interviews from 8 countries) but also a slight delay in the deliverables.

The WP D1 (Policy instruments) and WP D2 (Business models and models for stakeholder dialogue) reports progressed at the lats months in the spring 2022, especially in developing the analysis, discussion, and conclusion sections. The final versions are being prepared by the deliverables leaders and the D1 report was sent to the ExCo reviewers in May 2022.

WP D1 report describes the policy options that local authorities have at the district level to support district renovation, including energy efficiency and renewable energy systems. Furthermore, the report explores how policy instruments are assessed by various types of actors, particularly for upscaling (combining) energy efficiency measures at residential buildings and renewable energy systems at the district level. The report provides a "catalogue" of policy instruments, presents, and discusses both quantitative and qualitative research results on the most promising policy instruments, and is completed with a discussion per country and on the

EU level, followed by a conclusion. An executive summary is also prepared, as well as a terminology list and annexes.

WP D2 was produced, reviewed internally in two phases, and is being finalised for ExCo review by end-May 2022. It includes a "catalogue" of business models, key considerations in combining energy renovation of buildings and energy supply business models, and Stakeholders' views. The information about the business model's main characteristics and relevant actors brings in supporting elements for the stakeholders' dialogue in terms of identifying the actors that need to communicate, their roles, and partnerships.

Regarding WP D3 – Guidelines, the work proceeded with the elaboration of an extended structure and progressive input for the guidelines. Recommendations for the guidelines were collected during a workshop held as part of the Annex meeting in March 2022. The workshop session organised by D3 addressed open questions and goals, aiming to concretise possible advice about target groups, district types, and framework conditions. Extensive recommendations were collected and clustered. An update of the guidelines was presented and discussed at the March meeting, resulting in further advice from Annex members. The guidelines for policymakers are in an advanced stage. The investor guidance will be further elaborated to focus on more prominent investors with "interface functions" to urban development (housing and urban development companies, energy suppliers). A draft version for internal review of the WP D3 guidelines was finished by the end of May 2022. The final version of the guidelines for ExCo review is expected for June 2022.

Regarding WP D4 – Dissemination, several actions took place where the project activities and results were disseminated mainly through the Annex 75 website and social media targeted to different groups interested in the topic. A final Annex meeting (the 27th of June 2022) and an IEA EBC Annex 75 workshop (the 28th of June 2022) are also planned to take place in Vienna, supported by the Austrian Institute of Technology (AIT). Additional national workshops are also being planned in Austria, the Netherlands, Spain, and Switzerland. The possibility of IEA EBC Annex 75 to organise a workshop at the International Conference SBE Delft, the Netherlands, 11-13 October 2022 is being evaluated. Next October, IEA EBC Annex 75 will also be represented in the IEA EBC Future Buildings Forum in Canada.

5.5 Journal papers etc.

Several papers were finalized. Below is mentioned the two Danish contributions.

Cost-effective building renovation at district level combining energy efficiency & renewables – Methodology assessment proposed in IEA-Annex 75 and a demonstration case study".

Authors: Jon Terés-Zubiaga, Roman Bolliger, Manuela G. Almeida, Ricardo Barbosa, Jørgen Rose, Kirsten E. Thomsen, Eduardo Montero, Raúl Briones-Llorente.

The paper was printed in "Energy and Buildings" - Volume 224, 1 October 2020, 110280 and can be found on the project website.

Abstract: Building renovation plays a key role in reducing greenhouse gas emissions and achieving the climate protection goals. The district scale approach is one of the most effective approaches to accelerate this process of reducing the energy consumption in the building sector as increasing its renovation rates. In this context, the Energy in Buildings and Communities Programme of the IEA, IEA-EBC started in 2017 the project "Annex 75: Cost-Effective Building renovation at District Level Combining Energy Efficiency and Renewables" aiming to explore optimal opportunities of district renovations from a cost-benefit perspective. IEA Annex 75 is a cooperative effort of participants from 13 different countries: Austria, Belgium, China, Czech Republic, Denmark, Germany, Italy, The Netherlands, Norway, Portugal, Spain, Sweden and Switzerland. In this paper, key elements of the methodology developed in Annex 75 project are presented. This methodology aims to facilitate the identification of optimal solutions in different European countries, enabling to explore similarities and differences amongst them, with a particular focus on the balance between energy efficiency measures and renewable energy measures. After a detailed description of the developed methodology, it is also applied to a case study located in Portugal and results obtained are analysed in detail. The paper demonstrates the usefulness of the methodology for evaluating and identifying optimal solutions in renovations at district scale, as well as for successfully addressing the research questions investigated by the Annex 75 project. They also provide some insights regarding the specific case study, showing that, although district systems are not usual in the current Portuguese context, these centralised solutions in renovations at district level are cost-effective interventions that can lead to significant reductions of greenhouse gas emissions and non-renewable primary energy use.

Building renovation at district level – Lessons learned from case studies in IEA EBC Annex 75.

Authors: Jørgen Rose, Kirsten Engelund Thomsen, Silvia Domingo-Irigoyen, Roman Bolliger, David Venus, Thaleia Konstantinou, Erwin Mlecnik, Manuela Almeida, Ricardo Barbosa, Jon Terés-Zubiaga, Erik Johansson, Henrik Davidsson, Mira Conci, Tiziano Dalla Mora, Simone Ferrari, Federica Zagarella, Ana Sanchez Ostiz, Jorge San Miguel-Bellod, Aurora Monge-Barrio, Juan Maria Hidalgo-Betanzos.

The paper is printed in “Sustainable Cities and Society” – volume 72, (2021) 103037 and can be found on the project's website.

Abstract: Renovation at district scale is a key strategy to reduce CO_2 emissions by optimising the implementation of renewable energy sources and taking advantage of economy of scale. This paper focuses on analysing good practice examples on energy renovations at district scale. The multi-perspective analysis of nine exemplary renovation projects in six European countries include identification of drivers and barriers of different stakeholders. It was found that the drivers for a district renovation are not restricted to energy savings, but typically also include improving the overall quality of life as well as the image and economic value of a district. Moreover, the need for financial models that can alleviate split-incentive problems between investors and resident organizations was identified. Barriers for carrying out a district renovation include that there is a need to comply with energy standards, that the renovation scope had to be limited to avoid a noticeable rent increase and that resettling of tenants during the renovation is often not possible. Lessons learned include that good communication amongst the different stakeholders, especially with residents, plays a key role for the success of the project. Furthermore, a strong leadership is needed to coordinate activities due to the great number of stakeholders.

In relation to the project, Manuela Almeida and Jørgen Rose are guest-editors of a special issue of the Sustainability journal (MDPI) with the title "Building Renovation—Towards a Decarbonized Building Stock 2050" https://www.mdpi.com/journal/sustainability/special_issues/building_renovation_2050. The special issue will publish 5+ papers related to the Annex 75 project by participating authors. The Danish team will contribute to the special issue with a paper as follows.

The balance between energy efficiency and renewable energy for district renovations in Denmark

Authors: Jørgen Rose, Kirsten Engelund Thomsen and Ole Balslev-Olesen.

Abstract: To mitigate climate change, it is necessary to reduce the energy-related CO2 emissions from the existing building stock significantly. Emissions can be reduced by either increasing the energy efficiency of buildings and supply system or by increasing the share of renewable energy in the energy system. Therefore, balancing energy efficiency and renewable energy is key in achieving a future fossil-free society. In Denmark

there is a long tradition for district heating which means that a major part of the transition from fossil fuels to renewables can be achieved at the supply system level rather than on individual building level. What remains is to determine which level of energy efficiency is needed on the building level, so that the district heating can deliver fossil fuel free heat and domestic hot water throughout the year.

This paper presents calculations performed on a generic Danish district that is undergoing a major renovation. The generic district is based on an existing district in Aalborg and consists of 1,019 dwellings spread over three different building typologies: single family houses, detached houses, and multi-storey apartment buildings. The district was built in the 70es, so constructions generally have low insulation levels. The purpose of the investigation was to determine which combination of energy saving measures would achieve the optimal level of energy efficiency. Energy saving measures included adding insulation to building envelopes, replacing windows, installing individual heat pumps, photovoltaics, solar thermal and mechanical ventilation with heat recovery. Measures on individual buildings were combined with energy improvements to the supply system. Calculations were made with a district heating with average data for district heating in Denmark, district heating based on natural gas and district heating from renewable energy sources such as solar heating, biofuels, and heat pump, respectively. Also, individual heating systems were investigated based on fossil fuel and renewables, respectively. The calculations include costs for investment, maintenance and operating as a function of the primary energy needs. Furthermore, GWP (global warming potential) was calculated and included CO2 emissions from space heating, domestic hot water and electricity for operation and household.

The calculations show that for the generic Danish district, which is already connected to a district heating network, the optimal solution is to add 200 mm insulation to roofs and 150 mm insulation to walls and replacing the existing windows with new 3-layer low energy windows. The calculations also show that balanced mechanical ventilation with heat recovery is not profitable, however, in Denmark this measure would always be carried out anyway, since this will have a significant impact on the indoor climate – at least in bigger buildings. The calculations described in this paper are part of a larger investigation carried out in IEA EBC Annex 75, where 8 different European countries carry out similar analysis. The purpose of this joint effort is to determine differences, similarities and generally achieving a better understanding on how to balance energy efficiency and renewable energy under different circumstances.

Conference papers

Annex 75 participants published a paper related to research performed in the scope of the project work:

Zubiaga, J., Almeida, M. Morck, O., Bolliger, R. Venus, D.
"Potential of Buildings Renovation at District Level for Reducing CO2 emissions and fostering urban regeneration" in Proceedings of 10th European Conference on Energy Efficiency and Sustainability in Architecture and Planning, Vitoria-Gasteiz, 2019

Conference presentations

Annex 75 participants presented work related to research performed in the scope of the project in the following conference:

Neighbourhood consultancy centres for the adoption of low-carbon technologies by homeowners: Experiences from Dutch initiatives.

Authors: E. Mlecnik, Oubbol Oung, Ariane Lelieveld, Marianne de Snoo, Coen Vos - Energy Evaluation Europe 2021 conference.

5.6 Social media - LinkedIn, Facebook etc.

During the Annex' lifetime, social media accounts on Facebook, Twitter and LinkedIn were continually updated with relevant news related to the project itself and the general subject of the district's energy renewal and to some side events organised or co-organised by Annex 75 participants. Besides open generalised social media, a ResearchGate page for the project is also active for scientific dissemination and is being updated with journal and conference papers prepared in the context of the Annex 75 project.

Facebook: https://www.facebook.com/ebcannex75

Twitter: https://twitter.com/iea_ebc_annex75

LinkedIn: https://www.linkedin.com/company/ebc-annex-75-project/

ResearchGate:https://www.researchgate.net/project/IEA-EBC-Annex-75-Cost-effective-Building-Renovation-at-District-Level-Combining-Energy-Efficiency-Renewables

Newsletters

The newsletters have been published from 2017 to 2022. The sixth Annex 75 newsletter is being prepared in June with the main findings and conclusions of the project.

All deliverables described will be uploaded on the website as soon as approval from the EXCO exists: https://annex75.iea-ebc.org/.

5.7 Activities in the extension of the project (134-21014)

The purpose of the extension was to ensure continued Danish participation in IEA Annex 75 project. In the original application, funding covered the 4-year project, but due to the Corona pandemic, the project has been extended by six months. The supplementary application concerns a grant to Department of the Built Environment, AAU to cover participation in the last six months of the project and a minor extension of hours in 2021 to increase the benefits of the Danish participation in Annex 75. BUILD will participate in a project meeting and a workshop in June 2022, and prepare an additional conference paper/journal article on the generic calculations made in subtask B. In addition, the application covers funding for Kuben Management to complete LCA calculations and prepare a report on the generic calculations together with AAU.

At the meeting in June 2022, it was announced that the IEA Annex 75 project had been postponed until November 2022. BUILD will end the Danish project at the end of June 2022 but will continue for the rest of the year to help complete the final reports.

6. Utilisation of project results

The project involves participation in the IEA project, so there is no apparent technology added value for users. The project has generated some of the necessary knowledge to help Denmark to meet stringent national energy policy objectives on reducing greenhouse gas emissions and energy use in buildings in cities at district level, combining both energy efficiency measures and renewable energy measures. Given the limitations due to available financial resources and the large number of investments needed to transform the cities' energy use in buildings, the identification of cost-effective strategies is important for accelerating the necessary transition towards low-emission and low-energy districts.

The project has had the purpose of securing Danish participation in an IEA project and did not have the purpose to develop commercial products. However, it should not be excluded those future methods developed during the project can be commercialized at a later stage.

The Danish participation did not involve PhD-students.

7. Project conclusion and perspective

The project aimed to investigate cost-effective strategies for reducing greenhouse gas emissions and energy use in buildings in cities at district level, combining both energy efficiency measures and renewable energy measures. The objective was to provide guidance to policy makers, companies working in the field of the energy transition, as well as building owners for transforming cost-effectively the city's energy use in the existing building stock towards low emission and low energy solutions. The Annex focused mainly on residential buildings, both single and multifamily houses.

In contrast to the construction of new buildings, there are often architectural and technical hurdles to achieving low emissions and low energy use in existing buildings. Also, the cost-effectiveness of reaching a high energy performance in existing buildings is often lower than in the construction of new buildings. The transformation of existing buildings into low-emission and low-energy ones is a particular challenge in cities, where many buildings continue to rely to a large extent on heat supply by fossil fuels. At the same time, there are specific opportunities for district-level solutions in cities that must be explored.

The Annex 75 project looked for optimal solutions between energy efficiency measures and renewable energy measures and making use of the potential of low-grade renewable energy sources in cities combined with improving the energy performance of the building envelope is a key to transforming the energy system in cities deeply, thereby reducing non-renewable energy use distinctly.

All primary project objectives have been fulfilled i.e., to give an overview on various technology options, taking into account existing and emerging efficient technologies with potential to be successfully applied within that context, and how challenges specifically occurring in an urban context can be overcome; To develop a methodology which can be applied to urban districts in order to identify such cost-effective strategies, supporting decision makers in the evaluation of the efficiency, impacts, cost-effectiveness and acceptance of various strategies for renovating urban districts; To illustrate the development of such strategies in selected case studies and gather related best-practice examples; To give recommendations to policy makers and energy related companies on how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures in building renovation at district level, and to give guidance to building owners/investors on related cost-effective renovation strategies.

Several reports, guidelines, tools, and papers for international journals have been produced to support decision-makers from public and private sectors in making better decisions. The Danish team was responsible for writing a Technology Overview Report including the following main parts: Overview on state-of-the-art technology, Techno-economic characterization of technology options, Identification of interdependencies, obstacles, and success factors for combining energy efficiency measures with renewable integration and Outlook to potentials and future developments.

A cross-section analysis of the case studies has helped identify similarities, differences, and general findings. The analysis covered: goals of the interventions, the balance between energy efficiency and renewable energy sources, drivers, e.g., decisive aspects for the successful implementation of interventions, the main barriers and influencing factors, policy instruments, business models examples and the most important lessons learned. Dissemination of project news and results are carried out on the project website (annex75.iea-ebc.org) and through social media.

IEA Annex 75 project was organized as an international network project, expecting to clarify the cost-effectiveness of various approaches combining both energy efficiency measures and renewable energy measures at the district level. Buildings are a major source of greenhouse gas emissions, and cost-effectively reducing their energy consumption and associated emissions is particularly challenging for the existing building stock mainly because of the existence of many architectural and technical hurdles.

The main results from the project are the online version of the IEA EBC Annex 75 common tool, which allows assessing the renovation strategies and scenarios at the district scale using the Annex 75 methodology; Methodology Report on cost-efficient building renovation at district level to assess the optimal balance between energy efficiency measures and renewable energy measures at district level; The case studies/success stories collection and analysis of these; And the recommendations, in form of guidelines, to policymakers and local energy-related companies on how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures for the transformation of existing districts into low-energy and low-emission districts.

The results from the Annex 75 will continue in the next months as additional national workshops are being planned in Austria, the Netherlands, Spain, and Switzerland during 2022. An Annex 75 webinar to present the main findings, conclusions, and recommendations of Annex 75 is being planned for September 2022 and a webinar is also being planned to present the Annex 75 common tool to interested parties outside IEA EBC Annex 75. The possibility of organising an IEA EBC Annex 75 workshop at the International Conference SBE Delft, the Netherlands, 11-13 October 2022 (Innovations for the Urban Energy Transition: Preparing for the European Renovation Wave) is being evaluated and in October, IEA EBC Annex 75 will be represented in the IEA EBC Future Buildings Forum in Canada.

8. Appendices

Link to relevant pages

Website: https://annex75.iea-ebc.org/

Facebook: https://www.facebook.com/ebcannex75

Twitter: https://twitter.com/iea_ebc_annex75

LinkedIn: https://www.linkedin.com/company/ebc-annex-75-project/

ResearchGate: https://www.researchgate.net/project/IEA-EBC-Annex-75-Cost-effective-Building-

Renovation-at-District-Level-Combining-Energy-Efficiency-Renewables

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