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EBC Annex 64 Optimised Performance of Energy Supply Systems with Exergy Principles

Project Summary Report

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EBC Annex 64 Optimised Performance of Energy Supply Systems with Exergy Principles

Project Summary Report

Edited by
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Cover picture: View over the city of Kassel. Source City of Kassel/ Germany
Source: Fraunhofer Institute for Energy Economics and Energy System Technology IEE

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Project Summary

The energy demand of the building sector for heating and cooling is responsible for more than one third of the final energy consumption in Europe and worldwide. Commonly this energy is provided through different fossil fuel based systems. These combustion processes cause greenhouse gas (GHG) emissions and are regarded as one of the core challenge in fighting climate change and in the energy transition. While a lot has already been achieved, especially regarding the share of renewables in the electricity sector, there are still large potentials in the heating sector. Exploiting these potentials and synergies demands an overall analysis of the energy conversion processes within communities to achieve a holistic understanding of these processes.

The term exergy is important in this understanding because it takes account of the ‘energy quality’ and can help to ensure that the most appropriate source is used for a given application. For example in space heating processes natural gas, a high quality/ high exergy source, is often burned to heat water to 70°C-80°C which is in turn used for a low exergy application of heating rooms in a home to 20°C. The same gas could be burned to deliver temperatures of 1,000°C in industrial processes and the waste heat from such processes can be more appropriately used for low exergy applications as space heating.

Communities are characterised by a wide range of energy demands, for instance heating, cooling and electricity demands. Different energy quality levels (as part of exergy) are required as heat and cold flows or as electricity and fuels. On the community level there is the possibility of supplying this energy through different sources; for instance, through roof-top photovoltaics as “high-exergy” electricity or” low-exergy” as low-temperature heat from e.g. geothermal sources or waste heat. The fluctuating electricity supply from decentralised renewable electricity production poses both opportunities and challenges for future community energy systems. The interaction between (matched) energy demand and available (fluctuating) energy sources at different quality levels (exergy factor), especially for heating and cooling supplies, has to be solved at a local level, within the community.

To identify potential savings and synergies a holistic analysis of energy flows is necessary, which allows the detection of available quality levels. The analysis has to be carried out from generation to final use in order to reduce significantly the share of primary or high-grade fossil energy used and to optimise exergy efficiency. In practical implementation, advanced technologies and innovative supply concepts must be adapted and further developed to realise the identified potentials together with the involved industry partner (system provider and consultants).

On the community scale, different types of supply systems require different supply temperatures. To obtain the maximum output from a given primary energy flow, different temperature levels can e.g. be cascaded according to the requirements of the building typology and technology. This demands an intelligent arrangement and management of the temperature levels and flows within the system. Bi-directional concepts and short term storage can be elements of a system which is not only energy efficient, but also exergy efficient. As a high-exergy resource electricity plays a special role within the evaluation processes, it is feasible, on an exergy basis, to weigh the impact of extra electricity use, for instance for pumping or ventilation, on a thermodynamically correct basis against the heat and cold applications. On this basis, a discussion on a proper and workable set of indicators will have to be held to reflect aspects of renewable and non-renewable electricity and fluctuating supply in electrical energy systems.

This collaborative project which started in 2013 is founded on the findings of previous projects such as EBC Annex 37 and EBC Annex 49 which dealt mainly with the assessment of building supply. As part of the EBC Annex 64, this assessment framework has been extended for analysing community energy supply. This project focuses on both the theoretical and methodological tools as well as on modelling and on practical implementation aspects and on the evaluation of the practical application of the so-called “low-exergy approach” for community supply. A number of tools have already been evaluated within the project. The resulting work contributes to technology development, the understanding of system synergies and existing implementation barriers.

The main objective is to demonstrate the advantages of exergy analysis and the potential of low exergy thinking on a community level as energy and cost efficient solution in achieving 100% renewable and GHG emission-free energy systems. So the purpose is to show the means to realise a CO_2 neutral heating and cooling energy supply on a community scale. The intention is to reach these goals by providing and collecting suitable assessment methods and planning approaches, which have been tested on real cases in this project. Furthermore the project provides guidelines, recommendations, a set of best-practice examples and a large amount of background material which can be accessed via the project homepage (www.annex64.org) or can be found in the published final report of the project [1] . For a further development of the method more and a wide range of applications are needed to gain more practical experiences to be able to integrate the findings of the project in standard planning procedures.

The material and the results obtained are intended primarily to address the 3 following target groups:

- The energy supply and technology industry will find development ideas for future products, business models and services in the field of dynamic energy supply systems. With the breaking down of traditional centralised top-down solutions in energy supply, new fields of business can be created in combination with overall system improvement.
- Project developer and housing companies as potential customers from the above mentioned industries will benefit from innovative and more efficient technologies, as well as from improved business concepts.
- Communities will profit from the improved and more differentiated understanding of their local potentials and supply options. Communities are supported in regaining strategic competence in long-term development issues in the energy sector.

To make it easier for the target groups to access the information and material a cooperation is established with the IEA cooperation platform on District Heating and Cooling (DHC) (www.iea-dhc.org) and with the LowEx researcher's network LowEx Net (www.lowex.net).

The following main recommendations can be derived from the findings of this project:
Exergy analysis as a thermodynamic concept is a method for evaluation and improvement of energy system in communities by reducing destruction and losses. Exergy is a central indication for the optimisation of heat and cold based processes on a community level. For that reason exergy should be established as standard optimization indicator for energy systems, since it indicates how well the working potential of resources is being used. But in real systems the final aim is rarely to use the maximum potential of our resources. Other criteria are usually more important such as costs, emissions, environmental impacts etc. Exergy can be linked to these, but is not inherently connected. The connection to other objectives, such as primary energy or emissions, should be made through the exergy optimization steps and weighting factors.

The project outcome delivers tailored models and approaches for different system configurations as well as boundary conditions on a community scale. Conducted case study applications prove reliability of exergy models and their outcome.

In any case, the application of a simplified "exergy thinking" approach for planning and development projects should be always considered:

- Matching the energy quality levels of demand and supply
- Clustering of energy demand exergy-wise
- Identification of the local renewable energy and waste heat utilisation potentials according to the above mentioned clusters.

- Optimisation of all energy conversion processes to achieve maximum efficiency.

Based on the results obtained, it was highlighted that the exergetic assessment promotes the planning process through the “LowEx” Thinking approach. This approach contributes significantly to a more efficient energy supply at the communal level by a reduced consumption of fossil fuels and an increased share of renewable energies on a long term horizon.

Project duration
2013 - 2018 (completed)

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Project Outcomes

1. Background

The energy demand for heating and cooling in the building sector is responsible for more than one third of the final energy consumption in Europe and worldwide. Commonly this energy is provided through different fossil fuel based systems using combustion processes. These combustion processes cause greenhouse gas (GHG) emissions, which are regarded as one of the core challenge in fighting climate change and energy transition. National and international agreements (e.g. the European 20-20-20-targets or the Kyoto protocol) limit the GHG emissions of industrialized countries respectively for climate protection. Country specific targets are meant to facilitate the practical implementation of measures. While a lot has already been achieved, especially regarding the increased share of renewables in the electricity system, there are still large unutilised potentials in the heating and cooling sector and especially on the community scale. Exploiting these potentials and synergies demands an overall analysis and holistic understanding of conversion processes within communities. Here the exergy concept is applied to archive better overall energy system designs.

The project communities are defined as a larger group of buildings such as a block or a neighbourhood which are characterised by a wide range of energy demands in different sectors, for instance heating and cooling demands, and lighting and ventilation. Different energy quality levels (as part of exergy) are required as heat or cold flows or as electricity and fuels. On the community level there is the possibility of supplying this energy through different sources; e.g. low-temperature heat from geothermal sources at a low exergy level or through roof-top photovoltaics as high-exergy electricity. The fluctuating electricity supply from renewable electricity production e.g. wind and PV power offers both chances and challenges for future community energy systems. The interaction between (matched) energy demand and available (fluctuating) energy sources at different quality levels (exergy factor), especially for covering the heating and cooling demand, has to be solved at a local level, within the community [2], [3].

To identify potential savings and synergies a holistic analysis of energy flows is necessary. This allows the detection of available quality levels. These are taken into account, from generation to final use, to significantly reduce the share of primary or high-grade fossil energy used and to optimise exergy efficiency [4] . In practical implementation, advanced technologies must be adapted and further developed to realise the identified potentials. At the same time, as the use of high quality energy for heating and cooling is reduced, there is more reason to apply integral approaches in regards to other processes in which energy/exergy is used in communities.

2. The LowEx Approach for Communities

Basically, the physical property "exergy" can be described as a product of energy and "energy quality". The higher the temperature of a heat flow is above reference temperature, the higher the energy quality. To simplify thermodynamic principles for the scope of this activity it can be stated that: The lower the temperature of a thermal energy supply flow for heating, the lower its energy quality is and, therefore, the associated exergy flow [5], [6], [7]. In this way exergy is utilised to optimise the efficiency of a community supply system. This is called the low exergy (LowEx) approach. The LowEx approach entails matching the quality levels of energy supply and demand in order to optimise the utilisation of high-value energy resources, such as combustible fuels, and minimise energy losses and irreversible dissipation (internal losses) [8] .

On the community scale, different types of supply systems require different supply temperatures. To obtain the maximum output from a given primary energy flow, different temperature levels can be cascaded according to the requirements of the building typology and technology. This demands an intelligent arrangement and management of the temperature levels and flows within the system. Bi-directional concepts and short term storage can be elements of a system which is not only energy efficient, but also exergy efficient. As high-exergy resource electricity plays a special role within the evaluation processes, it is feasible, on an exergy basis, to weigh the impact of extra electricity use, for instance for pumping or ventilation, on a thermodynamically correct basis against the heat and cold applications. On this basis, a discussion on a proper and workable set of indicators will have to be held to reflect aspects of renewable and non-renewable electricity and fluctuating supply in electrical energy systems.

Current projects and analysed cases show the potential in terms of improved energy efficiency and GHG emissions reductions. Some successful conducted studies indicate a cost reduction potential for innovative low temperature heat grid community solutions based on the exergy thinking concept and a CO_2 free heat delivery process (e.g. [9]). These promising cases are analysed in detail and described in the final project report [1] .

A so-called 'LowEx Community' could be defined as a community for which the energy system is designed in such a way that exergy destruction for the required energy services as space heating and domestic hot water preparation is minimised.

3. Exergy analysis framework

The exergy concept can be used in the development of sustainable community energy supply systems. This can be done from the early stage until the detailing and optimisation phase. First, by considering exergy principles in the development of the potential solutions more favourable solutions can be obtained. In later stages of a project, exergy can be used to further improve and optimize the energy systems considered.

Exergy is a thermodynamic concept that defines the thermodynamic work potential of a system [10]. Exergy analysis provides critical insight into the maximum (work) potential of energy resources. This insight cannot be obtained with energy analysis based solely on the first law of thermodynamics (see also [8]. When exergy losses are minimized, the required input of high-quality resources is also minimized. Exergy analysis can thereby minimize fossil fuel inputs or improve renewable and sustainable systems.

However, exergy analysis does not inherently include other objectives such as maximizing the use of renewables or minimizing emissions, nor are costs inherently the same as exergy, although there may be a relation between these. Especially the relation between exergy and renewability or CO_2 emissions is often discussed.

In line with the quality factor or exergy factor, 'low-ex' or 'low quality' energy sources refer to sources with a small exergy content relative to the energy content, that is: with a low quality factor. A 'low-exergy' energy is a source that can produce little work, relative to its energy content, or that theoretically requires little work to be

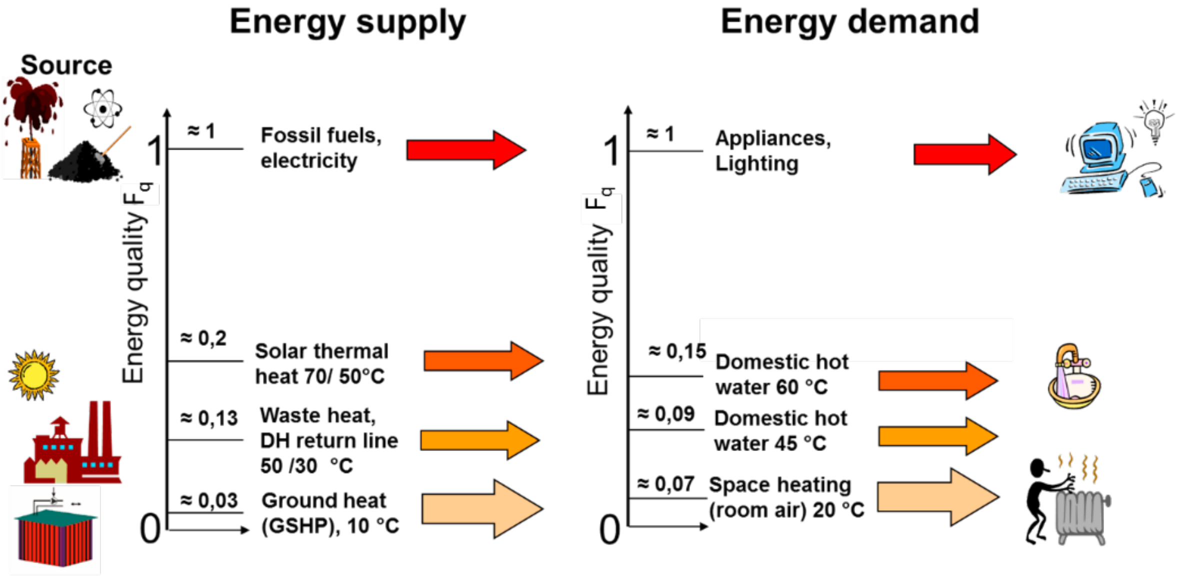

Figure 1: Different quality factors (Fq) of demand side and supply side for quality matched low temperature district heating supply

produced. Basically, it can be said that the higher the temperature of a heat flow is above the reference temperature (which is in many cases equal to the ambient temperature, see further in this chapter), the higher the energy quality [8]. Especially in connection with buildings that require only low temperatures for space heating and hot water production, the utilisation of fairly low temperatures (such as geothermal heat and solar heat) offer great possibilities for high efficient supply (see Fehler! Verweisquelle konnte nicht gefunden werden.).

Now that we have discussed the definition of exergy and the relation with other performance indicators, we will look at how to apply the exergy concept in the planning and development of community energy systems.

Three phases can be distinguished: firstly, the pre-planning phase, where ambition are set and the first options for the community energy system are explored and roughly assessed; secondly the design development phase, which leads to a draft design of the community energy system. After that a detailed design phase will start, where refining and optimization takes place. This will lead to a detailed design of the community energy system. In all phases exergy can play a role [12] :

Phase 1: Pre-planning phase: Exergy thinking by using exergy principles
In the pre-planning phase the ambitions are set and various options for the community energy system are explored and roughly assessed. This development can be partly based on exergy thinking: exergy principles can be applied to the first ideas and options for the community energy system.

Phase 2: Design development phase
One or more draft energy configurations can be further developed and exergy analysis can play an essential role in this phase. The exergy analysis shows in which configuration and in which component the biggest exergy losses occur. This means the system can be improved and insight can be obtained on whether a system can be improved and how. This leads to a choice of a most promising energy configuration and a first optimization of it.

Phase 3: Detailed design phase
When designing the final configuration and operation of a community energy system, exergy can also play a role. In this case, more detailed exergy analyses can be used. These are in principle based on the 10 steps described below, but are more complex and can be based on various (dynamic) energy simulation tools.

In order to evaluate the exergy performance of potential energy systems and develop these into a draft design, a simplified exergy analysis should be performed. This way the overall exergy efficiency can be determined and, more importantly, insight in the losses per component and thereby the improvement possibilities can be obtained.

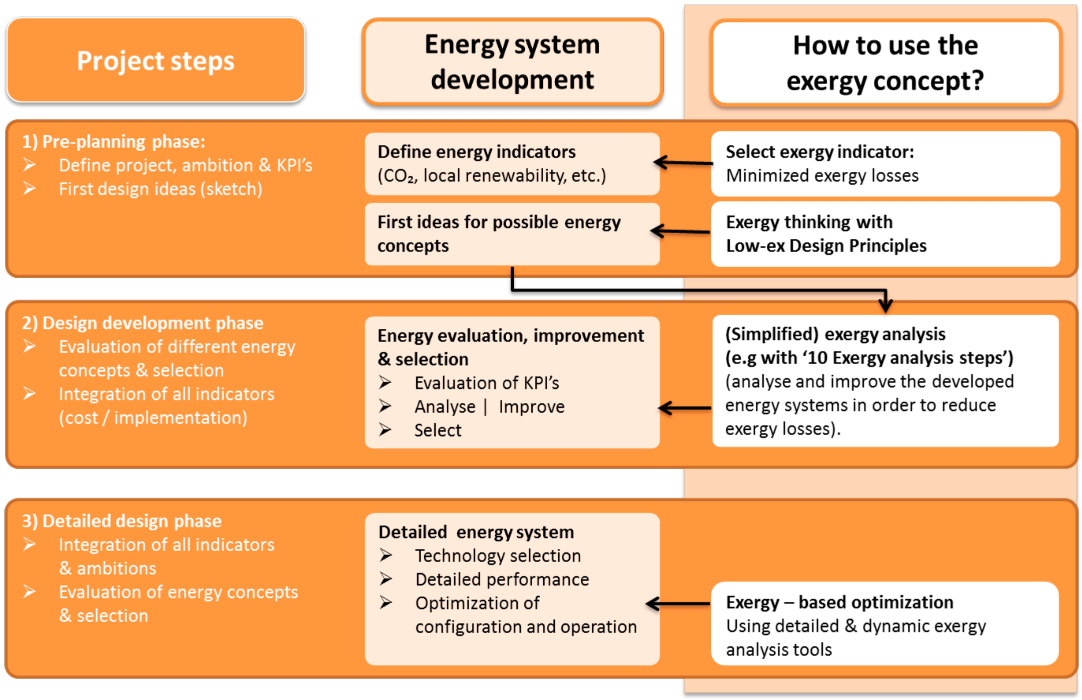

Figure 2: Overview of the different steps in the development of community energy systems, with related exergy approaches.

This analysis can be described in the following 10 steps:

1. Define the system boundaries of the project
2. Indicate the reference temperature (Tref)
3. Define the system configuration according to input is equal to output approach
4. Determine energy values of all inputs and output
5. Determine the exergy of all inputs and outputs, (using the quality or exergy factor of the energy)
6. Display exergy values in a clear way
7. Analyse losses
8. Propose improvements (to reduce losses)
9. Repeat step from step 4, until satisfied with results
10. 10.Present final version including final performance

(describing improvements and justifying remaining exergy losses)

4. LowEx supply technologies

Next to the planning approach the most promising and efficient supply technologies allowing a flexible supply of different demands with maximal share of low-valued local and renewable energy sources are identified. The technological considerations include both demand and supply side aspects. Hence the requirements for efficient buildings and user behavior are discussed. Furthermore, decentralised and centralised supply solutions and storage technologies, which serve as interfaces for community supply, are compared. Subsequently different supply technologies (e.g. heat pumps or solar thermal collectors) are described. As part of the supply solutions the significance of the regarded supply options in the context of a demand-adapted community supply was discussed. Furthermore, approaches for the exergetic assessment of the respective system component were discussed [1] .

5. Case studies across scales

Different case studies, from different scales (building, district and city) and different countries are presented as part of the conducted work. The examples consider the heat and electricity domains in one system in a way that makes calculations, comparisons (between systems taken with similar assumptions) and interpretations more consistent and useful compared to the energy approach.

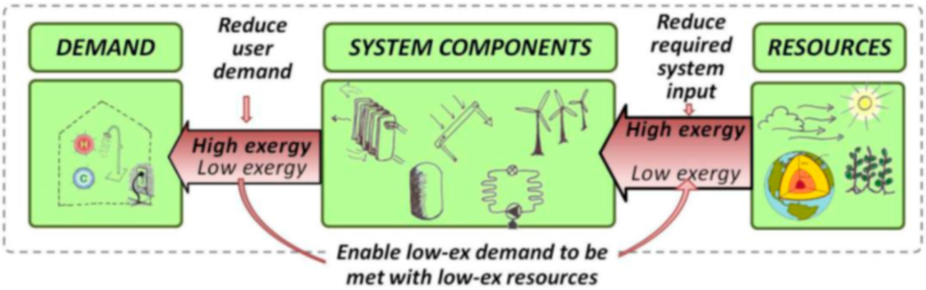

Figure 3: The exergy supply chain. Scheme of energy systems for the built environment: the exergy approach can support systems where the low exergy demand can be met with low exergy resources [13].

In order to deal with various challenges such as improving the system performances in terms of sustainability and efficiency exergy analysis was done using different methods and tools. Exergy analysis identifies the components or sub-systems that have potential for improvement. The case studies presented cover several scales and the different solutions highlighted at one specific scale can be scaledup or down to be replicated. Exergy analysis was showed to be useful at all stages of development of an energy system: from the design phase to the operating and the renovation phases [1].

Until now the exergy approach is neither popular nor extensively used for several reasons. First of all, the concept of exergy is newer and more abstract than the concept of energy as it is related to a specific system with its intrinsic constraints, boundary conditions and reference temperature. Another noticeable limitation of the exergy approach is that in order to be able to compare results, one should take care to make calculations with similar system boundaries and reference temperatures. Any comparison of uneven systems could lead to misinterpretations and biased or

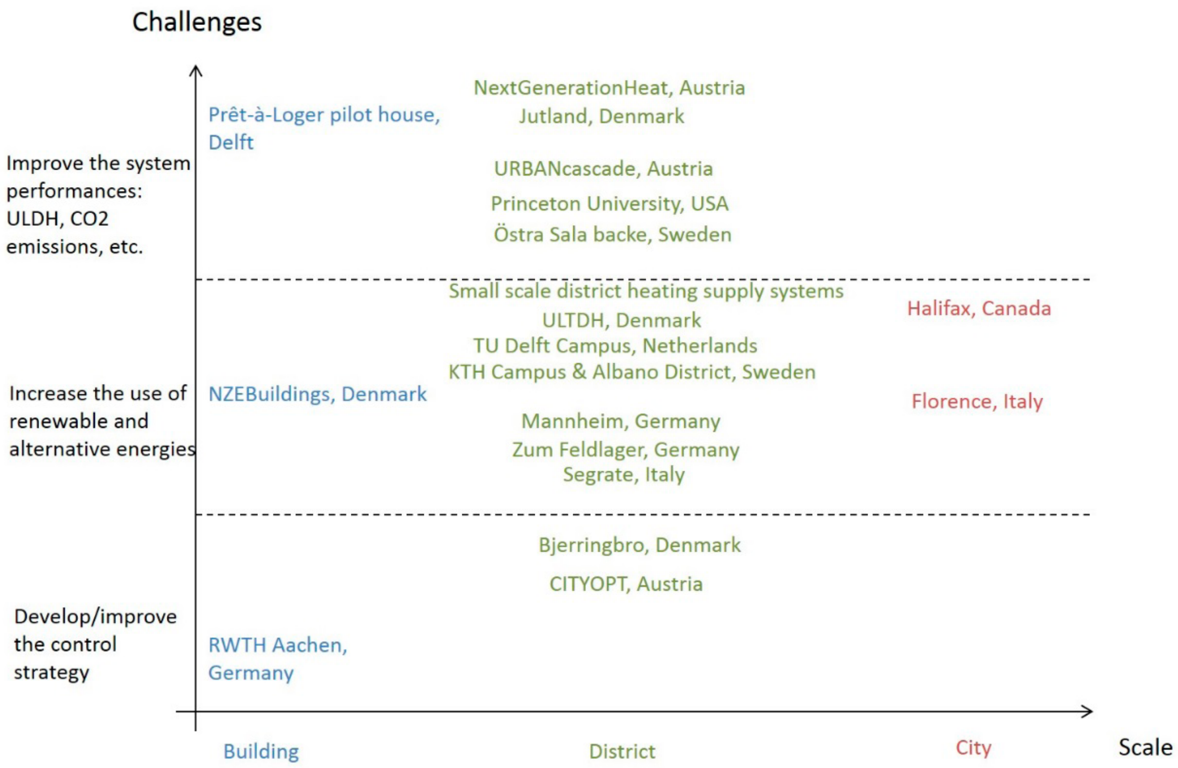

Figure 4: Overview of all reported case studies. For each case study, detailed

wrong conclusions. Indeed, the input of exergy varies greatly for the chosen system boundaries of a project. The broader the system boundaries, the larger the analysis. Considering a restricted system allows focusing on specific solutions to improve the system efficiency. However, the improvement identified at a lower system may not imply better exergy efficiency if a larger system is considered. That is the reason why for same case studies the optimisation algorithms investigated several system boundary conditions for different subsystems.

From the different case studies, the following can be drawn:

- Buildings destroy more input exergy than they lose and produce, about 84%-93% of exergy consumed by buildings is destroyed by irreversibilities.
- Exergy-based control is suitable to achieve efficient building operation. Using dynamic simulation models, the exergy analysis can be fully automatized and used for model-based control.
- The exergy analyses based on annual measurements show that ultra-low temperature district heating (ULTDH) systems with local electric booster have higher exergy efficiency compared to existing district heating systems.
- A low energy demand can be achieved by high buildings standard and low thermal losses among the network, wide energy share produced from renewables

and good exergy efficiency, compared to traditional thermal systems.

- Old production systems can be significantly improved in terms of exergy input and exergy efficiency by replacing part of the heat production from fossil fuels by heat production from low-exergy sources.
- Lowering supply and/or return temperatures increases the exergy efficiency of district heating networks and consequently whole system. However one has to keep in mind when decreasing the supply temperature in the network, the water flow should be carefully considered to avoid an increase of the pumping cost.
- •The low-exergy approach allows identifying which component/ configuration of the system to focus on, in order to implement/improve low-temperature district heating networks and so to save fossil energy, having a lower overall exergy input and also reduced CO_2 emissions. By implementing ULTDH, distribution heat losses can be saved substantially.

6. Models and tools

As part of the work within the project the assessment methodology of tools and calculation methods have been assessed. In total, 14 models and tools related to exergy assessment, including six models, five methods and six tools are identified and collected. Five of those can assess energy systems by using optimisation algorithms.

The models and tools are presented to identify the applicable stages, design stage or operation stage. Seven models can be applied in the design stage and nine models and tools can be applied in the operation stage. In addition, the boundary of systems to study is shown, in which seven of those can assess energy systems from the building scale to community scales. Especially, REMM and BEX cover all scale of boundary depending on the problems. Four models such as DEH, ExEx, DyEx, DEA can be applied in operation stage for systems in single building scale. Thus, these have an important role in assessing on-site energy control and decision-making towards achieving low exergy processes.

The objective functions of the models and tools are presented as well. All models and tools can evaluate not only single objective function but also more than two objectives. LowEx:CAT and REMM define and use their original objective functions. LowEx:CAT evaluates demand of space, future potential of energy suppliers in addition to efficiencies of energy and exergy, CO_2 emissions, and economic impacts. REMM was further utilised to improve the status of districts in an original net zero target, namely, the target of a Net-Zero Exergy District (NZEXD). NZEXD is a district that produces the same amount of energy at the same grade and quality as used on an annual basis.

	Tool or model	Assessment			Optimisation
		Model	Method	Tool	
1	OLEC		X	X	
2	LowEx:CAT	X	X		
3	GICOP-DHS	X			yes
4	MODEO	X			yes
5	REMM	X		X	yes
6	CARNOT			X	yes
7	BEX	X			
8	ULTDH		X		
9	DEH		X		
10	ExEx		X		yes
11	DyEx			X	
12	DEA			X	
13	RS4DEA	X			
14	SPM2.x			X	

Table 1 Classification and type of the regarded models in the IEA EBC Annex 64 project

7. Towards LowEx Communities

The building sector is causing large GHG) emissions due to the energy demand for heating and cooling. Commonly fossil fuel based systems using combustion processes are used to satisfy these demands. The reduction of the GHG emissions is regarded as one of the core challenge in fighting climate change and energy transition. Exploiting these potentials and synergies demands an overall analysis and holistic understanding of conversion processes within communities. Here the exergy concept is applied to archive better overall energy system designs.

The main objective of the reported research activity is to demonstrate the advantages of exergy evaluation and the potential of low exergy thinking on a community level as energy and cost efficient solution in achieving 100% renewable and GHG emission-free energy systems. The intention is to reach these goals by providing and collecting suitable assessment methods (e.g. holistic balancing methods). Furthermore, recommendations, best-practice examples and background material for designers and decision makers in the fields of building, energy production/supply and politics are provided in the report. Central challenges in achieving the objectives are the identification of the most promising and efficient technical solutions for practical implementation and aspects of future network management and business models for distribution and operation. Regarded aspects of transition management and policy will ensure the feasibility of the practical implementation.

The project outcome can also be used as a basis for future work using the models and methodologies developed which offer the possibility of more “sustainable” community energy systems. In this context the exergy analysis has the potential to support strategic targets such as the reduction of energy spending and the increase of the share of renewable energy on a long-term horizon.

Project Participants

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Germany	Fraunhofer Institute for Energy Economics and Energy System Technology University of Kassel, Solar and Systems E.ON Energy Research Center, RWTH Aachen University Technical University Berlin Technical University Darmstadt
Italy	Politecnico di Milano University of Florence
Sweden	Uponor AB KTH – The Royal Institute of Technology
The Netherlands	Delft University of Technology Huygen Engineers & Consultants Netherlands Enterprise Agency
USA	Princeton University
Observer:	
Turkey	The Scientific and Technological Research Council of Turkey

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EBC and the IEA

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 31 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. The mission of the IEA Energy in Buildings and Communities (IEA EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)
The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

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 (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18:	Demand Controlled Ventilation Systems (*)
Annex 19:	Low Slope Roof Systems (*)
Annex 20:	Air Flow Patterns within Buildings (*)
Annex 21:	Thermal Modelling (*)
Annex 22:	Energy Efficient Communities (*)
Annex 23:	Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24:	Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25:	Real time HVAC Simulation (*)
Annex 26:	Energy Efficient Ventilation of Large Enclosures (*)
Annex 27:	Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28:	Low Energy Cooling Systems (*)
Annex 29:	Daylight in Buildings (*)
Annex 30:	Bringing Simulation to Application (*)
Annex 31:	Energy-Related Environmental Impact of Buildings (*)

Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (*)
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements (*)
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings (*)
Annex 73: Towards Net Zero Resilient Energy Public Communities (*)
Annex 74: Competition and Living Lab Platform (*)
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables (*)
Annex 76: Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions (*)
Annex 77: Integrated Solutions for Daylight and Electric Lighting (*)
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

Annex 79: Occupant-centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90: Low Carbon, High Comfort Integrated Lighting
Annex 91: Open BIM for Energy Efficient 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

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