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OPTIMISING COMMUNITY ENERGY SUPPLY WITH EXERGY PRINCIPLES

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Abstract

The building sector is characterised by a wide range of heating and cooling energy demands. This energy is mainly provided by the combustion of fossil fuels, which is responsible for greenhouse gas (GHG) emissions. While much has already been achieved in energy efficiency, there are still large potentials in providing heating and cooling energy with lower or without CO_2 emissions. At the community level, different energy sources are available that do not involve combustion processes. These energies are often characterised by high fluctuations and different exergy levels or 'qualities': e.g. electricity (high-exergy) from photovoltaics or low temperature (low-exergy) heat e.g. from solar energy or waste heat sources. Low energy qualities are of particular interest, because these can supply most heating and cooling demands very efficiently. The application of exergy principles is especially important, allowing the detection of different available energy-quality levels and the identification of optimal contribution to an efficient supply. From this, appropriate strategies and technologies with great potential for the use of low-valued energy sources (LowEx) and a high share of renewable energies for heating and cooling of entire cities can be derived.

An additional task is to develop and test appropriate business models for the implementation on energy systems based on low exergy principles. For this reason, it is important to demonstrate the potential of low exergy thinking on a community level as energy and a cost efficient solution in achieving 100% renewable and GHG emission-free energy systems.

The paper presents the key ideas of the international co-operative work in the general framework of the International Energy Agency (IEA), the EBC Annex 64 on "LowEx Communities - Optimised Performance of Community Energy Supply Systems with Exergy Principles".

Keywords - Low Energy Buildings; Low Exergy Communities; Low Temperature Supply Structures

1. Introduction

The energy demand of communities for heating and cooling is responsible for more than one third of the final energy consumption in industrialised countries. Commonly this energy is provided by different systems based on fossil fuels. The involved combustion processes cause greenhouse gas (GHG) emissions and are regarded one core barrier in fighting climate change. National and international agreements (e.g. the European 20-20-20-targets or the Kyoto protocol) limit the GHG emissions of the industrialised 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 share of renewables in the electricity system, there are still large improvement potentials in the heating and cooling sector and on the community scale. Exploiting these potentials and synergies, demands an overall analysis and holistic understanding of conversion processes within communities. Communities are characterised by a wide range of energy demands in different sectors, for instance heating and cooling demands, and lighting and ventilation in the building stock. Different energy quality levels (as part of exergy) are required as heat / cold flows or as electricity and fuels. On the community level there is the chance to supply this energy by different sources; for instance, through roof-top photovoltaics as high-exergy electricity or as low-temperature heat from geothermal sources. The fluctuating electricity supply from decentralised renewable electricity production imposes both chances and challenges for future communal energy systems. The interaction between (matched) energy demand and available (fluctuating) energy sources at different quality levels (carnot 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 all energy flows is necessary. This allows identifying available quality levels. These are taken into account, from generation to final use. The analysis helps to reduce the share of primary or high-grade fossil energy used and to optimise exergy efficiency significantly by pinpointing the largest saving potentials. In practical implementation, advanced technologies have to 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 are more options to apply integral approaches with regard to other processes in which energy/exergy is used in communities [1].

Within the international co-operative work a discussion on appropriate additional indicators, supplementing the exergy assessment was initialized in order to come to a common understanding of how to weigh high-exergy electricity for heating and cooling purposes under the preconditions of local availability. In this context the application of exergy analysis provides the necessary basis for tools, guidelines, recommendations, best-practice examples and background material for policy and decision makers in the fields of low exergy generation, low exergy distribution and low exergy consumption. In particular the planned guidebook is intended to support decision makers and urban planners to integrate low exergy technologies into energy transition strategic processes and policies. Policy and decision makers will profit from the improved and more differentiated understanding of local potentials and supply options. Greater local energy autonomy and impulses for local economy can support communities in gaining strategic competence in long term development issues in the energy sector.

2. Background

THE LOWEX APPROACH

Basically, the physical property “exergy” can be described as a product of energy and “energy quality” (Carnot factor q). The higher the temperature of a heat flow is above the chosen reference temperature (e.g. outdoor air temperature), the higher is the energy quality. To simplify the 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 is its energy quality and, therefore, the associated exergy flow. In this way exergy can be used to optimise the efficiency of a communal 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).

$$dEx_Q = dQ \cdot \underbrace{\left(1 - \frac{T_0}{T}\right)}_{CarnotFactor=q} \qquad (1)$$

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 mass 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 exergy terms, 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 proper and workable set of indicators to reflect aspects of renewable and nonrenewable electricity and fluctuating supply in electrical energy systems has to be discussed.

On-going projects and evaluated 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 of about 10-18% and a CO_2 free heat delivery process [6]. These promising cases are analysed with specific focus on exergy aspects in greater detail and described as an output of the annex working phase.

To heat indoor spaces to 20°C, heat has to be supplied at a temperature slightly higher than 20°C. An exergetic analysis shows that the required energy quality, the exergy fraction or quality factor q for this application is very low (q ≈ 7 %). If the production of domestic hot water is considered to be heating water up to temperatures of about 55°C, the needed energy quality is slightly higher (q ≈ 15 %). For the operation of different electric household appliances and lighting, the highest possible quality (q ≈ 100 %) is necessary. An adaptation of the quality levels of supply and demand could be managed by covering, for example, the heating demand with suitable energy sources, as there is available district heating with a quality level of about 30 % (see Fig. 1).

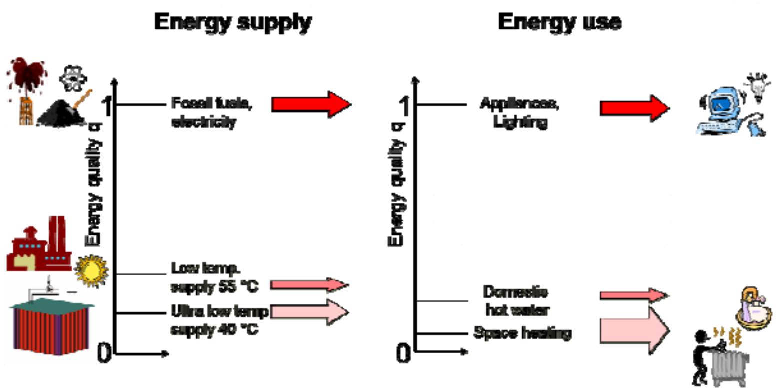

Fig. 1: Application of LowEx approach for optimization of community demand adapted supply. The very efficient so called low exergy supply and use are of particular interest (see green boxes).

EXERGY ASSESSMENT FOR COMMUNITY SUPPLY

The scope of the annex covers the improvement of energy conversion chains on a community level, using exergy as the primary indicator. The fundamental idea follows the hypothesis that by optimising the exergy chain, the overall system performance can be improved and CO_2 emissions can be reduced. In particular, the method of exergy analyses has been found to provide the most accurate and meaningful assessment of the thermodynamic features for any process. Exergy offers a clear, quantitative indication of both the irreversibilities and the degree of matching between the resources used and the end-use energy flows.

In comparison to plain energy analysis, exergy based system optimisation facilitates the integration of renewable heat and cold sources that are most often available in the communal context at fairly low temperatures. The optimal integration of decentralised supply modules of heat and cold enables the realisation of smart bi-directional supply grids in the heat and cold supply systems similar to ‘smart-grid’ approaches for the electricity sector. For the analysis it is necessary to define the system boundaries properly. The exact definition of the boundaries of the area to be examined (building, group of buildings, block, quarter or community) depends on the objectives of the case-study research project (see: Focus of involved research projects).

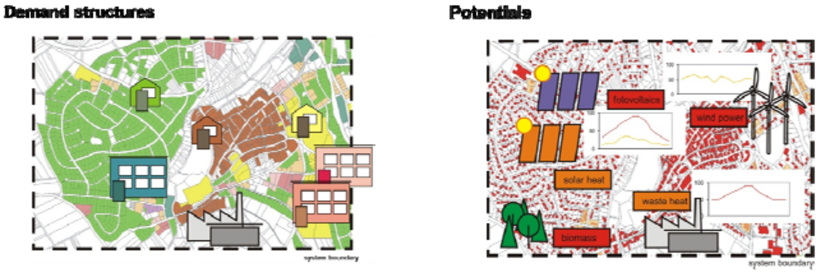

Fig. 2: The boundary of the systems which are studied. Demand structures of different buildings and buildings groups (left). Sources and supply structures (right) adapted for supply of demand side **Fehler! Verweisquelle konnte nicht gefunden werden.**.

The EBC Annex 64 focuses both on the theoretical and methodological tools and modelling and on practical implementation. The scope is to evaluate the practical application of low exergy (LowEx) approaches on a community scale. Thereby, the annex shall contribute to technology development, the understanding of system synergies and existing implementation barriers.

LOW EXERGY THINKING FOR COMMUNITIES

The main objective of the annex is to demonstrate 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. In the course of this activity, the aim is to develop and improve means for increasing the overall energy and exergy efficiency of communities by matching demand and supply and by the integration of renewable energy sources. The central focus of all considerations is thermal energy at different exergy levels. Electrical energy will be taken into account as auxiliary energy. Electricity from a renewable fluctuating supply should be discussed as a contribution to the heat and cold supply of a community if it is thermally stored (e.g. storage tanks or usage of the building mass) and used for heating or cooling purposes (e.g. heat pumps). Another objective within the international co-operative work is the discussion of appropriate additional indicators, supplementing the exergy assessment. This should lead to a common understanding of the experts of how to weigh high-exergy electricity for heating and cooling purposes under the precondition of local availability. Another objective is the application of exergy analysis as a basis for providing tools, guidelines, recommendations, best-practice examples and background material for designers and decision makers in the fields of low exergy generation, low exergy distribution and low exergy consumption. 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. Aspects of transition management and policy will ensure the feasibility. A close cooperation with other IEA initiatives, as DHC Annex TS1, SHC Task 52, ECES Annex 28, EBC Annex 63 and others have already been established.

BENEFITS OF THE APPLICATION OF THE LOWEX APPROACH

The advantages of the application of the LowEx approach in the holistic assessment of a community are manifold:

- Customers benefit in various ways. First of all, the use of low exergy sources and surface heating ensures a good comfort level and a sustainable supply. Customers do not have to worry about maintenance, fuel supply and optimal operation of heating systems.
- The environment benefits from the exergy concept. The total GHG emissions in communities can be substantially reduced as a result of the use of more efficient energy conversion processes. This concept supports the setup of sustainable structures and secure energy systems for future developments on the community scale.
- From an economical point of view, high price stability can be expected due to the use of locally available, renewable, or surplus heat energy sources. An additional advantage of this is a lower dependency on foreign fuel supplies. The high overall system performance that can be achieved by using low temperature sources would lead to reduced resource consumption and therefore lower costs for fuels. This would also increase price stability and could potentially provide heat at very competitive prices.

3. Description of different Research Activities

OPTIMISATION DEMAND PROFILES AND BUSINESS MODELS

Energy demands currently are commonly supplied by centralised or decentralised systems designed and optimised for single demand profile. Therefore, energy demands of several yet different building types should be combined to pave the way for utilisation of unused synergies within existing communal building and supply structures. The research activities in field of "optimisation of demand profiles" are strongly focused on the demand of buildings as part of multifarious community supply systems. As part of the work, the previously developed the exergetic assessment methods from IEA EBC Annex 37 [2] and IEA EBC Annex 49 [3] will be applied and further developed. The focus here is particularly on so-called LowEx system distribution and supply concepts of different building classes. For this reason the optimisation potentials of heating and cooling tasks of buildings as well as building groups as one part of multifarious community supply systems. Furthermore business models are part of this work. They are important to ensure the economic feasibility and realistic implementation environments.

The following figure shows the different energy needs that occur in municipal supply systems. For example, the red-colored buildings represent existing buildings with low energy standard (high exergy demand), the bright yellow building represent plus-energy buildings.

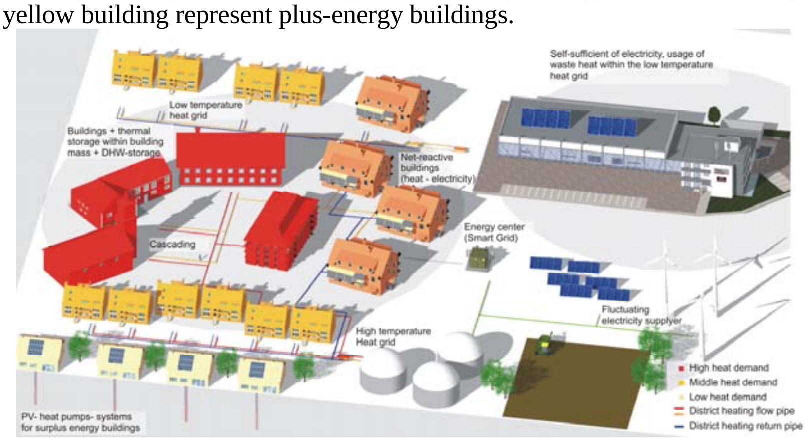

Fig. 3: Different energy demand of different energy classes and supply options based on renewable energy sources **Fehler! Verweisquelle konnte nicht gefunden werden.**.

OPTIMISATION OF SUPPLY PROFILES

Development and identification of concepts allowing a flexible supply of different demands with maximum share of local and renewable energy sources. Thereby chances for an efficient use of decentralized renewable-energy based systems such as CHP units, heat pumps and solar thermal collector fields as well as surplus heat (secondary energy) are enhanced. In this context, an all electrical supply and the use of heat pumps for the heating and cooling of the building stock is a promising option, too. Electrical energy from fluctuating energy sources will only be considered if they are thermally stored (e.g. storage tanks or usage of the building mass) and used for heating or cooling purposes (e.g. heat pumps). In this case only, an exergetic assessment is required and the signified contribution to greenhouse gas reduction is available.

REALISATION AND DEVELOPMENT OF “MODEL CITIES”

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ASSESSMENT METHODOLOGY

The main objective is to collect and further development of existing (exergy) assessment methods. This step is used to identify the most appropriate method (e.g. Excel Tools or Simulations Tools) for each user group. Based on the respective method it should be possible to display various stages of planning or design of buildings, groups of buildings and community supply systems. In particular, the further development of approaches from previous EBC Annex 37 [2] and Annex 49 [3] is pursued here. In addition to these objectives, it is possible to develop a simplified approach or to identify new approaches. All method should contribute to a more flexible, efficient and renewable energy supply in community systems.

4. Expexted Outcome and Results from the Project

The following results expected from the activities within the research activities within the framework of the International Energy Agency (IEA), the EBC Annex 64:

- Analysis concept and design guidelines with regard to the overall exergy performance of community supply and demand. This could include a possible classification of technologies in terms of performance, improvement potential and innovation prospects.
- Overview of the feasibility, efficiency potentials and impacts of integral energy system solutions for existing community settings, criteria for decision making in the project development phase.

- Analysis framework and open-platform software and tools for community energy system design and performance assessment.
- Summary of intelligent management and control strategies and system solutions for an efficient energy supply system at community level based on exergy principles.
- Set of existing and close to market systems and technological solutions and best integration into overall energy system design.
- Description and collection of good practices and examples of system concepts, technologies, management and control strategies for maximum share of renewable energy sources and maximum efficiency of the energy and exergy potentials available on a community scale.

The primary deliverable is an easy to understand and practical, applicable design guidebook for key people in communities. It is to contain an executive summary for decision makers and will cover issues on how to implement advanced supply technologies at a community level. Further it is focused on how to optimise supply structures to ensure reduced costs for the system solution, while providing a high standard of comfort to the occupants of the buildings.

The dissemination of documents and other information is to be focused on providing practitioners with. research results. Methods of information dissemination are to include conventional means such as presentations at workshops and practice articles. The project homepage will be used extensively to spread information. Publications may be written in English and in the languages of the participants' countries. However, the translation of the key findings into English will allow for a broader distribution of knowledge. A communication platform will be developed using local networks and energy related associations. Regular workshops will be organised in all participating countries to show the latest project results and to provide an exchange platform for the target audience. Some of the workshops might be organised within the framework of national or international conferences or symposia.

5. Conclusions

Communities are characterized by a wide range of heating and cooling energy demands. This energy is mainly provided by the combustion of fossil fuels, which is responsible for greenhouse gas (GHG) emissions. National and international agreements limit the GHG emissions of industrialized countries, respectively, for climate protection. While a lot has already been achieved there are still large potentials in providing heating and cooling energy. At the community level, different renewable sources are available. These energies are characterised by high fluctuations and different qualities: e.g. photovoltaic as electricity (high-exergy) or low temperature (low-exergy) heat from renewable energy sources. Low energy qualities are of particular interest, because the low exergy (LowEx) supply is very efficient. These described properties represent a major challenge. For solving these challenges, the identification of potential savings and synergies by performing holistic analysis of energy flows is necessary. The application of exergy principles is especially important, allowing the detection of different available energy-quality levels and the identification of optimal contribution to an efficient supply. From this, appropriate strategies and technologies with great potential for promoting the usage of low-valued energy sources (LowEx) and a high share of renewable energies for heating and cooling of entire cities can be derived.

In the framework of the EBC project 'Annex 64 on LowEx Communities – Optimized Performance of Community Energy Supply System with Exergy Principles' advanced technologies have to be adapted and further developed to realize the identified potentials. It is important to demonstrate the potential of low exergy thinking on a community level as energy and a cost efficient solution for achieving 100 % renewable and GHG emission-free energy systems.

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