Low Exergy Systems for High-Performance Buildings and Communities

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ABSTRACT

There is an obvious and indisputable need for an increase in the efficiency of energy utilization in buildings. Heating, cooling and lighting appliances in buildings account for more than one third of the world's primary energy demand. In turn, building stock is a major contributor to energy-related environmental problems. There are great potentials, which can be obtained through a more efficient use of energy in buildings.

A careful look at the exergy flows in buildings and the related supply structures, similar to other thermodynamic systems such as power stations, can help identify the potential of increased efficiency in energy utilization. Through the analyses, it can be shown that calculations based on the energy conservation and primary energy concept alone are inadequate for gaining a full understanding of all important aspects of energy utilization processes. For example, the high potential for a further increase in the efficiency of boilers whose energy efficiency is close to 100%, can not be quantified by energy analysis alone, but it can be shown by using exergy analysis (Schmidt and Shukuya 2003), the exergy efficiency of a common gas boiler is about 8%.

This paper outlines the international co-operative work in the general framework of the International Energy Agency Energy Conservation in Buildings and Communities Systems (IEA ECBCS), the: Annex 49 "Low Exergy Systems for High Performance Buildings and Communities" (Annex 49 2007).

1. INTRODUCTION

As a consequence of the latest reports on climate change and the needed reduction in CO_2 emissions, huge efforts must be made in the future to conserve high quality (primary) energy resources. A new dimension will be added to this problem if countries with fast growing economies continue to increase their consumption of fossil energy sources in the same manner as they do now. Even though there is still considerable energy saving potential in the building stock, the results of the recently finished IEA-ECBCS-Annex 37, "Low Exergy Systems for Heating and Cooling of Buildings" (Annex 37 2006), show that there is an equal or greater potential in exergy management (Ala-Juusela et al 2004). This implies working with the whole energy chain, taking into consideration the different quality levels involved, from generation to final use, in order to significantly reduce the fraction of primary or high-grade energy used and thereby minimise exergy consumption (Schmidt 2004). New advanced forms of technology have to be implemented. At the same time, as the use of high quality energy for heating and cooling is reduced, there is more reason to apply an integral approach, which includes all other processes where energy/exergy is used in buildings. In recent years, we have made substantial progress in the development of new and integrated techniques for improving energy use, such as heat pumps, co-generation, thermally activated building components, and methods for harvesting renewable energy directly from solar radiation, from the ground and various other waste heat sources (Schmidt, Henning and Müller (2006).

The results obtained in the research projects on optimised rational exergy consumption in buildings are promising and elucidate a huge potential for introducing new components, techniques and system solutions to create low exergy built environments. The exergy conversion, e.g. thermal energy or electricity production, plays a crucial part in possible future activities in the overall system optimisation of the entire energy system within a building.

2. THE EXERGY CONCEPT

Exergy is a concept which helps us distinguish between two parts of energy: exergy and anergy. Only the exergy part of any energy flow can be converted into some kind of high-grade energy such as mechanical work or electricity. Anergy, on the other hand, refers to the part of the energy flow which cannot be converted into high-grade energy, e.g. low-grade waste heat from a power plant, whose temperature already reaches the surrounding temperature. Exergy can be regarded as the valuable part of energy, while anergy designates the portion with no value.

Unless a suitable use for exergy is found, e.g. waste-heat utilisation in buildings, the low-value part of the original energy flow will eventually dissipate into the environment. Such unalterable dissipation is designated as irreversibility. The exergy content of a given flow of energy depends on the attributes, e.g. the temperature, pressure, and chemical composition, of both the substance carrying the energy (energy carrier), and the surrounding environment. The more different the attributes of the energy carrier and the environment are, the higher the exergy content of the energy carrier is. For example, high-pressure steam required for electric power generation has a higher exergy content than warm water needed by a dishwasher (Moran 1989).

The Low Exergy (LowEx) approach entails matching the quality levels of exergy supply and demand, in order to streamline the utilization of high-value energy resources and minimize the irreversible dissipation of low-value energy into the environment (Schmidt 2004); (Shukuya and Hammache 2002). This approach is the key concept for the work of Annex 49 on energy use and supply structures in the built environment.

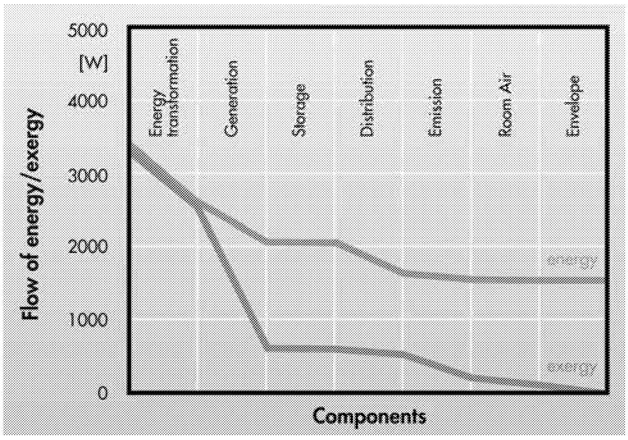

Figure 1: An example of an exergy and energy flow analysis of a building

To clarify these ideas, different uses of energy within buildings are explained: if we heat indoor space up to 20°C, we have to supply heat at a slightly higher temperature 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% only). If the production of domestic hot water is considered as heating water up to temperatures of about 55°C, the needed energy quality is slightly higher (q ≈ 15%). For cooking or heating of, for example, a sauna, we need an even higher quality level (q ≈ 28%), and for the operation of different household appliances and lighting we need the highest possible quality (q ≈ 100%).

On the other hand, our energy supply structures are not sophisticated in the same manner as the use. Energy is commonly supplied as electricity or as a fossil energy carrier. The energy quality of the supply for all different uses are the same and unnecessarily high (q ≈ 100%).

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%. There is a large variety of technical solutions to supply buildings with the lowest possible supply temperatures (q ≈13%) on the market.

Commonly known water-borne floor heating systems are one of these solutions.

For the following considerations, a single-family dwelling has been chosen as an example. For this home, an indoor air temperature of 21°C is assumed as the reference temperature, and the ambient air temperature during a typical winter day is 0°C. The calculation for this study have been conducted with the Annex 49 analysis tool, an Excel based spreadsheet tool for steady state calculations. The method described in detail in and based on (Schmidt 2004). The calculated figures are actual loads for typical conditions.

For the building service equipment and the heating system of the building, three different variants have been studied intensively:

1. A condensing boiler as the primary heat generator and standard radiators with the temperature levels for supply and return of 55/45°C have been assumed as the emission system.
2. A biomass-fired boiler (e.g. wooden pellet burner) is the heat generator and a floor heating system with temperature levels for supply and return of 28/22°C is the chosen emission system.
3. A ground source heat pump with a ground heat exchanger is the primary heat source and a floor heating systems with temperature levels for supply and return of 28/22°C is the chosen emission system.

By doing this comparison of an energetic and exergetic assessment of the primary energy demand from fossil and renewable sources it can be clearly shown that the different building service system configurations could handle the same requirements to fulfil the heating task of the same building, with a largely varying amount of exergy. Especially the condensing boiler, where natural gas is used and burned, utilises about 100% exergy for that task . This is also true for the wooden pellet burner. Other systems are able to satisfy the requirements with less than half of the exergy, like the third system configuration.

The exergetic assessment of the regarded heating systems opens up for the possibility to compare the performance (and the efficient use of different the energy sources) in an equal and thermodynamic way. This basis is free from the influence of political discussions and national borders. The potential of renewable energy sources has also correctly been taken into consideration. It can be concluded that a rational use of energy has to be assessed with an additional exergy analysis and that exergy use should be limited, as it is done today with primary energy. This has to happen under the consideration of the entire building as one system (Ala-Juusela 2004, Schmidt 2004).

In Germany, the typical primary energy efficiency for heating of newly erected dwellings, equipped with good building service systems, is about 70%. If exergy is considered, the picture changes: the exergetic efficiency of the heating process is only about 10%.

3. SCOPE AND OBJECTIVES

The scope of this activity is to improve, on a community and building level, the design of energy use strategies which account for the different qualities of energy sources, from generation and distribution, to consumption within in the built environment. In particular, this method of exergy analysis has been found to provide the most correct and insightful assessment of the thermodynamic features of any process and offers a clear, quantitative indication of both the irreversibility and the degree of matching between the resources used and the end-use energy flows (Sciubba and Ulgiati 2005). To satisfy the demands for the heating and cooling of buildings, the exergy content required is very low, since a room temperature level of about 20°C is very close to the ambient conditions. Nevertheless, high quality energy sources, like fossil fuels, are commonly used to satisfy these small demands for exergy (Schmidt 2004). From an economical point of view, exergy should mainly be used in industry to allow for the production of high quality products.

It is known that the total energy use caused by buildings accounts for more than one third of the world’s primary energy demand (ECBCS 2007). There is however substantial saving potential in the building stock. The implementation of exergy analyses paves the way for new possibilities of increasing the overall efficiency of the energy chain. Exergy analysis can support the development and selection of new types of technology and concepts with the potential of lowering exergy consumption for built environments and the related supplies. It can also quantify this potential. Up to now, considerable effort has been made to reduce the energy demand of the building stock and to increase the energy conversion factors in power stations. The new approach is not necessarily focused only on a further reduction of the energy flow through a building's envelope, but also aims at satisfying the remaining thermal energy demand using only low quality energy, if the demands for heating and cooling have already been minimized. This creates the potential for reducing the total amount of exergy needed by the energy supply-demand chain, and for providing a more customized distribution of exergy to consumers with different exergy requirements.

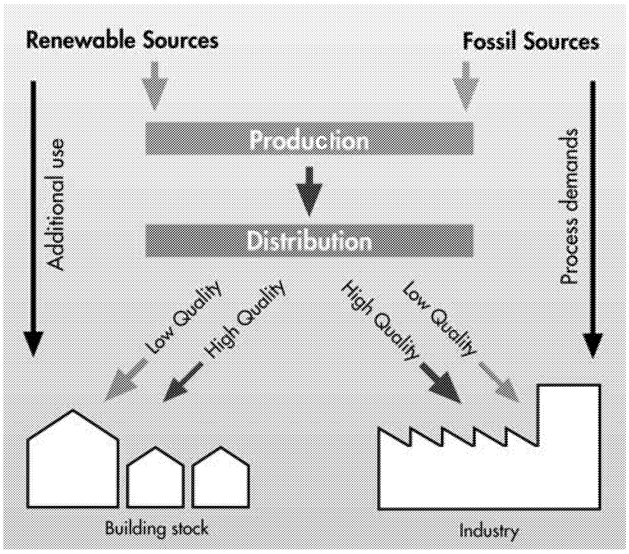

Figure 2. Desirable energy/exergy flow to the building stock and industry. In the building stock, there should be a larger share of low valued energy, whereas high quality energy should be left for other purposes, e.g. industrial processes.

The main objective of the annex is to use exergy analysis as a basis for providing tools, guidelines, recommendations, best-practice examples and background materials to designers and decision makers in building, energy production and political fields. Another important objective is to promote possible energy/exergy and cost-efficient measures for retrofit and new buildings, such as dwellings and commercial/public buildings, and their related performance analyses viewed from a community level, including the energy supplies.

The major benefit of following low exergy design principles is the resulting decrease in the exergy demand in the built environment. By following the exergy concept, the total CO_2 emissions for the building stock will be substantially reduced as a result of the use of more efficient energy conversion processes. This new concept supports structures for setting up sustainable and secure energy systems for future building stock.

The strategies developed for a better and exergy optimised building design, aimed at a future of clean, clever and competitive energy use, will help in pinpointing specific actions to reach this goal. Additionally, the exergy demand of buildings will be reduced due to new, enhanced heating and cooling systems.

4. IDENTIFIED RESEARCH ISSUES

The exergy concept applied to buildings and the related supply structures leads to new research topics for building stock. The IEA ECBCS Annex 49 is addressing the following research items (Annex 49 2007):

- Combined exergy/energy analyses for community supply structures and buildings, especially those with changing ambient and boundary conditions. This will lead to the implementation of dynamic analyses for complex systems.
- Optimisation strategies for low exergy distribution and building technology system configurations.
- A mandatory holistic system approach to investigate the dependencies between energy production and the use of energy in buildings. This implies the feedback and the response of the building to the grid and energy production strategies.
- Integrated use of local renewable energy sources. Known and new, innovative techniques will be evaluated using new analysis tools. The results will indicate directions for new developments.

- Better control strategies for building service systems to reduce the overall exergy demand.
- Exergy as an indicator for sustainability and for long term, cost efficient solutions.
- Indoor comfort provided by placing the minimum possible exergy demand on building service systems.

5. STRUCTURE OF THE ACTIVITY

To accomplish these objectives, participants will carry out research and work on developments within the general framework of the following four subtasks: The first subtask, "Exergy Analysis Methodologies", is aimed at development, assessment and analysis methodologies, including a tool development for design and performance analysis of the regarded systems. The second subtask, "Exergy efficient community supply systems", focuses on the development of exergy distribution, and generation and storage system concepts at a community level. A third subtask, "Exergy efficient building technologies", is based on the reduction of exergy demand for the heating, cooling and ventilating of buildings. The last subtask, "Knowledge transfer, dissemination", concentrates on the collection and spreading of information on ongoing and finished work.

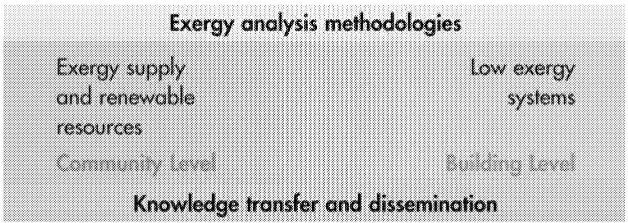

Figure 3. Subtask structure of the ECBCS Annex 49

The community and the building level are directly connected by the final energy conversion process. Nonetheless, the distribution concept for exergy has to be fixed at the community level.

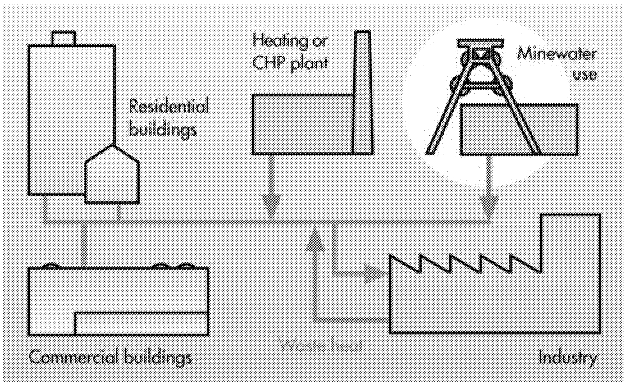

Figure 4. The integration of energy sources from our environment, e.g. the use of water from abandoned mines for heating and cooling buildings, requires exergy efficient supply systems at the community level and adapted building service systems.

6. EXPECTED RESULTS

The primary presentation of the annex is expected to be an IT based guidebook on how to implement advanced LowEx technology at a community level in the built environment and how to optimise supply structures to ensure low exergy demand of the system solution, while providing good comfort to the occupants and users of the buildings. Furthermore, the work will focus on analysis concepts and design guidelines with regard to exergy metrics for performance and sustainability. A collection of best-practice examples of new and retrofit buildings and techniques will show the potentials of the new approach. With this basis, recommendations for policy measures will be suggested and the aim is to conduct pre-normative work (Annex 49 2007).

The focus of the dissemination of documents and other information is to transfer the research results to be used by practitioners. Methods of information dissemination are to include conventional methods such as newsletters and articles, as well as new media, and the Internet is to be used intensively to spread information. Workshops will be organised in different countries to show the latest project results and to provide an exchange platform for the target audience (notably, energy managers, designers, and energy service companies).

7. OTHER RELATED ACTIVITIES

The International Society of Low Exergy Systems in Buildings (LowExNet) was founded by participants of the completed IEA ECBCS Annex 37. LowExNet members are working with exergy issues, supporting the work in the framework of Annex 49 and have been presenting their results and findings in a number of workshops and seminars, mainly in the framework of international conferences within the field of building technology, building physics and building services. The LowExNet group offers a platform for discussion and information dissemination on the proposed activities. To strengthen and expand the scientific collaboration in the LowEx field, a number of national (e.g. German and Dutch) and European projects have been started (LowExNet 2007). Furthermore, a close collaboration to the ASHRAE Technical Group 1 (TG1) on "Exergy Analyses for Sustainable Buildings" has been established.

8. CONCLUSIONS

The major benefit of following low exergy design principles is the resulting decrease in the exergy demand in the built environment and related energy supplies. By following the exergy concept, the total CO_2 emissions for the building stock will also be substantially reduced as a result of the use of more efficient energy conversion processes. This new concept supports structures for setting up sustainable and secure energy systems for future building stock. The strategies developed for a better and exergy optimised building design, aimed at a future of clean, clever and competitive energy use, will help to pinpoint specific actions required to reach this goal. Additionally, the exergy demand of buildings will be reduced due to enhanced new heating and cooling systems. The target is to establish a holistic approach for an affordable, comfortable and healthy built environment, while obtaining a minimum input of exergy, and implementing a substantial amount of renewable energy sources into the energy supply of buildings.

Additional and more extensive information can be found on the homepages (Annex 49 2007) and (LowExNet 2007).

9. ACKNOWLEDGEMENTS

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