Low Exergy Systems for High-Performance Built Environments

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ABSTRACT

It is often claimed that energy is consumed, not only in everyday conversation but also in scientific discussions associated with energy and environmental issues. This claim conflicts with the first law of thermodynamics stating that the total amount of energy is conserved, even though forms of energy may change from one to another. This is why we need to use the thermodynamic concept, exergy, to fully understand what is consumed.

An optimisation of the exergy flows in buildings and the related supply structures, similar to other thermodynamic systems such as power stations, can help in identifying the potential of increased efficiency in energy utilization. Through 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. The high potential for a further increase in the efficiency of; for example, boilers, can not be quantified by energy analysis - the energy efficiency is close to 1; however, this potential can be showed by using exergy analysis (Schmidt and Shukuya 2003).

This paper outlines the international co-operation work in the general framework of the International Energy Agency (IEA), the ECBCS Annex 49 “Low Exergy Systems for High Performance Buildings and Communities” (Annex 49 2006).

KEYWORDS

Exergy analysis, energy efficient buildings and communities

INTRODUCTION

As a consequence of the Kyoto protocol and the needed reduction in CO_2 emissions, huge efforts must be made in the future to conserve high quality, or 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 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 research projects on optimised exergy use 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. heat or electricity production, plays a crucial part in possible future activities in the overall system optimisation of the entire energy system within a building.

THE EXERGY CONCEPT AND THE LOWEX APPROACH

Exergy is a concept which helps us distinguish between two parts of an energy flow: 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. Exergy can be regarded as the valuable part of energy, while anergy designates the low-value portion.

Unless a suitable use for it is found, e.g. waste-heat utilization in buildings, the low-value part of the original energy flow will eventually dissipate into the environment and be irreversibly lost. 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 electrical 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 utilisation of high-value energy resources and minimise the irreversible dissipation of low-value energy into the environment (Shukuya and Hammache 2004, Schmidt 2004).

SCOPE AND OBJECTIVES OF THE ECBCS ANNEX 49

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 analyses 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 (Scibba 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. See Figure 1.

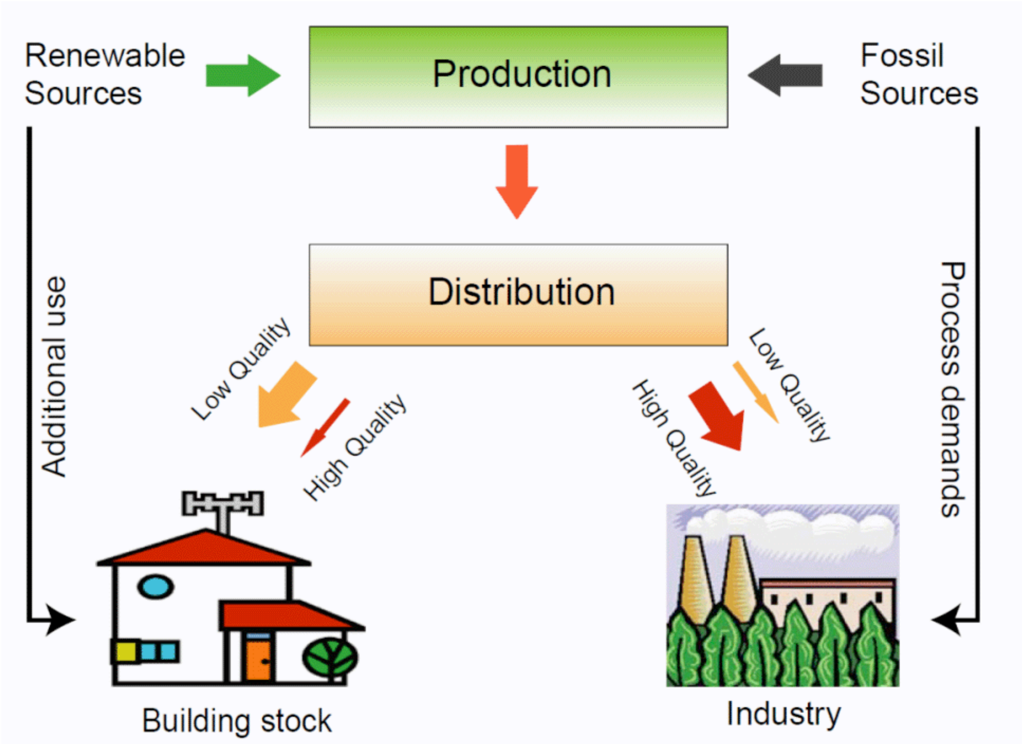

Figure 1: Desirable energy/exergy flow to the building stock and industry.

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 2006). 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. It can also quantify this potential. Up to now, considerable effort has been made to reduce the energy demand of the building stock. The new approach is not necessarily focussed on a further reduction of the energy flow through a building's envelope. When the demands for heating and cooling have already been minimised, the low-exergy approach aims at satisfying the remaining thermal energy demand using only low quality energy. This creates the potential for reducing the total amount of exergy needed by the energy supply-demand chain, and for providing a more customised distribution of exergy to consumers with different exergy requirements.

The main objective of the annex is to use exergy analysis as a basis for providing tools, guidelines, recommendations, best-practice examples and background material 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.

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, aiming 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.

IDENTIFIED RESEARCH ISSUES

The exergy concept applied to buildings leads to new research topics for building stock. The ECBCS Annex 49 is addressing the following research items (Annex 49 2006):

- 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.

STRUCTURE OF THE NEW 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, A “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, B “Exergy efficient community supply systems”, focuses on the development of exergy distribution, and generation and storage system concepts. A third subtask, C “Exergy efficient building technologies”, is based on the reduction of exergy demand for heating, cooling and ventilating of buildings. The last subtask, D “Knowledge transfer, dissemination”, concentrates on the collection and spreading of information on ongoing and finished work. Figure 2 shows the structure of the subtasks.

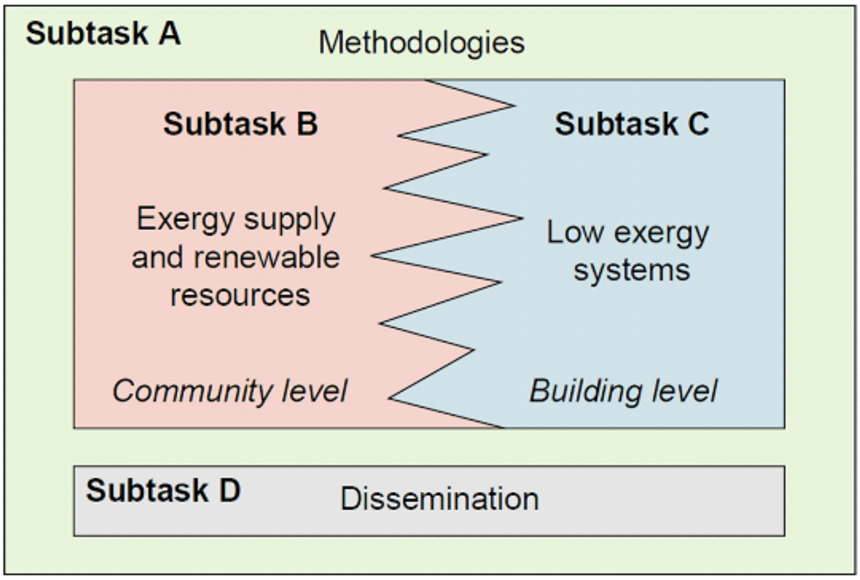

Figure 2: Subtask structure of the ECBCS Annex 49

The community[1] 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.

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. This will include a possible classification of low-exergy forms of technology in terms of performance, improvement potential and innovation prospects. A collection of best-practice examples for 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 pre-normative work will be conducted (Annex 49 2006).

The focus of the dissemination of documents and other information will be to transfer the research results to be used by practitioners. Methods of information dissemination will include conventional methods such as newsletters and articles, as well as new media; 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).

[1] A community (e.g. a district) is defined as a group of buildings connected to one energy supply system.

OTHER RELATED ACTIVITIES

The International Society of Low Exergy Systems in Buildings (LowExNet) was founded by participants of the completed ECBCS Annex 37. LowExNet members are working with exergy issues 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 and European projects are starting or in proposal (LowExNet 2006).

SUMMARY / CONCLUSIONS

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 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, aiming 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.

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