LOW EXERGY SYSTEMS FOR HIGH-PERFORMANCE BUILDINGS AND COMMUNITIES

Dietrich Schmidt[1] and Herena Torio[1]

[1] Fraunhofer Institute for Building Physics, Kassel (Germany)

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, 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 finished IEA ECBCS Annex 37, Low Exergy Systems for Heating and Cooling of Buildings (Annex 37, 2011), 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 need 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 et al 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 (Schmidt and Torio 2011). The exergy conversion, e.g. heat or electricity production, plays a crucial role in possible future activities in the overall system optimisation of the entire energy system within a building. New solutions can be obtained by taking advantage of the design of entire quarters or community structures into consideration. Then, by coupling a group of buildings or by the possible use of new energy sources (e.g. the use of water in old coal mines to heat and cool entire cities (Op’t Veld, Demollin-Schneiders 2007)) a more efficient use of energy is possible.

2. The Concept of Exergy Analyses in the Built Environment

The exergy of an energy flow represents the part of that energy flow which can be completely transformed into any other energy form and mechanical work. On the contrary, the part which can-not be transformed is designated as anergy. So, 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 and we can derive an energy quality measure by using this concept. Unless a suitable use for exergy is found, e.g. waste-heat utilisation in buildings, the low-value part (small exergy fraction in this flow) 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 carry-ing 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).

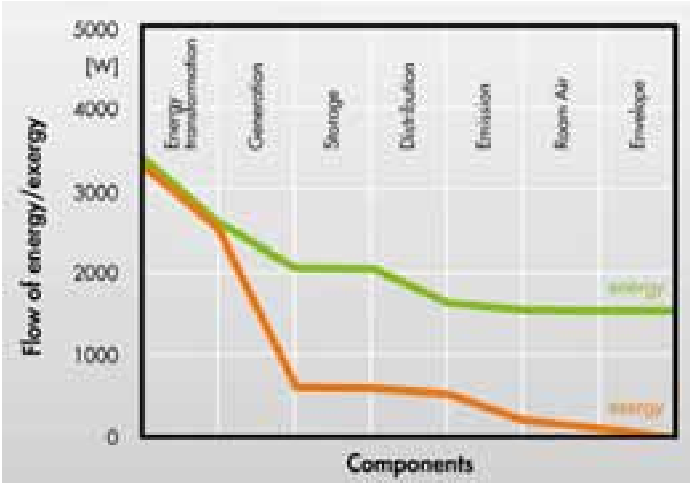


Fig. 1: Results of an analysis of energy and exergy flows through a building

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, Hammache 2002), (Sciubba, Ulgiati 2005). This approach is the key concept for the work of Annex 49 on energy use and supply structures in the built environment (Schmidt and Torio 2011).

3. Scope and Objectives of ECBCS Annex 49

The scope of this international activity within the frame of the International Energy Agency 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, 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 2011). 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 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.

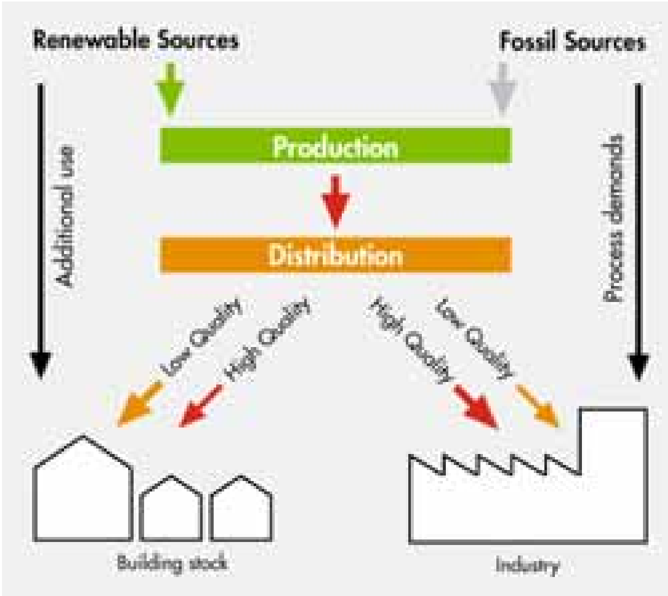


Fig. 2: Desirable energy/exergy flow to the building stock and industry. In the building stock, there should be a larger share of low valued energy, whereas high quality energy should be left for other purposes, e.g. industrial processes.

The main objective of the annex is to use exergy analysis as a basis for providing tools, guidelines, recommendations, best-practice examples and background 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, 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 finished ECBCS Annex 49 has been addressing the following research items (Annex 49, 2011), (Schmidt and Torio 2011):

- 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 conversion and the use of energy in buildings. This implies the feedback and the response of the building to the grid and energy conversion strategies.
- The evaluation of known and new, innovative techniques by using developed analysis tools are showing ways to integrate local renewable energy sources. 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 more sustainable energy systems and for long term, cost efficient solutions.
- Indoor comfort provided by placing the minimum possible exergy demand on building service systems.

5. Structure of ECBCS Annex 49

To accomplish these objectives, participants carried out research and work on developments within the general framework of the following four subtasks: The first subtask, “Exergy Analysis Methodologies”, was 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”, focused on the development of exergy distribution, and generation and storage system concepts at a community level. A third subtask, “Exergy efficient building technologies”, was based on the reduction of exergy demand for the heating, cooling and ventilating of buildings. The last subtask, “Knowledge transfer, dissemination”, concentrated on the collection and spreading of information on ongoing and finished work.

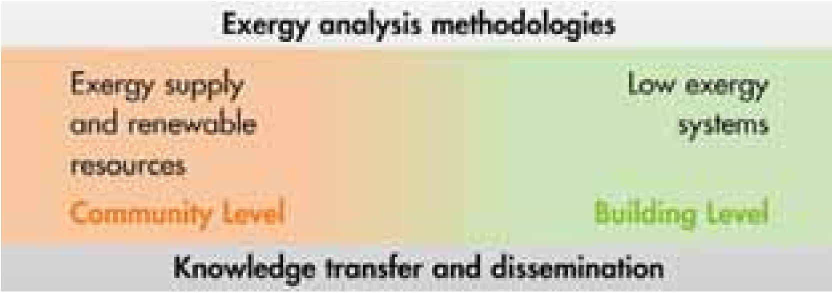


Fig. 3: Subtask structure of the ECBCS Annex 49

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.

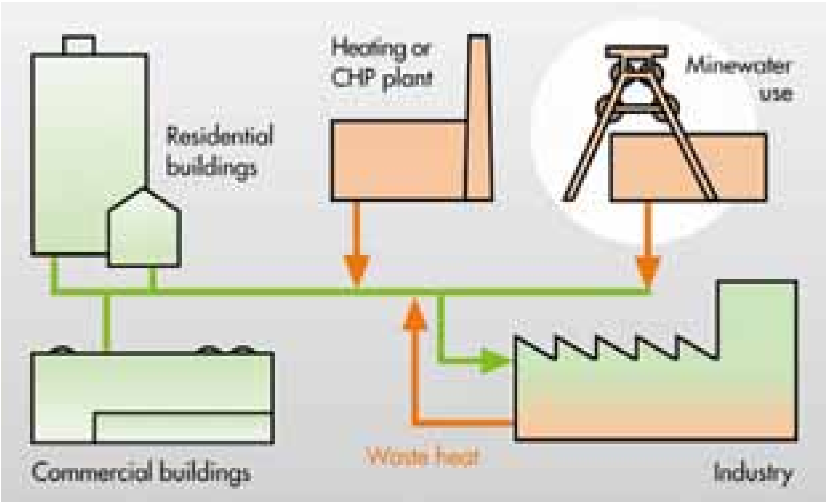


Fig. 4: The integration of energy sources from our environment, e.g. the use of water from abandoned mines for heating and cooling buildings, requires exergy efficient supply systems at the community level and adapted building service systems.

6. Results

The concept of exergy analyses has been transformed into a number of software tools on the basis of developed models during the course of the Annex 49 projects (Schmidt and Torio 2011).

For the first time a building exergy calculation has been implemented in a Building Information Modelling (BIM) tool. A new energy and exergy tool called the Design Performance Viewer (DPV) has been developed in the Building Systems Group at the ETH in Zurich based on the Excel tool developed in the IEA ECBCS Annex 37 and being expanded in the Annex 49. The tool integrates with the Autodesk Revit software allowing planners, designers, and architects to obtain an easy-to-understand graphical display of the energetic and exergetic performance of their building. The tool can be implemented in all phases of design and most importantly, allows the user to observe potential impacts of changes during the earliest and most influential phases of the design process. This facilitates an awareness of energy and exergy performance throughout a project, instead of energy analysis just being an afterthought at the end of a project.

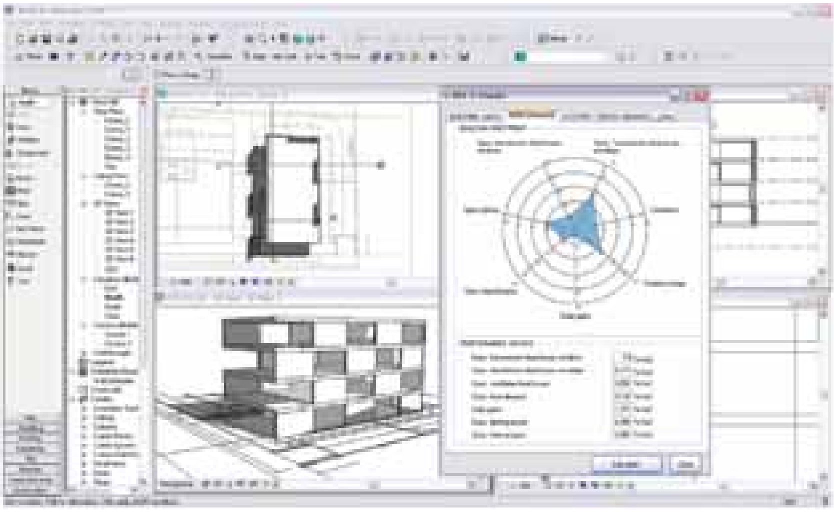
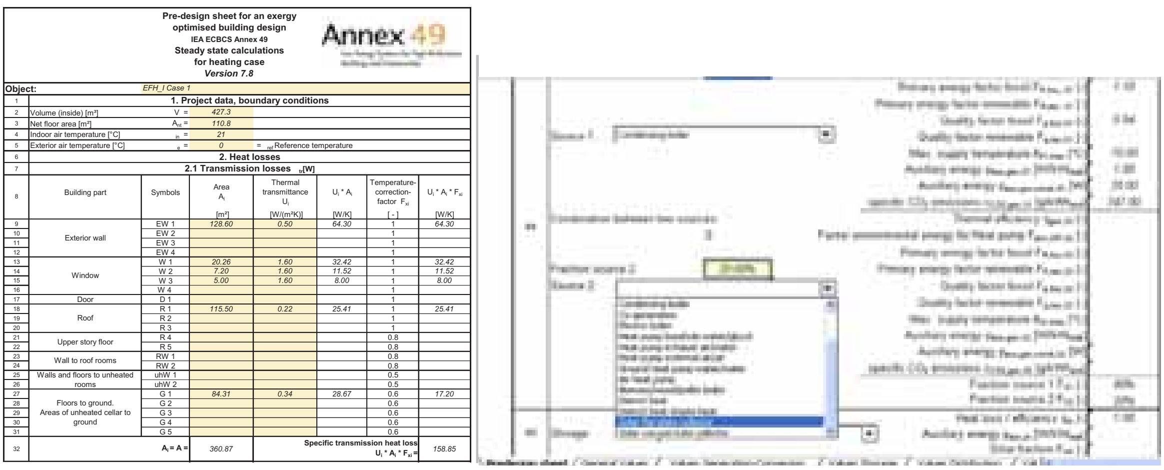


Fig. 5: Screenshot from DPV tool with spider graph for comparing the performance of different parts of building design

An other example is the excel-based pre-design tool, which aims at increasing the understanding of the exergy flows within the built environment and at facilitating further improvements on the energy use in this sector. It is a simple and transparent tool which brings the exergy approach in an easy to understand and comprehensible manner for its users, such as architects and construction engineers.



Pre-design sheet for an exergy optimised building design
IEA ECBCS Annex 49
Steady state calculations for heating case
Version 7.8

Annex 49

Object: *EFH_I Case 1*

1	**1. Project data, boundary conditions**						
2	Volume (inside) [m³]	V =	427.3				
3	Net floor area [m²]	A_{nt} =	110.8				
4	Indoor air temperature [°C]	$_{in}$ =	21				
5	Exterior air temperature [°C]	$_{e}$ =	0	= $_{ref}$ Reference temperature			
6	**2. Heat losses**						
7	**2.1 Transmission losses $_{tr}$[W]**						
8	Building part	Symbols	Area A_i [m²]	Thermal transmittance U_i [W/(m²K)]	U_i * A_i [W/K]	Temperature-correction-factor F_{xi} [-]	U_i * A_i * F_{xi} [W/K]
9	Exterior wall	EW 1	128.60	0.50	64.30	1	64.30
10		EW 2				1	
11		EW 3				1	
12		EW 4				1	
13	Window	W 1	20.26	1.60	32.42	1	32.42
14		W 2	7.20	1.60	11.52	1	11.52
15		W 3	5.00	1.60	8.00	1	8.00
16		W 4				1	
17	Door	D 1				1	
18	Roof	R 1	115.50	0.22	25.41	1	25.41
19		R 2				1	
20		R 3				1	
21	Upper story floor	R 4				0.8	
22		R 5				0.8	
23	Wall to roof rooms	RW 1				0.8	
24		RW 2				0.8	
25	Walls and floors to unheated rooms	uhW 1				0.5	
26		uhW 2				0.5	
27	Floors to ground. Areas of unheated cellar to ground	G 1	84.31	0.34	28.67	0.6	17.20
28		G 2				0.6	
29		G 3				0.6	
30		G 4				0.6	
31		G 5				0.6	
32		A_i = A =	360.87	Specific transmission heat loss U_i * A_i * F_{xi} =			158.85

Fig. 6: Fields for input data to define the building envelope in the pre-design excel tool (left) and drop-down menus for selecting building services (right) within the Annex 49 pre-design tool.

The field of application is mainly focused on buildings with normal and low internal temperatures respectively, as e.g. residential buildings, day-care facilities for children and office buildings. From the user, a definition of the building details (e.g. building envelope, air tightness,…) is required. By means of several drop-down menus, different building systems can be chosen to supply the required building demands. This allows limiting the required number of input data. Energy calculations are based on the German energy saving Standard (EnEV-2006) and follow a steady-state approach.

The primary presentation of the annex is a guidebook on how to implement advanced LowEx technology at a community level in the built environment and how to find supply structures to ensure low exergy demand of the system solution, while providing good comfort to the occupants and users of the buildings. This guidebook has been published by the Annex 49 in spring 2011. Furthermore, the guidebook will focus on analysis concepts and design guidelines with regard to exergy metrics for performance. 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 the aim is to conduct pre-normative work (Schmidt and Torio 2011). 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 newsletters and articles, as well as the Internet is to be used intensively to spread information. Workshops have been 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 to increase the exchange between researchers working within the field of exergy. 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 2011). Furthermore, a close collaboration to the ASHRAE Technical Committee TC 7.4 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. One major implication is to avoid burning processes in the energy conversion process, since these are always causing large exergy destructions. The target is to establish a more 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 (Schmidt and Torio 2011). Additional and more extensive information can be found on the homepages (Annex 49, 2011) and (LowExNet 2011).

9. Acknowledgements

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10. References

Ala-Juusela M. (ed.), 2004. Heating and Cooling with Focus on Increased Energy Efficiency and Improved Comfort. Guidebook to IEA ECBCS Annex 37. VTT Research notes 2256, VTT Building and Transport, Espoo, Finland.

Annex 37, 2011. Energy Conservation in Buildings and Community Systems – Low Exergy Systems for Heating and Cooling of Buildings, Homepage, http://virtual.vtt.fi/annex37/.

Annex 49, 2011. Energy Conservation in Buildings and Community Systems – Low Exergy Systems for High Performance Buildings and Communities, Homepage, http://www.annex49.com/.

ECBCS, 2011. Energy Conservation in Buildings and Community Service Program. International Energy Agency. Homepage: http://www.ecbcs.org.

LowExNet, 2011. Network of the International Society for Low Exergy Systems in Buildings. Homepage: http://www.lowex.net, 2011.

Moran M.J., 1989. Availability Analysis – a Guide to Efficient Energy Use. Corrected edition. ASME Press, New York, USA.

Op't Veld P. and Demollin-Schneiders E., 2007. Low Exergy in Practice – The Minewater Project in Heerlen, the Netherlands. In: ECBCS Annex 49 Newsletter, No. 1, Fraunhofer IBP, Germany.

Schmidt D. and Shukuya M., 2003. New ways towards increased efficiency in the utilization of energy flows in buildings. In: Proceedings to the Second International Building Physics Conference 2003, September 14-18, Leuven, Belgium. pp. 671-681.

Schmidt D., 2004. Design of Low Exergy Buildings- Method and a Pre-Design Tool. In: The International Journal of Low Energy and Sustainable Buildings, Vol. 3, pp. 1-47.

Schmidt D., Henning H.-M. and Müller D., 2006. Heating and Cooling with Advanced Low Exergy Systems. In: Proceedings of the EPIC2006AIVC Conference, November 20-22, Lyon, France.

Schmidt, D. and Torio, H., 2011. Exergy Assessment Guidebook for the Built Environment. Fraunhofer Verlag, Stuttgart, Germany

Sciubba E. and Ulgiati S., 2005. Energy and Exergy Analyses: Complementary Methods or irreducible Ideological Options? In: Energy, Vol. 30, pp. 1953-1988.

Shukuya M. and Hammache A., 2002. Introduction to the Concept of Exergy – for a Better Understanding of Low-Temperature-Heating and High-Temperature-Cooling Systems, VTT research notes 2158, Espoo, Finland.