Heating and Cooling with Advanced Low Exergy Systems

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ABSTRACT

There is an obvious and indisputable need for an increase in the efficiency of energy utilisation in buildings. Until now, so-called energy saving measures and analyses of energy flows in buildings have commonly been based on the energy conservation principle, the first law of thermodynamics. A method for carrying out exergy analyses which combines both the first and second law of thermodynamics allows for a better understanding and design of energy flows in buildings. Consequently, a more holistic view of the calculations is gained for all processes involved.

In agreement to these findings, new innovative heating, cooling and ventilation appliances have been developed within the framework of a German national collaboration project. This paper describes both the structure and work plan of the German alliance project on low exergy systems and the achievements in the development of innovative system solutions brought about by this close collaboration between leading German industry and research institutes.

KEYWORDS

Exergy analysis, energy efficient buildings, innovative HVAC systems

INTRODUCTION

In Germany, as in other industrialised countries, about 40% of the total energy consumption is caused by the heating, cooling and ventilating of buildings (ECBCS 2006). To keep indoor environments at a comfortable temperature of about 20°C throughout the year, high quality, mostly fossil, energy sources, e.g. mineral oil, natural gas or electricity, are used. It is obvious and indisputable, for economic and ecological reasons, that it is necessary to increase energy efficiency and use energy as effectively as possible.

New developments show that the heating and cooling of rooms can be performed using systems other than just traditional systems and fossil energy sources. New innovative systems use very small temperature differences between the heat carrier medium and the room. By doing so, high quality energy sources can be used more efficiently and passive effects can be used more effectively. In addition, also renewable energy sources, like thermal solar heating and the natural coolness of the ground for cooling offices during hot summer days, can be integrated into the energy supply in a better way.

These developments are supported by the 5th Energy Program of the Federal Government on “Innovation and New Energy Technologies” which was issued on June 1st, 2005 (BMWi 2005). In this framework program outlining German research strategies in the energy field for the next years, the development of new systems, which improve the use of the energy quality, namely the use of exergy, is one key issue in building related research activities. The alliance project “LowEx” has been initiated in order to coordinate the different product and concept developments, assure information exchange and develop a common concept for performance assessment and evaluation.

BACKGROUND: THE EXERGY CONCEPT AND LOWEX APPROACH

Energy is, again, an issue in political discussions, not only, but mainly, due to the increasing costs of satisfying our energy demand. In these discussions, major emphasis is put on the importance of using energy more efficiently, and there is a willingness to “save” energy and reduce energy “consumption”. This is not only part of everyday conversation but also in scientific discussions associated with energy and environmental issues. This claim conflicts with the first law of thermodynamics, which states that the total amount of energy is conserved, even though forms of energy may change from one to another. This is why a concept taking the second law of thermodynamics into consideration is needed to fully understand what is consumed (Schmidt and Shukuya 2003, Ala-Juusela 2004). The exergy concept is such a concept.

An optimisation of the exergy flows in building, similar to other thermodynamic systems such as power stations, can help in identifying the potential of increased efficiency in energy utilisation. It can be shown through analyses and examples 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 utilisation 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 shown by using exergy analysis (Schmidt and Shukuya 2003).

Exergy is the part of any energy flow which can be converted into some kind of high-grade energy such as mechanical work or electricity. Anergy, the remaining rest, 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 (Shukuya and Hammache 2004, Schmidt 2004, Moran 1989). The Low Exergy (LowEx) approach entails matching the quality levels of exergy supply and demand, in order to streamline and optimise the utilisation of high-value energy resources and minimise the irreversible dissipation of low-value energy into the environment (Schmidt and Müller 2006).

THE GERMAN ALLIANCE PROJECT

As described above, the German alliance project “LowEx” has been initiated to enhance the development of new and more efficient heating and cooling systems for buildings, which are also able to be run using more renewable and natural energy sources.

Objectives

The general statement on this activity can be described in more specific objectives and working fields to be conducted during the course of this project. They are as follows:

- Development of systems to harvest low exergy sinks and sources (e.g. ambient air, ground, and water).
- Development of efficient heat carriers and transport systems, which consume low amount of exergy.
- Development of LowEx emission systems in rooms, that are able to operate with small driving temperature differences.
- Development of active façade constructions.
- Development of LowEx storage systems.
- System integration and operation of LowEx systems.

Structure

To cover and work on all of these objectives, the alliance project "LowEx" has been subdivided into separate working areas. Two main working areas and one overlap or integral area can be identified. In the first area on **building systems**, the use of so-called phase change materials (PCM) in the building construction is mainly investigated and new product developments are initiated. In the second working area on **supply systems**, the application of so-called capillary tubes, also in combination with other technologies, is the primary area of work. As the organization of the two main working areas is not specific enough for a number of innovative solutions in sub-projects, a third area for **integral projects** has been created, with a view on the holistic system approach and the application of the new techniques in the practice of building operation.

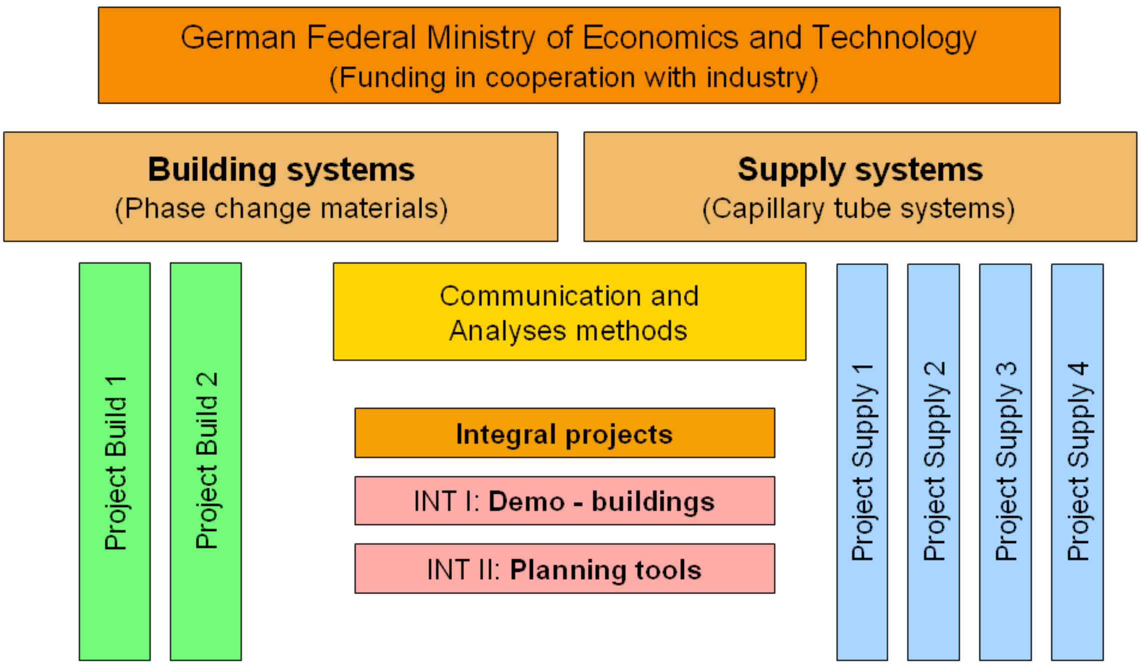

Figure 1: The structure of the ongoing German alliance project "LowEx"

Currently, nineteen sub-projects, with partners from leading German research institutes and industry, are being carried out within the framework of the alliance project “LowEx”.

WORKING AREA: BUILDING SYSTEMS

Based on the LowEx principles, new innovative HVAC system solutions are developed like storage systems, utilising so-called PCM (phase change material) in building construction and inside the HVAC equipment. With phase change materials, the latent heat storage effect, i.e. heat uptake, storage and release by melting and freezing of special materials at suitable temperatures (e.g. 24-26°C), is utilised. The PCM material can be encapsulated into microcapsules and integrated in building materials such as plaster or gypsum boards, or it can be packed in a macro scale into packages. By implementing PCM material in the building construction, the thermal storage capacity of the entire construction can be increased significantly. Thereby a dampening effect and increased comfort for summer conditions in light-weight constructions can be achieved. Another application is the integration of PCM storages in decentralized air handling units to increase the efficiency of night cooling. Some night coolness is stored in the system and released during hot summer days. These systems can be integrated in the construction of the façade.

An innovative approach is the development of new heat carrier fluids with PCM materials, so-called PCM slurries, to increase the storage capacity of the heat carrier. Energy for the fluid transport, e.g. electricity to operate pumps, can thereby be saved. The possible utilisation of PCM microcapsules in water or glycol, and PCM in emulsions, is being investigated. This technology also offers a new way of storing cold with PCM material, with suitable melting points.

WORKING AREA: SUPPLY SYSTEMS

The base technology for this working area is the implementation of so-called capillary tube systems. Thin plastic tubes of about 4 mm in diameter are placed in parallel to each other at a distance of about 15 mm and mounted together to grid systems, of about 2.5 m long and 1 m wide, with supply and collector tubes at the end. Thereby, a prefabricated and comparably cheap system can be achieved. These tubes can be used in thermally activated surface systems, such as floor, wall and ceiling heating and cooling systems, with a typical power output of about 80 W/m² for heating and 40 W/m² for cooling. Since the system is quite thin, it is possible to use it in retrofit measures, too. In the alliance project, applications such as active surfaces and active façade constructions, and air to water and ground heat exchangers are being investigated. The thermal activation of basements, by using the floors of cool basements for the cooling of offices, is also an application.

These capillary tube systems can also be used for horizontal ground heat exchangers to utilise the ground as a heat source or sink. Furthermore, the application, together with a PCM suspension as a heat carrier, is a current research topic.

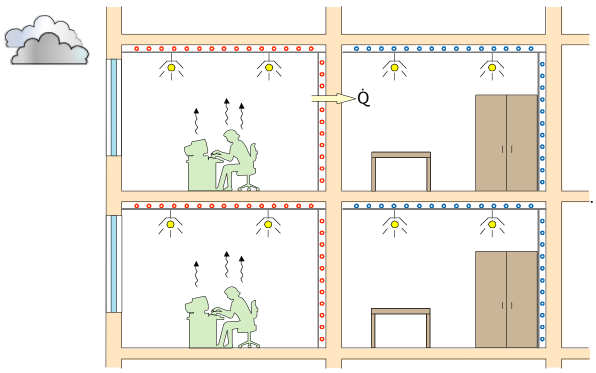

Figure 2: Displacement of heat between rooms with different thermal loads (e.g. North-South, server rooms) with capillary tube systems

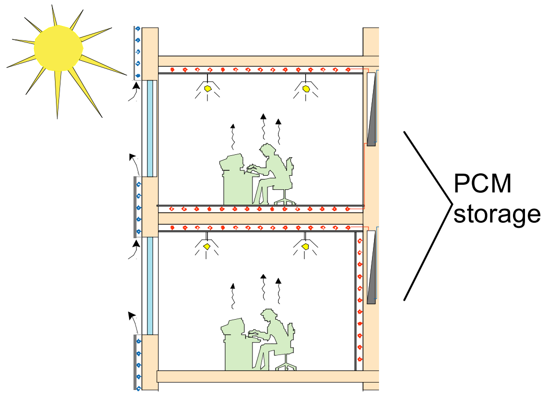

Figure 3: Active exterior façade construction for active night cooling in combination with PCM storages in the building construction

INTEGRAL PROJECTS

Main working items in integral sub-projects are the development of software tools for an energy/exergy assessment or for special studies, and dynamic analyses of complex systems. For these studies, the development of new models for innovative system solutions and components is needed and ongoing.

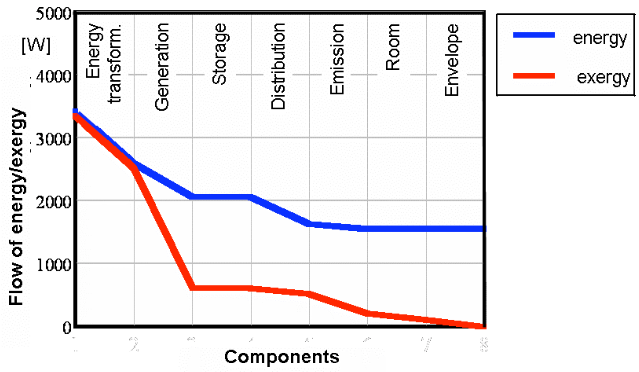

Figure 4: Results from a simplified tool for exergy analyses (Schmidt 2004)

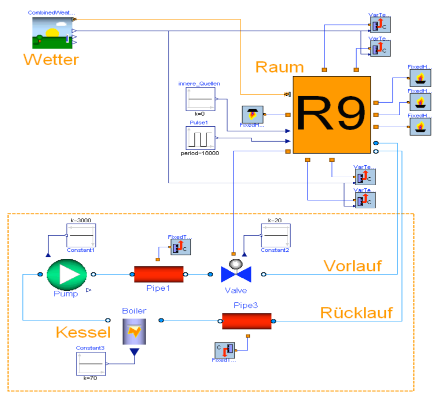

Figure 5: Detailed dynamic model for system optimisation

Other integral projects working with demonstration activities are being set up as dissemination platforms, like the website of the project. Further information in German and details about the sub-projects and partners can be found at: www.lowex.info.

OTHER RELATED ACTIVITIES

Research and development of LowEx systems is not only ongoing in Germany. Thus, an international working activity in the general framework of the International Energy Agency (IEA), the ECBCS Annex 49 “Low Exergy Systems for High Performance

Buildings and Communities" has been initiated with participants from a number of countries (ECBCS 2006, Annex 49 2006, Schmidt and Müller 2006). Furthermore, the International Society of Low Exergy Systems in Buildings (LowExNet) is an active and informal network of researchers in this field of interest. 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 scientific collaboration in the LowEx field, a number of national and European projects have been either started or are in proposal (LowExNet 2006).

SUMMARY / CONCLUSIONS

As stated above, there is an obvious and indisputable need for an increase in the efficiency of energy utilisation in buildings. This is especially valid with regard to the great saving potentials in the field of buildings. Most of the regarded energy uses, e.g. the heating of rooms to about 20°C, are, from their nature, low exergetic. It can be shown that the energy concept alone is not adequate to gain a full understanding of all energy use processes in buildings. From that viewpoint, the exergy concept can close this gap and help to increase the understanding of energy flows. Energy manifests itself not only via its quantity, but also via its quality, its exergy.

All improvements and innovations of energy systems in buildings should be measured with the most efficient and best possible use of the energy quality. We should care more about the efficient use of high quality energy and try to save not only energy, but also exergy.

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