Increased Energy Efficiency and Improved Comfort

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ABSTRACT

This paper summarises the work of the LowEx co-operation /1/. The aim was to promote rational use of energy by encouraging the use of low temperature heating systems and high temperature cooling systems of buildings. These systems can use a variety of fuels and renewable energy sources. Energy is used efficiently while providing a comfortable indoor climate. Exergy defines the quality of energy and is a concept for designing and assessing different heating and cooling systems. Application of exergy analysis into buildings has not been common before. Low exergy systems are defined as heating or cooling systems that allow the use of low valued energy as the energy source. In practice, this means systems that provide heating or cooling energy at a temperature close to room temperature.

Low exergy systems successfully combine both traditional and innovative new approaches. Research shows that people living in houses with low exergy systems are very satisfied with indoor environment quality. The demonstration projects, in turn, show the wide variety of possibilities to apply low exergy heating and cooling systems in buildings. The Guidebook, which was the final product of LowEx cooperation, is meant to help engineering offices, consultants and architects in their search for energy efficient heating and cooling systems that can provide the occupants with comfortable, clean and healthy environment. In addition, some background information is offered for real estate builders, building maintenance managers, political decision makers and the public at large.

KEYWORDS

Exergy, energy efficiency, heating, cooling, thermal comfort, buildings

INTRODUCTION

The necessity for an increase in the efficiency of energy utilisation in buildings is obvious and indisputable. Heating, cooling and lighting appliances in buildings cause more than one third of the world's primary energy demand. Thus, the building stock contributes as a major actor to the energy related environmental problems. "Energy saving" and emission reduction are both affected by the energy efficiency of the built environment and the quality of the energy carrier in relation to the required quality of the energy. Taking into account qualitative aspects of energy leads to introduction of the exergy concept in comparison of systems.

Exergy is energy, which is entirely convertible into other types of energy. High valued energy such as electricity and mechanical workload consists of pure exergy. Energy, which has a very limited convertibility potential, such as heat close to room air temperature, is low valued energy. Low exergy heating and cooling systems allow the use of low valued energy, which is delivered by sustainable energy sources (e.g. by using heat pumps, solar collectors, either separate or linked to waste heat, energy storage etc.).

Future buildings should be planned to use or to be or to be suited to use sustainable energy sources for heating and cooling. One characteristic of these energy sources is that only a relatively moderate temperature level can be reached, if reasonably efficient systems are desired. The development of low temperature heating and high temperature cooling systems is a necessary prerequisite for the usage of alternative energy sources. The basis for the needed energy supply is to provide occupants with a comfortable, clean and healthy environment.

EXERGY CONCEPT

What we really should start talking about, is “saving exergy” and “exergy consumption”. One reason for using the exergy approach and not just settling for the primary energy approach is that it is physically more correct to talk about exergy than energy consumption and production. The fact, that there is an energy quality, can be illustrated by an example evident for us from our experience in daily life (Figure 1). It is obvious that 100 kJ electricity stored in a 12 V/2.3 Ah car-battery is more useful, easier to transform into something useful for us, than the same amount of energy stored in 1 kg water at a temperature of 43 °C in an ambient temperature of 20 °C. The electricity is suitable for running a machine, like a computer, operating a light bulb of 40 W for 42 min or at least heating 1 kg of water with 23 °C. The 100 kJ heat contained in the 1 kg water is only suitable for washing our hands or doing the dishes. It becomes clear that there is a difference between the types of energy. By introducing the term exergy we appreciate the fact that energy manifests itself by its quantity and its quality.

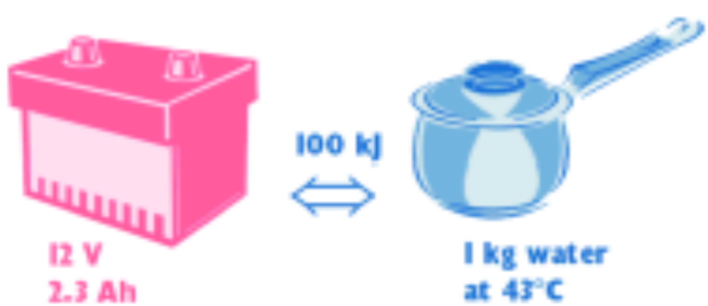


Figure 1: Both systems contain the same amount of energy but not the same amount of exergy.

Despite the efforts made to improve energy efficiency in buildings, the issue of gaining an overall assessment and comparing different energy sources still exists. Today's analysis and optimisation methods do not distinguish between different qualities of energy flows during the analysis. This exergy concept can be used to combine and compare all flows of energy according to their quantity and quality. Most of the energy is used to maintain room temperatures at around 20 °C. In this sense, because of the low temperature level, the exergy demand for applications in room conditioning is naturally low. In most cases, however, this demand is satisfied with high quality sources, such as fossil fuels or using electricity. Exergy analysis provides us with additional information on where and when the losses occur. It helps us to see in which part of the energy chain the biggest savings can be achieved.

Also we humans feed on exergy contained by food, and thereby consume it within our body so that we can sense, think and perform any physical work by contracting our muscles. The lowest human body exergy consumption occurs at thermally neutral condition. Figure 2 shows a new relationship between the human body exergy consumption, thermal comfort (PMV*=0), room air temperature and mean radiant temperature. The lowest exergy consumption rate emerges at the point where the room air temperature equals 18 °C and mean radiant temperature 25 °C. This suggests that the use of radiant warm exergy is more effective than the use of convective warm exergy for a heating purpose to realise both thermal comfort and as low exergy consumption within the human body as possible. It is interesting to see that, from the exergetic point of view, there is an optimal combination of room air temperature and mean radiant temperature which results in thermally neutral conditions, namely PMV*=0, although, from the conventional energetic point of view, there are many combinations of room air temperature and mean radiant temperature.

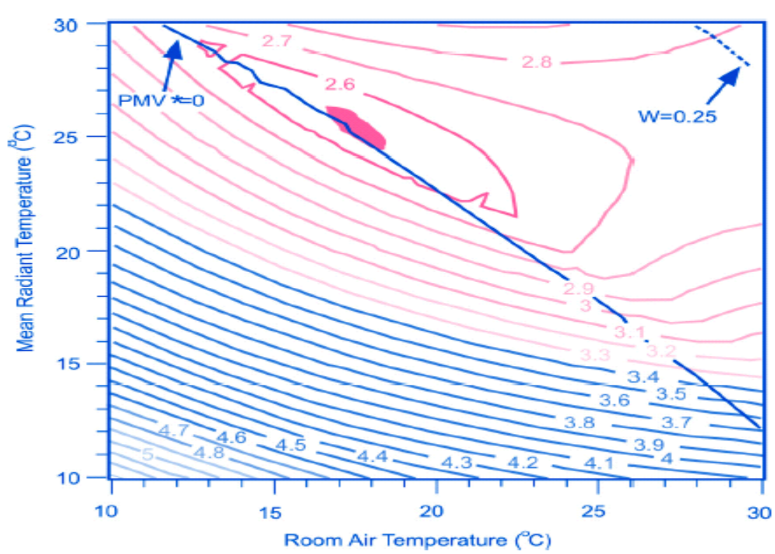
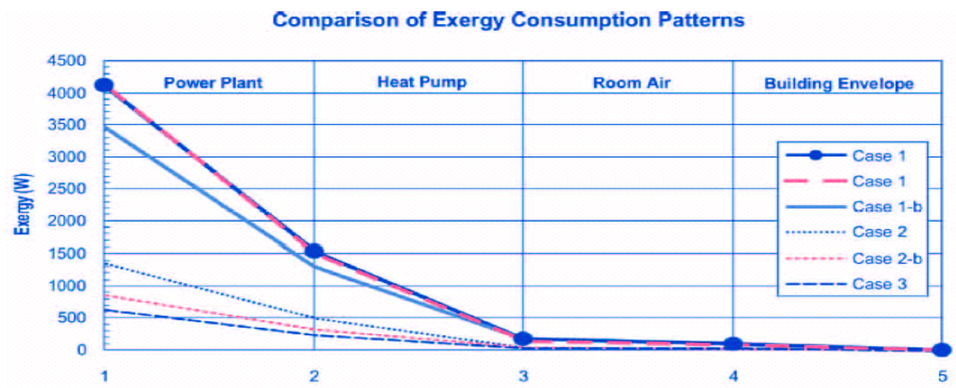


Figure 2: Relationship between exergy consumption within the human body (W/m^2), room air temperature, and mean radiant temperature. The solid line descending from the upper left corner to the lower right corner indicates thermally neutral conditions (PMV=0). The broken line in the upper right corner is skin wetness up to the amount which most people find tolerable (W=0.25). There is an optimal combination of room air and mean radiant temperatures which results in the lowest exergy consumption and thermal comfort.*

EXERGY ANALYSIS TOOLS

To increase the understanding of exergy flows in buildings and to be able to find possibilities for further improvements in energy utilisation in buildings, pre-design analysis tools were produced during the LowEx work. It was recognised the importance of developing a simplified tools to visualise why low exergy systems would be advantageous in some energy chains compared to high exergy systems. These tools should be easy to use and show the exergy flow through a system or energy chain (see Figure 3).



Case 1	Base Case - Moderate Thermal Insulation of Building Envelope, Internal Shading Devices
Case 1-b	Improved COP Coefficient
Case 2	Improved Thermal Insulation, External Shading Devices
Case 2-b	Improved Thermal Insulation, External Shading Devices, Improved Electric Lighting
Case 3	Improved Thermal Insulation, COP and Electric Lighting, External Shading Deivices

Figure 3: Example of the output of pre-design tools.

LOW EXERGY TECHNOLOGIES AND SYSTEM CONCEPTS

For future buildings, a minimum of energy at a very low level of temperature difference between the system and the room should be used for thermal conditioning. In this way a maximum of high quality energy (exergy) could be saved. The big efforts made in the field of energy saving in buildings by constructing well-insulated and tight envelopes, sufficient window shading and the use of thermal storage result to a much better usage of the energy. But there is still a big saving potential left. To make the energy use in buildings even more efficient, new low temperature heating and cooling systems are required.

In recent years system solutions have appeared where heating and cooling is carried out in an integrated system solution where the energy use is planned in a wider and more general perspective. An example of this is the Sensus® building services system (Figure 4). The exergy consumption of the Sensus ® system is lower than in comparable high-standard systems, which also decreases environmental impact during use. Office ventilation employs a Sensus® ventilation unit connected to the Sensus panels with a three-pipe network. The ventilation units utilise surplus heat collected from the rooms with the cooling water system for the heating of intake air whenever heating is needed for the intake air. The ventilation machine also has an efficient rotating heat collector for the exhaust air (over 70 % heat efficiency). The Sensus® ventilation unit utilises outdoor air for cooling the cooling water for the rooms when outdoor temperature is sufficiently low (under +12–14 °C). This free cooling carried out with ventilation units operates alongside mechanical cooling when necessary. It has a considerably longer annual period of utilisation (over half of the year's working hours) than conventional free cooling. This lowers the electricity consumption of cooling unit in the Sensus® system in comparison with conventional solutions.

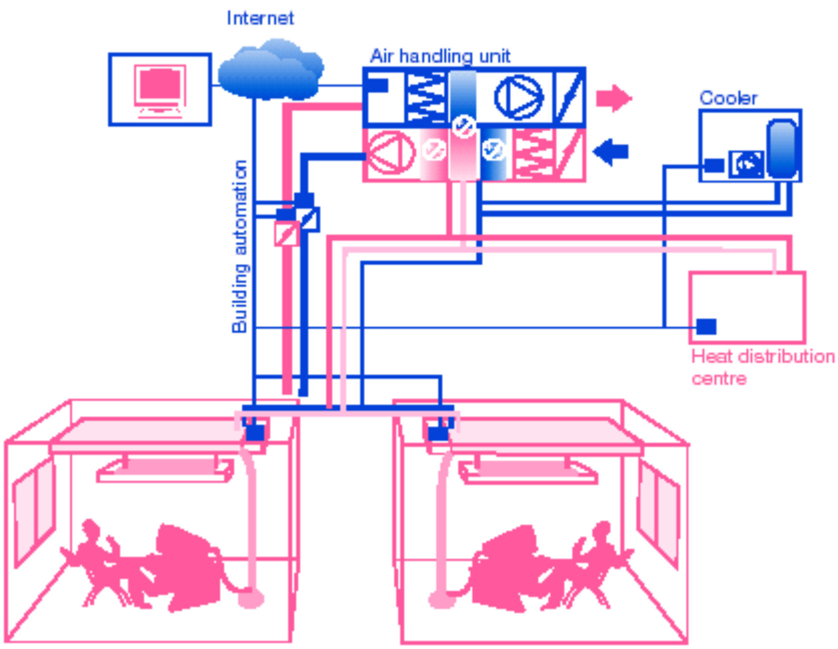


Figure 4: Sensus system solution.

EXPERIENCES FROM CASE STUDIES

One of the critical success factors for the implementation of, for example, low temperature heating systems in residential buildings is the way these systems are viewed and accepted by the occupants. According to occupant surveys notable was the very positive score for floor and wall heating. Although low temperature heating systems are very well accepted and appreciated, there are some negative aspects and disadvantages that should be taken into account and solved. These are, for example, system controllability per room (floor and wall heating) and the size, design and installation of low temperature radiators. The study shows that lowering the temperatures for heat distribution systems, besides the possibilities of savings in energy supply, gives additional benefits such as thermal comfort increases and the indoor air quality is also positively influenced.

CONCLUSIONS

Exergy defines the quality of energy and is an important tool for designing and assessing different heating and cooling systems. Low exergy systems are defined as heating or cooling systems that allow the use of low valued energy as the energy source. In practice, this means systems that provide heating or cooling energy at a temperature close to room temperature. Low temperature heating systems or high temperature cooling systems can use a variety of fuels and renewable energy sources. Exergy analysis is an important tool for the design of thermal systems since it provides the designer with additional information on where and why the losses occur. Exergy analysis can also be applied to human body to find optimal thermal conditions.

There are currently many low exergy technologies available. Low exergy systems successfully combine both traditional and innovative new approaches to heating and cooling of buildings. By using, for example, low temperature heating systems the room temperature can be decreased by a few degrees, which is more energy efficient and healthier for occupants. Low exergy heating and cooling systems are sustainable because they are flexible. Thorough planning and expert implementation are prerequisites for an appropriate and functional system.

The demonstration projects show the wide variety of possibilities to apply low exergy heating and cooling systems in buildings. The application of low exergy systems provides many additional benefits besides energy supply such as: improved thermal comfort, improved indoor air quality and reduced energy consumption. These aspects should be further promoted to increase the application of low exergy systems for heating and cooling of buildings. The building regulations and energy strategies should take the quality of energy into account more than today. Wide application of low exergy heating and cooling systems in buildings will create a building stock, which will be able to adapt to use of sustainable energy sources, when desired. Without this ability, the transfer towards an energy-wise sustainable world will be delayed for decades.

The Guidebook, which was the final product of LowEx co-operation, is meant to help engineering offices, consultants and architects in their search for energy efficient heating and cooling systems that can provide the occupants with comfortable, clean and healthy environment. In addition, some background information is offered for real estate builders, building maintenance managers, political decision makers and the public at large. The Guidebook is available as a CD-rom version and also freely available on the internet (http://www.lowex.net/).

References

Ala-Juusela, M. (editor) 2004, Heating and Cooling with Focus on Increased Energy Efficiency and Improved Comfort, Guidebook to IEA ECBCS Annex 37, Low Exergy Systems for Heating and Cooling of Buildings. VTT Building and Transport, 292 p.