Low Exergy Systems for Heating and Cooling of Buildings

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ABSTRACT: The low exergy approach should be the key concept in any long term strategy aiming at creating a sustainable built environment.

In recent years, how to build sustainable houses has been a constant source of discussion. A highly efficient usage of energy and all of the potentials in the involved energy flows are undisputable mandatory for that. To find and to quantify further potentials in energy use, the thermodynamic concept of exergy can be beneficial. Energy, which is entirely convertible into other types of energy, is exergy (high valued energy such as electricity and mechanical workload). 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 use low valued energy, which could also easily be delivered by sustainable energy sources (e.g. by using heat pumps, solar collectors or others). Common energy carriers like fossil fuels deliver high valued energy.

Heat emission systems, that are often part of the building construction itself, have a much longer service lifetime than building service equipment, such as boilers or chillers. With appropriate emission systems, the overall system design of a building is flexible in meeting future requirements, and they are open to being supplied by low temperature energy sources, such as renewable ones. There are already a number of different low temperature components, systems and technologies on the market, such as the known hydronic floor heating systems. Examples of buildings equipped with low exergy heating and cooling systems from all over the world and from all kinds of buildings, from newly erected to retrofit, from dwellings to commercial buildings, and also cultural monuments, such as churches and castles are collected during the course of the project.

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1 INTRODUCTION

LowEx, the international low temperature heating systems research programme (Annex 37), is part of the International Energy Agency's (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS). The aim of the programme was to promote rational use of energy by encouraging the use of more efficient low temperature heating systems for heating and cooling of buildings.

All the results of that work are published in a Guidebook, see chapter 7. The Guidebook 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.

1.1 Background

"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, which is the key idea of Annex 37. 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 (easily) delivered by sustainable energy sources (e.g. by using heat pumps, solar collectors, either separate or linked to waste heat, energy storage etc.). Common energy carriers like fossil fuels deliver high valued energy. The reason for "energy saving" being in quotation marks in the first sentence, is that we actually are talking about saving exergy, not energy!

Future buildings should be planned to use 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.

2 THE EXERGY APPROACH

Today calculations of energy use in buildings are based solely on the energy conservation principle, the first law of thermodynamics. The energy conservation concept alone is not adequate enough to gain a full understanding of all the important aspects of energy utilisation processes. From this point of view, the method of exergy analyses based on a combination of the first and second law of thermodynamics is presented in the LowEx Guidebook, as the missing link needed to fill the gap in understanding and designing energy flows in buildings.

When we use such expressions as “energy consumption”, “energy saving”, and even “energy conservation”, we implicitly refer to “energy” as intense energy available from fossil fuels or from condensed uranium. But, it is confusing to use one of the most well established scientific terms, energy, to mean “to be conserved” and “to be consumed” simultaneously. This is why we need to use the thermodynamic concept, exergy, to articulate what is consumed.

2.1 Active and passive systems

Over the last two decades various so-called “energy saving” measures have been conceived, developed, and implemented in building envelope systems and also their associated environmental control systems such as lighting, heating, and cooling systems. Those measures can be categorised into two groups: those for “passive” systems and those for “active” systems. “Passive” systems are defined as building envelope systems to make use of various potentials to be found in the immediate environment such as the sun, wind, and others to illuminate, heat, ventilate, and cool the built environment.

2.2 Low exergy systems

Low-temperature-heating systems are such kind of “active” heating systems that should fit the built environment to be conditioned primarily by “passive” heating systems. A good thermal-environmental condition within built spaces in the winter season can be provided basically with the installation of thermally-well-insulated building materials with appropriate heat capacity, which make it possible to utilise heat sources of lower temperature for heating.

In summer season, a moderate thermal-environmental condition within built spaces may be provided with a combination of nocturnal ventilation, the installation of appropriate shading devices for glass windows, and the reduction of internal heat gain in addition to the use of thermally-well insulating materials with appropriate heat capacity for building envelopes. This would allow the utilisation of cold sources with higher temperature for cooling. The use of the exergy concept in describing various heating and cooling systems, whether they are passive or active, would enable us to have a better picture of what low-temperature-heating and high-temperature-cooling systems are.

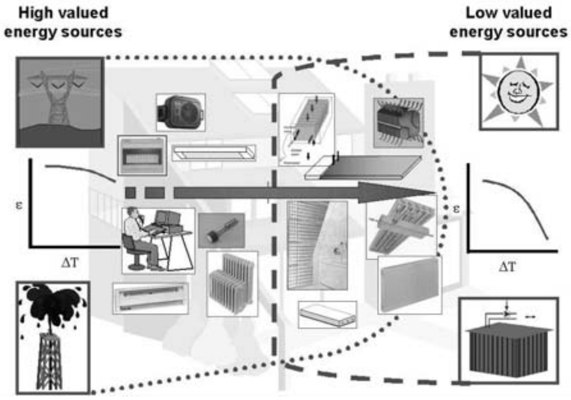

Figure 1: The transition from high valued energy sources to low valued energy sources requires appropriate heating and cooling systems in buildings.

Heating and cooling systems that provide heating or cooling energy at a temperature close to room temperature, i.e. low exergy systems, are a prerequisite for the efficient utilization of low valued energy sources. On the other hand, the efficiency of high valued energy sources is less dependent on the heating and cooling systems in buildings. The work of the Annex 37 concentrates on the heat distribution systems within a building, but includes analysis of the energy source (e.g. solar, heat pump, district heating) as well.

2.3 Human body and exergy analyses

Exergy analysis can also be applied to human body to find optimal thermal conditions. Studies conducted during LowEx project show that the lowest human body exergy consumption occurs at thermally neutral condition. Exergy consumption within the human body becomes higher in a cold environment due to larger difference in temperature between the human body and its surrounding space and also becomes higher in a hot environment mainly due to sweating. These findings suggest that heating and cooling systems may also work well in such conditions where the lowest amount of exergy is consumed by those systems. That is, we may be able to establish both thermal comfort and low-exergy consuming systems at the same time [2].

It is interesting to see that, from the exergetic view point, there is an optimal combination of room air temperature and mean radiant temperature which results in thermally neutral conditions, although, from the conventional energetic viewpoint, there are many combinations of room air temperature and mean radiant temperature. Some experienced scientists and engineers say that this is consistent with their experiences. The human body exergy analyses have now just started to articulate why Low-Exergy Systems are essential for creating rational and comfortable built environment.

3 ANALYSIS TOOLS FOR THE EXERGY CHAIN

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 have been produced during the course of the project work.

The participants wanted to develop a simplified tool to visualise why low exergy systems would be advantageous in some energy chains compared to high exergy systems. This tool should be easy to use and show the exergy flow through a system or energy chain. Finally, two pre-design tools were developed.

An important step in the entire analysis is the estimation of the energy demand of the actual building. The heat demand is a key figure in the analysis, it corresponds to the building's exergy load. A low exergy load means a thermally good constructed building envelope. The energy requirement for the service equipment is then estimated [4].

The main focus in this paper and in the LowEx project is on the system "building", whose system border to be analysed here encompass the building envelope. For the balance of energy flows through the building, all possible effects has to be taken into account, even the extraction and production of the energy carrier. The calculation of energy flows caused by a building starts much earlier [3].

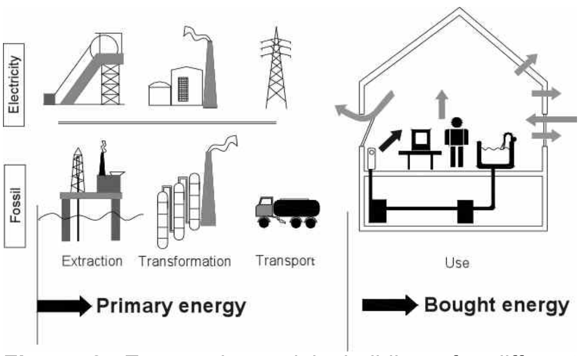

Figure 2: Energy demand in buildings for different applications from source to sink [1].

For a deeper analysis of the energy flows in a building, a closer focus on the building services system is needed. The entire flow from the source to the sink must be taken into consideration. All energy flows from the left-hand side, i.e. from the source, via a number of HVAC-components and the building structure itself, to the ultimate sink, the outdoor environment. Imperfections and losses in the different steps through the building are regarded, as well as the need for auxiliary energy. Energy, mainly in form of electricity, is needed to drive additional pumps and fans for the operation of the system [3].

Throughout the development of the "Educational Tool for Energy and Exergy Analyses of Heating and Cooling Applications in Buildings", the aim was to produce a "transparent" tool, easy to understand for the target group of architects and building designers, as a whole. Other requirements were that the exergy analysis approach is to be made clear and the required inputs need to be limited. Today, the Microsoft Excel spreadsheet based tool has two input pages and results are summarised on two additional pages, with diagrams.

4 CONCEPTS AND TECHNOLOGIES

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. The components and systems presented in the LowEx Guidebook show a step further in this direction.

The LowEx database in the LowEx Guidebook consists of sixty information sheets, which describe the technologies; their basic principles, technical risks and benefits, advantages, limitations and state-of-art (commercially available, prototype or innovative concept). The idea is to give a quick overview of the possibilities and limitations of the technologies.

There are a number of known systems already on the market, as for example the hydronic floor heating system, embedded pipes in concrete slabs or hollow core concrete slab constructions.

Some system concepts, which are compiled with these components, are also presented in the Guidebook as well as strategies for design LowEx systems.

5 EXAMPLES OF LOWEX BUILDINGS

In the LowEx Guidebook, examples of the use of Low Exergy systems in various buildings are presented. Together with the findings from a literature study and an occupant survey, the case examples give strong evidence that in addition to the desired heating or cooling effect, low exergy systems can provide occupants with a comfortable, clean and healthy environment.

The case examples show the wide variety of applications of low exergy systems. They also demonstrate the flexibility of the systems with regard to the energy source. There are examples of low exergy systems in dwellings and offices, but also in a museum, a church and a concert hall. In these examples there are systems that use heating or cooling energy from the sun, the ground, a district heating network as well as an electricity or gas network.

Findings from the literature show that 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. The occupant survey shows that all low temperature systems are well received. In particular, the occupants found the indoor climate to be significantly better in dwellings with floor and wall heating compared to their previous dwellings. The main disadvantage was controllability. The advantages and disadvantages, mentioned by the occupants in the survey, are similar to results in the literature.

Figure 3: The office building of the Centre for Sustainable Building equipped with embedded pipes in concrete slabs as the heating an cooling system and a ground heat exchange to collect ground coolness.

Table I: Distribution of building types

Type of building	Number of cases
New residential	9
Existing residential	4
New non-residential	10
Existing non-residential	3+3

Table II: Distribution of emission systems

Emission system	Number of cases
Low temp. floor system	15
Low temp. wall system	7
Low temp. ceiling system	8
Low temp. radiator / conv.	9
Low temp. air system	9
Cooling beams/ radiative panels	2
Activated thermal slab	2
Combined systems	15

Demonstration projects have been submitted by all participants: 27 examples plus 3 extra cases from the LowEx**x** group (LowEx applications in existing buildings). With 30 cases, distributed over new and existing buildings, residential and non-residential buildings with various technologies and emission systems, this gives a good overview of the application of LowEx systems for heating and cooling of buildings. Table I and Table II show the distribution of the cases. Most cases are new non-residential buildings. Floor heating is the most commonly used emission system in the case buildings. Most of the cases are low temperature heating cases; in only 12 cases high temperature cooling is applied. In the Guidebook the cases are presented in more detail.

5.1 Retrofits

The existing building stock is very important to focus on, the renewal of the building stock is very slow, and if we neglect the possibilities for Low Exergy systems in the existing buildings, the total effect will not be as large as we hope for. Some examples of LowEx systems in existing buildings are presented in the case examples (11 retrofit cases), one example is a historical building with a cultural heritage, which means an even greater challenge.

There are special issues to take in to consideration when we are talking about applying LowEx systems in existing buildings. The age of the building is not such an important issue when considering the possibilities for applying LowEx systems. The important aspects are the degree of protection of the building, the building type, the scale of renovation, replacement of installation and the type of LowEx system to be applied.

Even though the low temperature heating systems are functional systems with lots of advantages, we need to keep in mind that when we are talking about retrofits, there are also some technical limitations. For example, in old houses the walls are not always that good, and one can encounter really poor U-values, i.e. bad insulation standards. If this is the case, floor heating is not efficient enough to meet the heating demand.

Figure 4: St. Martin church in Teharje with frescos is equipped with a wall temperisation system.

6 MARKET POSSIBILITIES

6.1 Overview of the market situation

The application of LowEx systems is far more common in new buildings than in existing buildings. For example in The Netherlands and in Norway it is more or less common practices to install low temperature heating- or high temperature cooling systems in new residential buildings. For existing residential buildings it is more of an unknown concept but the trend is, however, positive. In Japan and Canada, hardly any cases with low exergy systems installed in existing residential buildings can be found.

The situation is somewhat similar for non-residential buildings. For these types of buildings, LowEx systems do not seem to be as common in the new building stock as for residential buildings.

Table III: Opportunities and threats for low exergy systems in retrofit

Reasons for applying LowExx: · esthetical · improved indoor climate/comfort · conservation of cultural heritage · lower energy use · use of renewable energy · energy efficiency · integration of heating and cooling systems. Limitations/Threats for applying LowExx: · Low price of fossil fuels, low electricity prices · Availability on the market/market price · No checking of regulations · Comfort criteria isn't that high in existing houses · Stick to tradition · Lack of knowledge	Opportunities for applying LowExx: · Large scale renovation in combination with: - acoustic matters - upgrading the building more luxury · Cooling can be added · Improving indoor climate · Adjusting office to modern IAQ standards: increased productivity of employees · Moisture problems -protection of art work · Extended use of the building · Flexibility · CO_2 saving potential · uncertainty of energy prices · Awareness is raising · Energy Performance Standard (EPS) based on primary energy

6.2 Summary of the market analyses

The market analyses in different countries were conducted as interviews with the main actors in the building field. The target groups for the interviews were: principal contractors, architects, consultants, manufacturers and suppliers, installers and end users. In order to reach a wider application of LowEx systems, arguments in favour of the use of these systems need to be communicated more clearly for all target groups in most countries. The positive associations need to be supported by good examples gained from the use of LowEx systems. When the additional benefits are reliably presented, people will most probably be willing to accept extra investment costs. Although thermal comfort is seen as an important factor, in some countries end users are still ready to accept incomplete comfort.

End users are usually not familiar with Low Temperature Systems (LTS), except in Germany where these are quite well known. Manufacturers and suppliers, however, are usually familiar with LTS. Knowledge of LTS varies considerably within the other interview groups in different countries and even within the countries. One group that should raise particular concern is the architects who are unfortunately not very familiar with LTS. This is the group that has great influence in implementing the systems into the market. In addition, although we know that LowEx systems offer some advantages for the architectural design, it seems that the architects are not aware of these advantages.

In general, LowEx systems seem to create very positive associations such as energy efficiency, comfort, soft heating or safety. There were a few comments about suspected comfort problems, but these were exceptional. Some doubts about the functionality and ease-of-use of the systems were expressed. Sometimes the systems are regarded as new and unusual systems, and are therefore seen as something with which to be careful. There are groups that prefer sticking to traditional systems. In many cases Low Temperature Heating was associated with floor heating, especially by architects but also by other groups and often the systems were associated with renewables. It seems that inadequate information about the systems is the major cause for negative associations.

There is a lot of variation in attitudes towards extra investment costs. In Finland, France and Germany extra costs are less accepted than in Sweden, Netherlands or Norway. In Canada people are mostly willing to pay for the extra benefits offered by the LowEx systems. Extra costs are sometimes accepted also in Japan, when the additional benefits are clearly communicated. In other countries, too, good arguments are needed to change the negative attitudes towards a willingness to make extra investments. In some countries LowEx systems are considered as luxury systems.

In most countries, thermal comfort is seen as a very important factor in building design by all interview groups. Incomplete comfort is, however, tolerated by end users in many countries. It seems that they do not know that they could demand better thermal comfort in their houses. Also, architects often ignore thermal comfort as a target. Controllability is often considered more important than thermal comfort.

7 GUIDEBOOK FOR LOW-EX SYSTEMS

The results of Annex 37 are presented in a form of a Summary Report of about 50 pages, which includes the LowEx Guidebook in a CD-ROM format. The CD-ROM is intended to be user friendly and the results are presented visually and interactively. It contains all the material produced within the project; newsletters, publications, the exergy analysis tools and the full version of the guidebook (also as a printable .pdf version). In addition a web-site containing the same information as the CD will be set up. The final products were officially published in June 2004.

The full version of the guidebook includes edited versions of the working papers written during the Annex, some summary tables and also material, which is exclusively written for the guidebook.

7.1 The International network LowExNet

Since the Annex 37 working group considered it very important to continue working with the topics described above the International Society for Low Exergy Systems in Buildings had been formed to further promote the use of the exergy concepts for more sustainable buildings. All deliverables of the Annex 37 are available via the LowExNet-site (www.lowex.net) .

Figure 5: The final products of the Annex 37 will be published in many formats.

8 CONCLUSIONS

The classical exergy analysis enables to pinpoint the location, to understand the cause, and to establish the true magnitude of waste and loss. Exergy analysis is therefore an important tool for the design of thermal systems since it provides the designer with answers to two important questions of where and why the losses occur. The designer can then proceed forward and work on how to improve the thermal system. Application of exergy analysis into buildings has not been usual before the implementation of Annex 37.

Exergy analysis can also be applied to human body to find optimal thermal conditions. Studies show that the lowest human body exergy consumption occurs at thermally neutral condition. These findings suggest that heating and cooling systems may also work well in such conditions where the lowest amount of exergy is consumed by those systems. That is, we may be able to establish both thermal comfort and low-exergy consuming systems at the same time [2]. The human body exergy analyses have now just started to articulate why Low-Exergy Systems are essential for creating rational and comfortable built environment.

There are currently many low exergy technologies available. Low temperature systems successfully combine both traditional and innovative new approaches to heating. Usually the heat is transferred into the room through air or liquid circulation systems and the same system can often be used for both heating and cooling.

Research shows that people living in houses with low temperature heating systems are very satisfied with ambient indoor air quality. In particular, thermal comfort levels are considered to be higher than in houses with a traditional heating system. Low temperature systems can utilise a variety of sources of heat including district heat, biofuel, solar energy, gas, oil or electricity, and so the user is not constrained by choices made in the planning phase.

Low temperature heat distribution systems have an operating life of at least 30-40 years during which time the user benefits from the economic advantages offered by flexibility of fuel choice. The life cycle costs of a low temperature heating system are about the same as of a traditional system. Although the initial investment might be slightly higher, the system offers increased flexibility in terms of fuel choice and increased energy efficiency.

The demonstration projects of Annex 37 show the wide variety of possibilities to apply low exergy heating and cooling systems in buildings. There are examples of low exergy systems in dwellings and offices, but also in a museum and a concert hall.

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 enery 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 sustainable energy world will be delayed for decades.

9 ACKNOWLEDGEMENT

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