news

ECBCS Annex 49

Low Exergy Systems for High-Performance Buildings and Communities

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RESEARCH ON THE FINANCIAL ASPECTS OF EXERGY IN THE BUILT ENVIRONMENT[1]

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Introduction

Since stated by the World Commission on Environment and Development in 1987, sustainable development receives world wide attention. In the building industry the term sustainable building is used to address all techniques and approaches in terms of source efficiency, quality improvements and pollution reduction, which not compromise the ability for future generations to meet their own needs [1].

Within sustainable development and sustainable building the reduction of energy use has much attention. E.g. in the Dutch building industry innovative techniques, like solar chimneys, heat pumps and mechanical ventilation systems with heat regeneration, are introduced to supply heat efficiently during winter and to keep the heat inside as long as possible by using new types of insulation and heat exchangers. It is even possible to build houses that offer comfortable temperatures without the necessity of any external energy infrastructure to supply them of resources or heat at all; autarkic houses.

The building industry is rather reluctant to apply these necessary energy saving techniques. Contractors often do not know which broad range of energy saving techniques is available and the direct costs of some of these existing techniques are simply too high, so it seems. Research is needed to explain the financial benefits of lowex techniques.

Research objective

The project research is aimed to contribute to the adoption of exergy saving techniques in the built environment by giving insights in their financial consequences. These techniques will help to lower the amount of harmful emissions and can provide the correct quality (in terms of the ability to generate mechanical work) and quantity of energy, expressed by exergy, in a more effective way. The relation between thermodynamics, economics, and sustainable development has been described most challenging by Valero et. al. [2].

Developing techniques for designing efficient and cost-effective energy systems is one of the foremost challenges energy engineers face. In a world with finite natural resources and increasing energy demand by developing countries, it becomes increasingly important to understand mechanisms which degrade energy and resources and to develop systematic approaches for improving the design of energy systems and reducing the impact on the environment. The second law of thermodynamics combined with economics represents a very powerful tool for the systematic study and optimization of energy systems.

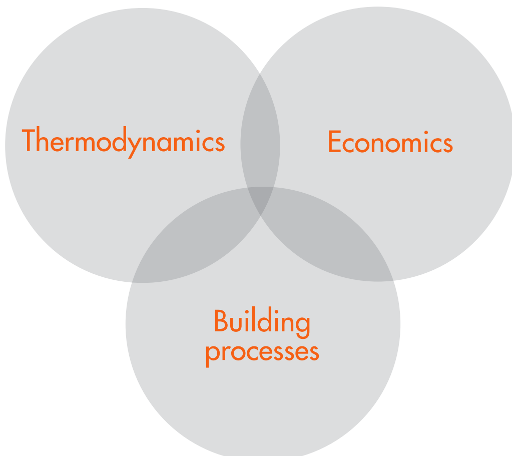

Figure 1: The research is conducted in an interdisciplinary field relating thermodynamics and economics in interaction with the building process.

[1] This article is based on the World Sustainable Building Conference 2008 paper "Profit of exergy in the built environment".

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In a time of governmental deregulation, improvements in adopting exergy saving techniques need to be facilitated by specifying the financial benefits for the stakeholders in the building process. The main question is "What are the financial benefits of exergetic optimization of real estate?".

Although there is a common awareness of the ecological and social benefits or other externalities of exergy saving techniques, the financial costs and benefits will be the major point of concern in the decision making process on investments in real estate.

Scientific relevance

By focusing on the financial benefits of exergy saving measures in real estate objects the research takes place in an area, in which three scientific fields overlap; building processes, economics and thermodynamics, as shown in Figure 1.

Building processes

E.g. in the Netherlands the implementation of energy saving measures in real estate is at this moment mainly enforced by law [3]. Although investments by commissioning commercial organizations or private persons are mainly weighed by their financial returns and technical aspects [4], it seems that the goal realization or development in sustainable building by the temporary organization of the building process also can be stimulated by respectively transactional or transformational leadership [5]. It is not only important to do research on the financial benefits and technical aspects, but also on the organization of the stakeholders in the building process.

A stakeholder analysis needs to clarify where in the process the objectives for reducing the exergy consumption are developed and where their financial consequences are addressed. It is important to know at which moments in the design, construction and utilization phase, intervention to adopt the exergy saving technologies is possible. The influence of the stakeholders and uncertainty in the early phases of the building process in relation to the project's value generation has been studied before by Kolltveit et al. [6], but this research did not specifically focus on energy or exergy saving techniques. Therefore this research can make an innovative contribution by specifying the opportunities and restraints in adopting energy saving techniques in building processes.

Thermodynamics

The basic methods of energy and exergy analysis from the field of thermodynamics are generally used to optimize the designs of power plants, but in recent years some building related installations have been analyzed. Methods to address the costs and benefits of exergetic optimization processes are referred to as thermoeconomics [7] or exergoeconomics [8].

The possibilities to reduce energy consumption and to save exergy in the built environment are numerous. An average dwelling in the Netherlands uses for example 1,736 m^3 natural gas and 3,346 kWh electricity each year [9]. This research will contribute to the knowledge on lowex techniques by conducting an experimental study of a passive solar system.

Economics

A basic method to specify the financial costs and benefits of real estate investments is Life Cycle Costing (LCC). It recognizes that the total cost of ownership of a product is not solely reflected in its purchase price. The purchase of certain products should in other words be considered as an investment for which both benefits and additional costs are incurred over the life of the product [10]. Although there are some difficulties still to overcome (see e.g. [11]), this method can be used for the analysis of design options regarding conventional energy efficiency.

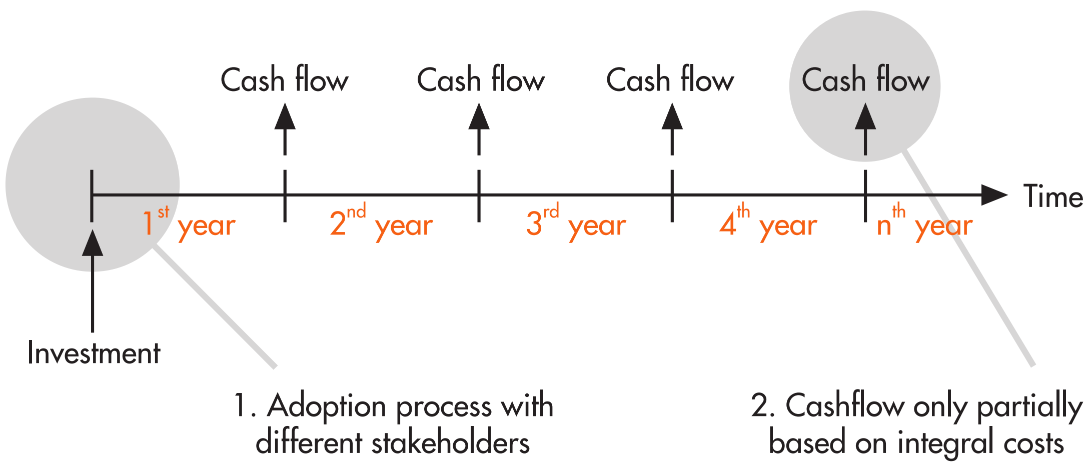

Figure 2: Model showing two problems regarding investments in exergy saving techniques.

The application of LCC does not take into account the possibilities of increasing the value of real estate by means of improving its efficient energy performance. Although this aspect is related to the willingness-to-pay principle, it is the first time that financial data from the existing building stock can be related to energy performance certificates based on the European Building Directive on Energy Performance.

Furthermore, in the case of residential real estate the availability of fuel resources are not accounted for in LCC yet, although the prices of car fuels for example are strongly related to their availability. Awerbuch [12] addressed the urgency to improve the traditional valuation models by introducing the Capital Asset Pricing Model (CAPM) for investments in photovoltaics. CAPM explains the relationship between risk and the investor-required return rate for an asset. Awerbuch's statement "by ignoring financial risk, lenders and investors understate the value of PV projects relative to fossil alternatives" and his suggested solution to use the portfolio theory of Markowitz [13] to relate cost and risk contribution of alternative resources, offer a basis to investigate the value of the quality of energy; the so called exergy. In Figure 2 the main focus of the exergy economic model is shown, namely stakeholders and the variables influencing the cash flow.

Conclusion

The appraisal of exergy saving investments does take the benefits during utilization into account (for example in the method of life cycle costing), but stakeholders in the building processes often do not communicate about, or take the time to weigh, the costs and benefits of life cycle investments. The Return on Investments (RoI) in exergy saving techniques will mostly benefit the user of the building. This user is in most cases not the same person or corporation as the constructor who paid for the investments during the construction phase. Methods for calculating the yearly cash flows do not incorporate all benefits of exergy saving techniques yet. The main contribution of this research can be found in offering a model to overcome these two aspects.

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COMPARISON OF ENERGY AND EXERGY FLOW BALANCES IN A TRADITIONAL AND A PASSIVE SINGLE-FAMILY HOUSES

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Introduction

Drastically decreasing resources of fossil fuels cause the need to search for energy efficient technological solutions. In the field of housing technology and construction those trends have resulted in the designs of the so called low-energy and passive houses. Those, however, are not ultimate and fully satisfying solutions. Further reducing of heat demand for buildings heating will probably require application of new notions and analytical tools allowing the energy efficiency assessment of various heating circuits. This assessment will be done to answer the question where in the entire process of energy flow and conversion the exergy losses are the greatest and occur the most frequently. This analysis does not take into consideration the materials and their components. The goal of the paper is to show the suitability of exergy analysis - made beside and not instead of the energy analysis - to present the actual processes of energy conversion in residential buildings. This will be shown by means of an example comparing two different building constructions, namely a traditional and a passive single family house.

Implementation of exergy analysis

One of the most important differences between the notion of energy and exergy is that energy is subject to the conservation law while the exergy conservation law does not exist. Losses of exergy are inevitable and at the same time unwanted as every loss of exergy cause a decrease of the use effect of a given process [1].

The notion of exergy is used to express what is used, consumed, while entropy describes what is removed. Exergy means the ability of energy to dissipate during its flow through the system while entropy expresses the state of dissipation.

The aim of such works is to design objects and heating systems with possibly low exergy (i.e. decreasing the input of exergy during heat generation and management).

Idea of passive house versus traditional

Exergy losses causing the need for exergy supply in buildings refer to three types of needs:

- exergy lost through external partitions of the building as the result of the processes of heat conductivity, conversion in wall and radiation
- exergy lost as a result of exchange of air in the building for the purpose of ventilation
- exergy lost in the energy flow needed to heat the domestic hot water for general use.

Continuous progress in technology of building materials, in manufacturing of windows and doors allow decreasing utilization of energy to satisfy the needs of the first type. Application of ground heat exchangers and balanced ventilation with heat recoverydecreases the needs of the second type. Solar energy is used to heat water increasingly frequently.

Low-energy house should consume 30% less energy as compared to a traditional house. Energy consumption per one m^2 square meter per year in the low-energy house with the usable area of 150 m^2 square meters should not exceed 35 kWh for heating purposes, 35 kWh for ventilation of the space and 15 kWh for domestic hot water preperation.

Energy and exergy balance spreadsheet of Annex 49

Calculations presented in this article have been carried out with the Annex 49 Excel-based tool. This tool allows simplified steady-state exergy analysis of several space heating and domestic hot water supply systems for residential buildings.

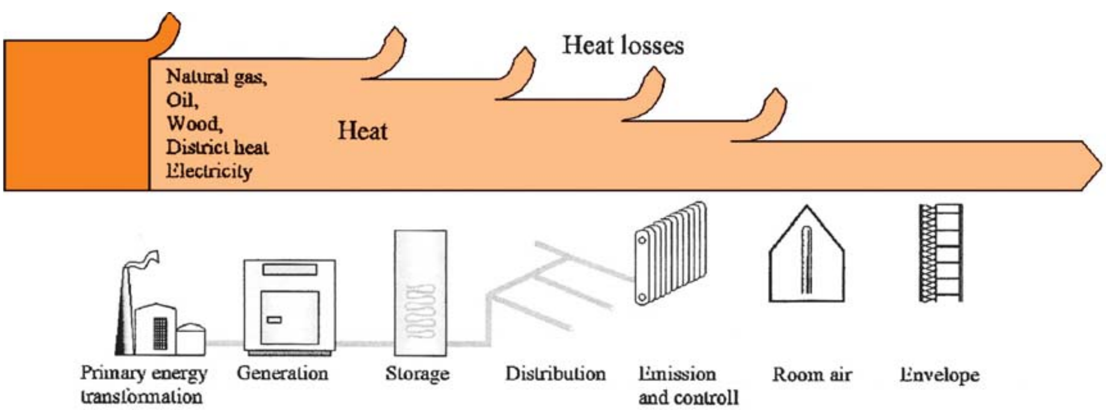

Figure 3: Energy stream in building services [2].

On the basis of the choice of the heat generating system the spreadsheet describes the efficiency, maximum supply temperature and the degree to which the system uses the renewable energy sources using "macros". Similarly, in selecting the heat generating system the spreadsheet selects characteristic values for a given type of installation such as the supply and return temperature, output and additional energy. Exergy analysis is done in the last module of the code. It progresses describing one by one the heat flow stages: building envelope (walls, roofing), indoor air, heat emission, heat distribution, energy storage, heat generation system, and primary energy transformations (Fig. 3) [3].

Description of houses under consideration

The computations were made for a passive house and traditional technology house according to the design by the Architecture Office Lipinscy Houses. The first detached passive house designed by the Lipinscy Domy was built in Smolec near Wroclaw.

1 - Passive house

The design was developed in collaboration with the specialists from the Institute of Passive Buildings at the Polish National Energy Conservation Agency in Warsaw. It received the positive opinion of the Passive House-Institute from Darmstadt/GER and at the further stage certification by that Institute. According to the energetic certificate issued by the above institutions its demand for thermal power is to be 1,9 kW (13,5 W/m^2), year final energy (heat) consumption for heating the building 13,5 kWh/m^2/a and 4,7 kWh/m^3/a. The seasonal demand for heat to heat that building will be 1944 kWh/a. This data are for the passive house located near Wrocław.

This house is designed fulfilling the passive solar design technique.

The Lipinscy passive house is equipped with mechanical ventilation including a heat recovery system. According to the passive house standards, the Awaduct Thermo ground heat exchanger (GHE) from the REHAU Company was installed. The ground heat exchanger preheats the supply air and air supply to the heat pump (air-water).

2 - Traditional house

The traditional house was supposed to be made on the basis of a similar design as the passive house and had the same heated space of volume of 456,1 m^3 and heated area of 153,7 m^2. The difference in construction lies in the thermal transmittance of external partitions made of different materials than the passive house. Thus, especially, the thermal transmittance U of the building elements are appropriately changed: exterior wall thermal transmittance is equal to 0.37 W/(m^{2}K), and appropriately the thermal transmittance of window 1,0 W/(m^{2}K), door 1.4 W/(m^{2}K), roof 0.27 W/(m^{2}K), and finally floors to ground 0.22 W/(m^{2}K).

The heating installation in the conventional house consisted of gas condensing boiler and central water heating installation equipped with conventional plate heaters. The boiler also supplied domestic hot water. Natural ventilation is assumed.

Results of calculations

Figures 5 shows the energy losses and gains in the two building cases analysed. Figure 4 shows the exergy supplied and demanded on the different subsystems in the traditional and passive houses.

It is easy to see that the heat losses through partition are about 80 % percent higher for the traditional house than for the passive one. Furthermore, the loss for ventilation is five times higher for the traditional house than passive, what is quite clearly because there is natural ventilation in traditional house versus mechanical in the passive house. Yet, auxiliary energy demand for the fan of the mechanical ventilation unit in the passive house amounts 112 W. Passive solar gains in the case of passive house are 2.5 times higher than in traditional house.

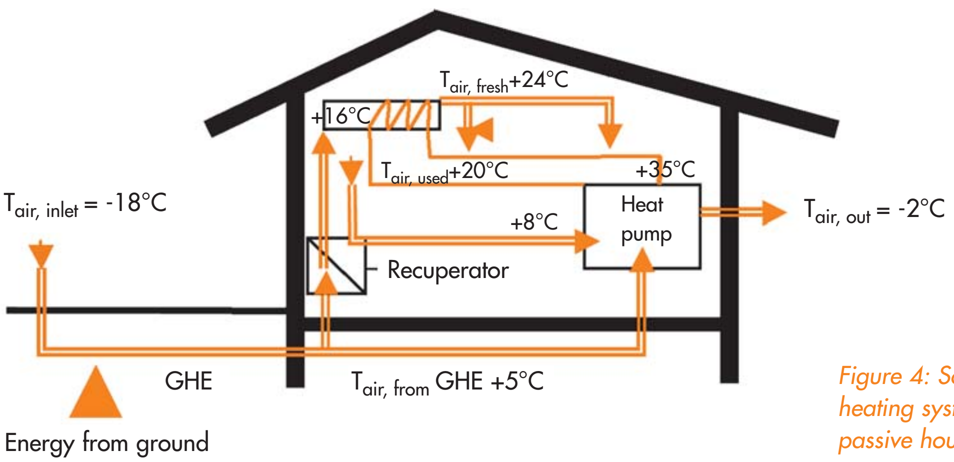

Figure 4: Scheme of the heating system for the passive house

Conclusions

Comparative analysis of the passive and traditional houses shows that the total demand for thermal power (converted to primary energy) of the traditional house is almost two times higher than that of the passive house. On the other hand losses of exergy at heat generation for central heating stage in the first stage is almost eight times higher than the losses of exergy in the passive house. The highest exergy losses occur in the heat source (particularly the water boiler).

Large exergy losses also occur in heat transmission (distribution) to heaters (or in air channels to blowers in the passive house). In case of the traditional house losses of exergy is five times higher as a consequence of the difference in supply temperatures of water 70°C and air 35°C systems. As a consequence there is also around 3,5 times higher losses of exergy in transmission of heat from heating elements to the air in the premises.

Poorer insulation properties of the traditional building cause only two times increase of losses of exergy through the roofing (as compared to seven times higher losses in the boiler).

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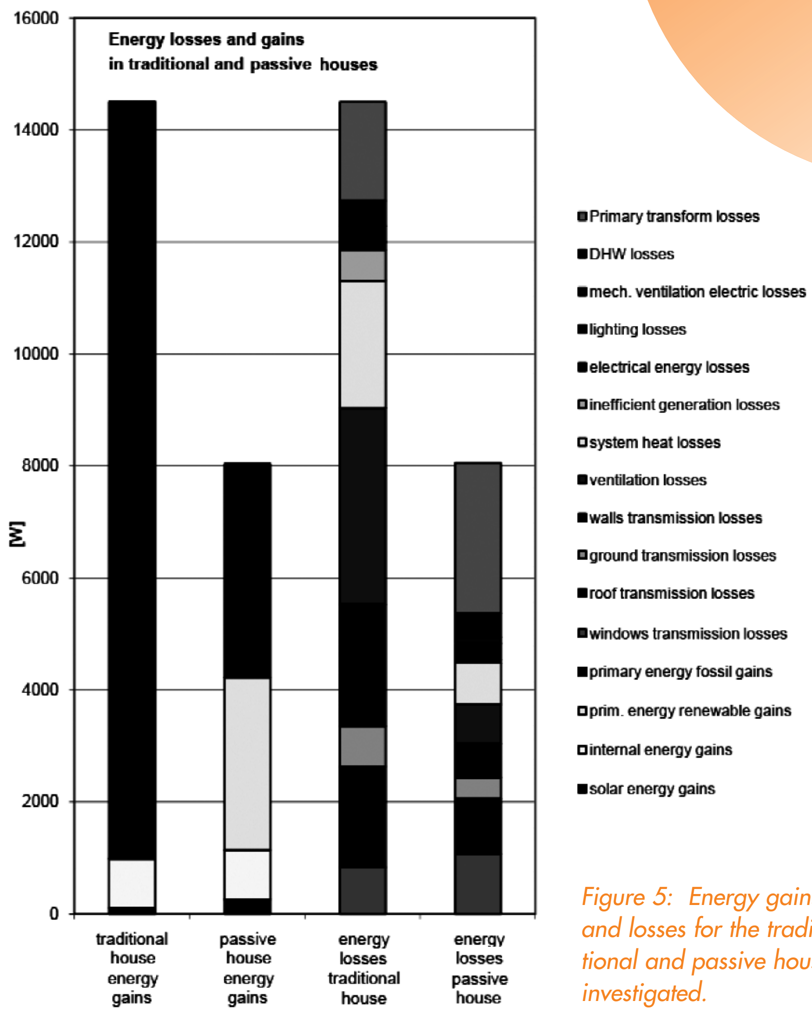

Figure 5: Energy gains and losses for the traditional and passive houses investigated.

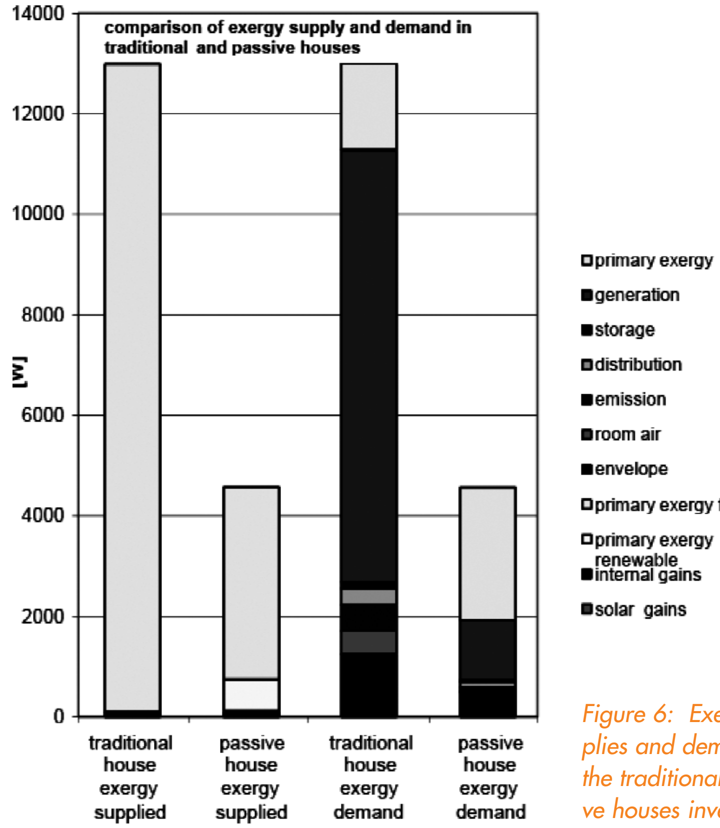

Figure 6: Exergy supplies and demands for the traditional and passive houses investigated.

THE INTERNATIONAL LOWEX CONFERENCE "THE FUTURE FOR SUSTAINABLE BUILT ENVIRONMENTS INTEGRATING THE LOW EXERGY APPROACH"

To bring the outcomes from exergy analysis in the built environment to the top of the research agenda, an international conference on this issues was organized jointly by the IEA ECBCS Annex 49 working group and the group of the European COSTeXergy project "Analysis and Design of Innovative Systems for Low Exergy in the Built Environment" (www.costexergy.eu). Front-edge results in the field of exergy analyses of buildings and communities were presented and discussed by participants from research institutions, universities, industry partners, policy makers and politicians.

Figure 7: Dr. Murad Atif, chairman of the IEA ECBCS Programme attended the Conference as keynote speaker.

The conference held on the 21st of April 2009 in Heerlen/The Netherlands, aimed at strengthening the political awareness on the importance and applicability of this thermodynamic approach to building systems and communities. Issues on building technologies and innovative components for future energy supply in buildings as well as concepts for community scales and planning strategies were presented and discussed.

Figure 8: Discussion among the participants.

The venue of „Gen Coel" in Heerlen (The Netherlands), were the conference was hosted, is one of the main locations for an Annex 49 community case study. In this project water reservoirs from old coal mines are used to run district networks for providing heat and cold to several building sites (a description of the project can be found in www.remininglowex.org). It represents a great example of the application of low exergy principles in the built environment, both on the field of building components and community energy supply structures.

Outcomes

Within the first session on building technology the experts were concerned about how a faster implementation of the upcoming ideas could be managed. While good technologies already exist, there is still room for a development of new technologies, but marketing measures are needed. Also demonstration, education and awareness rising is mandatory to succeed with the new innovative ideas. The importance of a proper consideration of changing indoor conditions on human comfort and health was also discussed.

Figure 9: Facilities of the Minewater Project at the Gen Coel Energy Center in Heerlen, were a technical tour was offered during the Conference.

The use of so-called capillary tube systems in combination with PCM (phase change material) thermal storages was also dealt with. The technology is very promising, but measured data from built case studies are needed. Moreover, the problem of better understanding of heat storage phenomena in buildings and the feedback on the new ideas were discussed.

Within the second session on communities the discussion in the beginning focused mainly on the planned developments on the Hoogeschool Zuyd campus. Different options for an energy and exergy efficient supply system were discussed. The connection to the Heerlen Minewater grid was also an issue. The question on how to involve students in the proceeding building and energy concepts was raised. The participants agreed on the necessity to put effort into educational involvement to disseminate the ideas of exergy efficiency.

A reader from the Conference with all posters and presentations held during the event can be downloaded at www.costexergy.eu/conference

Annex 49

Low Exergy Systems for High-Performance Buildings and Communities

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ECBCS ANNEX 49

Annex 49 is a task-shared international research project initiated within the framework of the International Energy Agency (IEA) programme on Energy Conservation in Buildings and Community Systems (ECBCS).

Annex 49 is a three year project starting in November 2006, following a preparation phase of one year. About 12 countries are currently participating.

For up-to-date date information see:

www.annex49.com

Announcements

- **Final (6th) Annex 49 expert meeting**
  3rd - 4th September 2009
  Espoo, Finland

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