news

ECBCS Annex 49

Low Exergy Systems for High-Performance Buildings and Communities

Newsletter No. 2 September 2007

LOWEX CONCEPTS

Christina Sager[1] and Mia Ala-Juusela[2]

LowEx as "…a system able to provide the best matching between the quality levels of the energy demand and of the energy supply on a single building or community level" (P. Caputo and A. Angelotti).

Looking at the energy efficiency of buildings, the current discussion is focused on quantitative aspects. This is caused, of course, by the available and "state-of-the-art" approaches to energy evaluation and legal requirements. Today, the primary energy demand is widely accepted and used in indicating the environmental impact of domestic energy consumption. The current standardised procedures are therefore based on the first law of thermodynamics combined with primary energy factors, which are based on the fossil energy demand. First of all, this approach leads to a saving policy that can help in reducing the consumption of fossil fuels and help draw attention to renewable energy sources.

The neglected aspect within this discussion is the question of energy qualities. So far, this quality aspect of energy based on the second law of thermodynamics is implied in the common experience of "energy loss" by using energy for heating and cooling purposes. Contrary to the first law of thermodynamics, energy resources are being consumed, and have to be replaced and paid for. Energy in the form of indoor air warmth transmitted through exterior walls and windows, is irretrievably lost for our heating purposes.

The exergy balance puts these losses into figures and allows for the minimization of losses which occur over the energy transformation chain. By taking into account the quality aspects of energy sources it becomes possible to match not only energy quantities, something which must be done in any case to ensure thermal comfort, but, in addition, to provide comfort using energy sources with similar qualities.

Almost exclusively nowadays, we meet our heating and cooling requirements by supplying fossil fuels or electricity. These are among the most high quality and potent energy resources available on earth. Then, we use them to provide nothing more than warm water of about 40° to 70°C for heating or DHW. The energy balance veils these tremendous quality losses. Nevertheless, the word exergy, for an average engineer, still sounds like a misspelling, despite its in-depth meaning.

The question of how to define the term "LowEx" in the context of various applications in the building sector still awaits consensus among the LowEx-experts' community. In the following the main topics will be outlined and existing positions stated. This may serve as a starting point for finding appropriate solutions in the near future. The forum that hosts these strategy discussions evolved from the consortium of IEA ECBCS Annex 49.

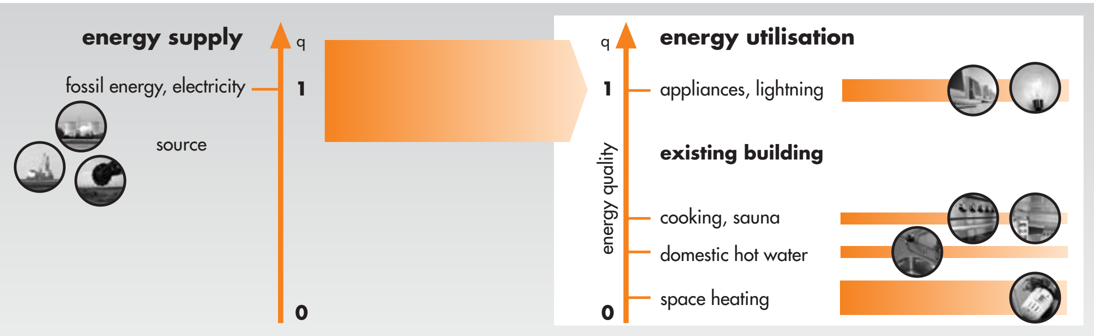

Fig. 1: Energy utilisation within a typical building for various uses at different quality (exergy) level and the common satisfaction of the demand with high exergy sources only.

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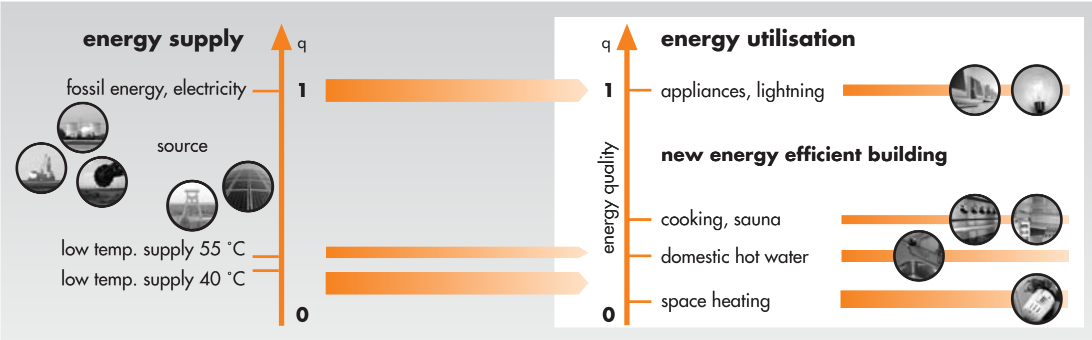

Fig. 2: The energy demand can be reduced by energy saving measures and energy can be supplied from suitable sources at different quality (exergy) level (compare to figure 1)

Definition of LowEx Systems

In the preceding Annex 37, the focus was limited to the building boundaries, including the building structure and the heating and cooling systems. These heating and cooling systems were simply defined as "heating and cooling systems that allow the use of low valued energy as the energy source". This definition includes high exergy sources in order to emphasize the enormous flexibility of the LowEx systems. With these systems you are not limited to the (traditional) HighEx sources (such as fossil fuels or electricity), but also able to replace them by a LowEx source, if available.

The systems have been described as: "systems that provide heating or cooling energy at a temperature close to room temperature". There are currently many low exergy technologies available. Usually, 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." Some examples of generation, conversion and storage systems have been described in the LowEx Guidebook, the final report of Annex 37. The focus in that work did not go beyond the boundaries of the building. Now, in Annex 49, the scope includes the community level and the energy sources in the exergy analysis, which requires an adapted approach to the LowEx concept. This is discussed in more detail by Ken Church and Paola Caputo in the following article.

Current suggestions for definitions among the Annex 49 participants (see last page) are:
LowEx is "…a system able to provide the best matching between the quality levels of the energy demand and of the energy supply on a single building or community level" (P. Caputo and A. Angelotti).
"A LowEx system is one that makes an efficient use of the energy flows, i.e. which is able to match the quality levels of energy supplied and demanded." (H. Torío)
"LowEx systems … are (heating and cooling) systems that (are able to) provide maximum thermal comfort with minimum use of exergy and best matching of the quality level of the energy supply to the demand of energy. The aim is to find the best possible use for the local renewable and waste energy sources before resorting to fossil fuels." (M. Ala-Juusela, based on the suggestions from Annex 49 working group)

Definition of LowEx benchmarks

In the discussion of LowEx benchmarks or targets the question arises on how to really make a step forward to the common energy analysis. The mere replacement of an existing and accepted procedure is difficult to present without clearly pointing out the added value of this undisputedly more complicated exergy calculation.

In going one step beyond the integration of quality aspects this added value may be formed. In order to make the term exergy manageable for planners and to allow a comparison between different engineering solutions a new indicator should be introduced. The described indicator has been developed by Dietrich Schmidt and his team at the Fraunhofer Institute for Building Physics. The central idea of the "exergy expenditure figure" is the ratio between the exergy demand drawn from a component by the energetic use it delivers.

For example: a component, like a heat exchanger, is designed for a certain power. Let us assume that it has to warm up a room, which is done by supplying a certain amount of heat. Energy is being transferred and supplied. This process ought to take place using the smallest possible amount of supplied exergy, auxiliary energies and as few losses as possible of the regarded component.

By calculating the actual necessary exergy demand of the task (heating of room) a baseline can be defined of the absolute minimum of required exergy. Using this baseline on common (realistic) systems, a benchmark for maximum "exergy expenditures" may be defined according to available, state-of-the-art technologies.

"A LowEx system is one that makes an efficient use of the energy flows, i.e. which is able to match the quality levels of energy supplied and demanded." (H. Torío)

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EXERGY AS A TOOL FOR EVALUATING ENERGY SUPPLIES ON COMMUNITY LEVEL

Ken Church[1] and Paola Caputo[2]

The greatest environmental impact would be achieved by altering the basic premise of the system, namely the fuel supply itself. This change would likely be the expensive but also the most far reaching of the alternatives.

Background

Selection of energy supplies in the community or municipal arena has, to date been based more upon commercial availability than on the appropriate nature of the energy supply. This approach reflects the wide scale availability of the energy supplies, typical of a mature supply industry as well as the lack of any economic relationship between supply and demand.

The consideration of climate change and the relationship between global warming and the use of fossil fuels has compounded the desire to minimise reliance on fossil fuels, primarily oil and natural gas. The discussion of recent years has returned again to the future supply of fossil fuels throughout the world. This time, the issue related to the physical availability of energy sources, as opposed to political control. Macroeconomic calculations indicate that within the world, adequate supplies of both oil and gas exist, but, the location of the oil and gas resources and the geopolitical regimes in existence do cast large shadows of doubt over the availability of the supplies.

Economic hardship caused by the energy markets at the national and international level has a direct and immediate impact on the growth and competitiveness of the municipalities and their constituent community, regardless of their size or location.

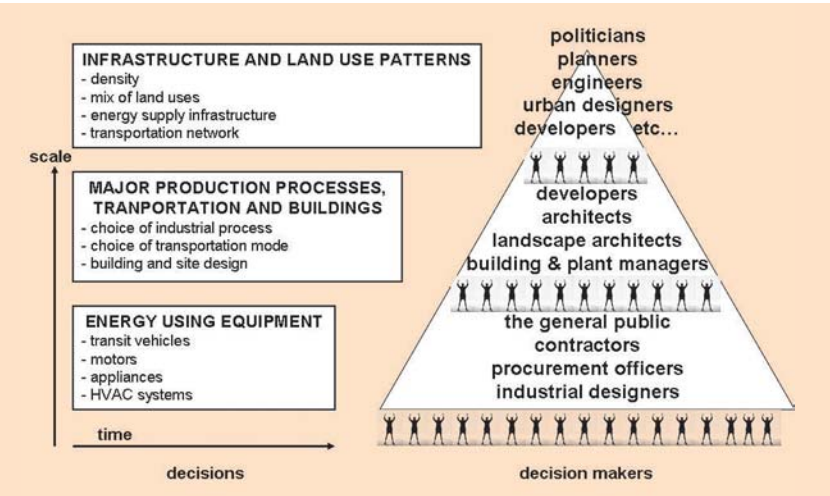

Fig. 3: The hierarchy of energy related decisions

The link between energy and lifestyle has strengthened as globalisation has increased. In all aspects of life we see examples of where the energy marketplace affects the local economy: the price of food, clothing and even urban form is now visibly affected by the price of fossil fuel. The challenge for any community is therefore to manage that link between energy and lifestyle.

With the drive towards lowest first cost, technology today has become fuel specific and its inability to transfer between fuel sources implies a significant level of investment required, more than originally planned, to retrofit existing urban infrastructure. Natural caution will make municipalities reluctant to make such large levels of investment without a sound decision-making basis. To date, tools to make such decisions have not been available.

The ability of an energy supply to suite a particular end use requires an exergy assessment and demands the tool that is to be developed within Annex 49. The tool must allow the user (municipality, utility, etc) to compare and select the most appropriate energy supply for the task. The process of selection must be moved from the utility to the municipality and driven by the needs of the community.

Figure 3 suggests that change in energy use patterns may be made within a community at a variety of levels. The simplest change is often at the level of the end-user. For example a manufacturer might improve the efficiency of his refrigerator; his car, or his light bulbs. Each end-user would purchase this new product based upon anticipated cost savings but for significant savings to be made, the number of end-users purchasing this new product must be large.

A change in energy type at the system level would involve fewer stakeholders but increased investment. The investment would however have a greater final impact on the community or the environment. For example a power generation plant may convert from simple cycle to combined cycle. It will retain natural gas as its fuel while it increases its electrical efficiency. Likewise, a simple cycle plant might decide to recover its rejected heat and employ this within a district energy system, displacing oil heating in community buildings. Both options require significant investment but should (theoretically) be easier to initiate, having fewer decision makers in the decision making process.

The greatest environmental impact would be achieved by altering the basic premise of the system, namely the fuel supply itself. At the community level this change would likely be the most expensive alternative but also the furthest reaching. The Annex 49 tool is to be focused at this level of change thus making it essential to follow be a rigorous approach in its decision-making process.

Decision making criteria at the municipal level differ from those found in an industrial or commercial setting. Municipal leaders are required to consider many of the externalities related to a technical issue that industry partners would consider beyond their responsibility. Hence, any suggestion that an alternative energy system could be employed within their community must be seen as bringing to that community benefits and improvements above and beyond mere thermodynamic efficiency.

At the level of municipal staff or energy utility then the economic issues take precedence. Municipal employees have traditionally been employed for their engineering or technical expertise, leaving the social or political issues to the elected comrades.

Exergy has the potential of starting the process of drawing together the industrial and social components of energy supply through its involvement of quality and quantity. By addressing the nature of the energy source in terms of scientific elements, exergy has the capacity to respond in financial terms to concerns that might otherwise have caused the rejection of alternative energy options.

The Tool

The focus of the research conducted under Annex 49 will is to develop a simplified description of exergy in terms of "efficiency" for a variety of the more conventional energy systems, comparing it to conventional energy efficiency calculations. The high level exergy evaluation of the entire system would provide visible key elements that link energy pathways with the community's environment, geography, economy and possibly cultural understanding. It will also allow the decision makers to identify the impact of conventional energy systems and provide support for a transition to alternative supplies.

Evaluation of the entire energy generation and distribution process to a level of detail consistent with those of Annex 37 would be too complex to be practical. The tool should therefore consider an energy generation / distribution system as a series of finite elements, possibly with default values of exergy losses based upon simple supply conditions. The user would select their proposed end-use technology and/or conditions and compare it with the appropriate energy supply.

The output would need to include some form of improvement factor over a base case conditions, typically a natural gas or oil fired technology.

The supply technologies that could be evaluated as being possible for municipal use include:

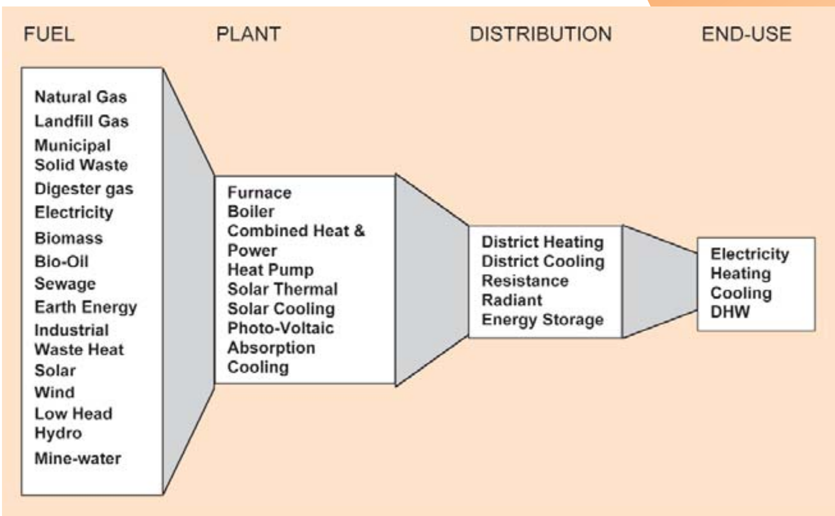

Fig. 4: Optional Systems

To avoid the number of permutations from becoming unmanageable, only pragmatic options will be considered where the technology already exists or is close to being commercialised.

For each option, where possible, an exergy review would be considered for the various typical stages of development. For example the use of landfill gas in combined heat and power might look as follows:

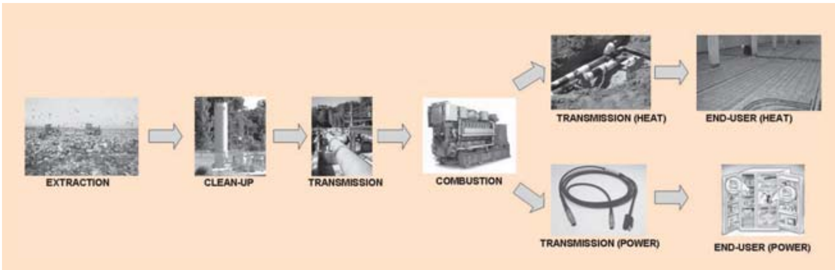

Fig. 5: Landfill Gas Application

For each of the activities a typical or range of efficiencies both of energy and exergy would be identified, allowing the user to compare and contrast his or her options. For example, the overall exergy efficiency might change if the reciprocating engine of figure 5 above was replaced by a steam boiler. A summation of the individual packages would indicate the overall result.

The final product could be a spreadsheet tool into which the user submits key data describing the application; data such as the type of energy sources available, their geographic distribution and condition, the characteristics of the community and the type of load. The spreadsheet would draw upon default data for each section of the possible arrangements and present a list of the most appropriate systems, from an exergy perspective.

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THE EXERGY CONCEPT AND ITS RELATIONS TO PASSIVE/ACTIVE TECHNOLOGIES AND RENEWABLE /NON-RENEWABLE ENERGY SOURCES

[1] Masanori Shukuya

Technology for conditioning the built-environment, which is the closest environmental space to us all, must have started to emerge some fifty-thousand years ago.

We define a system conditioning the built-environmental space to be safe, healthy, and comfortable as "built-environmental system". This is the system that controls light, heat, air quality, moisture (water), and sound indoors in order to fulfill a required level of human well-being. Building elements such as walls, windows, roofs, and floors as a whole are called "building envelope systems". Ancient people must have tried making various openings in building envelopes, with or without the aid of shutters or other things, in addition to making the use of fire as a light and heat source so that the indoor conditions could come as close to the desired level of comfort as possible. This was done by applying a variety of the available building technology of that time.

Passive Technologies

Building envelope systems which have openings to condition the indoor environment within a range of comfort levels are called "passive systems". We call the prcocess of designing, constructing, and managing the passive systems "passive technology".

The significant characteristic of passive systems is that the given forms are different from a region to region. Whenever we discuss the characteristics of passive systems, it is necessary for us to take a look at two different aspects of the systems: one is the structure ("katachi" in Japanese), the given forms as mentioned above and the other is the function ("kata" in Japanese). The structure (katachi) is associated with space and the function (kata) with time. The structure is something to see and the function is something to read.

The structure and the function of the passive systems clearly reflect the characteristics of local climatic conditions. We can conclude that the essential feature of passive systems is such diversity.

Climatic patterns vary between regions. Yokohama, where I live, for example, is one of the regions where it becomes hot and humid in summer while, though mild, cold and dry in winter. Wherever on the Earth, whether it is Yokohama, Singapore, San-Francisco, or Stockholm, each region has its own climatic pattern. Vernacular buildings in respective regions, having developed over years, from generation to generation have their own forms, namely the structure (katachi), reflecting their climatic characteristics. All of such forms are closely related to the respective function (kata) of the buildings themselves.

The structure (katachi) and the function (kata) of the passive systems reflect clearly the characteristics of local climatic conditions. We can find various examples in respective regions on the Earth; figure 6 shows one such example in Japan. We can conclude that the essential feature of passive systems is such diversity.

Fig. 6: A Japanese vernacular house with thatched roof. A bunch of dried straw having hollow space filled with air plays a key role on controlling the indoor environmental condition.

Active Technologies

One of the most dramatic events which have happened over the course of human evolution is the use of fire.

The use of fire actually has changed into the use of electricity. At an electric-power plant, whether it is liquefied-natural-gas fired or nuclear-fission based, the liquid water is heated and turns into the water vapour with a very high temperature and pressure, while on the other hand the water vapor is cooled and condensed again into liquid water again usually by the sea or river water available nearby. The flow of high-temperature and high-pressure water vapour to low-temperature and low-pressure liquid water enables a turbine (a wheel) to rotate: the work is produced in the flow of "heat". This work is in fact "exergy" itself.

The contemporary lighting, heating, cooling, and ventilating system components such as lamps, fans, pumps, and heat pumps perform their function with the electricity supplied from the power plants. Their function is realised by the delivered "work" delivered through the electricity grids. We call such built-environmental control systems, which rely on the "work" delivered by the electricity, "active systems" and their associated building technology "active technology". Active systems and technology include those making direct use of fossil fuels.

The Exergy Concept

The maximum available work is "exergy" itself. The essence of the work is to move something from one place to another. A lump of matter, a solid, consists of atomic and molecular particles. Each of the particles forming the shape of this matter has its own relative position to all other particles. Therefore, the work is to move all those particles moving from one location to another conserving each of the relative positions (see figure 7). This unique characteristic of solid is different from liquid and gas, both of which have no specific shape themselves. In order to move the liquid or gas, we need a container made of solid.

The concept of exergy can be regarded as such a maximum ability to move all those particles conserving their relative positions. In reality, there is more or less friction so that a portion of that maximum ability is inevitably destroyed. In other words, the parallel movement turns, in part, into the random motion of the particles; this process is the dispersion of energy. In other words, the destruction of work is the production of heat. This dispersion is in fact exactly the consumption of exergy.

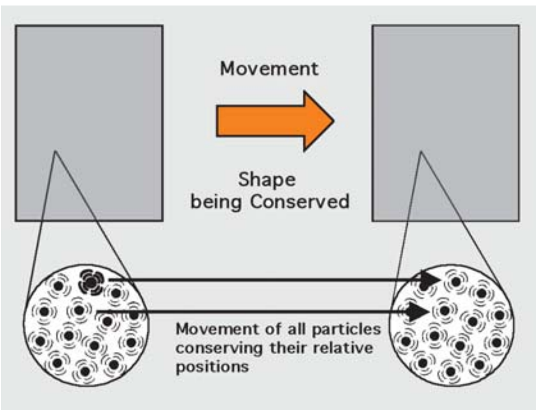

Fig. 7: A lump of matter moves from one place to another conserving its shape. This is, from a microscopic view point, nothing other than that all atomic and molecular particles composing of this matter move in parallel manner so that they keep respective positions remain unchanged. Such ability of energy to move a lump of matter is "exergy".

We humans have become capable of controlling indoor luminance, temperature, and humidity at any level desired. This technology has made lower ceiling heights, deep room space, large glass window areas and other things possible and has developed into a symbol of contemporary civilization. We can see a lot of such examples especially in high-rise buildings built in urban areas worldwide. Their basic forms are the same despite the fact that they are built under a variety of climatic conditions.

Fig. 8: An example of high rise twin-tower building that was realized by active technology. This form of high-rise building can be seen anywhere in the urban areas worldwide.

The active technology has realised "universality". The basic forms of these buildings are the same despite the fact that they are built under a variety of climatic conditions.

The active technology has realized such "universality" and helped grow together with "architectural civilization (or urbanism)"; this is in good contrast to "architectural culture" developed together with passive technology whose significant characteristic is "diversity".

Renewable and Non-Renewable Energy Sources

The rapid growth of contemporary global human society over the last half century has been sustainable so far dependent very much on the combustion of fossil fuels such as coal, oil, and natural gas, and also on the nuclear fission, while at the same time we have come to recognize that we now face the so-

The development of "low-exergy systems" should firstly prepare building envelope systems that can make the renewable exergy sources be consumed to operate a building. Secondly, active systems are to be developed which consume as little non-renewable exergy as possible to enhance the function of passive systems.

called energy and environmental problems and also that we need to find their solutions. With this in mind, it is necessary for us to seek such active systems that can enhance the merits of passive systems or that can revitalise the forgotten passive systems to meet indoor requirements. In the future, passive and active systems should be much more advanced than conventional systems. I believe that the exergy concept must play a key role for such purposes, or at least that it can help us renew our way of thinking.

So-called renewable energy is strictly speaking to be called “renewable exergy” and the same applies to non-renewable energy, namely to be called “non-renewable exergy”. Renewable exergy sources are such as the sun, which illuminates the Earth, the soil under the ground surface, which has warm or cool exergies depending on the annual variation of ambient air temperature, the sky, which has an average temperature always lower than that near the ground surface, rain water, snow and others. Non-renewable exergy sources are coal, oil, natural gas and uranium mines.

It must be recognized that it is necessary for all the exergies mentioned above, whether renewable or non-renewable, to be produced with the consumption of a rather large amount of exergy. This is due to the theorem of exergy consumption [1] [2].

It took very long years, around two to three billion years [3], for the non-renewable exergies to be produced. This is why they are called non-renewables. Although the values of their exergy-to-energy ratio are usually very high, over 0.85, we should not forget that there was a huge hidden amount of solar exergy consumption and its associated entropy disposal to the universe taking so many years. The high values of exergy-to-energy ratio of the non-renewables are due to the "exergy-entropy process" which has taken place over the last billions of years.

The exergy-to-energy ratio of solar radiation presently coming from the present sun is over 0.9 for direct component and slightly smaller, about 0.7, for diffuse component coming from the sky. The reason for their high values is due to almost constant flow of dense light particles resulting from nuclear fusion, which occurs at a very far distant, safe location in the universe. Once the solar radiation is absorbed on the building envelope surfaces or the ground surfaces, a large portion of its exergy is consumed and the rest turns into warm exergy. The light particles, which were originally quite parallel to each other turn into a series of the dispersing random motion of the molecules composing of building walls and others. The ratio of the produced warm exergy to the solar exergy is usually only 0.05 or even smaller; in other words, 0.95 or more is consumed inevitably, whether we make use of it or not.

Conclusions

Passive systems described above work with the consumption of renewable exergy, while on the other hand, active systems work with the consumption of non-renewable exergy. To produce exergy, whether it is renewable or non-renewable, it is necessary for a system to consume a certain, not necessarily small, amount of exergy.

The development of “low-exergy systems” should first prepare building envelope systems that can allow for the availability of the renewable exergies, allowing them to be consumed so as to illuminate, heat, cool, and ventilate the built-environmental space in the natural course of exergy-entropy process. Secondly, they should aid in developing active systems with rational sizes, which consume as little non-renewable exergy as possible in order to enhance the function of passive systems that fulfil their purposes through the rational production and consumption of renewable exergy.

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Annex 49

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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

- **3rd Expert Meeting** at the Vienna University of Technology on April 14-15, 2008 in Vienna (Austria)
- **4th Expert Meeting** on August 27-28, 2008 in Reykjavik (Iceland)
- **Joint Workshop** with IEA DHC "Future energy saving potential from DHC and LowEx activities", on August 29, 2008 in Reykjavik (Iceland)

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