About Remining-lowex

Remining-lowex is a FP6 CONCERTOII project concerning the redevelopment of European Mining Areas into Sustainable Communities by Integrating Supply and Demand, based on Low Exergy Principles. The participating communities are Heerlen, the Netherlands and Zagorje ob Savi, Slovenia. Associated communities are Czeladz Poland and Bourgas Bulgaria.

The project concerning the redevelopment of European Mining Areas into sustainable communities by integrating supply and demand, based on low-exergy principles. It intends to use locally available, low-valued energy sources for heating and cooling of buildings. The source for thermal supply is water from abandoned mines- minewater. The Remining-lowex supply system is based on low exergy principles that are implemented by an integrated design of buildings and energy concepts.

To show the applicability of minewater use and the low-exergy principles, the project focuses on pilot implementation projects, which are supported by research, training and dissemination.

Homepage: www.remining-lowex.org

REMINING LOWEX

CONCERTO

Training: LowEx-Method

from BLACK to GREEN

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Motivation

Remining LowEx is a project of the European Union's 6th framework CONCERTO research program. The project intends to use locally available, low-temperature geothermal energy from abandoned mines as energy source for heating and cooling of buildings. The Remining-LowEx supply concept is based on low exergy principles. For this an adjusted building design and supply system has to be developed and realised. There are some global goals that are important for the project:

- to reduce the overall demand for fossil fuels in buildings,
- to reduce import dependencies on fossil fuels for communities,
- to supply buildings with a matching renbewable energy supply with high thermal comfort,
- to stabilise energy prices on a local basis,
- to strengthen local economies by local profit binding and money reflux,
- to reduce CO_2-emissions and environmental impacts.

To show the feasibility of minewater use and the low exergy design principles the project focuses on pilot implementations, supported by research, training and dissemination activities. The pilot sites are located in Heerlen (NL), Czeladz (PL), Zargorje op savi (SLO) and Borgas (BG). While Czeladz and Borgas have the status of observer locations, an operating energy system based on minewater was realsied in Heerlen. In Zagorje a system of a smaller scale is being set up.

Figure 1 shows that the building sector is responsible for about one third of the overall European final energy consumption. 92% of the energy is commonly supplied as electricity or as fossil fuels. This leads to the continuously high CO_2 emissions and the upcoming shortage of fossil fuels. The CO_2 concentrations in the atmosphere lead to unpredictable risks of risisng temperatures and changing weather conditions. The LowEx approach is aiming at a contribution for a more sustainable and low carbon energy

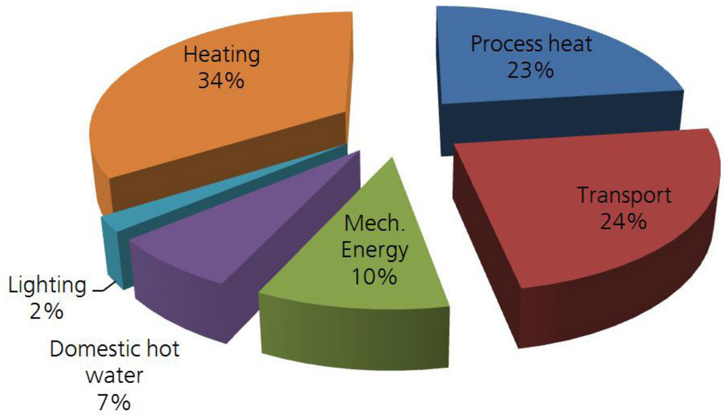

Figure 1: European final energy consumption by demand sectors [source: Anton Maas, Uni Kassel].

LowEx for beginners: from energy to exergy

The brochures LowEx Method and LowEx Technologies are meant to give interested stakeholders a first introduction to the design approach using low exergy principles for minewater use. Decision makers in municipalities and municipal utilities shall be provided with fundamental information to decide if an energy supply system based on minewater is feasible for their community. This basic training allows the realisation of an adapted use of minewater for heating and cooling buildings. The brochure LowEx Method includes an introduction to the energetic and exergetic assessment of buildings and their supply systems.

The introduction starts with some basics in thermodynamics and the low exergy principles. Starting from the common approach of energy balancing, the additional benefits of exergy calculations are introduced. The lowexergy principles, based on on the thermodynamic relashionship between energy, exergy and entropy are make the implementation into real systems feasible. Low-temperature systems like minewater systems use these principles for heating and cooling of buildings. Important aspects for a correct exergy analysis are the quality factors of the energy supply as well as the considered boundary conditions and reference temperatures. The principle correlations are addressed in the course to enable stakeholders to make correct assumptions for a pre-design.Two existing calculation tools for energy and exergy analysis of buildings and communities are presented. The energy and exergy efficiencies are explained with numerous examples of systems and system components.

Example:

Usable or unusable? With the help of pumps, which are used for the extraction of minewater from mine shafts, this relationship becomes clearer. The „useful“ part of the energy is the electricity, which is provided for pumps. During the pumping process, however, an effect occurs, in which energy is produced, which is no longer usable. These „not useful“ energies, for example, are pressure losses and the slight warming of the tube walls and blades of the pump. Neither the pressure losses nor the friction loss in pipe walls and blades are usable in the desired process. This is ccommonly called „lost energy“. The more correct describtion is „lost exergy“ indeed.

Thermodynamic basics

What's energy?

Energy is the most common indicator used for the optimisation of energy use and the affects of energy use for the environment. In relation to the energy consumption CO_2-emissions are calculated. On the first glance enrgy is an easy to use indicator. From everyday experience it is known that energy exists everywhere and in different forms. The most common in the scope of minewater use are:

- Thermal energy (heat energy): heating and cooling,
- Mechanical energy: pumping of water from the mine shafts to the surface
- Electrical energy: lighting, operation of pumps and heat pumps
- Chemical energy: batteries, fossil fuels in energy stations

Figure 2 shows two different forms of energy. On the left side is a battery containing chemical energy and providing electrical energy and on the right side a pot filled with warm water containing thermal energy.
Both sources contain 100kJ (0.03 kWh) energy. But it is evident that both energy sources are not the same. The battery can be used for numerous electrical applications while the warm water can only fulfill very limited services. The energy content of the battery is of higher quality than the energy in the warm water. This quality aspect and the ability to perform work is described with the term exergy.

Within the framework of the project Remining LowEx, thermal respectively heat energy is of central importance. Main goal of the project Remining LowEx is to use low temperature heat (geothermal energy) from the mine shafts for heating and cooling of buildings. This is possible because the temperatures from the mine shafts match the respective purposes quite well. In that case there is no high-quality needed to warm or cool the buildings. The available quality of teh minewater is sufficient for the purpose. This way the use of high-quality energy sources, like fossil fuels, can be avoided and saved for processes taht are dependent on the high quality content, like power plants for electricity production.

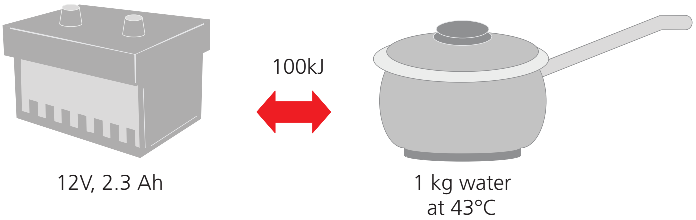

Figure 2: Different forms of energy, (left) electrical energy and (right) thermal energy.

Thermodynamic basics

The laws of physics: First and Second Law of Thermodynamics

First Law of Thermodynamics

According to the first Law of Thermodynamics, energy can neither be created nor destroyed but only converted into different forms. Over all conversion processes the amount of a certain amount of heat causes the effect to increase the room temperature. For that reason the first law is a physical method to quantify different forms of energy, i.e. how much energy amount has to be used

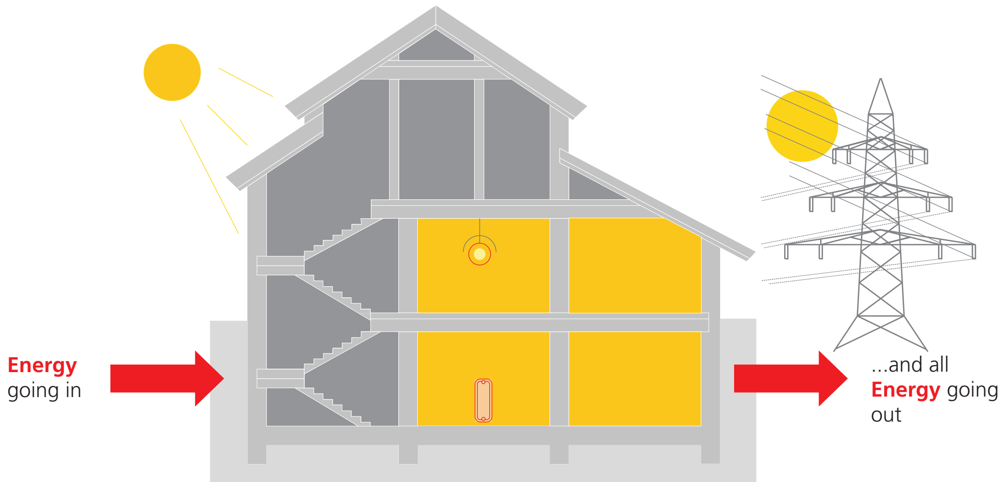

Figure 3: First Law Energy supply principle: All energy entering the building is eventually leaving the building again [source: Fraunhofer IBP].

energy is preserved. This is why the first law is also called "principle of conservation of energy".

Figure 3 shows the main principle of the first law of thermodynamics: First the energy enters the building (natural gas, solar heat, electricity etc.) then it is transformed and performs some work (heating, cooling, lighting, etc.) and finally all energy transmits through the exterior walls and leaves the building.

According to Figure 3 the process of the first Law of Thermodynamics is acting on the principle of cause and effect. For example for covering the heat demand. Therefore statements to the energy conservation are possible. Available energy systems in buildings are designed and improved based on this law. Highly efficient condensing boilers, with efficiencies of up to 98% are a consequence of this analysis framework.

The energy approach neglects the different qualities of energy (s.Fig. 2) though, because there is no differentiation between the chemical energy supplied and the building and the outgoing heat. Despite the reduction of overall demand and the increase of tranformation efficiencies the First Law Thinking offers no further optimisation

Thermodynamic basics

Second Law of Thermodynamics

The Second Law of Thermodynamics includes the ability to perfom work into the calculation. This is the quality factor, which is described by exergy. First of all, the second law of thermodynamics states that energy is always flowing from hot to cold, from higher potential to lower potential. This effect continues until equilibrium is reached. This means that a warm but unheated room will cool down until the ambient temperature is reached.

Entropy

The thermodynamic assessment of the quality of energy of a system can be represented by the the physical value „entropy." Entropy is not visible or tangible and therefore not measurable. The increase of entropy can only be calculated for any thermodynamic process. Behind the concept of entropy lies the idea of growing disorder.

In general, the more disorder in a considered system prevails, the harder it is to convert one energy form into another.

Example:

Basic principles of heat transmission: Transmission system: The greater the temperature differences of the heat transfer between the emission system and the room air, the more exergy is lost and entropy is created. Larger emission surfaces reduce the exergy loss because the temperature differences are smaller. Floor and wall heating systems or concrete core activation work with small temperature differences.

The Second Law on Thermodynamics introduces the terms exergy, anergy and entropy which are explained in the following chapters. For a given energy flow and a defined process, exergy descibes the useful part of the energy and anergy represents the unusable part. Over the transformation process the entropy increases.

The higher the entropy the higher are the losses in the regarded system. The German scientist Rudolf Clausius is credited with the first formulation of the second law, now known as the Clausius statement:

„No process is possible whose sole result is the transfer of heat from a body of lower temperature to a body of higher temperature."

For this reason, entropy can be understood as a quality characteristic of the grade of disorder and transformability. The total entropy of any isolated thermodynamic system tends to increase over time and reach a maximum value. This means that a conversion of energy is always possible in only one direction.

The entropy principle is important as the scientific foundation of the lowexergy design principles because it shows the irreversibility of energy transfromation processes. Once high quality energy sources liek fuels are burned to produce warm water, the potential is irretrievably lost. The entropy within the system maximises despite the energy conservation principle.

Example:

It is possible to use the entire electrical output of a radiator to heat up a room, but it is impossible to use the warm room air to produce electricity.

Thermodynamic basics

Example:
Energy, exergy and entropy flow in and out a building envelope system (s. Fig. 4). Exergy is the useable and convertible part of energy and will be described in the next chapter. We assume a steady-state condition, which means the environment conditions are stable with the right-hand side of the system being warmer (indoor) than the left-hand side (outdoor). The particles in the warmer side of the building envelope vibrate rather strongly (low amount of entropy); that is; the energy flowing into the building envelope accompanied by a certain amount of exergy. The vibration disperses (high amount of entropy) in the course of energy transfer; that is, a part of the exergy is consumed as the exergy flows. As a result, the energy flowing out the building envelope is accompanied with a smaller amount of exergy.

Anergy and Exergy
To show that the first Law of Thermodynamics represents no contradiction to the Second Law of Thermodynamics, the terms exergy and anergy are introduced. Regarding a defined process, two different forms of energy can be examined: High-valued, convertible and for the process usable energy is called exergy. Exergy determines the quality of energy. The part which is not usable is called anergy. Energy determines the quantity: The sum of exergy and anergy is energy.

exergy + anergy = energy

Figure 5 shows this coherence:

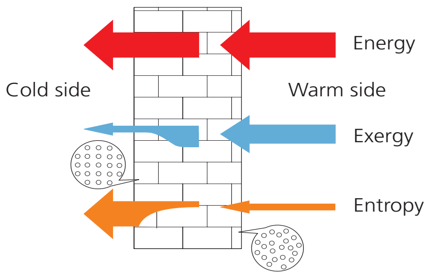

Figure 4: Energy, exergy and entropy flow in and out a building envelope system [source: Shukuya and Hammache 2006].

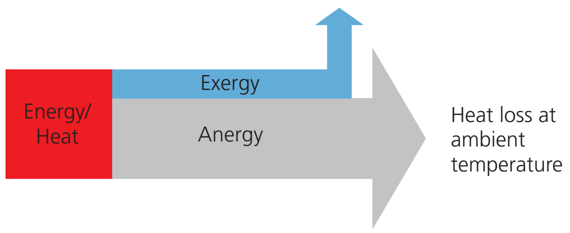

Figure 5: Relationship between energy, exergy and anergy.

Example for Exergy and Anergy:
One of the „most valuable“ energy forms is electricity. The electricity is basically pure exergy. Electrical energy can be converted into various other forms of energy (light, motion, heat)
Anergy is the non-usable part of an energy flow and equates e.g. heat losses at ambient temperature, e.g. the heat that a light bulp emits is not usable for lighting purposes.

Thermodynamic basics

The reference environment

Energy is an indirectly observed physical quantity. Energy is not dependent on the environment properties but depends on the Energy can be contained in a system in different forms. In contrast to that the exergy depends on properties of both a matter or energy flow and the environment. That is why for exergy analysis a reference environment has to be defined.

The reference environment for exergy analysis is considered as the ultimate sink (or source) of all energy processes within the analysed system. Most energy processes in the building sector occur due to temperature or pressure differences to the ambient air. To calculate under steady-state conditions, the reference environment is assumed to be in thermodynamic equilibrium, i.e. no temperature or pressure differences exist within different parts of it. For evaluating heating and cooling systems, a stationary or dynamic reference environment can be used.

The stationary reference environment depends on the climatic conditions and is primarily used for overall system evaluations in the pre-design phase of a project. Thus, the stationary reference environment only represents a snapshot and gives information about a cetain state of the systems' behaviour. For the analysis of the exergy performance of different heating systems usually a steady-state analysis gives sufficient information. Especially when different options are compared under the same reference conditions. There is no common standard for reference environments in exergy analysis. For the analysis of heating systems there are different options to define the reference temperatures. Usually the desired indoor air temperature is used and either the mean outdoor temperature during the heating season or alternatively sometimes the environment temperature is set to 0° Celcius. Most important is to use the same refence temperatures for all compared variations.

A dynamic reference environment can be used for dynamic evaluation of single system components or cooling systems but also for optimization of the entire energy chain of a building. The dynamic reference environment bases on a local weather data file, which is set with optional hourly or minute time steps. The advantage of the dynamic reference environment is a precise image of a longer period with representation of changing environment conditions. The disadvantage is the high computational and programming effort for the dynamic simulations. Dynamic refence environments are especially important for summer conditions with less stable and fluctuating conditions.

The Exergy Concept

Exergy, the quality of energy, is based on a combined analysis of the First and Second Law of Thermodynamics. This where the design principles of lowexergy have their scientific foundation. Exergy represents the part of an energy flow which can be transformed into another form of energy, thereby depicting the potential of a given energy quantity to perform work or, in other words, its quality.

of the importance of moving away from burning processes for supplying the heating demands in buildings, and paves the way for a new technique of designing energy supply systems based on the use of renewable and low temperature heat sources, like minewater.
This optimisation is based on LowExergy principles or the so called „LowEx“ concept. The goal of the „LowEx“ concept is to adapt

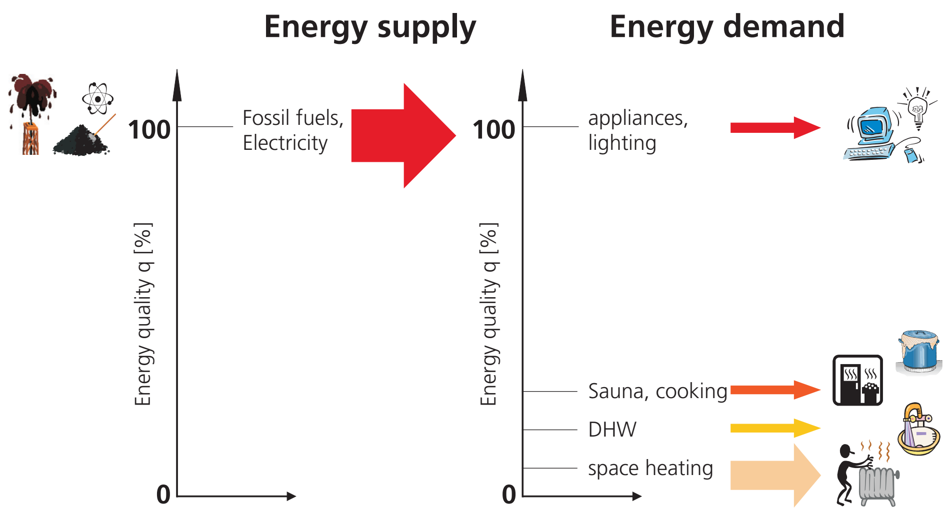

Figure 6: Energy supply using fossil fuels for a building with reduced heat demand [source: Fraunhofer IBP].

In every energy system, some part of the exergy which is supplied to the process is being consumed or lost to make the process work.
In the case of the highly efficient boilers when used to supply low temperature heat, the potential to produce work (exergy) of the fuels fed into the boiler is almost completely lost in the combustion process. Due to this loss of energy potential, a large consumption of exergy occurs. Even though the energy efficiency of the boiler is near 100%, the exergy efficiency is lower than 10% (s. Fig. 6, right side). A combined energy and exergy assessment permits an understanding

both the quantity and quality level of the supply and demand of a building. A good adaptation in the quantity leads to energy and exergy savings. Good quality matching to a more sensitive use of energy sources, e.g. thermal solar systems, waste heat from industrial processes and the use of minewater.
The following chapters introduce “LowEx”-systems using minewater and the exergetic and energetic calculation method. In addition, a definition to “LowEx”-buildings is given and two calculation tools are introduced, which can be used for energetic and exergetic analysis of building and community systems.

Energy and Exergy Analysis

The improvement of the energy demand of buildings generally takes into account the entire chain of energy conversion and all building related energy demands like heating, cooling and artificial lighting. This approach provides the basis for the EPBD (Energy Performance of Buildings Directive). On the European level the EPBD defines the targets that the member states shall regulate regarding the performance of existing and new buildings. The Directive aims at a significant decrease in energy demand and CO_2-emissions from the building sector.

The aim of these building standard regulations for buildings is the efficient use of energy. Figure 8 shows the development of primary energy demand in typical residential buildings over the last forty years. Due to the required high insulation levels for walls, roofs, windows and doors, the energy demand in buildings is today 10 times lower than 40 years ago.

For achieving these goals calculation standards and tools were developed, including all intermediate steps from used energy to primary energy (s. Fig. 9).

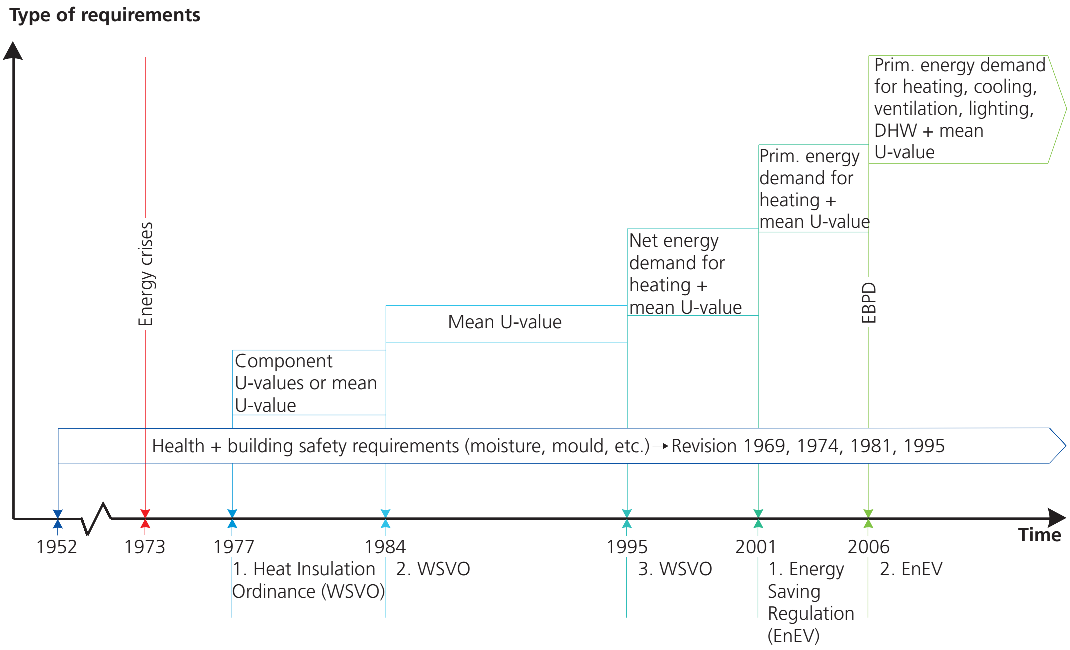

Figure 7: Legal requirements for energy efficiency in buildings.

Figure 7 shows the development of energy saving regulations in Germany since the first regulations on thermal insulation and the development of the Energy Savings Ordinance. Many European member states have a similar tradition in regulating energy demand in buildings or are now setting-up regulations in the course of the EPBD implementation.

The first module of this approach operates with “primary energy”. This form of energy describes that kind of energy which is containing in fuels or environmental energy before transport and transformation (natural deposits of gas / coal, solar radiation, wind power, geothermal power- like mine water).

REMINING LOWEX

Energy and Exergy Analysis

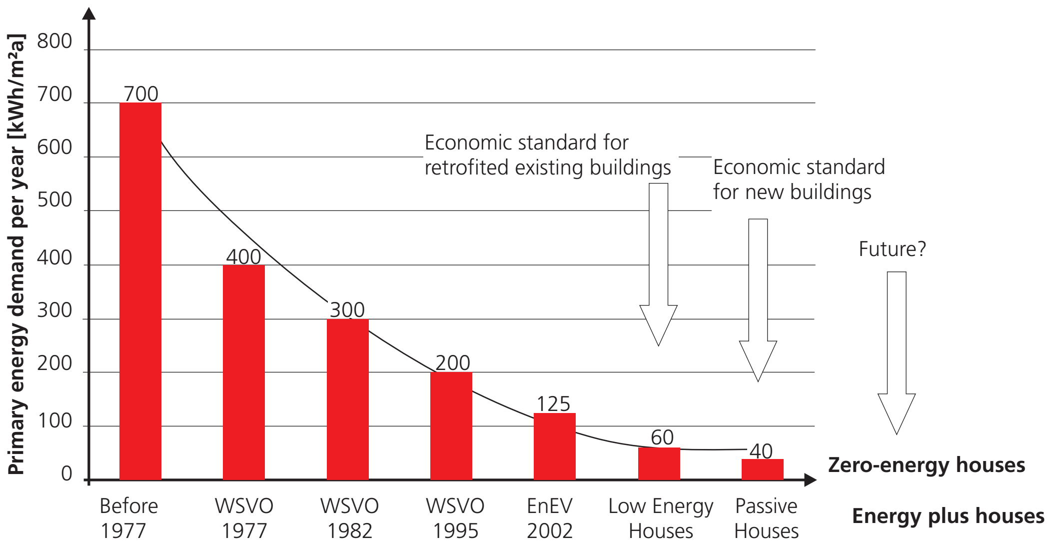

Figure 8: Energy efficiency in buildings has significantly improved over the last 40 years.

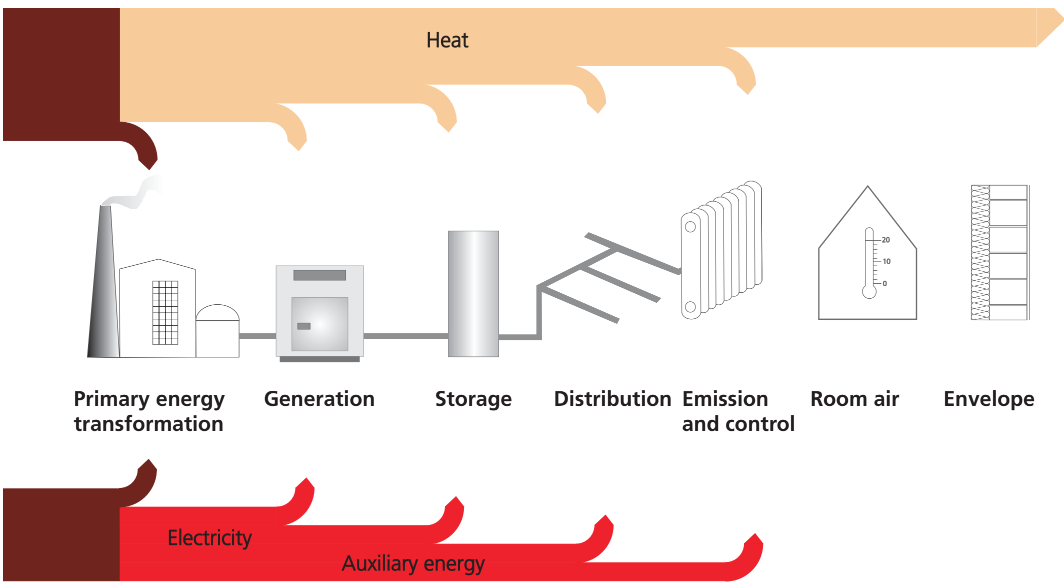

Figure 9: Energy supply chain for space heating in buildings, from primary energy transformation to final energy.

Energy and Exergy Analysis

After calculating the energy demand of a building, which depends mainly on the insulation level, a conversion system has to be used to conver final energy, which are energy carrieres deliverd to the building boundary, into heating and cooling energy. The total amount of required final energy, or the amount of energy carriers that have to be bought, depends on the conversion efficiencies and storage and transmission losses of the system. To provide final energy some effort is necessary to exloit, process and transport the energy carriers. This effort is represented by the primary energy factor. Table 1 shows the different energy forms of the energy chain. The fossil sources are displayed in red and the renewable sources are displayed in green.

Furthermore the possible conversion products are shown (final energy) and for which application (useful energy) they are required.
Moreover the color of the arrows symbolizes the different qualities of the available useful energy (red = high temperature, orange = medium temperature, pale red = low temperature). It should be noted that particular energy sources are not able to deliver high temperatures. Combustion processes (red arrows in column final energy) are able to deliver all kind of temperatures. Additionally Table 1 shows the energy carriers favorable for LowExergy applications and minewater projects.

Table 1: Primary energy, end energy and useful energy of the energy chain [source: Fraunhofer IBP].

Primary energy sources	End energy	Useful energy	
Wind	Electricity	Electricity	High Exergy
Coal	Coal Electricity	Heat Electricity	High Exergy
Natural gas	LNG Electricity	Heat Electricity	High Exergy
Biomass/ bio fuels	Processed wood Electricity	Heat Electricity	High Exergy
Ground source heat		Heat	Low Exergy
Solar radiation		Heat Electricity	Low Exergy

REMINING LOWEX

Energy and Exergy Analysis

Example:

Energy balance: The energy balance of a building is the sum of demanded heat for heating (Q_h) and domestic hot water (Q_w) and auxiliary energy in the form of electricity (Q_{aux}), minus the solar gains of solar radiation (Q_r). From an exergy point of view these different energies cannot be handled in such a way because there is heat at different temperature levels and high exergy sources of different forms, electricity and radiation, involved. From an exergy point of view this means „comparing apples with pears“.

$$Q = Q_h + Q_w + Q_{aux} - Q_r$$

Figure 10: Example for an energy balance [source: Fraunhofer IBP].

In setting up energy balances for buildings, only the quantative GJ are regarded, neglecting the different energy types with their potentials and qualities.
This is where the exergy concept can add additional information to the energy concept. The value of exergy, and with it the quality of the regarded energy flows, is given by a quality factor q. The quality factor, so-called Carnot-factor, is a function of temperatures at a heat flow (T) and temperature at a reference environment (T_0).

The Carnot-factor represents the maximum fraction of a heat flow, which can be converted into work and is defined as:

$$\eta_{carnot} = (T-T_0)/T = 1- T_0/T$$

Each heating or cooling system can be described by its Carnot-factor. The Carnot-factor for low-temperature systems, like heating with mine water, is smaller than the Carnot-factor for combustion processes.

Example:

Low-quality source minewater: Minewater is not freely available and takes more or less effort
to use it. Its supply temperature is about 35°C. When assuming a reference environment under winter conditions the outdoor-air temperature (reference temperature) is 0°C and the corresponding quality-level is q = 11 %. This corresponds to an ideal quality level for low-temperature heating in buildings, which is slightly higher than the required quality level in buildings q = 7 %, for heating a room at a temperature of 21°C.

Example:

High-quality source electricity: In the case of using electricity to heat the room, the quality level q = 100 % is much higher than using minewater q = 11 %. This is because electricity is a high-quality source, which can be converted into different kinds of work. Therefore, electricity should not be used for heating but for high-quality demands like lighting and electrical appliances that depend on electricity as energy supply.

REMINING LOWEX

Energy and Exergy Analysis

In Figure 11 some energy sources and energy applications in buildings or community system are classified according to their quality level (i.e. exergy content). Ideally, high-quality sources are used only to provide high quality applications, whereas low-quality sources should be used for low-quality applications.

For creating the exergy balance of a system, all energies are multiplied with its associated quality factor.

Exergy = Energy x quality factor (q)

Additionally this equation shows that energy is a quantitative parameter and exergy is a qualitative parameter.

Source	Quality	Uses
Oil Coal Uranium (Fossil fuels) Wind energy	High	Lighting Electrical appliances
High temp. Waste heat from industrial processes (200°C)	Medium	Cooking Washing machine
Low temp. waste heat, e.g. From CHP (50-100°C) Ground heat	Low	DHW Space heating HT LT

Figure 11: Simplyfied classification of energy sources and uses for buildings according to their quality level [source: Fraunhofer IBP].

Energy and Exergy Analysis

LowEx-Systems

„LowEx"-systems (low-exergy systems) for heating and cooling of buildings can be defined as systems, which enable the use of low-quality energy sources.
Systems can be chategorised into high-temperature combustion processes: high-quality systems and low-temperature heat: low-quality. For heating rooms low-qualitative sources can be used without limiting on comfort issues. With an appropriate transmission system the supply temperatures can be kept low.

In exergy terms this means large savings of exergy because combustion and mixture processes are avoided. The main objective of „LowEx"-systems is to encourage the exploitation of local renewable low-temperature sources (e.g. solar thermal, geothermal) and waste heat (e.g. waste heat from industrial processes), before using fossil energy sources. In practice, this means that systems provide heating or cooling on a temperature level close to room

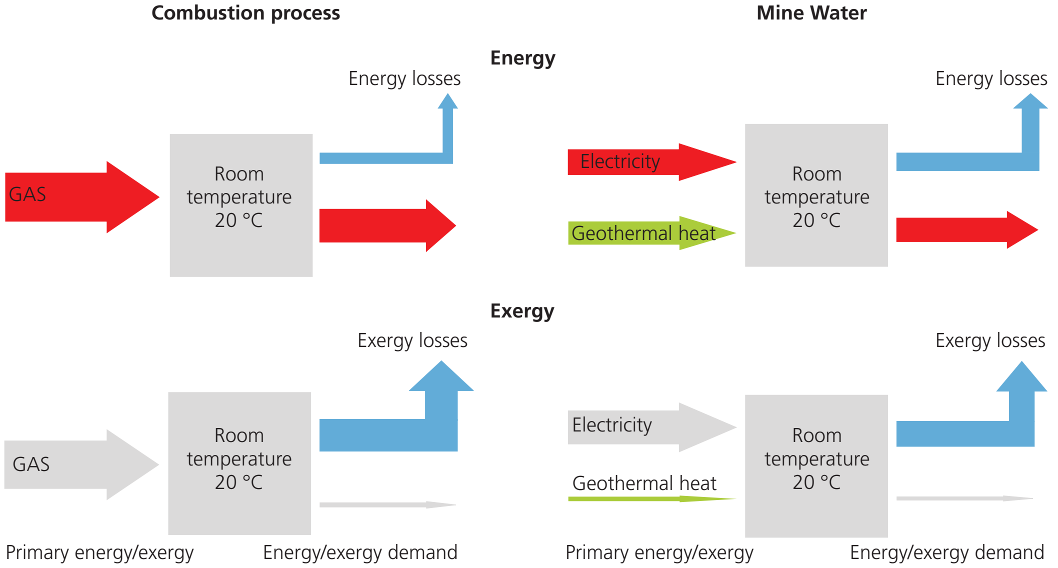

Figure 12: Energy and exergy supply of a well-insulated building with different heating systems [source: Fraunhofer IBP].

Example:
Comparison of energy and exergy within a combustion process and a process using minewater (s. Fig.12).It is assumed that a room with the same insulation level should be heated up to 20 °C. The heating by a gas-fired condensing boiler shows that a big portion of fossil exergy has to be expended for achieving the desired room temperature. This is caused by high-exergy losses occurring in the combustion process by using high-temperature heat for covering a low-temperature demand. The energy losses are relatively low because of the high-energy efficiency of the condensing boiler of 95%. However, the application of minewater for space heating shows that a large portion of the heat demand can be covered by low-temperature heat (minewater). When the minewater has to be pumped to its destination, a pump is required and therefore electricity is needed. Only the required electricity affects the exergy balance negativly, so here a special attention has to be paid to using efficient pumps.

Energy and Exergy Analysis

LowEx-Buildings

Because of the comparatively low temperatures which are supplied by the minewater, special requirements for LowEx-buildings have to be set. On the one hand the overall energy consumption has to be reduced and on the other hand the building envelope has to have a good quality.

- The facade ensures comfortable indoor conditions and is the central building element to apply efficiency measures to.
- Thermal insulation is a cost effective way to improve the exergy efficiency of buildings.
- Thermal bridges are areas of the envelope of a building where more heat is conducted from the inside to the outside than in an undisturbed area. Thermal bridges are not only spots of unnecessary exergy loss but can also cause building damages or hygienic problems be supporting mould formation and have to bve avoided.

For further information about construction details see our technical brochure.

LowEx-Communities

Communities are complex energy systems, with diverse energy supply chains and many interconnections. This variety offers opportunities for efficiency synergies on community level and greater overall system optimisation. Innovative large scale solutions like a minewater supply can only be realised at a community scale. The barriers can be a lack of knowledge among decision makers, a lack of planning instruments and tools and the existing fossil based infrastructure.

For estimating the potentials of the community a status analysis can be the first step. Mapping demands and potentials as well as the existing supply infrastructure will give a good overview on possible options. On that basis, a strategy can be developed of how to replace existing high-exergy structures by low-exergy solutions or where the efficiency of the supply systems can be improved by integrating low temperature energy sources. Because the energy grid is an essential backbone of any local or district heating and cooling network it is very imporatnt to locate the potential supply sources in relation to the existing demands.

Figure 13: Mapping the demand and supply structures and the energy potentials can help getting a first idea of how to exploit low temperature energy sources for heating and cooling [source: Fraunhofer IBP].

Energy and Exergy Analysis

A potential analysis can be classified using different exergy levels. In a very simple categories high-exergy and low-exergy sources can be differentiated (s. Fig. 14). High-exergy sources represent electricity and chemical energy carriers oil, gas, wood, which can supply high-temperatures and energy for high-quality demands like electrical appliances. Low-exergy represents all heat applications, waste heat or minewater.

Generally high-exergy applications often offer the chance for a cascading exergy use. Cogeneration processes produce electricity and heat that can supply a district heating network. Waste heat at a temperature level of 80°C can be used for heating existing buildings with a high demand (s. Fig. 15). The return is often still warm enough to sufficiently supply a well-insulated low-energy building. The energy flow is used several times using as much exergy as possible.

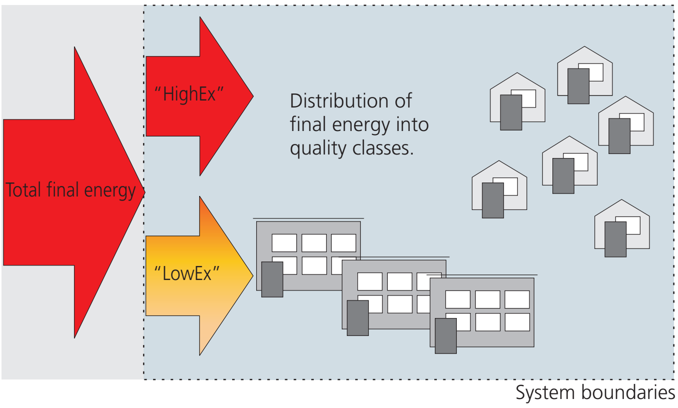

Figure 14: Building supply with high-exergy and low-exergy sources [source: Fraunhofer IBP].

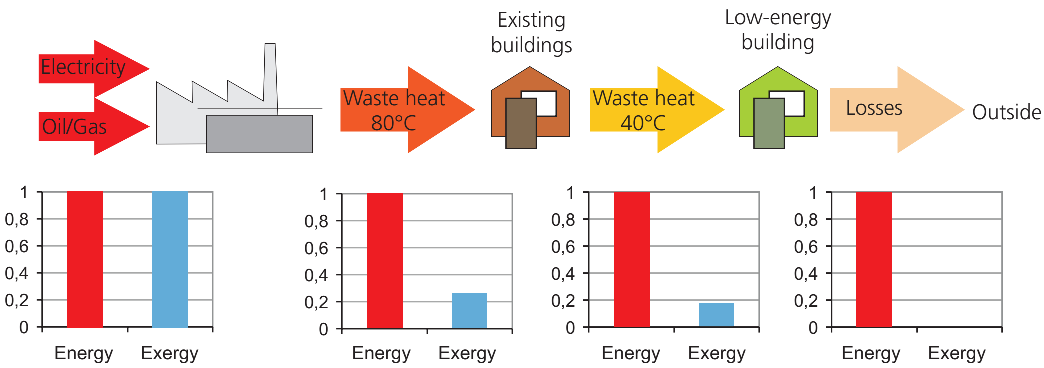

Figure 15: Cascading of a heat flow after cogeneration or industrial processes [source: Fraunhofer IBP].

Energy and Exergy Analysis - Summary

When using minewater from abandoned and flooded mines the different temperature levels of deeper and more shallow reservoirs can be used. The temperatures to be found underground depend on the geothermal situation and the depth of the reservoir. According to the natural temperature rise because of geothermal gradiance the infiltrating water is warmed up in the minewater reservoir. If there is high geothermal activity, the temperature levels may be sufficient for heating buildings directly. In other cases heat pumps can be used to provide the necessary temperature lift. From the shallow reservoirs cooling energy can be extracted to be used directly on a high-temperature cooling basis.

To make minewater supply work, the connected building should be well-insulated and provide a floor heating system to work with low temepartures. To supply the domestic hot water for buildings additional measures have to be taken. The low-temperatures supplied by minewater have to be raised to the hygenic requirement level by electrical or heat pump appliances. A domestic hot water supply by solar heat can reduce the electricity demand somewhat but regarding the base load at low-temperatures solar energy competes minewater use. In a smart bi-directional heat grid decentral solar feed-in could contribute to a seasonal storage effect within the minewater reservoir or serve as a buffer for high-demand periods. High-temperature cooling can replace effectivly electricity appliances for cooling making use of the same emission systems for summer and winter and add additional comfort for residential buildings. Concrete core activation, which allows a moderate floor, wall or ceiling cooling in buildings is a robust and low-exergy emission concept.

If low exergy sources are available, the reduction of the buildings' energy demand is necessary although no minimisation has to be achieved. Low-temperature district heating networks allow supplying space heating demand in highly insulated buildings very efficiently. There is a remaining electricity demand for domestic hot water at higher temperatures. Using low-temperature heat for preheating the domestic hot water can reduce the exergy demand significantly compared to electrical boilers. Highly efficient heat pumps enhance the overall efficiency further.

REMINING LOWEX

Tools

In order to promote the use of the exergy concept among building planners and decision makers a number of software tools has been developed within the IEA ECBCS Annex 49. These have different levels of complexity and can be used for various problems (Table 2).
For these training materials two tools are examplarily shown, which allow to analyse energy supply systems in buildings and communities regarding the energy and exergy performance.
The Annex 49 pre-design tool is a MS Excel-based calculation tool intended to analyse energy supply systems in buildings. It is based on a simplified steady-state approach for energy and exergy analysis. The tool allows depicting the overall performance of energy supply systems in buildings, as well as the exergy performance of single components of such supply systems (i.e. boiler, solar collectors, floor heating systems).
The tool is based on the German energy saving Standard (EnEV 2007), which targets the limitation of the energy consumption of buildings. Thereby, the application is focusing mainly on buildings with normal and low internal temperatures respectively, as e.g. residential buildings, day-care facilities for children, schools and office buildings.
The tool is based on the MS Excel tool developed within the IEA ECBCS Annex 37. Main changes introduced in the ECBCS Annex 49 pre-design tool are:

- Two different energy sources, or energy supply systems for DHW and space heating demands can be combined, e.g. solar thermal collectors and heat pumps, boilers, etc.
- Renewable energy flows are accounted for, both in energy and exergy terms, in the generation and primary energy transformation subsystems.
- Renewable and fossil energy and exergy flows are regarded separately, allowing good traceability of different energy sources on the energy supply chain.

Table 2: Summary of tools for exergy analysis in the built environment developed during the ECBCS Annex 49 project [source: Annex 49].

Tool	Ideal User	Calculation level
Annex 49 pre-design tool	Engineer/Architect	System/Building
Cascadia	Engineer/Planer	Community
SEPE	Engineer	System/Component
DVP	Engineer/Architect	Building
Human Body	Engineer	Occupant
Decission tree	Owner/Planer	System/Building

Tools

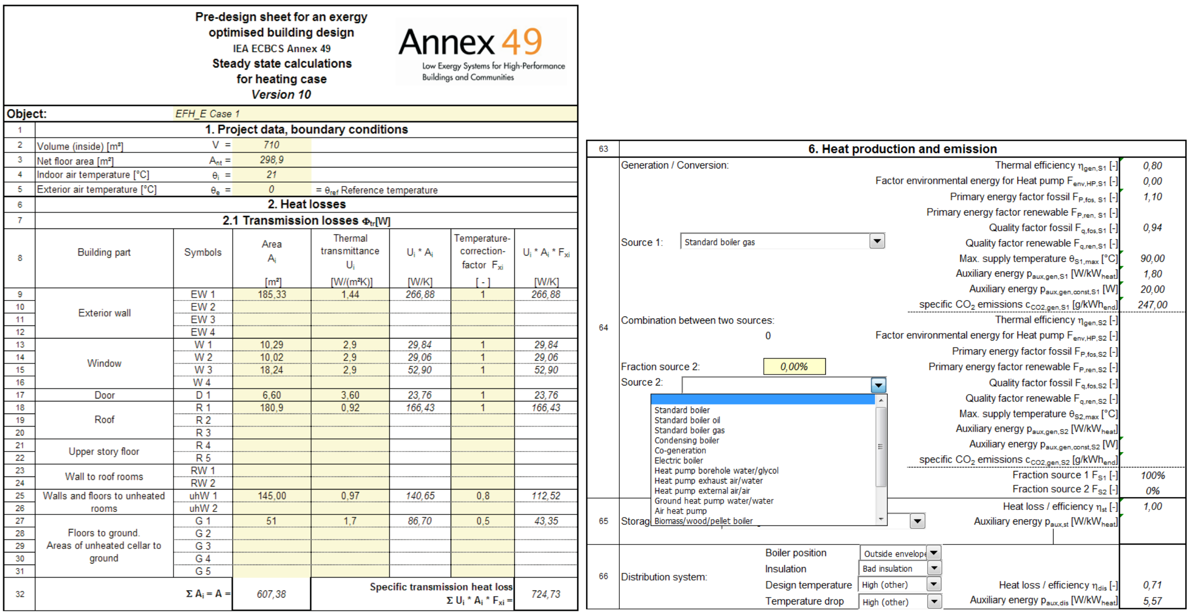

Figure 16: Input data sheet to define the building envelope in the Annex 49 pre-design tool (left) and drop-down menus for selecting building services (right) [source: Fraunhofer IBP].

The MS Excel-based tool “Cascadia” intends to provide insight in the exergy performance of different energy supply systems for communities. The tool aims at introducing the exergy concept to municipal planners and decision makers, so that main conclusions from exergy analysis on a community level can be integrated on the design process.
Cascadia is based on the calculation method implemented in the spread sheet Annex 49 pre-design tool.
While the model in the pre-design tool is focused upon individual building components, radiators, heat transfer equipment, etc., the model used in Cascadia represents the building as a simple thermal load and emphasises more in the form of the energy supply and its distribution network.

Tools

The model of the neighbourhood, shown in Figure 17, consists of a centralised energy plant supplying a district heating pipe network. Heating loads are from a typical neighbourhood, including high rise apartment buildings, low-rise or detached residential homes and a retail sector comprised of strip malls or single storey retail buildings. Individual buildings are connected to the district energy system in a parallel configuration with supply and return lines, whereby the three categories of buildings – high rise, residential and retail, are connected sequentially.
The model includes an allowance for both space heating and internal electrical loads. Building details provided to the model relate to the heat loss and ventilation requirements of the building and the electrical loads (pumps, fans, plug loads, etc.) associated

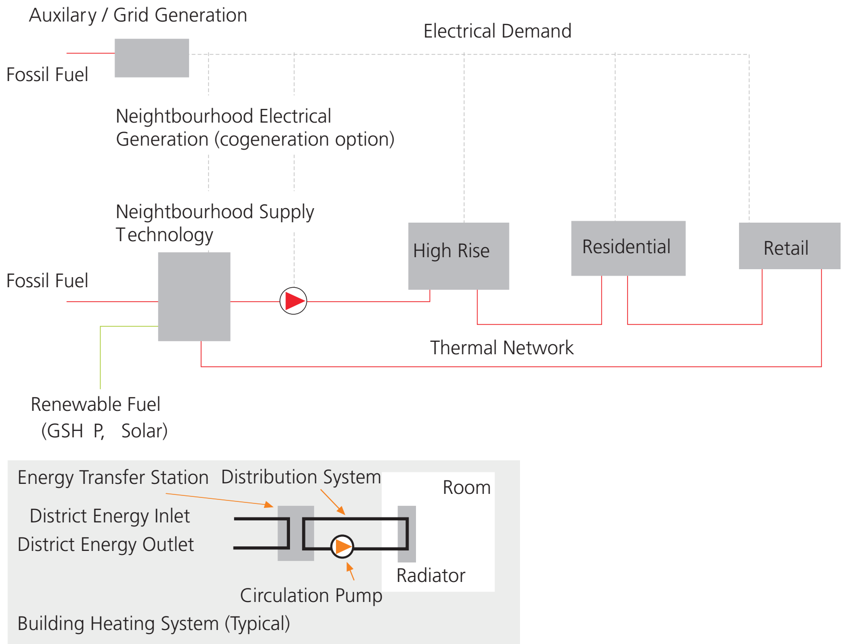

Figure 17: Scheme for neighbourhood design implemented in Cascadia [source: Annex 49].

Evaluation Indicators: Efficiency

Energy Efficiency

The energy efficiency describes the quality of energy conversion und transfer processes and is a dimensionless performance measure. The energy efficiency can be calculated as the ratio between „useful work produced“, the output of the system, and the „energy supplied“, the input of the system. The more the value approaches 1, the more efficient is the system.

$$\eta = P_{out} / P_{in}$$

$$= \text{Useful work / Energy supplied}$$

Exergy Efficiency

Exergy efficiency factors

In order to optimize the performance of different heating and cooling systems, a comparison of the exergy efficiency of the systems is required. As any other efficiency, exergy efficiencies are defined as the ratio between the obtained output and the input required. Exergy efficiencies help to identify the level of exergy destruction (or exergy loss) within an energy process (Cornelissen, 1997). Therefore exergy efficiencies allow to quantify how close a system is to ideal hyothetical performance or where the energy and exergy inputs of the system are used best (Torío et al., 2009). Efficiencies for the evaluation of the exergy efficiency are:

- Simple and rational exergy efficiency
- Single and overall exergy efficiency

The simple and rational exergy efficiency varies in terms of considering the exergy output. The simple exergy efficiency considers any kind of output as such, be it desirable or not for the investigated use. In turn, the rational efficiency considers the difference between “desired output” and any other kind of outflow from the system.
Depending on whether the exergy efficiency refers to a single component or process of an energy system, or whether it refers to all processes and components of the system, so-called “single” and “overall” exergy efficiencies can be used.

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Evaluation Indicators: Efficiency

<u>Diagrams:</u>
For illustrating the results, two diagrams can be used:

- PER-exergy-efficiency diagram
- Arrow diagram.

The Primary Energy Ratio (PER)-Exergy efficiency diagram (s. Fig. 18) characterises the exergy performance and use of renewable energy in the supply of a community project. PER is calculated as the ratio between the useful energy output, i.e. the energy demand to be supplied, and the fossil energy input required for its supply. High PER values indicate that the proportion of fossil energy in the supply is low, and, thus greater share of renewable energy sources is present in the supply. Exergy efficiency is represented on the Y-axis. PER ratio is represented on the X-axis. Each case (variation) is represented by both factors (dots in the diagram). Ideally, high values for the exergy efficiency and PER ratio should be obtained. White dots show both parameters for different supply concepts, characterising the performance of the case. Dots in the upper right corner indicate good exergy performance and high use of renewable energy sources. Supply concepts on the area close to the upper right corner would correspond to LowEx community concepts. In turn, dots close to the lower left corner depict cases with low exergy efficiency and high fossil fuel share in the energy supply.

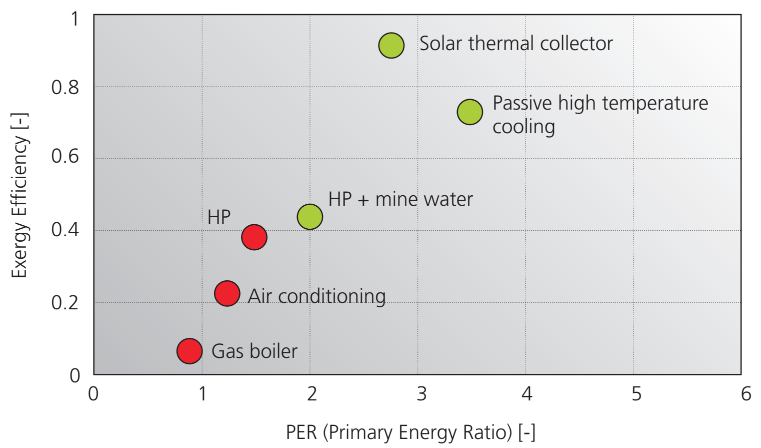

Figure 18: PER ratio vs. Exergy efficiency diagram for the energy supply options chosen in Heerlen (represented by the white dots). For comparison, grey dots represent the performance of conventional technologies [source: Erwin Roijen, Cauberg-Huygen].

Evaluation Indicators: Efficiency

The arrow diagram shows the matching of the quality levels of the energy supplied and the energy demanded in the building. The diagram is a qualitative representation of the quality and quantity of energy demands and supply in buildings (s. Fig. 19).

The position of the arrows on the Y-axis represents the quality factor on a scale from 0, no quality, to 1, high quality. The size of the arrows represents the quantity of energy needed. The diagram can be used to show and explain the relationship between exergy levels on the demand and the supply side. As well the effect of different measures can be shown. For example does the mere retrofitting or insulation of a building only affect the size of the arrows while the supply side will still be high quality. Only if both

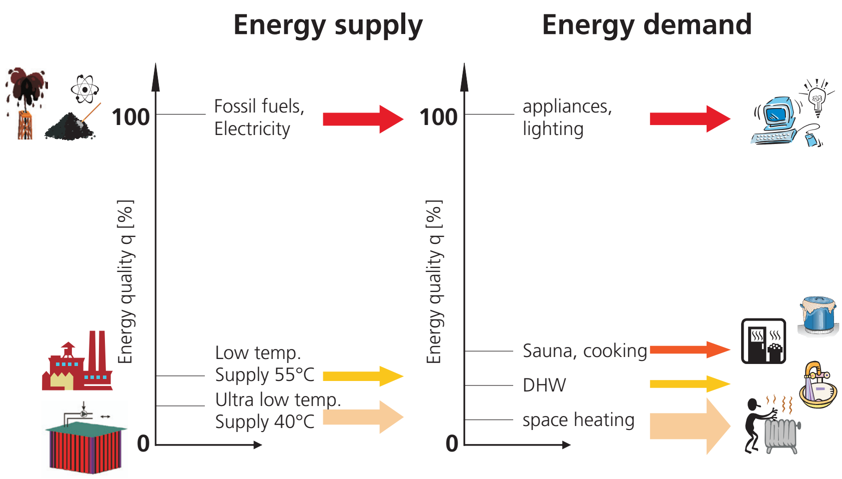

Figure 19: Arrow diagram [source: Fraunhofer IBP].