The EC REMINING-lowex project in Heerlen the Netherlands: development from a geothermal to a polygeneration concept

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Abstract

For the last 10 years numerous research and commercial initiatives have been undertaken in Europe in relation to development of the low temperature resources in coal mining fields. One of the most successful of them is the Minewater project in Heerlen, the Netherlands, where a low-temperature district heating system was launched on October 2008. Other projects are carried on in Germany, Spain, France and Russia. Continuation of research on utilization of geothermal energy from abandoned mines is one of the goals of the 6th Framework Program project EC REMINING-lowex (Redevelopment of European Mining Areas into Sustainable Communities by Integrating Supply and Demand Side based on Low Exergy Principles). In the project four local communities participate from the Netherlands, Slovenia Poland and Bulgaria. The project initially aims to demonstrate the use of locally available low valued renewable energy sources, specifically water from abandoned mines for the heating and cooling of buildings. The system is based on low energy principles, and is facilitated by an integrated design of buildings and energy concepts. With the new plans for the connection of the Educational Campus Heerlen with an own energy supply, containing biomass cogeneration with absorption cooling, and a solar plant (PV and thermal), with an out coupling to the minewater grid, as well as the plans to feed in local industrial waste heat the initial concept develops into a polygeneration project.

Keywords

Geothermal minewater use, low exergy, polygeneration

Introduction

Abandoned and flooded mines have a high potential for geothermal utilization as well as for heat and cold storage of water volumes in remaining underground spaces. The use of heat and cold from minewater is one of the important aspects of rational and sustainable utilization of post mining infrastructure and may bring positive socio-economic results, social rehabilitation and improved health for communities living in European areas with (former) mining activity. In Heerlen, the Netherlands, the redevelopment of a former mining area, including a large scale new building plan, is being realised with a low exergy infrastructure for heating and cooling of buildings, using minewater of different temperature levels as sustainable source. Mines have large water volumes with different temperature levels. In Heerlen the deeper layers (700 – 800 m) have temperatures of ~30°C; shallow layers (200 m) of 15..20°C. These water volumes can be considered as heat/cold storage as well as geothermal sources. Most crucial however is that these sources provide low valued energy (low exergy). As on the demand side heating and cooling for buildings also require low valued energy the intended design strategy is to realise the climatisation of the buildings in this pilot preferably directly by minewater. The combination of low temperature emission systems with advanced ventilation technologies and integrated design of buildings and building services provide an excellent thermal comfort for 365 days a year, including sustainable heating and cooling and improved indoor air quality.

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This sustainable energy concept gives a reduction of primary energy and CO_2 of 50% in comparison with a traditional concept (level 2005).

The energy concept

The minewater energy concept in Heerlen is in principle as follows. Minewater is extracted from four different wells with different temperature levels. In the concession of the former ON III mine (location 1 Heerlerheide) mining took place to a level of 800 m. In this concession the warm wells (~ 30°C) can be found. In the former ON I mine (location 2 Heerlen SON) mining took place to a level of 400 m and here the relatively cold wells are situated. The extracted minewater is transported by a primary energy grid to local energy stations. In these energy stations heat exchange takes place between the primary grid (wells to energy station) and the secondary grid (energy station to buildings). The secondary energy grid provides low temperature heating (35°C – 45°C) and high temperature cooling (16 ..18°C) supply and one combined return (20..25°C) to an intermediate well.

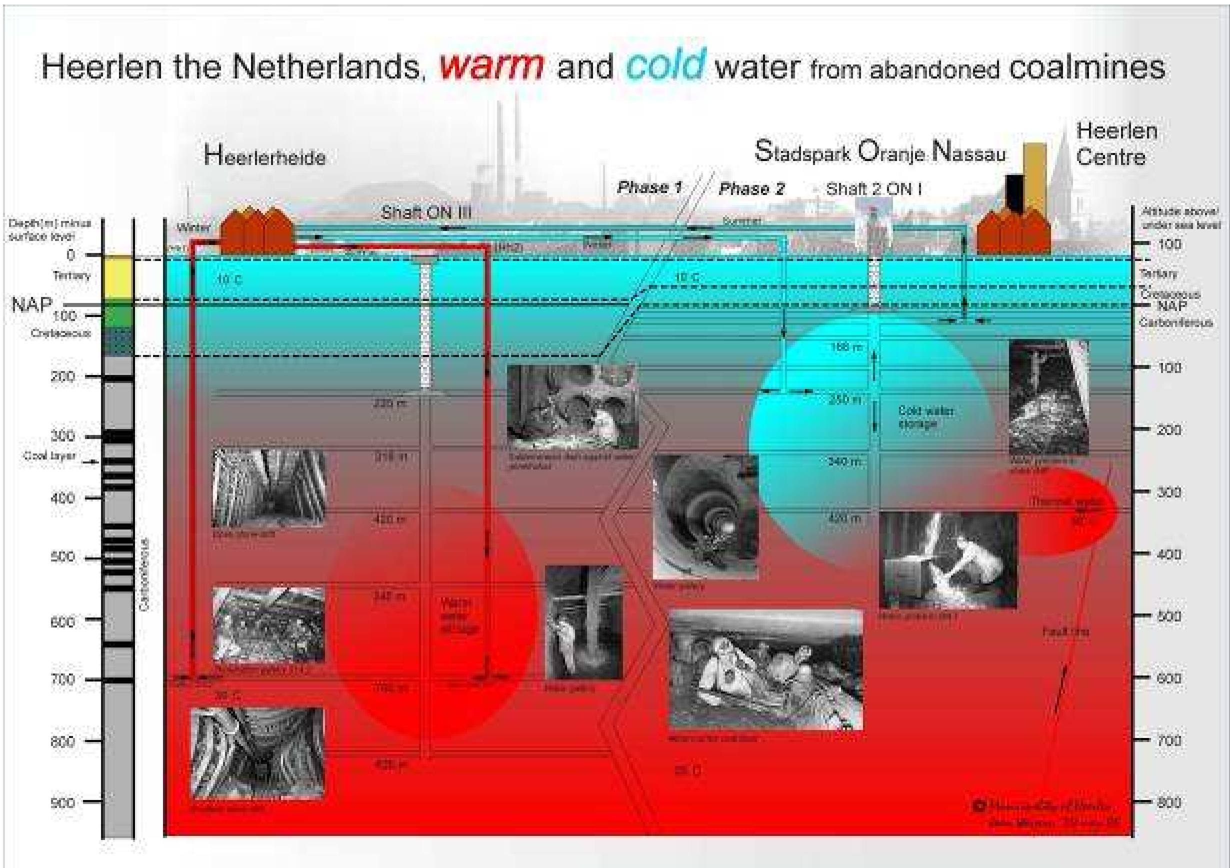

Figure 1: Schematic cross section of the underground conditions of the ON I and ON III mines

The five well locations and energy stations are connected by a three pipelines (warm, cold and return) of 7 km each. Warm water is transported from the warm wells at the north and cold water is transported from the shallow wells at the southern region to several local energy stations. Return water of 20..25°C is transported to an intermediate well (450 m). The temperature levels of the heating and cooling supply are "guarded" in the local energy stations by a polygeneration concept existing of electric heat pumps in combination with gas fired high-efficiency boilers. The surplus of heat in buildings (for example, in summer, cooling, process heat) which can not used directly in the local energy stations can be lead back to the minewater volumes for storage. Domestic hot water is prepared in local sub-energy stations in the buildings by heat pumps, small scale CHP or condensing gas boiler, depending on type of

building and specific energy profile. The total system will be controlled by an intelligent energy management system including telemetering of the energy uses/flows at the end-users.
The location of the wells has been determined as a result of geological research. The final determination of the location took place in narrow collaboration with former miners, using their knowledge about the underground circumstances at the time the mines were abandoned. The drilling of the warm wells took place from February to June 2006. The two warm wells and the first primary net (i.e. the connection between the two warm wells) was completed in June 2006, followed by a successful testing in July.

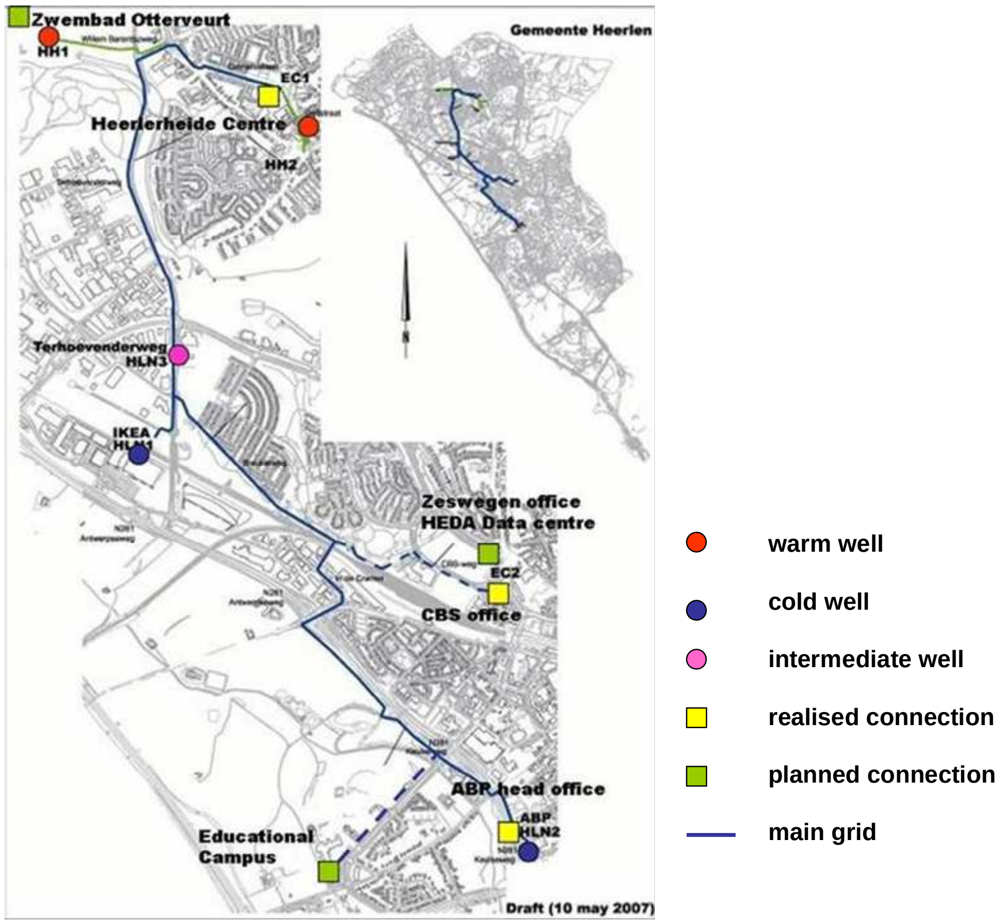

Figure 2. Lay out of the total minewater grid in Heerlen

Integrated Design Approach versus traditional approach

The present development of energy efficient buildings in an increasing way requires an integral design approach. A couple of decades ago energy efficient design and building mostly focussed on improving a certain technique or apparatus. Nowadays an energy efficient building, supported by an energy efficient installation, has to be combined into one integrated energy efficient concept with an optimal performance in terms of indoor climate, thermal comfort, sustainability and user's satisfaction. This asks for an integral design approach in which well balanced choices are being made. In sustainable building projects it is crucial to consider the design and realization of the sources, the heat generation (especially with non-traditional solutions such as heat pumps, cogeneration, heat/cold storage) distribution and emission together, including all possible interactions with the building, building properties and building users. Only this approach can lead to a set of well defined performance criteria concerning energy performance, sustainability, indoor air quality, thermal comfort (365 days/year, winter and summer conditions), and health. Next to it is necessary to have specific emphasis on investments and energy exploitation, as well as communication to the end-users. A traditional approach is often based on partial optimization of the different disciplines. An integrated approach will achieve a total optimization, taken into account all disciplines and their interaction. Basis is a set of unambiguous well defined performance criteria. The design strategy applied in this approach is the so called Trias Energetica. It is a three step approach that gives a strategy to establish priorities for realising an optimal sustainable energy solution, containing the following steps:

Step 1: Limitation of energy demand
Step 2: Maximizing share of renewables
Step3: Maximizing efficiency of using fossil fuels for remaining energy demand

with as an overall prerequisite: limit the temperature levels of heat and cold supply (conform 2nd law of thermo dynamics).

In general the heating and cooling of buildings can be realized with very low valued energy, with medium temperatures close to required room temperatures. The better the building properties (extreme high thermal insulation, high air tightness and suitable emission systems) the closer the temperatures of heat and cold supply can be to room temperatures. In order to utilize these moderated temperatures for heating and cooling the buildings must comply with a number of boundary conditions as presented in table 1.

Table 1: Generic overview of measures to make buildings suitable for low temperature geothermal sources in comparison with current practice.

	Building Reg's NL	Practice 2008 NL	Mine water (Lowex)
Thermal insulation	Envelope U = 0.37 Glazing U = 3.0	Envelope U = 0.30 Glazing U = 1.5	Envelope U < 0.25 Glazing U < 1.2
Ventilation	No system requirements	No system requirements In practice 50% ME and 50% MVHR	MVHR with η = 95% Or demand controlled natural ventilation
Air tightness	n50 = 3	n50 < 2	n50 <1
Emission system	No requirements	Radiators	Floor heating and cooling (residential) Concrete core activation (non residential)
HVAC system/efficiency	No requirements (but in EPR)	Condensing boilers η = 95% No cooling	Mine water with heat pumps (boiler back up) Sustainable cooling
Energy performance (EPC) dwellings	0.8	0,8	0,5

The demonstration locations

Location Heerlerheide Centre

This plan is situated on the concession of the ON III pit in a relatively deep mined area with warm wells (up to 30°C). The plans include the following activities for *new buildings:*

- 33.000 m^2 (330) dwellings (single family dwellings and residential buildings)
- 3.800 m^2 commercial buildings
- 2.500 m^2 public and cultural buildings
- 11.500 m^2 health care buildings
- 2.200 m^2 educational buildings

The first new building and construction activities in Heerlerheide Centre have started in 2006. The total plan will be realised between 2006 and 2011. All planned buildings will be connected to the energy supply (heating and cooling) from minewater. All buildings are planned in a very compact area which is very favourable for energy distribution. The building location is situated between two warm wells. Next to it, the planned building functions require heating as well as cooling. The energy supply includes the building of an energy station and a small scale distribution grid from this station to the buildings. In the energy station the minewater is brought to the necessary heating and cooling levels by heat pumps. In order to facilitate the process and to guarantee all real estate developers, involved in this building plan, the delivery of energy to the buildings the main investor, Housing Corporation Weller, is realising the exploitation of the energy supply, including the building and construction of the energy station and distribution grid. It is important to realise, that with minor modifications this energy supply can also be functional and operational without the application of minewater.

Figure 3 Heerlerheide Centre, cultural building with energy station, school and apartments

<u>Location 'SON'</u>

The development of Stadspark Oranje Nassau (SON) has a strategic significance for the social and economical rehabilitation of Heerlen. This plan will be realized in combination with sustainable mobility and accessibility. The total program contains the realisation of the new buildings such as the CBS office (21.000m^2), a new commercial office (17.000m^2) and a data centre. The new CBS office is completed in June 2009 and is connected to the minewater grid. Heating and cooling is realised by a demand controlled low temperature VAV system.

Figure 4 New CBS and retrofitted ABP building

Connection to Educational Campus

The educational Arcus College, Sintermeertencollege, Zuyd and Open University Netherlands, jointly established the Education Campus Heerlen. The Educational Campus has far-reaching energy and climate targets. Building, maintenance, renovation and operation of buildings and infrastructure in a sustainable manner achieved as far as possible according to the Cradle to Cradle principle. At least a total of 50% CO2 reduction should be achieved. These reductions are achieved by measures according to the method of the Trias Energetica and deployment of renewable energy sources. Furthermore, the educational institutions set the target for 2025 in a joint CO2 reduction of 80% in 2025 to achieve. This will partly be achieved by a collective optimum energy and sustainable energy infrastructure.
Low-quality energy from the environment will be used according to the ex-low approach.
The Educational Campus will have a new renewable energy supply:

- Bio cogeneration plant in combination with absorption cooling
- Solar (Thermal and PV)
- Connection to minewater grid
- Lowex principles:
  - Existing buildings higher temperatures (cogeneration)
  - New buildings low temperatures (minewater)
  - Out coupling of residual heat and cold with minewater grid
  - Energy management: direct use in other buildings, recharging wells

Arcus college

The Arcus College concerns new construction of two buildings of 25,000 m2 and 8760 m2 The entire construction of the Arcus College will be made suitable for the application of low-grade energy for heating and cooling and will therefore provided with concrete core activation.

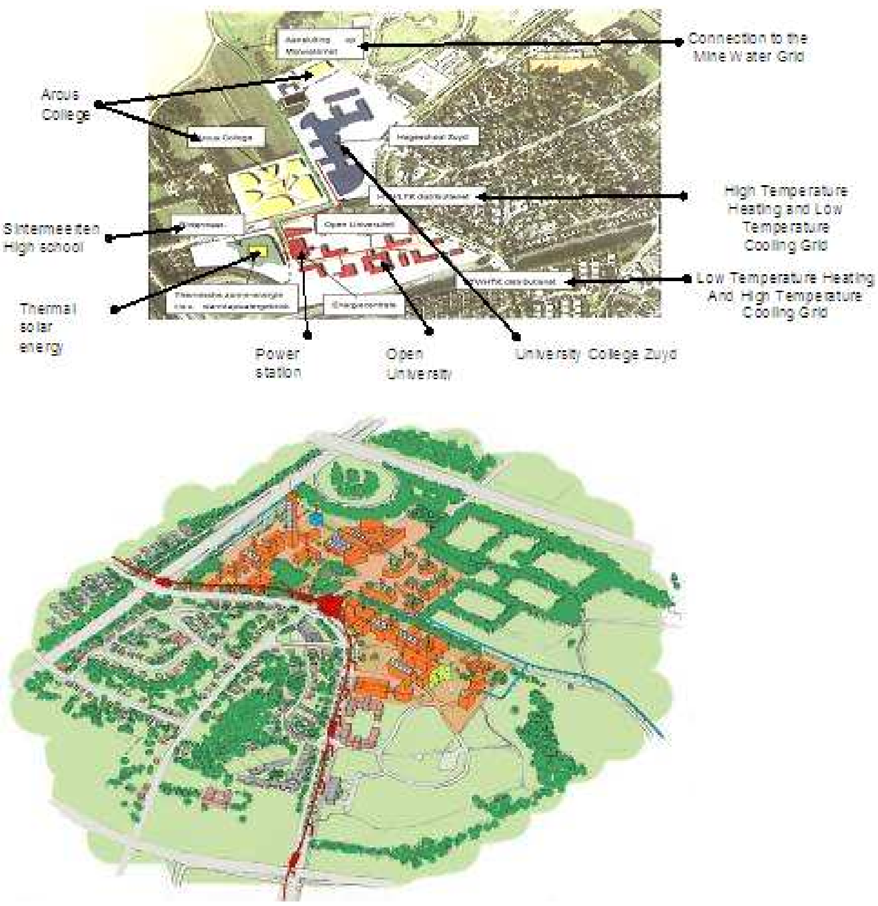

Figure 5 Overview of the Campus Site

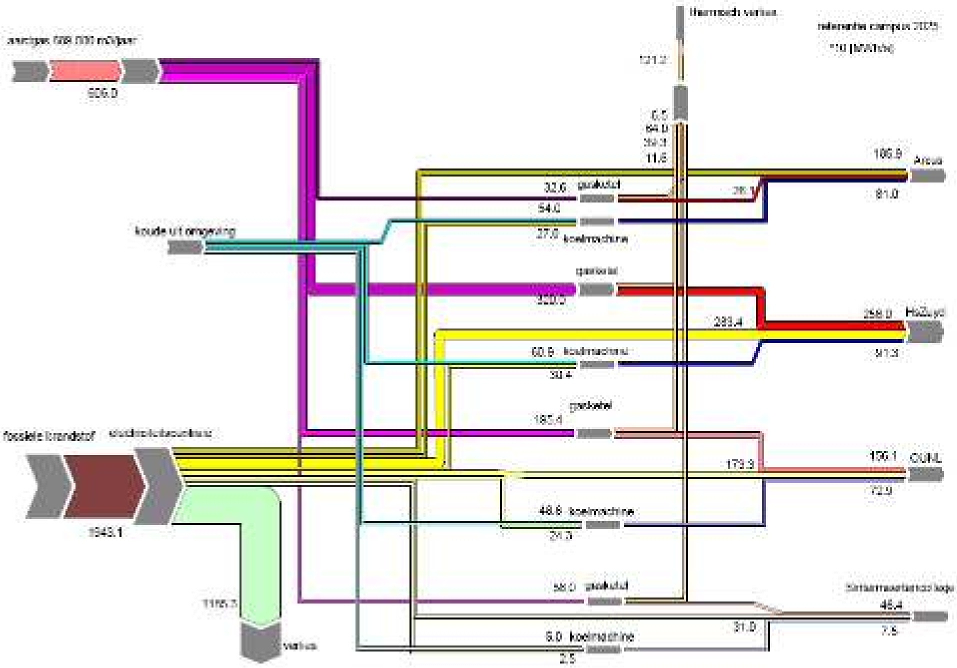

Figure 6 Sankey diagram energy flows existing situation Educational Campus Heerlen

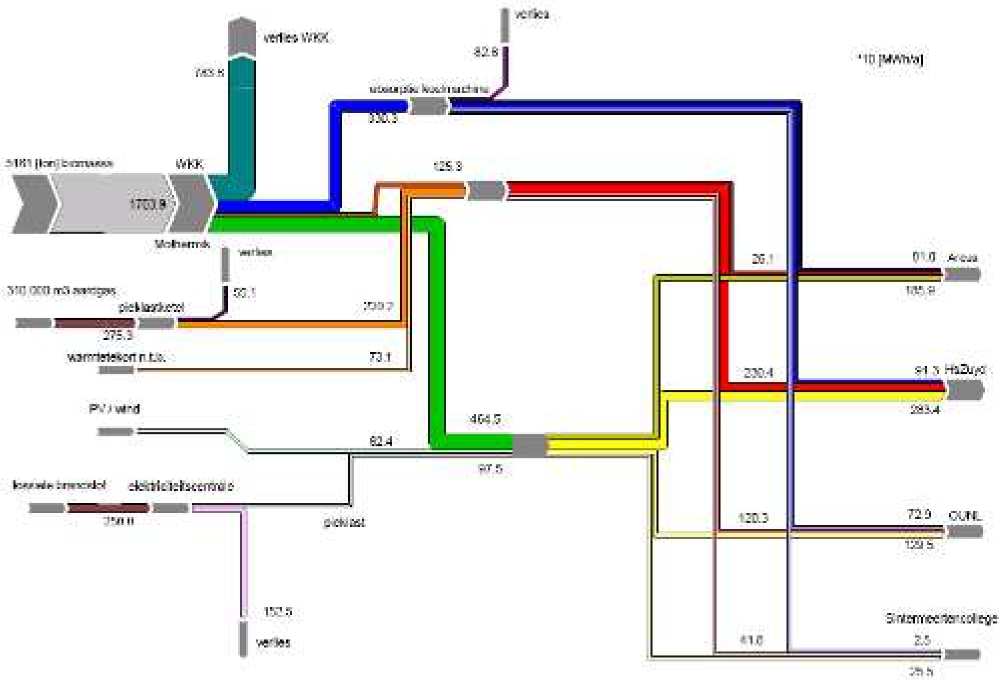

Figure 7 Sankey diagram energy flows Educational Campus with polygeneration

5. Balancing Supply and Demand side

For the elaboration of the final energy concepts following questions should be answered:

- total heating and cooling demand, how to control and limit this demand
- the target values for percentage of renewables in total energy demand
- what is the available amount of renewable energy from minewater (i.e. how much water can be extracted) and other renewables
- what is the most efficient conversion technology for the (not sustainable) back-up system.

This input is necessary for the integrated design process including buildings, sources and energy systems, distribution and emission systems. An important tool for the assessment of this process and balancing demand and supply side is the energy profile of a building, expressed in a load-duration curve, based on dynamic calculations (using TRNSYS) of the energy demands of the buildings. This curve is a profile representing the energy demand over a total year, including heating and cooling. This curve also provides a good indication of the maximal capacities for heating and cooling as well as the balance between heating and cooling demand. Important for balancing the supply and the demand side is the tuning and balancing between the cold and heat sources, in this case, the deep (warm) and shallow (cold) wells. This assessment takes place in relation to the required temperature levels, the yearly extracted volumes and the energy demands of buildings; this in relation to the available water volumes in the reservoirs. The load duration curves give important information about:

- the balance between cold and heat demands:
- the effect of optimisation (for example limiting heat losses by thermal insulation or heat recovery, etc.);
- the way how to limit the installed capacity of heat pumps, CHP and other heat generation, and, on the other hand, how to increase the number of operation hours, in combination with storage, to increase the efficiency and to decrease investment costs.

In order to establish a balance between the rational use of energy needs on the building side and the renewable energy supply a total annual heat-load duration curve of the total building plans in Heerlerheide Centre and SON is calculated by dynamic simulations with TRNSYS. In figure 8 the combined heat-load duration curve for Heerlerheide is shown.

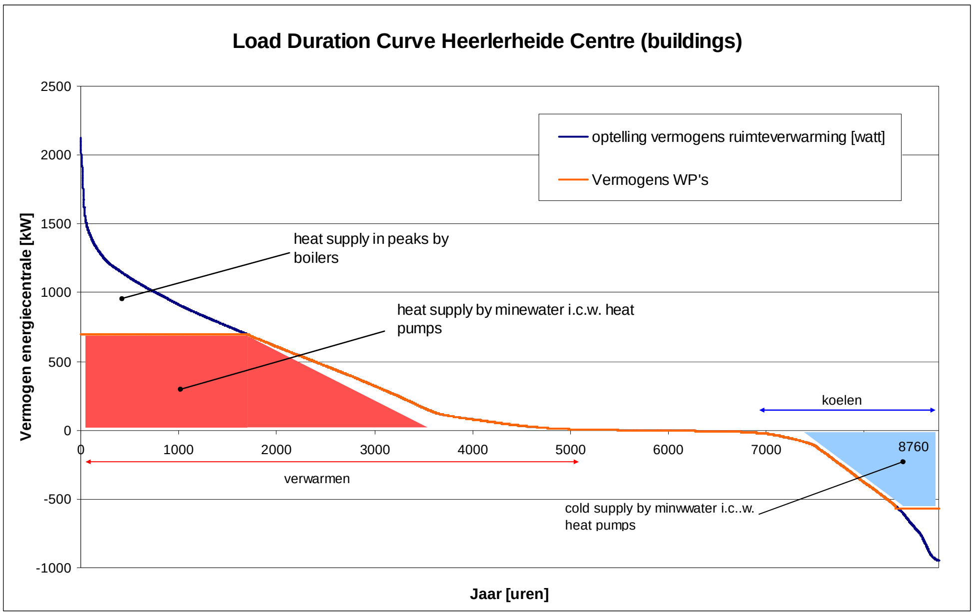

Figure 8 Annual heat load-duration curve Heerlerheide

The peak for heating power is about 2.2 MW; this is about 20 % lower than calculated with traditional heat loss calculations and can be explained by the internal gains and heat accumulation as taken into account only in the TRNSYS calculations. The four heat pumps in the Heerlerheide energy station will have a combined peak capacity of 700 kW_{th} and thus covering up to 80 % of the annual heat demand. Due to the small temperature step, the average COP of the heat pumps is ~ 5.6, but can raise up to 8 under favourable circumstances. A total heating capacity of 2.7 MW gas-fired condensing boilers will be installed as back-up and for peak moments (20 % annual). The heat-load curve also shows a period of ~ 2000 hours/year without any heating or cooling demand. The maximum cooling demand is ~ 1 MW and can be mainly covered by the minewater and inversed heat pumps. The heat and cold of the energy station are supplied tot the individual buildings by district heating. The supply temperature for the floor heating depends on the outdoor temperature and will be maximum 45°C at -10°C outside. The calculated seasonal average supply temperature will be 35°C and thus fit perfectly into the principle of 'very low heating".

Monitoring takes place since the beginning of 2009. In January 2009 the average outdoor temperature was 1^0C; peaks in the supply temperature did not exceed 40^0C; in week 3 2009, extreme outdoor temperatures were reached of -18^0C; even then the supply temperature did not exceed 36^0C, see figure 9.

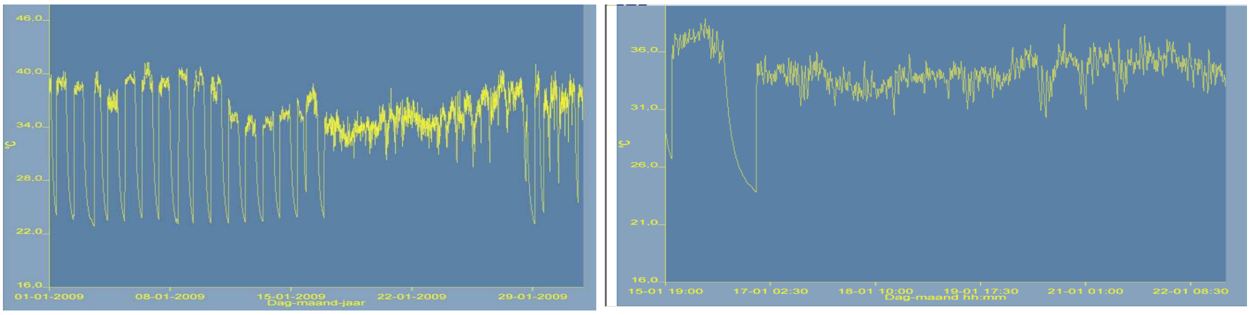

Figure 9 Monitored supply temperatures to the apartments, January 2009 and week 3 2009 in detail

Domestic hot water is prepared by preheating the cold water with the supply for central heating and after heated to 70°C with condensing high-efficiency boilers. In this way, the minewater heat pumps preheat about 30 % of annual demand for domestic hot water.

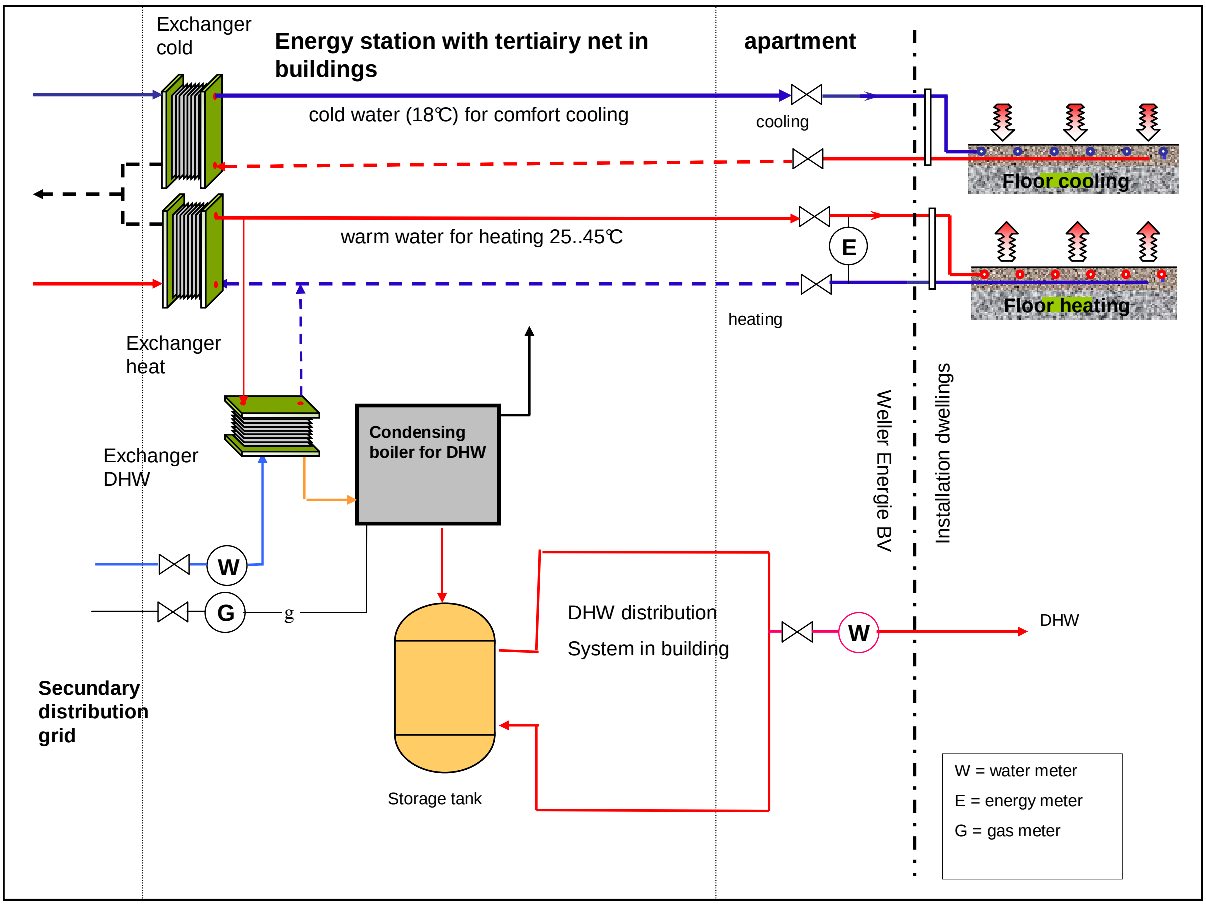

Figure 10: Energy concept buildings Heerlerheide

All the dwellings at Heerlerheide will have floor heating and cooling. This requires good information to the habitants about the typical thermal behaviour of floor heating and –cooling, including the restrictions on tapestry. The ventilation of all dwellings consists of mechanical supply and exhaust with high-efficiency heat-recovery (η = 90 %). Commissioning of these systems is important to get properly functioning HVAC-systems under all circumstances. The lack of a infrastructure for natural gas forces the habitants to electric cooking, a non-traditional solution in the Netherlands.

Low Exergy Secondary grids

In Heerlen different solutions for distribution systems have been applied. In Heerlerheide Centre a central solution is applied with one central energy station where mine water is exchanged an post processed and a secondary distribution grid to the buildings. In the buildings there is a tertiary grid to for example to the apartment. A special feature in Heerlerheide is that apartments (social housing segment) have cooling. In Heerlen Centre decentralised solutions are applied. In this part there are larger office buildings with their own energy stations where the mine water is exchanged and post processed, specifically to the building needs (which can differ to a large extent).

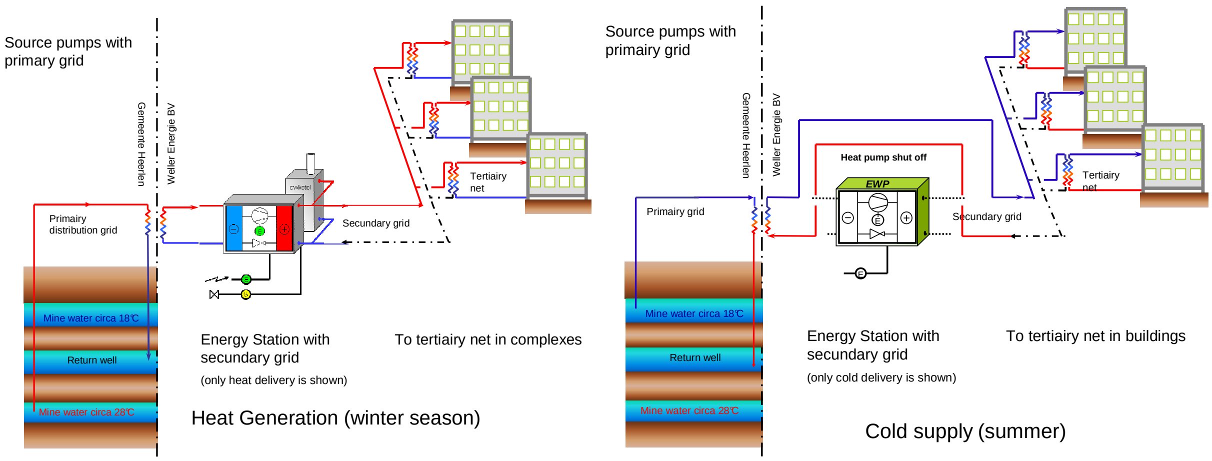

Figure 11: Secondary Distribution grid Heerlerheide (winter and summer situation)

Economic Feasibility by private organized energy exploitation

Despite the rather high level of investments for the energy installations and buildings measures this concept can be economically feasible by private organized energy exploitation. In this case, the main investors will also organize the energy exploitation, i.e., in separate private owned Energy Exploitation constructions. These private organized companies can use lower internal interest rates, 6 to 8% instead of the usual 12 to 15% of utilities and district heating companies. The main reason is that profits from selling energy are not considered as a core business. By establishing connection fees for heating and cooling and avoiding a gas infrastructure on building/dwelling level, as well as avoiding extra cooling installations, these constructions offer possibilities for economical sound energy exploitation. Economical benefits will also occur because of the integrated design and especially combining heating and cooling in the same emission system (i.e. floor heating and cooling, thermally activated building components etc.). Using these combined emission systems avoids the investment costs for a separate cooling system. The economic value of the heat and cold out of the minewater is expressed in a GJ-price en is determined by three factors:

- the running costs of the minewater company, including electricity for the well pumps and transportation, maintenance, replacements and administration

- the costs of the upgrading of the low valued heat and cold by the heat pumps and gas fired boilers
- the reference energy bill of the end-user as a limit, (according to the Dutch so called NMDA-principle (= costs are not more then usual))

The first and second costs are estimated from the load-duration curves, but can still be influenced by the positive effect of the siphon-principle between the wells (this reduces the pump energy of the wells significantly). At the other hand, the end-user will probably compare his energy bill to that of a similar dwelling with conventional heating. The calculations of the reference energy-costs are subject to many discussions and points of view, due to different interests. In basic, for the Minewater project the reference energy costs (including conventional cooling) are calculated at the level of the actual building decree. The individual consumption of cooling is not metered, but charged to a fixed rate. In this way, the metering costs are avoided, habitants start cooling as early as possible to get a maximum effect out of the limited capacity of the floor cooling and as much as possible heat is returned into the mines (heat storage). In fact, a standard or general tariff for low-exergy cooling is not yet available in the Netherlands. Essential for the economic study is the distinction between the variable and fixed costs. This ratio should be roughly equal for supplier and buyer.
The energetic and financial performance of minewater as an energy source depends on a variety of parameters. A basic calculation model which compares a minewater solution to a conventional solution at a unit level of 1 GJ is used to identify them. Important parameters are:

- direct or indirect heating and cooling by minewater (practice: mix of systems)
- effectiveness of pumping and distributing the minewater
- type of ownership of the wells and/or the buildings
- cost of capital for the investments
- cost of fossil energy (natural gas versus electricity) and their future price development

Direct heating and cooling is strongly preferred because of the high energy savings, the clear structure of costs, low investments and less dependency on fossil fuel prices. A disadvantage of direct heating and cooling with the minewater is the sensitivity for fluctuations of the minewater temperature (if any). If the minewater temperature and the buildings services temperature don’t match, post processing by heat pumps is an option. In this case, an optimization of the temperature difference (ΔT) for heat extraction is necessary.
A special point of attention the is electricity use for the pumps, which are considerably high. One of the factors is the length of the grid and the fact that a certain velocity (and pressure) is necessary to avoid scaling in the pipes. The overall performance of the pumping and distribution of minewater can be improved by creating a closed loop between the wells (reduces hydrostatic pressure difference) or by a turbine in the injection well. Both techniques need more study.

Conclusions

Abandoned and flooded mines can be reutilized for a new sustainable energy supply for heating and cooling of buildings. The minewater project in Heerlen shows that temperatures of ~30 °C can be found at 700 m; the temperature of the shallow wells is to be expected 16..18 °C at 250 m. These temperatures can be used for heating and cooling of buildings if these buildings are very well insulated, have energy efficient ventilation systems and have emission systems suitable to operate with moderated temperatures like floor heating or concrete core activation. Despite the rather high investment costs such projects can be economical profitable avoiding additional cooling systems and by integrated design and if energy exploitation is organised by the investors. Although the project is more or less an experiment, the project is already scaled up to extra buildings to make it commercial profitable. This requires a reliable and efficient distribution system that lasts for at least 30 years and therefore extra measures have to be taken to prevent scaling and corrosion in the piping. For the post-pilot period also extra measures will be taken, like oversized, insulated transportation pipes with leakage detection.

A important recommendation is to locate the wells and end-users as close a possible, thus avoiding necessary permits (archaeological, flora and fauna, civil infrastructure) and costs for the transport pipes. Another main recommendation is to integrate the Low-ex concept already at the first drafts of the building design and keep on convincing the building parties about the concept, of course with regard to the actual building design. A strict separation should be made between the distinct temperature levels for heating, cooling and DHW on the one hand and the seasonal influences at the other hand. Use of electricity for the transport pumps should not be neglected.

Further recommendations are:
- a small as possible distance between the minewater source and energy demander(-s);
- matching temperatures for minewater versus building services (in general, only the latter can be influenced by lowex emission systems);
- a clear business model and financial forecast appoints the economic and energetic return of the system.

In fact, the optimum between reducing the energy demands to allow low-ex solutions and the possibility of earning back the (extra) investments done for allowing low-ex energy sources by "selling" enough energy is fragile.

Acknowledgements
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