Economical & energetic parameters of minewater as an energy source
Method and case studies for CONCRETO Remining-lowex

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Reference **Work package 4.3**

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Prepared for	CONCRETO Remining-lowex
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Contents

Chapter Title **Page**

1 Introduction

In the framework of the CONCERTO Remining-lowex program, work package 4 focuses on the economical and energetic performance of minewater as an energy source. A first sensitivity study is done by Cauberg-Huygen, indicating the economical and energetic parameters which may affect the feasibility of minewater as an energy source.

A clear distinction should be made between direct heating and cooling buildings by mine water on the one hand, and minewater as a thermal half fabricate which needs post processing at the other hand. Both cases will be discussed next.

The overall energy costs and performance of heating and cooling with minewater are compared to traditional solutions based on fossil fuels. Therefore, all costs are converted to 1 GJ of thermal energy (heat or cold).

2 Parameter assessment direct heating and cooling by mine water

2.1 Technical principle

In this case, a clear match is achieved between the minewater temperature and the temperature levels of the buildings climate system. Figure 2.1 shows an example, in which the temperature level of shallow minewater (e.g. 14℃) matches the temperature levels of for example concrete core activation. The minewater is directly used to the cool the building mass, for example at a 15 → 21℃ temperature extraction. The mine water returns with a temperature of app. 22℃ out of the building.

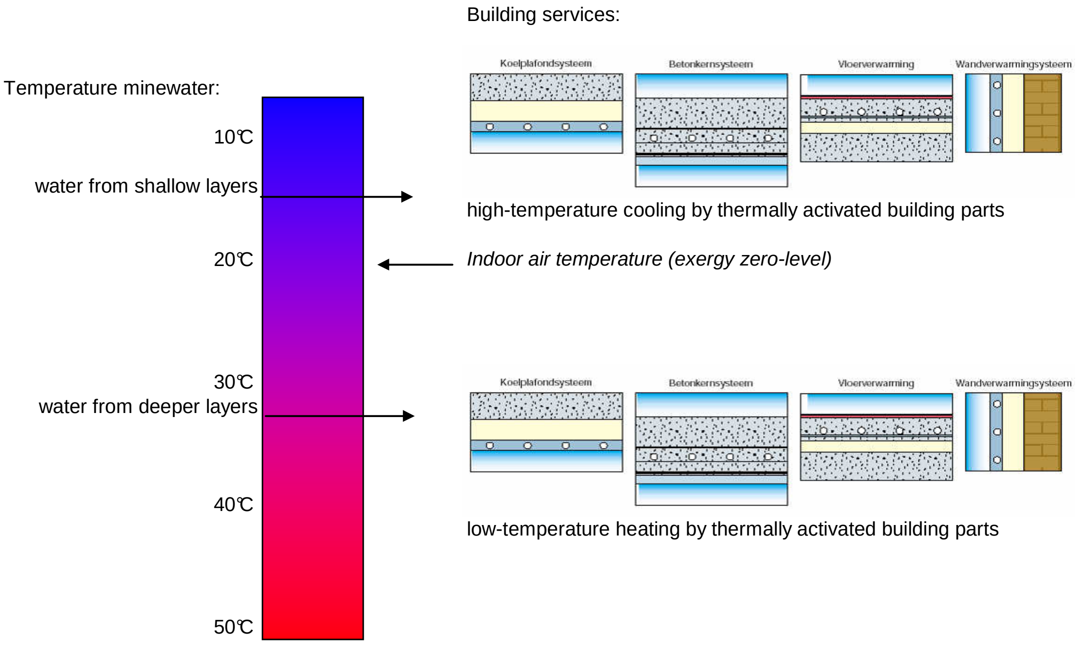


Figure 2.1: Temperature match minewater and low-ex climate systems

Boundary conditions

- A hydraulic separation between the mine water system and the building services is often necessary. A counter flow heat-exchanger causes a temperature drop and heat losses. This should be taken into account. The cold minewater should be slightly colder (app. 2℃) than the supply temperature for cooling; the warm mine water should be slightly warmer (app. 2℃) than the supply temperature for heating.
- The heating and cooling capacity of thermally activated building parts is limited. These emission systems are sensitive to excessive transmission and ventilation losses. The control of the heat- and cold losses by good thermal insulation, good air tightness of the building envelope and energy-efficient ventilation (e.g. by hat recovery) is therefore very important, but has no direct relation to the minewater as an energy source.

2.2 Cost aspects

The two main cost aspects are:
- the capital costs of the minewater infrastructure and low-ex building services;
- the running costs for pumping, distribution and control.

2.2.1 Capital costs of the minewater infrastructure and building services

In relation to the outline of the minewater reservoir and the location of the buildings, more or less investments have to be done for:
- drilling and development of the wells;
- pumps and pipelines for transportation of the minewater;
- heat exchangers and filters for handling over the energy to the building services;
- management and control of the system.

Most of these investments costs may reduce in future because of new techniques. Precise drilling techniques to hit a mine gallery are expensive, new (cheaper) drilling techniques are necessary. If possible, a mine shaft is used for the extraction and infiltration of the minewater and thus avoiding the drilling costs.

The investment costs for the pumps, pipelines, heat exchangers etc. can be reduced if the minimum quality level and required life time of these components are known properly and aren’t too short (the knowledge itself does not lengthen the depreciation period). In a pilot situation, some (cost increasing) precautions have to be taken because of a lack of precise information and knowledge.

Probably the most important parameter is the cost of capital itself. The interest rate and additional costs of the investments can vary from 4 to 15 % per year and can thus make or break a financial forecast. This kind of energy systems have a long term horizon, which can’t be combined with a short pay-back time.

2.3 Running costs for pumping, distribution and control

The pumping costs are related to:
- pump efficiency (typical number $\eta = 0,60$ for electric underwater pumps);
- pump pressure difference (hydrostatic, led pressure, pipeline resistance etc.);
- temperature difference at the heat or cold extraction.

The next figures show the influence of these parameters on the PER (primary energy ratio) for pumping energy. A PER of less then 1 indicates than the pumping of the minewater requires more energy than is extracted. A PER of more than 5 is favourable; 10 or more is excellent.

Table 2.1: PER pumping energy

Heat extraction [℃]	**total pump pressure difference [bar]**				
	5	**10**	**15**	**20**	**25**
2	3,6	1,8	1,2	0,9	0,7
4	7,3	3,6	2,4	1,8	1,5
6	10,9	5,4	3,6	2,7	2,2
8	14,5	7,3	4,8	3,6	2,9
10	18,1	9,1	6	4,5	3,6

Table 2.2: Pumping energy in relation to extracted energy

Heat extraction [℃]	**total pump pressure difference [bar]**				
	5	**10**	**15**	**20**	**25**
2	28%	56%	83%	111%	143%
4	14%	28%	42%	56%	67%
6	9%	19%	28%	37%	45%
8	7%	14%	21%	28%	34%
10	6%	11%	17%	22%	28%

Both tables show that:

- an increasing pump pressure difference;
- heat extraction with an decreasing temperature difference;

decreases the efficiency of minewater as an energy source rapidly.

3 Parameter assessment indirect heating and cooling by mine water

3.1 Technical description

In this case, the mine water temperature and the temperature levels of the buildings climate system don’t match. Figure 3.1 shows an example, in which the temperature level of the mine water (e.g. 30℃) does not correspond to the temperature level of for example heating by air (e.g. 45℃).

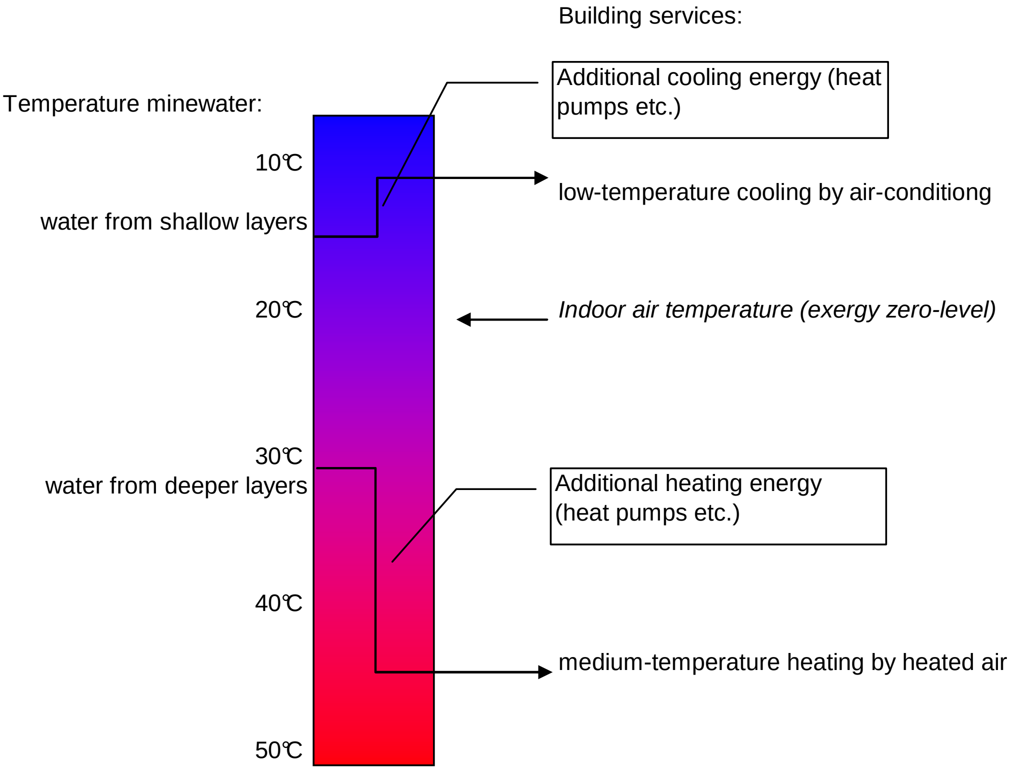


Figure 3.1: Indirect heating and cooling by minewater

A heat pump can bridge the temperature gap, but needs electric energy. The performance of a heat pump (COP-value) depends on the temperature step between the mine water and the climate system and the required temperature level. A small temperature step and a low end-temperature result in a high performance of the heat pump.

It is usually more profitable to combine a heatpump with a boiler on fossil fuels for peak moments than just a stand alone heatpump with 100 % capacity. This is called a bivalent system. Investment costs per kW thermal power of a heatpump are 5 to 10 times higher than the price of conventional boiler per kW. As a rule of thumb, 20% to 40% of the required heating power is installed as heatpump capacity and the rest as conventional boiler. The heatpump thus covers up to 90% of the annual heating demand, while at peak moments (highest power en temperatures required) the boiler can assist. Furthermore, the conventional boiler is a back-up in the case of a failure of the minewater / heatpump system.

From an economical point of view, this fuel mix of minewater, fossil energy and electricity gives some freedom in purchasing at the energy market. On the other hand, the total sum of the standing rights for each connection to the grid may affect the return of the project.

3.2 Cost aspects

The three main cost aspects are:
- capital costs of the wells, infrastructure and low-ex building services;
- pumping costs;
- costs of fossil fuels for after heating and cooling.

3.2.1 Capital costs of the minewater infrastructure and building services

Depending on the kind of minewater reservoir and the location of the buildings, more or less investments have to be done for:
- drilling and development of the wells;
- pumps and pipelines for transportation of the minewater;
- heat exchangers and filters to hand over the energy to the building services;
- heat pumps and/of gasfired boilers;
- management and control of the system.

Most of these investments costs may reduce because of new techniques. Precise drilling techniques to hit a mine gallery are expensive, new (cheaper) drilling techniques are necessary. If possible a, a mine shaft is used and thus avoiding the drilling costs.

The investment costs for the pumps, pipelines, heat exchangers etc. can be reduced if the minimum quality level and required life time of these components is properly known and aren't too short (the knowledge itself does not lengthen the depreciation period). In a pilot situation, some (cost raising) precautions have to be taken because of a lack of information and knowledge.

The allocation of the investments en running costs of equipment (heat pumps etc.) for upgrading the minewater energy to a suitable temperature level, can be part of negotiations between energy supplier and demander. The building owner will normally take these investments, with the assumption that his total energy costs will be such lower that these investments can be earned back within a reasonable timeframe. If the mine water supplier does the required upgrading itself, the end price of the delivered energy can be of course equal to common (fossil) energy price.

Probably the most important economical parameter is the cost of capital itself. The interest rate and additional costs of the investments can vary from 4 to 15 % and can thus make or break a financial forecast. This kind of energy systems have a long term horizon, which can't be combined with a short pay-back time.

3.2.2 Pumping costs

See paragraph 2.3.

3.2.3 Costs and environmental impact of extra fossil fuels for heating and cooling

The cost of natural gas and electricity is an important factor in the comparison of traditional heating versus heating by heat pumps on minewater. Traditional heating is often based on gas-fired boilers. At bulk consumption, natural gas is a relatively cheap energy source. Heating by heat pumps on minewater is typically based on electricity (well pumps, heat pumps).

At actual Dutch bulk tariffs, the next comparison can be made:

Table 3.1: Energy prices and emissions

Fuel	Unit price	Energy content	Price per unit	CO_2-emission
Natural gas	€ 0,46 excl. VAT	31,65 MJ/m^3	€ 0,015 / MJ excl. VAT	0,056 kg / MJ
Electricity	€ 0,12 excl. VAT	3,6 MJ/kWh	€ 0,033 / MJ excl. VAT	0,157 kg / MJ

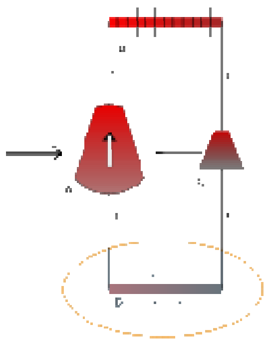
The difference in unit price and CO_2-emission is mainly due to the poor conversion efficiency of fossil fuels into electricity (typical value $\eta = 0,40$) versus the high-efficiency boiler technologies for generating heat out of natural gas. In the overall comparison, this effect should be taken into account.

The disadvantage of a higher CO_2-emission of electricity can be avoided by sustainable electricity generated by wind mills, solar panels etc. For the last five years, the price of gas in the Netherlands increased by 9 % versus 6 % for electricity. From an economical point of view, the general expectation is that electricity price will stabilize because of larger (renewable) production facilities and that gas price will still increase. This is a favourable scenario for minewater energy exploitation.

4 Post processing heat and cold by heat pumps

4.1 Introduction

The heat pump upgrades heat from a low temperature level into heat at a higher temperature level, at which it can be used for heating purposes. Even in wintertime with temperatures far below 0℃ the heat pump can take energy from the environment. This is performed by an endless "cooling" cycle. The cooling liquid evaporates at a very low temperature and takes a substantial amount of energy from the ambient (air, water, ground) when changing from a liquid to a gas phase. The compresssor compresses this refrigerant gas and thus brings it to a high temperature level. The hot gas is then condensated in a condenser where it transforms into a liquid state and gives the heat to the heating system. Then the refrigerant / working fluid is expanded again when passing through an expansion valve so that the circular process can continue. The heat pump extracts thermal energy from the environment - ground, water or air - and delivers it plus the driving power in the form of heat to the heating and hot water circuits of a building.



A is the compressor
B is the condensor
C is the turbine
D is the evaporator

Figure 4.1: Schematic view heat pump cycle

4.2 Coëfficiënt of Performance (COP)

The coefficient of performance COP indicates the delivered amount of heat relative to the drive power required.

COP = amount of heat delivered / drive power = (environmental energy + drive power) / drive power

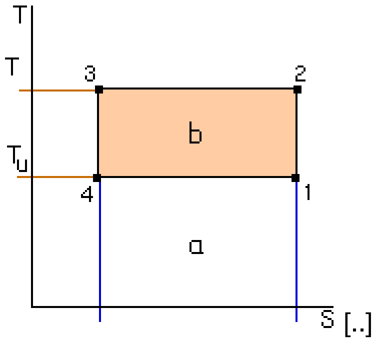
A coefficient of performance of 4 therefore means that quadruple the used electrical energy is disposable as usable thermal output. The coefficient of performance is an instantaneous value. The yearly performance figure results from the supplied energy in relation to the electrical driving power required for the entire heating season. It is the average integrated value of all COP values accumulated over a period of a year.

The heat pump cycle follows more or less the (ideal) Carnot cycle of a combustion engine in the reversed direction. Thus we can also calculate the COP by taking the temperature difference between heat source (evaporator) and heat sink (condenser):

$$e_c = T / (T - T_u) = T / DT$$

e_c = coefficient of performance according the ideal Carnot cycle
Tu = temperature of the environment from which the heat is taken from (cold side) [K]
T = temperature of the heat sink to which the heat is transferred (warm side) [K]
DT = temperature difference between warm and cold side [K]

A representation of the values of the variables T (temperature) and S (entropy), going through during the Carnot cycle:



The curve consists of two adiabatic curves (S = const) and two isotherms (T = const)
S = entropy = energy content

- Energy taken from the environment: Surface a;
- Driving power compressor: Surface b;
- Total delivered energy: Surface a + b;
- 1 - 2: temperature rise(stroke) during compression;
- 4 - 1: evaporation;
- 2 - 3: condensation;
- 3 - 4: expansion.

Example
T_u = 0℃ = 273 K, T = 50℃ = 323 K
$e_c = T / (T - T_u)$ = 323 / 323-273 = 6,46

Ideal processes are not possible. However the Coefficient Of Performance of the Heat Pump process including the losses, will be actually lower. Due to thermal, mechanical and electrical losses, as well as the power requirement of the auxiliary pump (eg brine circulating) the effectively achieved COP or E is smaller than Ec. For rough estimate E can be set equal to 0,6 x Ec

In all cases the coefficient of performance depends on the temperature difference between the heat source and the heat use: the lower the required temperature lift is, the more efficient and economical the heat pump works. Therefore the optimal design of the entire installation for low-ex applications is very important.

A more detailed formula on the COP is:

$$COP = \eta \cdot \frac{Thigh + \Delta Tcon}{(Thigh - Tlow) + \Delta Tevap + \Delta Tcon}$$

With:

η = Carnot efficiency ≈ 0,6
Thigh = max. temperature condenser [K]
Tlow = min. temperature evaporator [K]
ΔTevap = temperature difference over the evaporator [K]
ΔTcon = temperature difference over the condenser [K]

4.3 Heat pumps for post-processing mine water energy

If the minewater temperature and the building services temperature don’t match, post processing by heat pumps is an option. In this case, an optimization of the temperature difference for heat extraction is necessary. This because of two opposite effects:

- enlarging the temperature difference for heat extraction out of the minewater linearly reduces the required amount of minewater and thus the pumping and transportation costs;
- enlarging the temperature difference for heat extraction out of the minewater reduces the COP of a heat pump non-linear and thus increases the costs for post-processing.

4.3.1 Heating season

If the minewater is not warm enough for heating purposes, a heat pump can come between to get an adequate temperature level (see chapter 3). In the next table, a number of situations for heating are compared on the efficiency and the PER (primary energy ratio). For heating purposes, the ΔTevap is equal to

temperature difference for heat extraction out of the minewater. The ΔTcon is considered 10℃ in all cases. This means that 24 m^3 minewater is needed to deliver 1 GJ of heat at the primary heat exchanger. With 10% losses trough the heat exchanger, 26,4 m^3 of minewater is needed for 1 GJ.

Table 4.1: Comparison heat pump systems for heating

Heating system		**ΔTevap**	**Efficiency or COP***	**PER****	**CO_2-reduction**
Reference	0. Ref. Gas fired boiler HE	n/a	0,95	0,95	0 % (ref.)
	1. Ref. HP brine / water (12℃ / 35℃)	6℃	4,2	1,68	43 %
	2. Ref. HP brine/ water (12℃ / 55℃)	6℃	3,1	1,24	23 %
High temperature heating (>55℃)	3. HP mine water / water (25℃ / 55℃)	6℃	4,0	1,60	40 %
	4. HP mine water / water (25℃ / 55℃)	10℃	3,3	1,32	28 %
	5. HP mine water / water (25℃ / 55℃)	15℃	2,9	1,16	12 %
Low temperature heating (35℃) [low-ex]	6. HP mine water / water (25℃ / 35℃)	6℃	6,0	2,40	60 %
	7. HP mine water / water (25℃ / 35℃)	10℃	4,8	1,92	50 %
	8. HP mine water / water (25℃ / 35℃)	15℃	3,8	1,52	37 %

* The COP is calculated theoretically and checked with data from practise. For each individual case, the COP should be checked with manufacturer's data, especially when a high COP (8 and higher) is calculated.

** The PER is calculated with natural gas or oil =1 and electricity = 0,40. For a heat pump (HP): PER = 0,4*COP.

The tables show that the CO_2-emission is more than halved by a heat pump system under favourable conditions:

- high temperature of the minewater;
- low temperature emission systems;
- small temperature extraction from the minewater.

A minewater temperature of 25℃ and a low temperature emission system of 35℃ (scenario 7) is likely applicable in practise and may result in a COP of 4,0 with an halving of the CO_2-emission. High temperature emission systems (55℃ or more) result in poor energy savings.

4.3.2 Cooling season

If the minewater is not cold enough for direct cooling purposes, a heat pump can come between to get an adequate temperature level (see chapter 3). In the next table, a number of situations for cooling are compared on the efficiency and the PER (primary energy ratio). For cooling purposes, the ΔTcond is equal to temperature difference for heat extraction out of the minewater. The ΔTevap is considered 6℃ in all cases. This means that 40 m^3 minewater delivers 1 GJ of cold. With 10% losses at the exchanger, 44 m^3 minewater is needed for each GJ cold.

Table 4.2: Comparison heat pump systems for cooling

Cooling system		**ΔTcond**	**COP***	**PER****	**CO$_2$-reduction**
Reference	0. Air cooled HP (30℃ / 6℃)	6℃	3,5	1,4	0 % (ref.)
	1. Air cooled HP (20℃ / 6℃)	6℃	4,7	1,9	25 %
Low temperature cooling (6℃)	2. HP minewater / water (10℃ / 6℃)	6℃	7,0	2,8	49 %
	3. HP minewater / water (15℃ / 6℃)	6℃	5,7	2,3	39 %
	4. HP minewater / water (18℃ / 6℃)	6℃	5,1	2,0	30 %
High temperature cooling (12℃) [low-ex]	5. direct cooling (minewater / water) (10℃ / 12℃)	n/a	> 20	> 8	82 %
	6. HP minewater / water (15℃ / 12℃)	6℃	7,6	3,0	54 %
	7. HP minewater / water (18℃ /12℃)	6℃	6,6	2,6	46 %

* The COP is calculated theoretically. For each individual case, the COP should be checked with manufacturer's data, especially when a high COP is calculated.

** The PER is calculated with electricity = 0,40. For a heat pump (HP): PER = 0,4*COP.

The first reference for an air cooled HP is the COP at common design conditions, which means that a traditional air-conditioning system must can produce water of 6℃ at app. 37℃ outdoor. The second reference for an air cooled HP is the COP at the threshold outdoor conditions (20℃), at which cooling demands normally starts. In practice, the COP of a heat pump for cooling will vary between these extremes.

The tables show that the CO$_2$-emission is more than halved by a heat pump system under favourable conditions:

- low temperature of the minewater;
- high temperature cooling emission systems.

5 Case study 1: residential apartments

5.1 Case description

5.1.1 General

A common application of low valued geothermal energy are residential apartments. A collective installation of heat and cold storage in acquifers, heatpumps and low temperature emission systems.

In this case, a district of app. 300 residential apartments, some commercial and cultural buildings and a school should be heated and cooled by minewater. An central energy station is located in the neighbourhood and is also the hydraulic separation of the minewater and the building services. The fundamental idea of district heating is a network of pipes that transport heat from a small number of energy sources to many energy consumers.

Special attention should be paid to the tariffs of district heating for individual end-users (consumers), which may not exceed the tariff in a reference situation with individual (fossil) heating and cooling.

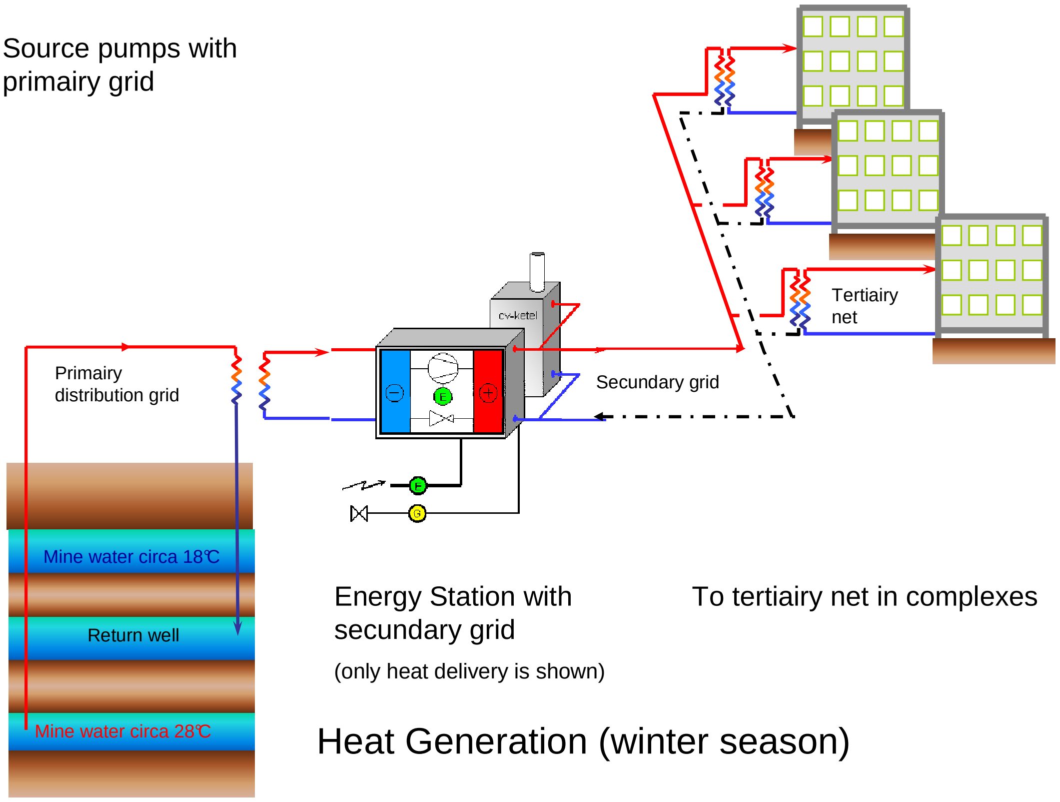


Figure 5.1: Schematic principle of heating with minewater

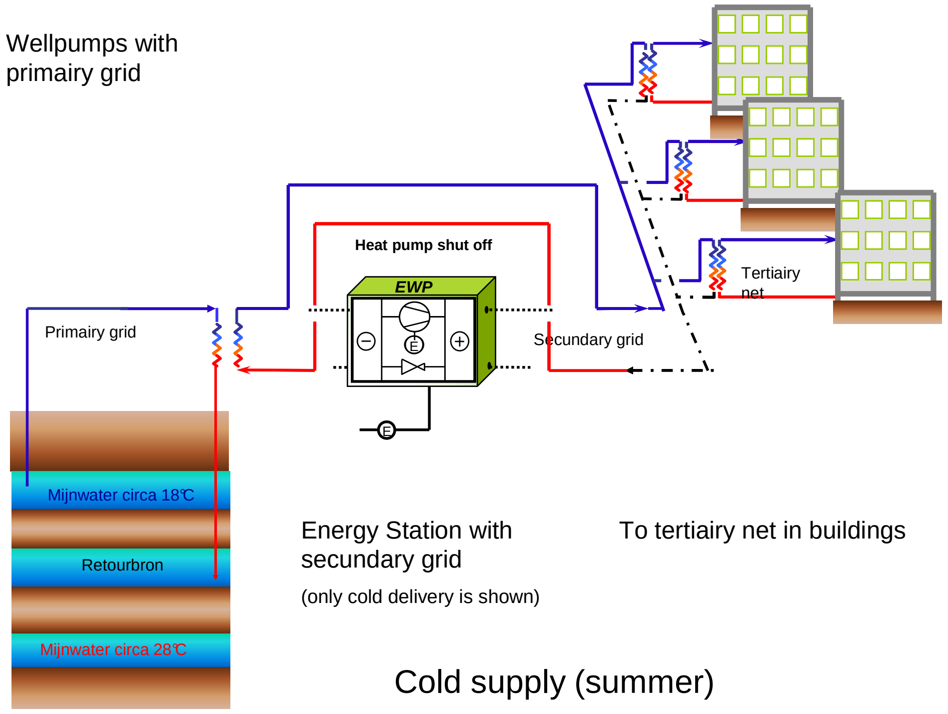


Figure 5.2: Schematic principle of direct cooling with minewater

5.1.2 Technical description

An important precondition for optimal use of the low-valued minewater energy is a low-ex emission system. In this case, floor heating for heating and cooling will be used with the next temperature levels:

- heating: supply temperature 40°C at -10°C outdoor and 30°C at 15°C outdoor;
- cooling: supply temperature 17°C (independent of outdoor temperature).

Because of temperature losses due to heat exchangers and during transportation from the central heat and cold generation to the end user, the temperatures should be:

- heat generation: 50°C at -10°C outdoor;
- cold generation: 15°C continuously.

Furthermore, the heat losses for transmission are limited by good thermal insulation (U ≈ 0,32 W/m^2.K) and high-efficiency glazing (U = 1,1 W/m^2.K, ZTA = 0,60) in a insulated frame. The heat losses for ventilation are minimised by individual mechanical ventilation with heat recovery (η = 0,90 %) and an air tight building envelope.

Special attention should be paid to the domestic hot water, which becomes dominant in low-exergy houses and can't be provided with minewater because of a constant demand of 65°C. For this case, the building services in each residential complex in the neighbourhood is shown in figure 5.3.

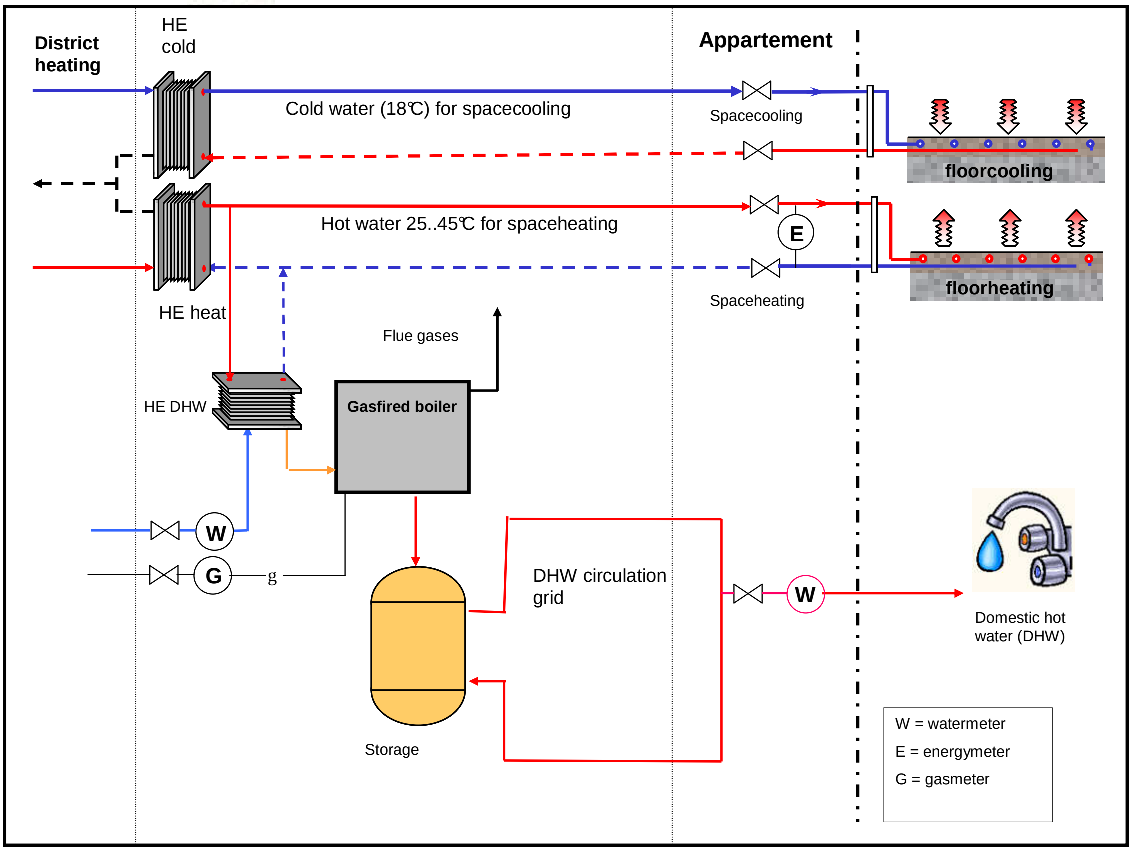


Figure 5.3: Schematic view of domestic services

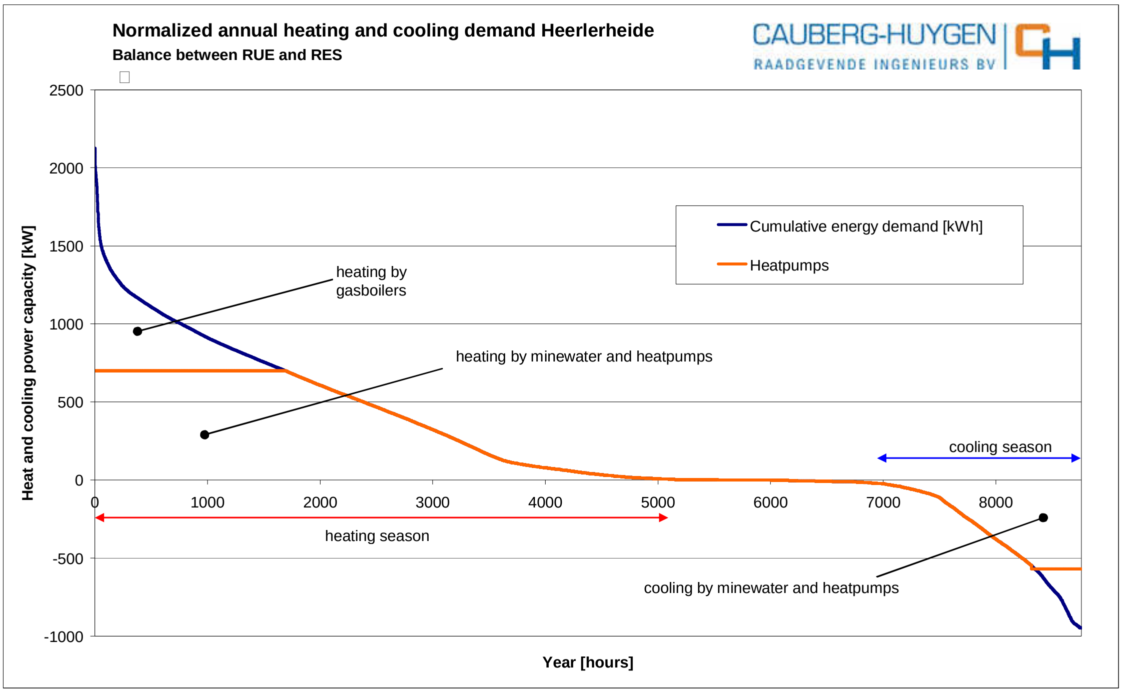


Figure 5.4: Normalized annual heating and cooling demand Heerlerheide

5.2 Energy savings

The energy savings are calculated as the difference of heating and cooling by traditional (fossil) fuels versus minewater in combination with heat pumps. The annual energy demand and hourly heating and cooling load is calculated by TRNSYS. TRNSYS is a computer tool, designed to simulate the transient performance of thermal energy systems and to predict the energy use in the building.

As a reference, the heat generation is done by a high-efficiency gas-fired boiler. Normally, residential have no cooling, but is desirable to have a comparison on equal comfort level and therefore it is assumed that the cold generation is done by conventional refrigerating (compression (COP = 3)).

In the scenario with minewater, the heat generation is primary done by a 700 kW heatpump (COP = 5,5) and secondary by a 2000 kW gas-fired boiler (η = 0,85). The heatpump covers up to 80 % of the annual heat demand, while the remaining peak load is covered by the boiler. The cold minewater (15℃) is used for direct low-ex cooling of the apartments.

Table 5.1: Case study residential apartments

Case study residential apartments	**Scenario**	
	Conventional (fossil energy)	**Heat pumps with minewater**
Energy demand:		
Total heat demand (space heating)	9.322 GJ	9.322 GJ
Total cold demand (space cooling)	2.306 GJ	2.306 GJ
Heat generation Energy station:		
- minewater	n/a	6.100 GJ [149.700 m^3]
- heat pumps	n/a	1.355 GJ [376.400 kWh_e]
- gas fired boilers	9.322 GJ [346.500 m^3 gas]	1.865 GJ [69.300 m^3 gas]
Cold generation:		
- minewater COP = 20	n/a	2.306 GJ [32.000 kWh_e] and [101.500 m^3 minewater]
- refrigerant COP = 3	2.306 GJ [213.500 kWh_e]	n/a
Overview:		
Total gas consumption central energy station	346.500 m^3 gas	69.300 m^3 gas
Total electricity consumption central energy station	213.500 kWh_e	408.400 kWh_e
CO_2 emissions	738 ton	355 ton (- 52 %)

5.3 Cost aspects

The next table shows the previous results, supplemented with a basic comparison on fuel costs. The costs for the minewater consumption itself is not included, because of the fact that there is no uniform tariff. This depends per location on the investment- and production costs of the minewater.
The difference between the reference energy costs and the scenario's with he minewater is in fact the available financial space for the minewater production and possible extra investments for low-ex buildings.

Table 5.2: Overview results en cost aspects

Par.	Description	Energy use	Total energy costs	CO_2-emission
5.2	Reference	Gas: 346.500 m^3 Elec.: 213.500 kWh	€ 185.000 excl. VAT	738 ton/a
5.2	Minewater 28℃ for heating Minewater 15℃ for direct cooling	Gas: 69.300 m^3 Elec.: 408.400 kWh	€ 80.900 excl. VAT (- 56 %)	355 ton/a (- 52 %)

6 Case study 2: high rise office building

6.1 Case description

6.1.1 General

A potential target group for minewater heating and cooling are commercial buildings, especially office buildings with a relatively high cool demand which can be fulfilled with minewater. Therefore, a typical high rise office building of 12 floors and circa 15.000 m^2 total floor area has been examined on the saving potential by the use of minewater for the conditioning of the indoor climate.

6.1.2 Technical description

An important precondition for optimal use of the low-valued minewater energy is a low-ex emission system. In this case, climate ceilings for heating and cooling will be used with the next temperature levels:

- heating: supply temperature 43℃ at -10℃ outdoor and 30℃ at 15℃ outdoor;
- cooling: supply temperature 17℃ (independent of outdoor temperature).

Because of temperature losses due to heat exchangers and during transportation from the central heat and cold generation to the end user, the temperatures should be:

- heat generation: 50℃ at -10℃ outdoor;
- cold generation: 14℃ continuously.

Furthermore, the heat losses for transmission are limited by good thermal insulation (U ≈ 0,32 $W/m^2.K$) and solar protected high-efficiency glazing (U = 1,3 $W/m^2.K$, ZTA = 0,30) in a insulated frame. The heat losses for ventilation are minimised by mechanical ventilation with heat recovery and an air tight building envelope.

In this case, the efficiency of heat and cold generation is compared with and without mine water. It is assumed that the transport energy within the building (auxiliary energy) and heat losses stay the same. Further assumptions are:

- CO_2 emission of natural gas:	1,78 kg/m^3;
- CO_2 emission of electricity generation:	0,566 kg/kWh;
- caloric value of natural gas:	31,65 MJ/m^3.

6.2 Energy savings

The energy savings are calculated as the difference of heating and cooling by traditional (fossil) fuels versus minewater in combination with heat pumps. The annual energy demand and hourly heating and cooling load is calculated by TRNSYS. TRNSYS is a computertool, designed to simulate the transient performance of thermal energy systems and to predict the energy use in the building.

With TRNSYS, the next numbers were calculated:

- total annual heat demand: 2310 GJ;
- total annual cooling demand: 698 GJ;
- maximum heat load: 650 kW;
- maximum cold load: 470 kW.

The next figure shows the annual distribution of the heat and cold demand:

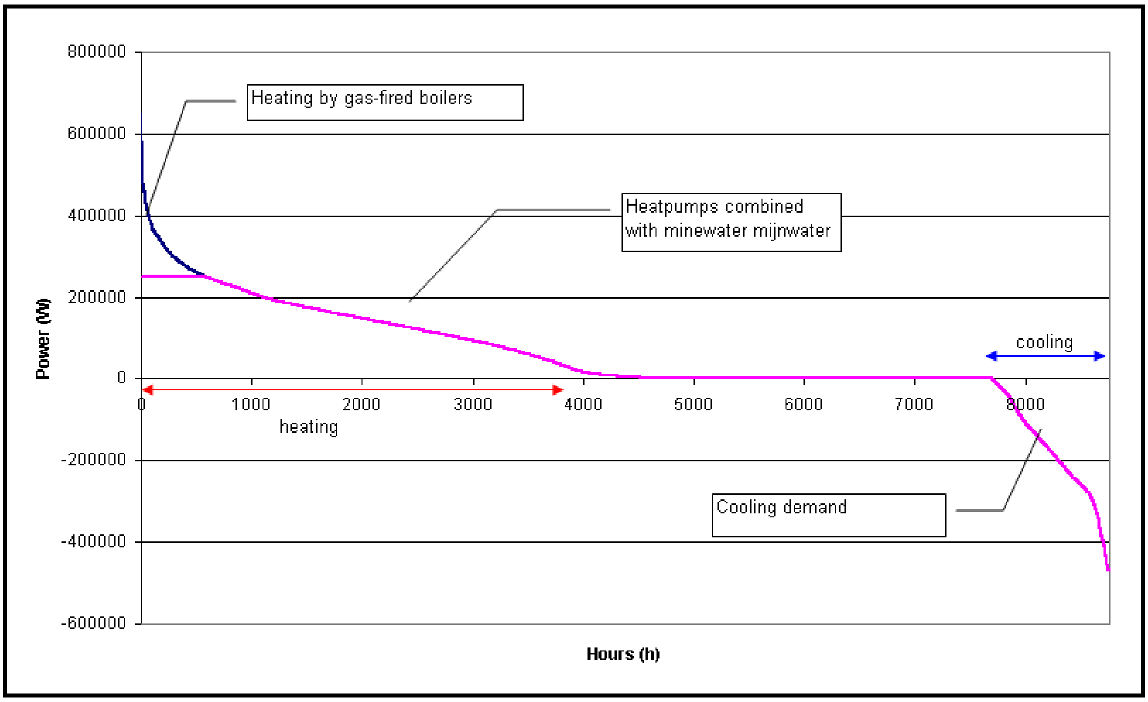


Figure 6.1: Annual energy load curve

The hourly heat or cold demand as a function of the outdoor temperature is shown in the next graph:

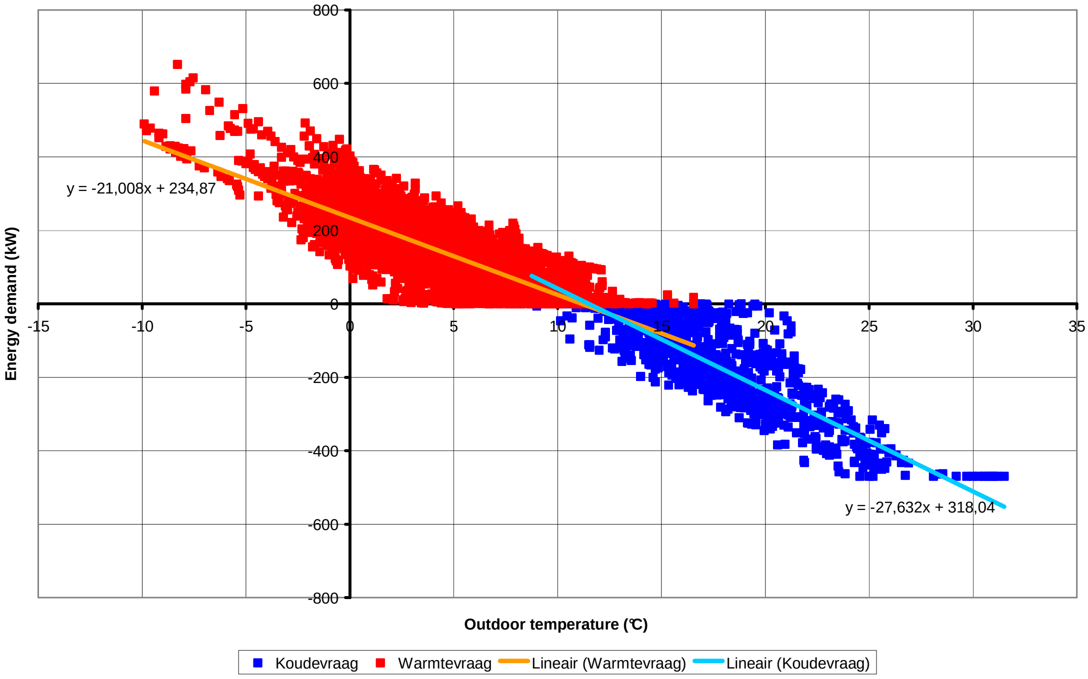


Figure 6.2 : Hourly heat or cooling load as function of the outdoor temperature

6.2.1 Reference

As a reference, the heat generation is done by a gas-fired boiler and the cold generation is done by conventional refrigerating (compression).

Heating

- total annual heat demand:	2310 GJ;
- average efficiency of heat generation:	85 %;
- annual gas consumption for space heating:	85.900 m^3.

Cooling

- total annual cooling demand:	698 GJ;
- average efficiency of cold generation (COP)[1]:	4,0 [-];
- annual electricity consumption for cooling:	48.500 kWh.

The total CO_2 emission in the reference situation is thus 153 + 27 = 180 ton/a.

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[1] Efficiency according to NEN 2916.

6.2.2 Minewater heating and cooling

In the scenario with minewater available, the heat generation is primary done by a 200 kW heatpump and secondary by a 450 kW gas-fired boiler (η = 0,85). The heatpump covers up to 87 % of the annual heat demand, while the remaining peak load is covered by the boiler.

The cold generation is done by a reversible heatpump, of which the condenser is cooled by minewater.

In order to show the influence of the minewater temperature on the overall performance, two possible scenario's are investigated. In the first scenario, there is warm minewater of 28°C available for heating and also minewater of 15°C for cooling purposes. In the second scenario, only minewater of 18°C is available for both heating and cooling.

Heating scenario 1 (minewater 28°C)
- total annual heat demand: 2310 GJ

Primary system for heat generation (heatpump)

- total annual heat load: 2010 GJ;
- average efficiency of heat generation (COP): 5,4 [-];
- annual electricity consumption for space heating: 124.650 kWh*;
- Minewater consumption: 43.200 m^3

* *The annual electricity consumption is the summation of the hourly heat load and COP. At lower outdoor temperatures the heat load is higher and COP lower, therefore the total annual electricity consumption is higher than calculated with the average COP.*

Secondary system (gas-fired boiler)

- total annual heat load: 300 GJ;
- average efficiency of heat generation: η= 85 %;
- annual gas consumption for space heating: 11.150 m^3.

The total CO_2 emission in this situation is thus 90 ton/a (42 % reduction).

Heating scenario 2 (minewater 18°C)
- total annual heat demand: 2310 GJ.

Primary system for heat generation (heatpump)

- total annual heat load: 2010 GJ;
- average efficiency of heat generation (COP): 4,2 [-];
- annual electricity consumption for space heating: 158.000 kWh*;
- mine water consumption: 37.700 m^3.

* *The annual electricity consumption is the summation of the hourly heat load and COP. At lower outdoor temperatures, the heat load is higher and COP lower, therefore the total annual electricity consumption is higher than calculated with the average COP.*

Secondary system (gas-fired boiler)

- total annual heat load: 300 GJ;
- average efficiency of heat generation: η= 85 % ;
- annual gas consumption for space heating: 11.150 m^3.

The total CO_2 emission in this situation is thus 109 ton/a (29 % reduction).

<u>Cooling scenario 1 (minewater 15°C)</u>

- total annual cooling demand: 698 GJ;
- efficiency of cold generation (COP): 11,0 [-];
- annual electricity consumption for cooling: 32.300 kWh**;
- mine water consumption: 30.700 m^3.

** there is no validation for the calculated high COP, the electricity consumption is estimated with COP = 6,0.

The total CO_2 emission in the scenario is thus 18 ton/a. (33 % reduction).

<u>Cooling scenario 2 (minewater 18°C)</u>

- total annual cooling demand: 698 GJ;
- average efficiency of cold generation (COP): 9,0 [-];
- annual electricity consumption for cooling: 35.200 kWh***;
- mine water consumption: 30.700 m^3.

*** there is no validation for the calculated high COP, the electricity consumption is estimated with COP = 5,5

The total CO_2 emission in the scenario is thus 20 ton/a. (26 % reduction).

6.3 Cost aspects

The next table shows the previous results, supplemented with a basic comparison on fuel costs. The costs for the minewater consumption itself is not included, because of the fact that there is no uniform tariff. This depends per location on the investment- and production costs of the minewater. The difference between the reference energy costs and the scenario's with he minewater is in fact the available financial space for the minewater production and possible extra investments for low-ex buildings.

Table 6.1: Overview results en cost aspects

Par.	**Description**	**Energy use**	**Total energy costs**	**CO_2-emission**
7.2.1	Reference	Gas: 85.900 m^3 Elec.: 48.500 kWh	€ 45.300 excl. VAT	180 ton/a
7.2.2	<u>Scenario 1</u> Minewater 28°C for heating Minewater 15°C for cooling	Gas: 11.150 m^3 Elec.: 157.000 kWh	€ 24.000 excl. VAT (- 47 %)	108 ton/a (- 40 %)
	<u>Scenario 2</u> Minewater 18°C for heating Minewater 18°C for cooling	Gas: 11.150 m^3 Elec.: 193.200 kWh	€ 28.300 excl. VAT (- 37 %)	129 ton/a (- 28 %)

7 Case study 3: product cooling in supermarkets

7.1 Case description

Shallow minewater with relatively low temperatures (between 10°C en 20°C) may be used for cooling purposes in a commercial environment. A special application is food cooling in a supermarket. A supermarket continuously needs to cool or freeze its products in special display furniture. Even in wintertime, typical 30 % of the cooling power in summertime is needed. In fact, the product cooling is one of the largest running costs of a super market. By using “free” cold minewater for cooling purposes, these costs may be reduced.

Instead of dry coolers, the minewater can be used to remove the condenser heat. The main advantages are:
- a constant temperature for condenser cooling, independent of the outdoor circumstances which results in a better performance of the refrigerant;
- the condenser heat can be re-used for other purposes like space heating;
- no fan energy for the dry coolers.

The main disadvantage is the pump energy needed to deliver the mine water to the supermarket.

This kind of optimization has not been done before, so the next case study is based on assumptions which can lead to some uncertainty in the results.

7.1.1 General

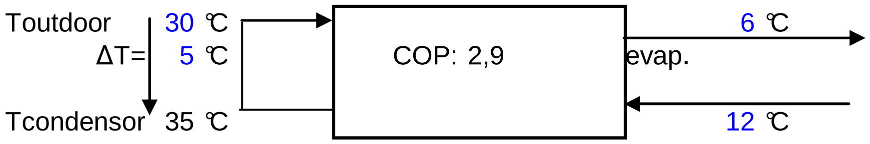
7.1.2 Technical description

Minewater can’t be used for direct cooling of the display furniture, but the cold generation can be optimised by cooling the condenser of the energy system with minewater. Normally, the condenser of the refrigerant disposes the heat into the outdoor air by dry coolers. At high outdoor temperatures, the efficiency of the refrigerant is therefore low and electric fans are needed to blow off the heat. If the minewater is used to remove the waste heat, the overall efficiency of the refrigerant becomes higher because of the constant temperature of the minewater and the absence of fan energy for the dry coolers. The waste heat of the cooling furniture can also be used for space heating (e.g. floor heating), but the main part is normally disposed trough dry coolers. Normally, the temperature of the dry cooler must be at least 5°C above the outdoor temperature to achieve the heat transfer. This leads to a design temperature of app. 35°C of the condenser, but results in a suboptimal design at lower outdoor temperatures.

7.2 Energy savings

7.2.1 Reference

A typical supermarket of 2.000 m^2 (2.600 m^2 including storage rooms etc) has an estimated annual electricity use of 350 MWh for the cooling of the cool furniture and freezer cabinets. This is used to deliver app. 290 GJ (1050 MWh, COP = 3) thermal energy per year:



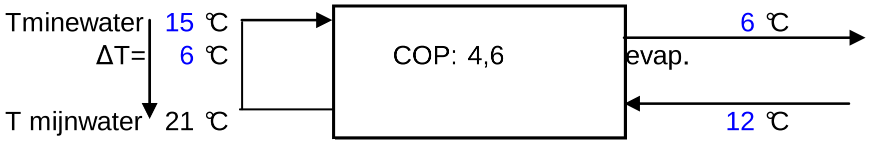
Furthermore, the fans of the dry coolers have an estimated electricity consumption of 40.000 kWh per year.

7.2.2 Minewater cooling

A rule of thumb for the efficiency improvement by lowering the temperature of condensors states 2 % extra efficiency per degree reduction. An average lowering of 10°C leads to 20 % less energy consumption.

A Dutch study on heat-cold storage for supermarkets[2] (brine) indicates a reduction of 8 % of the electricity consumption.

According to the method in chapter 4, the electricity use can be reduced to app. 230 MWh due to a better COP (4½ instead of 3):



This approach leads clearly to a higher saving potential (34 %) than the other two studies.

7.3 Conclusion

Because of a lack op validated data, at this moment a reduction of 20°C of the cooling energy of a large supermarket. This equals about 70 ton of CO_2 emission a year. More study and monitoring of realised systems with this concept is needed to verify this number.

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[2] Eindrapport onderzoek naar duurzame energietechnieken supermarkten (ref. MD.1225.016); Adviesburo Verhoef bv i.o.v. Fri-Jado Installatiegroep BV en SenterNovem; Projectnr. 2020-05-13-28-008; 16 augustus 2006; Apeldoorn.

8 Summary and conclusions

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.

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.

It may be undesirable to have minewater in the building services which makes a hydraulic separation necessary, mostly at an energy station with district heating or services to large commercial buildings. District heating schemes require a long term approach. It is therefore highly recommended to use a life cycle costing approach. Generally, smaller schemes are easier to initiate but larger schemes will deliver the better long-term savings. The cost effectiveness will depend on a range of factors including size of scheme, whether new-build or refurbishment, sectoral mix and available and applicable energy supply alternatives (eg on or off gas grid). Special attention should be paid to the domestic hot water, which becomes dominant in low-exergy houses and can’t be provided with minewater.

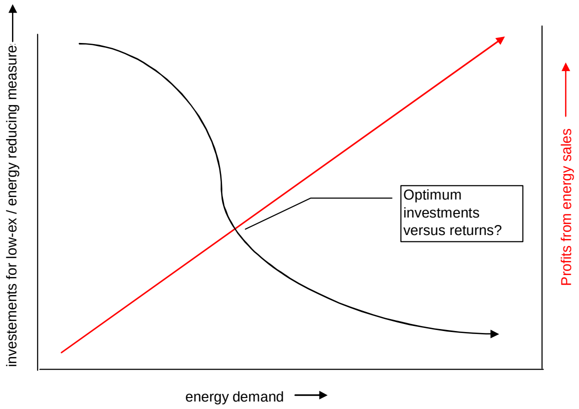
The business model and financial forecast for minewater as a commercial energy source is of particular importance. Preferably, all activities for the use of minewater for climatisation of buildings are in one hand. In practice, the pumping and distribution can be done by a different entity than the energy consumer. This requires clear appointments between the supply and demand side of minewater. For example, the pricing of the minewater can be put in the volume consumption (m^3 of minewater) or, as an alternative, in extracted energy (GJ) from the minewater. The first option allows relatively simple contracts between supplier and demander and stimulates the demander for maximum energy extraction. In the second case, the GJ-price for a half fabricate of energy should be defined at clear conditions like the temperature level and the minimum temperature difference for energy-extraction. Furthermore, the allocation of the cost for optional extra investments like back-up systems and low-exergy climatisation system requires negotiations between the supply- and demand side of minewater energy. A basic rule for the supplier of minewater energy is that the capital costs of the investments should be roughly covered up by the fixed costs like the standing right and that the variable costs like the electricity for the pumps should be covered of by the energy price per unit sold.

The supplier of minewater energy can state a fixed standing right to cover up his capital costs and a variable price (€ per GJ or m^3) to cover up the pump- and distribution costs.

General 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 low-ex 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 and contradictory. The next figure gives an illustration:



The case studies indicate a reduction in energy costs and CO_2-emissions of 20 to 40 % in comparison to conventional, fossil based heat and/or cold generation. The difference between the reference energy costs and the scenario’s with minewater is in fact the available financial space for the minewater production costs and possible extra investments for low-ex buildings.

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