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## **Minewater 2.0 project in Heerlen the Netherlands: transformation of a geothermal mine water pilot project into a full scale hybrid sustainable energy infrastructure for heating and cooling**

René Verhoeven<sup>1\*</sup>, Eric Willems<sup>2</sup>, Virginie Harcouët-Menou<sup>3</sup>, Eva De Boever<sup>3</sup>, Louis Hiddes<sup>1</sup>, Peter Op 't Veld<sup>2</sup>,  
Elianne Demollin<sup>1</sup>

<sup>1</sup> Mine Water Heerlen, PO Box 1, 6400AA Heerlen, The Netherlands

<sup>2</sup>Cauberg-Huygen Consulting Engineers, PO Box 480, 6200AL Maastricht, The Netherlands

<sup>3</sup> VITO, Boeretang 200, 2400 Mol, Belgium

### **Abstract**

In the last 10 years numerous research and commercial initiatives have been undertaken in Europe to develop abandoned coal mining fields into low-temperature resources. One of the most successful is the Minewater project of the municipality of Heerlen, the Netherlands, where a low-temperature district heating system was launched in operation in October 2008, under the European Interreg IIIB NWE programme and the 6th Framework Program project EC-REMINING-lowex. The Minewater project is now being upgraded from a straight forward pilot system to a full-scale hybrid sustainable energy structure called Minewater 2.0. A totally new concept which becomes an essential part of the Sustainable Energy Structure Plan of Heerlen and has the following landmarks:

- Energy exchange instead of energy supply: cluster grids for energy exchange between buildings and the existing mine water grid for energy exchange between cluster grids.
- Energy storage and regeneration in mine water reservoirs instead of depletion.
- Addition of poly-generation: bio-CHP, solar energy, feed in of waste heat (data centres and industry), cooling towers for peak cold demands.
- Enlargement hydraulic and thermal capacity mine water grid through improving well pumps, pressure boosting systems and reuse of the existing mine water return pipe for additional supply and disposal of hot mine water.

\* Rene Verhoeven. Tel: 00316 37330624 | E-mail: [r.verhoeven@mijnwater.heerlen.nl](mailto:r.verhoeven@mijnwater.heerlen.nl)

- Fully automatic and demand-driven supply of hot and cold mine water through usage of pressurized buffer systems at the extraction wells and sophisticated injections valves at the injection wells.
- All geographically dispersed mine water installations at buildings, clusters and wells are equipped with sophisticated process control units that communicate with a Central Monitoring System (CMS) through the internet. A very new application in the build environment.

The first phase of the Minewater 2.0 project is in operation since June 2013. In November 2013 at the congress we will be able to share the first experiences.

**Keywords:** Geothermal energy; mine water; smart heat and cold grid; energy storage.

## 1. Introduction

In the last 10 years numerous research and commercial initiatives have been undertaken in Europe to develop abandoned coal mining fields in to low-temperature resources. One of the most successful is the Minewater project of the municipality of Heerlen, the Netherlands, where a low-temperature district heating system was launched in operation in October 2008, under the European Interreg IIIB NWE programme and the 6th Framework Program project EC-REMINING-lowex. The Minewater project is now being upgraded from a straight forward pilot system to a full-scale hybrid sustainable energy structure called Minewater 2.0. In this paper the aspects and operation of this smart grid for heating and cooling is explained.

## 2. Minewater 1.0

Minewater 1.0 is the term used for the initial mine water system at Heerlen, developed in the period 2003 - 2008. A straight forward pilot system to investigate how the mine water of the abandoned coal mines of Oranje Nassau could be used as a geothermal source for the sustainable low-exergy heating and cooling of buildings. Five wells were drilled to the stone drifts in the underground (see figure 1). Two hot wells in the northern part of Heerlen with a depth of 700 meters below surface for the extraction of hot water with a temperature of about 28 °C, two cold wells in the southern part of Heerlen with a depth of 250 meters for the extraction of cold mine water with a temperature of about 16 °C. A fifth well in the middle part of Heerlen with a depth of 350 meters is used for the injecting of the cooled hot and warmed cold mine water with intermediate temperatures between 18-22 °C.

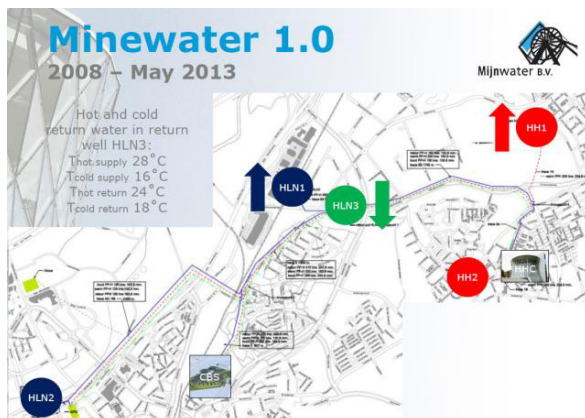


Fig. 1. Minewater 1.0 in geographical perspective

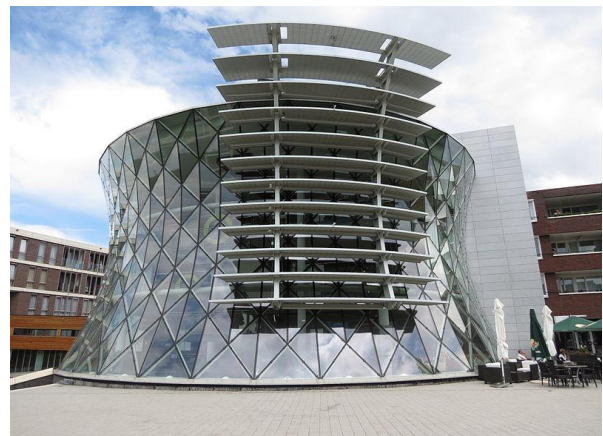


Fig. 2. The energy station is situated in the basement of the Heerlerheide Centrum (HHC).

Through a three-pipe mine water distribution network of seven kilometers in length, the so called mine water

backbone, the mine water from the wells is provided to the energy stations of the connected buildings. One pipe for delivery of hot mine water (insulated) from the hot wells HH1 and HH2, one pipe for the delivery of cold mine water (non-insulated) from the cold wells HLN1 and HLN2 and one return pipe (non-insulated) to return the used mine water (hot and cold) to the injection well HLN3. Energy exchange in the energy plant of the end-users takes place through heat exchangers. The hot mine water is cooled down by 10 °K and the cold mine water is heated up by 6 °K. Until 2012 one hot well HH1, one cold well HLN1 and the return well HLN3 were in operation with two end-users: the office of the Central Bureau of Statistics (CBS; 22.000 m<sup>2</sup>) and the complex Heerlerheide Centrum (HHC; homes, supermarket, offices, community facilities, catering; 30.000 m<sup>2</sup>) as shown in figure 2. Heat pumps in each building are used to provide the base load of heat and cold at the demanded low-ex temperatures.

Figure 3 shows the 3-D model of the mine water reservoir. The simulations are conducted by using a numerical model in which the detailed geometry of the relevant stone-drifts and shafts has been incorporated based on the original mine maps. The used model reflects the status and knowledge acquired until mid-2012. It has been calibrated based on pump tests that have been conducted in the early stages of the project and past production periods. The numerical model of the mine water reservoir takes into account heat transfer by advection, mixing of waters with different temperatures and heat conduction (exchange of heat between rock and water).

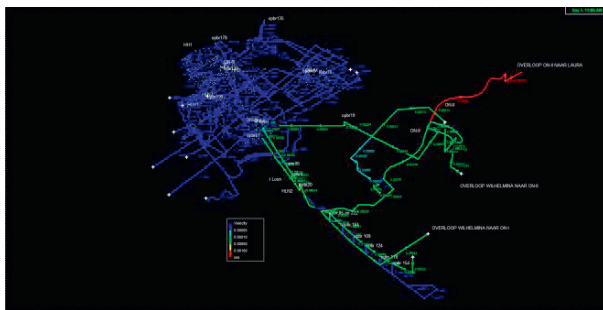


Fig. 3. 3D model of the underground geometry of the mines with overview of the flow and initial temperature conditions.(VITO).

In excellent operation conditions when the different parts of the reservoir are systematically allowed to rest, the perturbations following injection or production seem to be equilibrated by conduction effects (Figure 5, conduction factor  $K_b = 0.002$ ). In the Minewater 1.0 operation mode, however, water with intermediate temperatures is returned to the HLN3 well (see figure 4). This will affect the sustainable production of warm water at HH1 and certainly the production of cold water from HLN1, which is closely connected to the HLN3 shaft. As a consequence, when waters with anomalous temperatures are injected and circulated the reservoir starts to homogenize. The warm buffer at HH2 and cold buffer at HLN2 are in this case

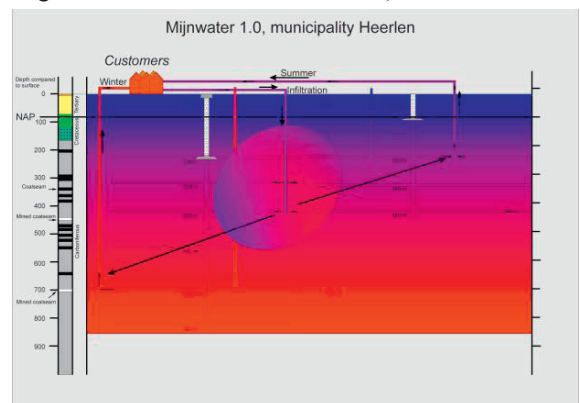


Fig. 4. Schematic display of cross section of the mine water reservoir with the typical flow pattern in Minewater 1.0 system.

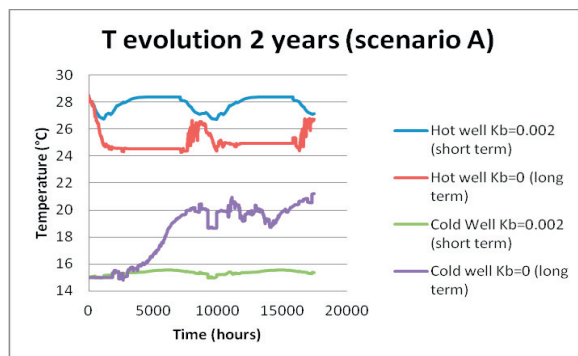


Fig. 5. Temperature evolution of the hot (HH1) and cold (HLN1) production wells for different conduction factors (VITO).

not sufficient to compensate for this temperature evolution. To illustrate this effect, a scenario is shown in Figure 5 in which the conduction factor is zero ( $K_b = 0$ ). These scenarios represent an extreme situation. In practice we observe that the use of the HLN3 well is an important parameter that makes the operation of the mine water less attractive for energy efficient applications.

Other restrictions of the Minewater 1.0 system are:

- A limited hydraulic and thermal capacity;
- Not demand-driven with in summer (April till September) only cold supply and winter (October till March) only heat supply;
- No energy exchange between buildings possible.

### 3. Minewater 2.0

To make the minewater system future proof and to overcome the restrictions of de mine water pilot system a total new concept Minewater 2.0 is developed based on the following elements:

- Energy exchange instead of energy supply;
- Energy storage instead of depletion;
- Addition of poly generation to the system;
- Maximizing the hydraulic and thermal capacity (reservoir, wells and distribution backbone);
- Fully automatically controlled and demand driven system (heat and cold supply at any time);
- The addition of heat and cold storage in the buildings and cluster grids (Minewater 3.0);
- A system suitable for demand and supply side management in near future (Minewater 3.0).

#### 3.1 Energy exchange, storage and regeneration of wells

##### 3.1.1. Energy exchange

Energy exchange will be realised by the means of:

- Local cluster grids for instant energy exchange (heat and cold) between the connected buildings in the cluster.
- Application of the existing mine water backbone for energy exchange (heat and cold) between the geographically dispersed cluster grids.

In this way a building is no longer only an energy consumer but also an energy supplier. A building that extracts heat from the cluster grid supplies cold to the grid, which can instantly be used by other buildings connected to the grid. Another important advantage of cluster networks is that these are closed systems and can be run with clean water. In cluster grids no special materials resistant to the corrosive mine water are needed like stainless steel (AISI 316) or plastic (PE or PP). Application of cast iron and a provision for simple water treatment are sufficient. This means an important cost reduction of the cluster grid.

##### 3.1.2. Energy storage and regeneration

The extraction wells (HH1 and HLN1) supply the shortage of heat and cold to the mine water backbone. Surplus of heat and cold will be stored in the mine water reservoir through the hot and cold injection well (HH2 en HLN2). The current return/injection well HLN3 will be out of order and only be used in case of exceptional situations. Minewater 2.0 needs to be future proof. Unwanted intermediate return temperatures as applied in de mine water pilot system (Minewater 1.0) cause depletion of the mine water reservoir. To eliminate this effect it is necessary that the used return mine water is heated up or cooled down properly to the natural geothermal temperature and brought back to the corresponding hot or cold part of the mine water reservoir (see figure 6).

It is also important that the heat and cold extraction and infiltration has to maintain a sort of energy balance on a yearly basis. In other words it is important that the mine water reservoir is regenerated. Determinative for the correct water return temperatures to the mine water reservoir is the operation of the energy stations of the end-users. They have to ensure that the hot water is cooled down ( $< 16^{\circ}\text{C}$ ) and heated up ( $> 28^{\circ}\text{C}$ ) sufficiently. This is included as one of the conditions in the contract for end users of mine water.

Figure 7 shows a schematic display of the cross section of the mine water reservoir with the enhanced flow pattern of the Minewater 2.0 system. With this flow pattern practically no exchange between the hot and cold part of the mine water reservoir occurs and in time a hot and cold bubble is built up which enlarges the useful energy storage capacity of the mine water reservoir.

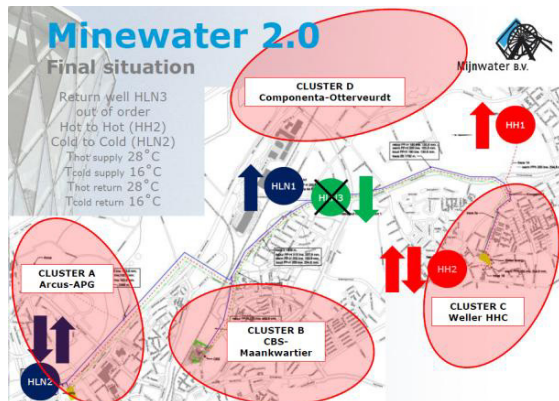


Fig. 6. Final situation of Minewater 2.0

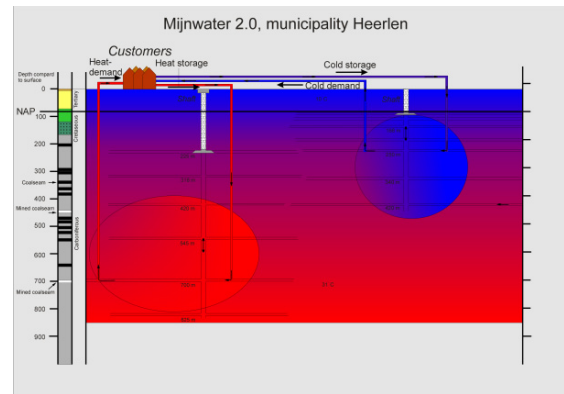


Fig. 7. Schematic display of the cross section of the mine water reservoir with the enhanced flow pattern of the Minewater 2.0

Figure 8 shows the status of the Minewater 2.0 project as in operation since June 2013. Two new connections are realized in 2013:

- Existing retrofitted low-ex building of APG (32.000 m<sup>2</sup>) in April;
- Newly constructed low-ex building Arcus College (30.000 m<sup>2</sup>) in October.

APG is a pension fund that owns a data centre. A heat pump will provide the cooling of the data centre and heating of the building. The waste heat of 15.000 GJ per year will be provided to the new cluster network A or heat exchange in the cluster and other buildings connected to the mine water backbone. APG will show a total CO<sub>2</sub> reduction of 118% compared to the existing situation, extraordinary for a building of 1974. The newly constructed Arcus College has heat pumps to provide the base load of heating and cooling. A total CO<sub>2</sub> reduction 45% is reached compared to traditional heating and cooling with natural gas boilers and electrical chillers. The existing connections CBS and HHC will in the near future become part of the clusters B and C which are in development. For so long the used mine water is disposed to HLN3. Small intermediate provisions will be made to integrate them in the Minewater 2.0 system.

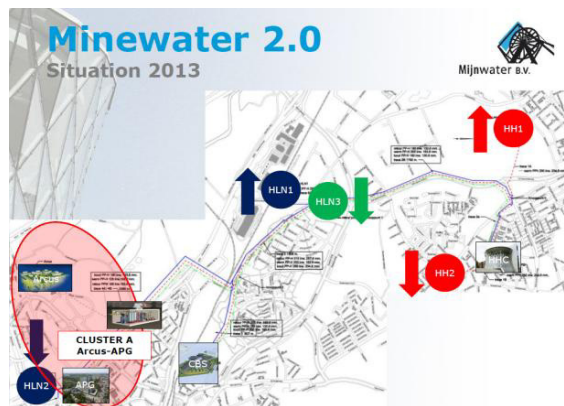


Fig. 8. Status Minewater 2.0 project as in operation since June 2013.

### 3.2 Poly generation

We further acknowledge that the capacity of the mine water system is finite. For realizing the goals of the Sustainable Structure Plan of Heerlen a combination of mine water with other renewable energy sources such as biomass and/or solar energy and waste heat is necessary. The mine water structure (back-bone and cluster networks) is the vehicle to provide these energy sources to buildings, or in other words: Minewater 2.0 will become a hybrid energy structure. A lot of initiatives are already in picture or in progress e.g. a bio-CHP, a closed greenhouse and waste heat of an additional data centre. All these energy sources are locally situated and will be connected to the nearest cluster grid to supply their heat and cold to the corresponding cluster and through the mine water backbone to other clusters. Cluster D for example will initially become a self-supporting cluster with heat exchange between a metal foundry and a swimming pool. Besides these options other poly generation options are in prospective like the use of cooling towers for peak cold demands.



### 3.3 Maximizing hydraulic and thermal capacity mine water system

Limitations in the mine water system can occur on three levels:

- Temperature, flow and storage capacity of the mine water reservoir;
- Flow of the mine water wells;
- Flow and grid capacity of the mine water backbone.

At this moment the hydraulic capacity is limited by the mine water backbone, especially the hot mine water pipe. In the near future the return pipe HLN3 will no longer be needed and can be used for supply and disposal of additional hot or cold mine water to enlarge the hydraulic mine water capacity. All wells are intended to become bidirectional. In the first phase of the Minewater 2.0 project which is realized now all wells are executed single acting.

The following measures are taken to maximize the hydraulic capacity of the current mine water backbone: replacing the well pumps and applying pressure booster systems at the hot and cold production wells, reuse of the existing mine water return pipe for additional supply and disposal of hot mine water, closed cluster grid A for the new connections (Arcus and APG) with circulation pumps at each building for energy exchange between the buildings in the cluster and the mine water backbone, booster pumps at the cluster grid A, application of sophisticated injections valves at the hot and cold injection wells.

### 3.4 Fully automatic and demand driven

The Minewater system 2.0 is fully automatic and demand driven with 3 levels of control. Each level works with another independent process control parameter:

- MI-Building: Temperature;
- MI-Cluster: Flow;
- MI-Wells: Pressure.

A simple principle which demands innovative practical solutions. How it works see chapter 4.

## 4. How it works

In the artist impression of the Minewater 2.0 system, as shown in figure 10, the three levels of control are distinguishable:

- MI-Building;
- MI-Cluster;
- MI-Wells (HH1, HH2, HLN1 & HLN2).

First we look at the cluster with the industrial building and greenhouse. Each building has its own pumping installation. The greenhouse has a limited heating demand and extracts hot water from the cluster grid and injects cold water to the cluster grid. In this way they instantly exchange heat and cold with each other. There is a net cooling demand so cold is supplied by the cluster installation. At the mine water side of this cluster installation a booster pump (blue) extracts cold mine water from the cold mine water pipe and injects hot mine water in the hot mine water pipe for transportation to the

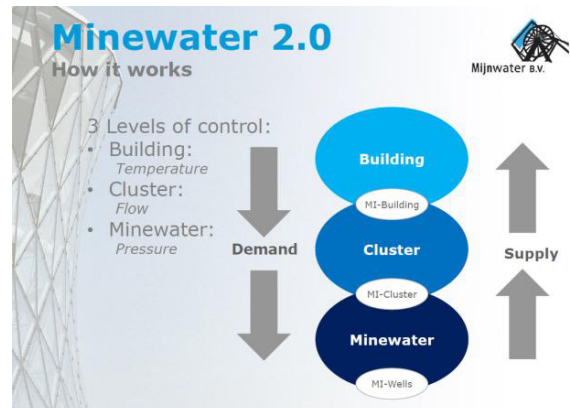


Fig. 9. Visualization of the three levels of control.

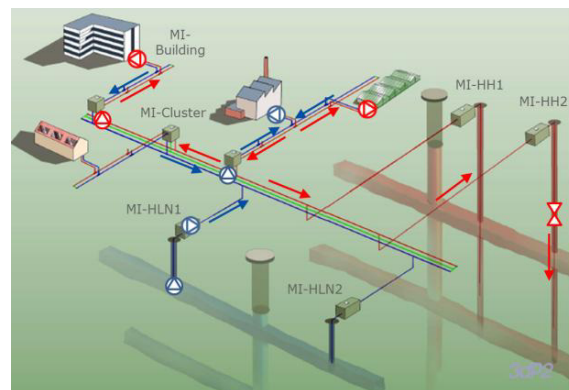


Fig. 10. Artist impression Minewater 2.0 with a typical process situation

other cluster which has a heating demand. The surplus of hot mine water is transported to the hot mine water injection well for storage. The cluster at the most left side of the figure has a heating demand and the booster pump (red) of the cluster installation extracts hot mine water from the hot mine water pipe and injects cold mine water in the cold mine water pipe for transportation back to the former cluster for cold exchange. The shortage of cold in the mine water grid is supplied by the cold production well and then the loop is complete.

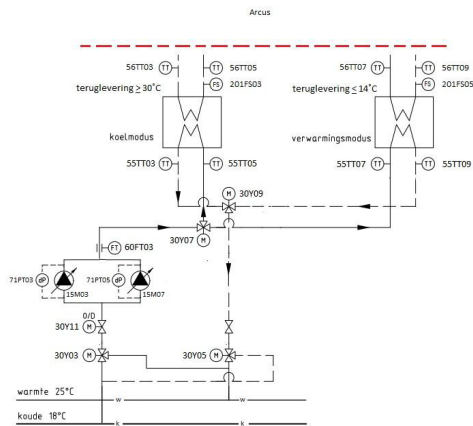


Fig. 11. Principle mine water installation building

return flows during cooling and  $< 15^{\circ}\text{C}$  for cold return flows during heating. For this purpose it is necessary that the building installation provides a sufficiently high  $> 30^{\circ}\text{C}$  (cooling) or low temperature  $< 14^{\circ}\text{C}$  (heating) to the heat exchanger on the secondary side, whether passive or active generated. In order to provide high efficiency operation of the heat pumps the heat exchangers are designed with a minimum temperature difference between the primary and secondary side of  $1^{\circ}\text{K}$ . Modern heat pumps supplied with heat from the mine water can achieve a COP of 5 up to 7.

#### 4.2 MI-Cluster

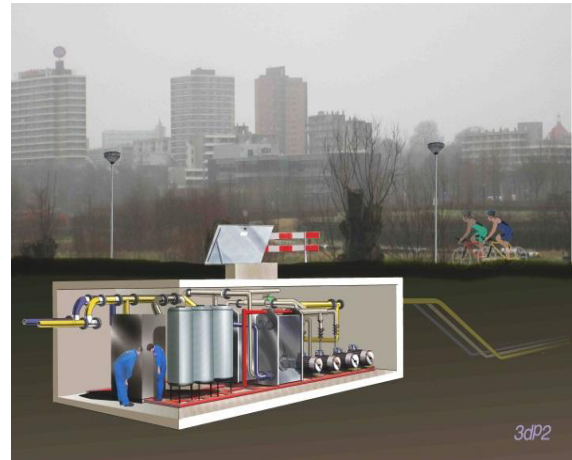
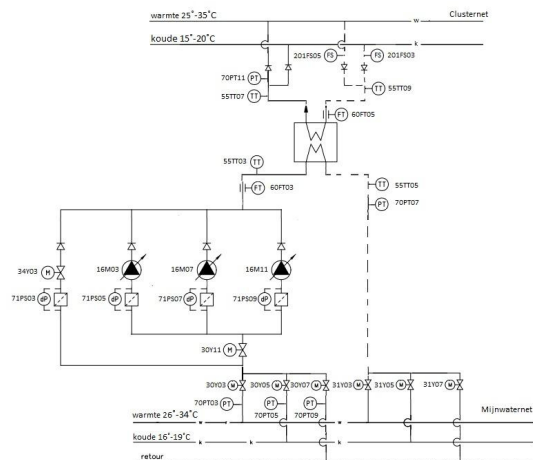


Fig. 12 and 13. Principle and artist impression cluster installation of the newly constructed cluster A.

The installation is located in the field, mounted on a skid and placed in an underground precast concrete basement, a very compact and cost-effective solution (see figure 13). The installation had to be compact to limit the size of the basement. Therefore a smart design was needed. Figure 12 shows the principle:

- No pumps are needed on the cluster grid side. The circulation pumps of the MI-Buildings take care of this flow.
- The heat exchangers are double acting. An ingenious system of non-return valves on the cluster side ensures that the cluster water (hot or cold) enters the heat exchanger always in the same flow direction. Two flow switches detect whether heating or cooling mode is needed.
- The booster pumps at the mine water side provide the requested heat or cold. They are controlled by flow, the same flow as measured at the cluster side. In this way optimal heat-exchange is guaranteed.
- Valves at the mine water side take care of the right flow direction (heating or cooling) in such a way that the mine water (hot or cold) enters the heat exchangers always from the same direction.
- The booster pumps can be seen as an additional boosting system to enlarge the hydraulic capacity of the mine water backbone.

### 4.3 MI-Wells

#### 4.3.1 Production wells

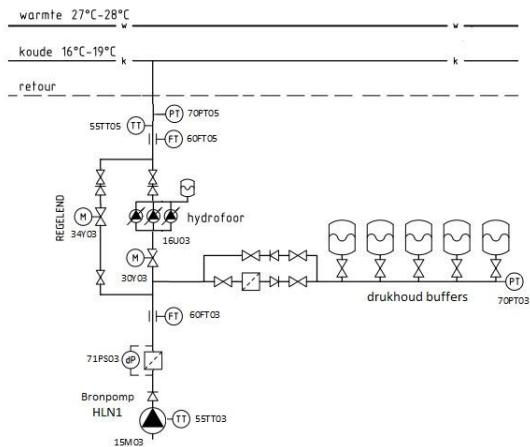


Fig. 14 and 15. Principle and putting in place of the mine water installation of the production well.

The functionality of the mine water installation at the extraction well can be divided in two parts. See figure 14. First part is the well pump which brings the mine water from about 120 m deep to the surface and delivers it with a pressure head of 3 bars to the pressure boosting system. Second part is the pressurized boosting system which provides the distribution and required pre-set pressure at the connected clusters and buildings. Because the system needs to operate fully automatic and demand driven a pressurized buffer system for start/stop operation of the well pumps is applied in case that the distributions flow is less than the required minimum flow of the well pumps. The mine water installations of the production wells are also prefabricated and mounted on skids and put in standardized precast concrete basements (see figure 15).

#### 4.3.2 Infiltration wells

The hot and cold infiltration wells fulfil two functions:

1. Injection of the surplus of the hot and cold mine water in the mine water reservoir with a minimal injection pressure of 2 bars to prevent degassing;
2. Support energy exchange through the mine water backbone between clusters. By means of algorithm per injection well it can be determined whether there is a surplus of heat and cold. With the measured extracted flows at the mine water backbone this can be defined.

The mine water 2.0 system sets high quality standards to fulfil the above mentioned requirements:



- High material quality. The mine water is corrosive, AISI316 is a prerequisite.
- Large depth. To prevent degassing the injection of the mine water needs to take place at a depth of 120 m below surface, 30 m below water level.
- Large capacity range. The injection valves must handle a flow from 0 to 230 m<sup>3</sup>/h.
- Remote adjustable injection pressure from 2 to 6 bars.
- Suitable for bidirectional use in future. During the extraction of the mine water by a well pump the valve must be fully opened with a minimum of pressure loss.
- Completely lockable in case of operation of the opposite injection well.
- Pressure resistant to 18 bars.

The valves are equipped with an independent hydraulic pressure control system with a simple control box so that the valves even at a great depth can be controlled with a remote-adjustable injection pressure. The valves are resistant to 18 bars. Because 24 bars can occur a second valve at ground level is provided in the well which completely closes when the injection well is not in operation.

#### 4.4 Central Monitoring System (CMS)

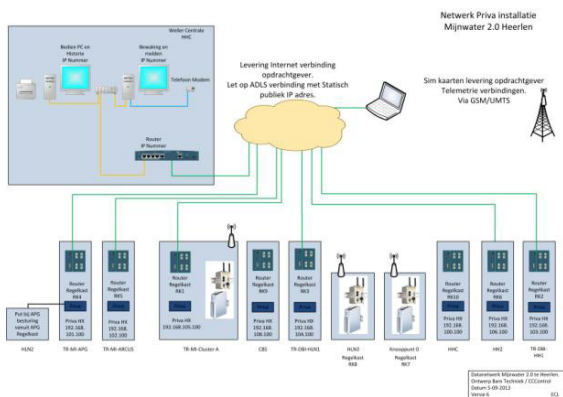


Fig. 16. Structure of the Central Monitoring System

For fully automatic demand driven operation of all the energy trains at the building, cluster and mine water level a very sophisticated process control and monitoring system is needed. Communication between the substations occurs through a fast internet connection. The central monitoring system is the central control room from which all substations are approached, visualized and monitored. All substations together form one virtual mine water installation.

### 5. Sound business case for Minewater 2.0

European Interreg 3B NWE programme and 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) are the main subsidies and funding for the Minewater 1.0. With these subsidies the municipality of Heerlen was able to cover the main risks and extra work for the drilling to the stone drifts and the start-up of the pilot projects Heerlerheide Centrum and CBS. With these pilot projects a lot of experience is gained about the financial exploitation. The experience is the basis for developing a Minewater Corporation that can offer commercial offers to interested building owners for connecting to the cluster grid. The building owner pays a standing charge for the mine water connection and normally runs his own heat pump installation. This charge is based on the capital and operational costs for the connection to the cluster grid. For optimal energy exchange and further development of the hybrid sustainable energy structure another even more interesting energy exploitation option is that the Minewater Corporation becomes the owner of the boiler house (heat pump included). In this case the Minewater Corporation sells heat and cold to the building owners. The fees for the heat and cold supply are based on the avoided costs by using gas boilers, electrical chillers and avoided additional measures for meeting the strict municipality energy performance regulations of Heerlen (50% lower than the national legislation). Because the mine water installation is more energy efficient the additional physical building properties have to be less heavy, but still higher than the national requirements. This leads to a more interesting business case for the Minewater Corporation and at the same time the building owners who also don't have to worry anymore about the efficient

operation of the boiler house and the requirements of the mine water connection. This becomes the responsibility of the Minewater Corporation who has more degrees of freedom in order to fill in the energy supply and exploitation in combination with other collective sustainable energy production plants connected to the Minewater 2.0 smart grid. Because the Minewater Corporation also owns the heat pump installation she has the position of buying centralized electricity for all the owned boiler houses and she can also benefit from PV-panels on the roofs of the buildings. At this time the Minewater Corporation makes a bid based on the two different options mentioned above. In all cases the commercial offer of the Minewater Corporation should be competitive to persuade potential customers to join the Minewater 2.0 system. By doing so the Minewater Corporation may be of interest for private shareholders to continue this business.

## 6. Conclusions

- The Mine water project in Heerlen is now being upgraded from the straightforward pilot system to a smart grid in heating and cooling with a full scale hybrid sustainable energy structure called Minewater 2.0 with 4 new connections in 2013 - 2014. In 2015 in total 500.000 m<sup>2</sup> floor area will be provided with mine water, which has a CO<sub>2</sub> emission reduction of 65% on heating and cooling for these connections.
- The Minewater 2.0 project demands smart cost effective solutions. No rocket science but creative thinking and new use of standard available solutions. Further technical development will be necessary to develop fine tuning in cost effective design and operation of the grid installations.
- Cluster grids are a profound solution to provide energy exchange between buildings.
- By poly generation the power of the application of cluster grids and capacity of the mine water grid can be strongly increased.
- Cluster grid applications are used in combination with low temperature geothermal sources (mine water) but can be applied in general with other sustainable heat and cold energy sources e.g. waste heat from data centres and closed greenhouses.
- The Minewater Corporation developing Minewater 2.0 proves that heat pump operation with low-ex heat sources can be commercial feasible.
- Because it is economic feasibility the Minewater 2.0 system can and will become an essential part of the Sustainable Energy Structure Plan of Heerlen which reaches out towards 2040.

## Acknowledgements

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