Update (Geo-) Thermal Smart Grid Mijnwater Heerlen

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ABSTRACT

The Mijnwater system was built up in several stages. In the period 2004 - 2008 (under the Interreg demonstration programme) the system (Minewater 1.0) was designed as a traditional unilateral network with a simple change-over system for heat and cold supply, the underground mine water reservoir purely was used as a geothermal source with limited capacity and Mijnwater acting solely as owner and operator of the grid.

After expanding, and due to the need to green the concept, the mine water system was transformed in the period 2012 – 2013 into a thermal smart grid (Minewater 2.0). This consisted of a bilateral cloud structure and cluster grids for instant exchange of heat and cold between buildings. The demand driven grid has 3 levels of control (building/cluster/minewater) with all-electric energy stations (heat pumps) located within the buildings. The new 2.0 system is suited for the implementation of multiple green energy sources and the mine water reservoir evolved to be utilised as an energy buffer. Mijnwater has become a (publicly owned) private company optimizing the business case, maintenance and operation and aiming for ownership and operation of the energy stations (heat pumps) in the buildings. Mijnwater developed a blue print for the overall Mijnwater 2.0 system based on an integral approach from mine water wells and grids to the energy stations and the heating and cooling systems in the buildings.

The Mijnwater system is moving towards a 'demand and supply controlled system' (Mijnwater 3.0). Based on smart storage and an intelligent top level control frame-work for operational management (predictive and adaptive), with multiple control strategies.

Currently, 175,000 m2 of building floor area are connected to the grid, expanding to 500,000 m2 in 2017 and 30 million euros have been invested to date. Energy contracts are closed for more than 300 dwellings, a college, a hotel, a sporting centre and several office buildings, one of which hosts a datacentre.

New elements are developed or under development:

- Smart bi-directional mine water wells;
- Smart hybrid energy stations;
- Smart storage - Energy Carrousel;
- Smart local area grids for existing dwellings.

In general the Mijnwater 2.0 system works very well as designed. Some parts operate even better than expected. Others initially failed during commissioning and needed improvement and/or mitigation. The following cases and lessons learned are being discussed:

- Production wells:
  - *Tuning productions wells and cluster installations;*
  - *Failure membranes pressurized buffers;*
  - *Leakage incident cold production well;*
- Behaviour cluster grid as a buffer;
- Hidden defects in system;
- Bio-fouling cluster grid A.

In the past 3 years the performance of the system was monitored which led to new insides and (proposals for) improvements. The following cases and lessons learned are being discussed:

- Performance network;
- Performance energy stations APG Pension Fund and Central Bureau of Statistics (CBS);
- Modification of minewater (exchange) installations in the buildings.

1. INTRODUCTION

The Mijnwater 2.0 development was first presented at the EGC 2013 in Pisa, Italy in June 2013 and at the IRES 2013 in Berlin, Germany in November 2013. The paper was published by Elsevier in the Energy Procedia ([1]).

At the EGC 2016, especially as winner of the EGEC European Geothermal Innovation Award 2015, Mijnwater likes to present the current status of the project, new technical developments and discuss some interesting learnings and improvements originating from operation and monitoring of the performance of the system over the past 3 years.

2. STATUS QUO

2.1 Minewater Ltd (Mijnwater B.V.)

Mijnwater has become a private company in November 2013, fully owned by the municipality of Heerlen. It is possible that other public shareholders will be on board in the future. Mijnwater sees itself as a modern utility company, the vehicle which enables the realization of a major part of the sustainable energy targets formulated in the ambition document of the Parkstad Region called PALET (Parkstad Limburg Energy Transition; [2]). The objective is to become a carbon neutral region in 2040. Parkstad Limburg is an association of 8 municipalities, former called the “Oostelijke Mijnstreek” (Eastern Mining Region) with 250,000 inhabitants and an annual energy bill of 550 million euros of which 66% is spent on buildings. Heerlen is the biggest municipality with almost 90,000 inhabitants and the regions business center.

Mijnwater is making a shift from just being owner and operator of the grid to additional ownership and operation of the decentralized energy stations (heat pumps) in the connected buildings. This enables Mijnwater to optimize the operation and business case of the total energy infrastructure.

2.2 Minewater 3.0

Mijnwater system is moving towards a ‘demand and supply controlled system’ (Mijnwater 3.0), based on smart storage and an intelligent top level control frame-work for operational management (predictive and adaptive) with control strategies including peak shaving and valley filling (optimal use of the network capacity), cell/cluster balancing (optimization energy exchange) and (electricity) market interaction (optimization of revenues and costs). The first step in this development is the granted Horizon 2020 project called STORM (Self-organizing Thermal Operational Resource Management) that started in March 2015 with five European partners ([3]). At the moment a prototype of the controller is tested at the Rottne demo site in Sweden. After some final adjustments the controller will be implemented in the Dutch demo site of the Mijnwater project in Heerlen as well. In the meantime business-as-usual data is gathered in order to evaluate the performance of the controller on business operations after two winter and one summer seasons. The STORM project will be completed in September 2018.

Dissemination of the STORM project is not part of this paper. The smart storage concept will be discussed in chapter 3 New developments.

2.3 Investment and connections

At the end of 2015 175,000 m2 of building floor area were connected to the grid and 30 million euros invested:

- 10 million euro of EU funding (Interreg IIIB; Remining low-ex);
- 3 million euro of National funding;
- 7 million euro of investment by the municipality Heerlen (current shareholder value 5 million euros);
- 10 million euro loan from the municipality of Heerlen.

Below an overview of the existing connections and status quo:

2008 – Heerlerheide Centrum (HHC); 30,000 m2; 200 apartments, offices, community center, supermarket; Since 2014 energy station owned and operated by Mijnwater including energy services; Energy station transformed to all-electric, including domestic hot water;

2009 – Central Bureau of Statistics (CBS); 22,000 m2; Bivalent energy station owned and operated by client; In discussion with client about out-sourcing and transformation of the energy station to all-electric; modification connection from mine water grid to cluster grid in Q1 2016;

2013 – Arcus College; 30,000 m2; bivalent energy station; Client is interested in out-sourcing energy station;

2013 – APG Pension Fund: 32,000 m2; Heat pump installation for reuse waste heat datacenter; Owned by client, operated by Mijnwater; In discussion with client about out-sourcing and transformation energy station to all-electric;

2014 – Rabobank: 3,200 m2; All-electric energy station owned and operated by client; In discussion with client about out-sourcing energy station;

2015 – Multifunctional (Sporting) Accommodation Bekkerveld (MAB): 3,200 m2; All-electric energy station, including domestic hot water; owned and operated by Mijnwater;

Ongoing since 2015 – Maankwartier; 50,000 m2; 100 apartments, offices, commercial, supermarket and hotel (80 rooms); All-electric energy station, including booster heat pumps for domestic hot

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water in the apartments; Owned, operated and powered by Mijnwater, including energy services;

In 2015 the cluster grid B was realized. To this cluster are connected the existing building of CBS and the new built Maankwartier;

In 2015 the cluster grid D was also realized, at first as a standalone cluster for the energy exchange between a foundry and swimming pool. Now it is developing into a full cluster connected to the mine water grid. Cluster D is not yet in operation as it is pending the development of the swimming pool and new developments in the cluster grid.

Cluster D is an industrial cluster with high potential for high and low temperature waste heat from a foundry and a detergent and beverage manufacturer see figure 1. Mijnwater is researching the possibilities of internal reuse at each site (closing the loop of cooling and heating) and external reuse between the sites through a cascaded cluster grid (high and low temperature) and through the mine water grid by other clusters.

Figure 1. Impression cluster D: heat recovery industry

2.4 Blueprint design

Mijnwater developed a blue print for the overall Mijnwater 2.0 system from mine water wells and grids to the energy stations and the heating and cooling systems in the buildings. An integral design is key for an optimal working low-exergy energy infrastructure like Heerlen. If one of the components in the total system fails all others will be affected (domino effect). The blueprint is part of the Mijnwater Master of Concept approach, which means that Mijnwater as a company defines and controls the concept from design to executions and commissioning. New innovations, applications and improvements are incorporated in the blue print. It is a document that evolves in time.

3. NEW DEVELOPMENTS

The following are new developments in the minewater thermal smart grid concept and will be discussed in turn:

- Smart bi-directional mine water wells;
- Smart hybrid energy stations;
- Smart storage - Energy Carrousel;
- Smart local area grids for existing dwellings.

3.1 Smart bi-directional mine water wells

Currently, mine water production and injection are executed by separate wells ([1]). For further capacity enlargement, back-up, and smart production and injection, all wells will be transformed into bi-directional wells in 2016. As an example figure 2 shows the scheme of the new bi-directional cold (current production) well HLN1.

The injection valves have a bi-directional operating mode. The well pumps are placed below the injection valves.

The existing production wells are equipped with a buffer and boosting system for start-up and start/stop operation of the well pump when flow demand < minimum flow ([1]).

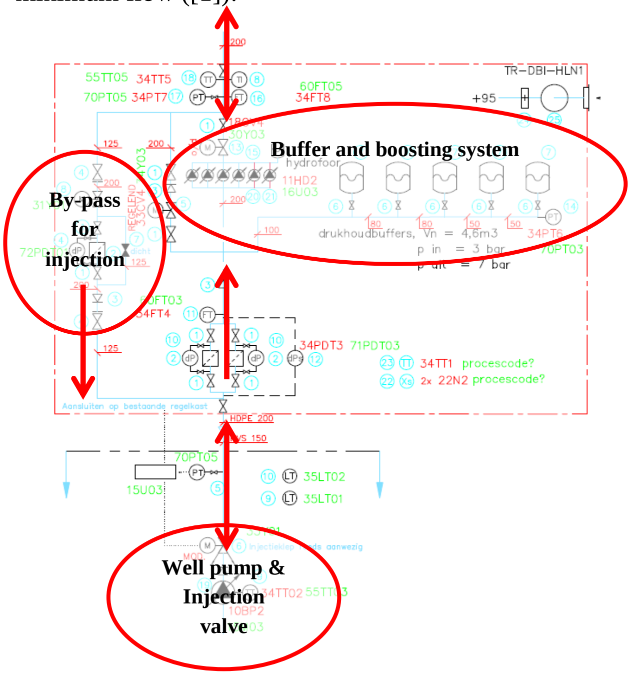

Figure 2. Transformation current production wells into bi-directional wells

The new well pumps in the existing injection wells will not be equipped with a buffer and boosting system and only be operated at flows > minimum flow (see also paragraph 4.1). Start-up will be done by the existing production well. At a higher flow, above a certain level, the second production well can take over. The first production well will automatically reduce flow and stop or at a higher demand (at least > 2 times minimum flow) be operated simultaneously. The way of operation separately or simultaneously depends upon the required heat or cold demand, corresponding pressure drops in the mine water grid and most importantly the efficiency of the pumps. All pumps have a strong efficiency drop at the left or right

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side of the pumping curve. Efficient operation will be part of the smart process control of the well and booster pumps.

3.2 Smart hybrid energy stations

All new energy stations designed, constructed and operated by Mijnwater have the following features:

1. Central heat pump station with multiple 2-stage skids for heating, cooling and/or domestic hot water;
2. Individual booster heat pumps for domestic hot water in the dwellings;
3. Smart hydraulic design for maximum passive reuse of heat and cold from the cluster grid.

3.2.1 Central heat pump station

The multiple 2-stage skids is built up of a small low temperature and high temperature heat pump (max. 100 kW each), connected in cascade to maximize efficiency. See figure 3 and 4 (Figure 4 see also attachment 1).

Figure 3. Multiple 2-stage heat pump skids

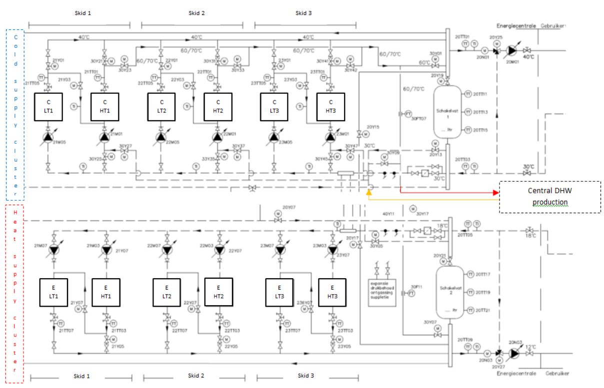

Figure 4. Scheme central heat pump station

Each heat pump can be operated in series or parallel at the condenser and/or evaporator side depending on the required heating and cooling temperature and delta T in the heating and cooling circuit. The normal supply temperature for heating is 30 to 40 ˚C depending on the outside temperature. The maximum heating temperature is 60 ˚C. The normal cooling temperature is 12 ˚C. The minimum cooling supply temperature is 6 ˚C during peak demands in summer.

In the case of central domestic hot water production (for example in a Hotel, sporting center or swimming pool) the second stage of the heat pump unit is provided with a high temperature heat pump for temperatures up to 68 ˚C with a switch to the header of the central domestic hot water circuit. During heating mode they can operate as low temperature heat pumps with supply to the header of the low temperature heating circuit.

3.2.2 Individual booster heat pump

In line with the low-exergy principle the energy support is tuned to the lowest acceptable temperature level which is needed by the end-consumer. Mijnwater has complied with this principle by offering (booster) heating capacity at the end consumer site. As such low temperature water is transported to the spot of final consumption and only lifting the necessary amount of water by a post heater to higher temperatures. For this aim Mijnwater applies individual booster heat pumps for domestic hot water in the dwellings as shown in figure 5. They are connected to the low temperature heating circuit (25 – 40˚C) fed by the central energy station. In this way only the domestic hot water is lifted to 65 ˚C instead of pumping around hot water during the whole year with additional high losses and low efficiencies. The individual booster heat pumps are owned, operated and controlled by Mijnwater and connected to the main power supply of the central energy station with corresponding large-scale consumer tariff. Customers pay for the consumed heat for the domestic hot water.

Figure 5. Individual booster heat pump dwelling

3.2.3 Hybrid proof hydraulic design

Due to new sources (waste heat/cold, solar thermal, biomass) and/or heat or cold input from other energy stations and buffers in the cluster grid, the temperatures in the cluster grid might be lifted (hot pipe) or declined (cold pipe) from the normal temperatures based on mine water (27/15˚C). By an adapted smart hydraulic design passive use of the heat or cold is enabled, to improve efficiency. Passive use means that part of the supplied heat or cold from the cluster grid can be used instantly without being upgraded by the heat pumps. The functionality is explained for several heating situations.

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Situation 1

Normal temperature in the cluster grid based on the mine water. The return temperature from the building is lower than the supply temperature from the grid. No passive use is possible. The temperature has to be fully lifted by the heat pump (HP) from 26 to 40 ˚C. The COP of the energy station is about 6.5.

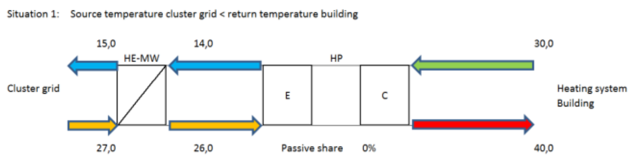

Figure 6. Temp cluster grid < return temp building

Situation 2

Temperature in the cluster grid is 35 ˚C, higher than the return temperature from the building.

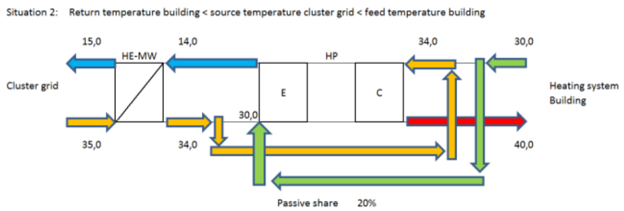

Figure 7. Temp cluster grid > return temp building

The difference in temperature can be used passively though a hydraulic switch of the supply flow from the cluster grid and return flow from the building as shown in the scheme in figure 7. The passive share is 20%. The COP of the energy station improves to 8.0.

Situation 3

The supply temperature from the cluster grid is 45 ˚C, higher than the demanded temperature to the heating system of the building (40 ˚C). The required return temperature to the cluster grid is still 15 ˚C because of supply of heat from the mine water grid. The return flow from the building needs to be cooled down before being discharged to the cluster grid. The situation is the same as situation 2 only the passive share rises to 47%. The COP of the energy station improves to 11.7.

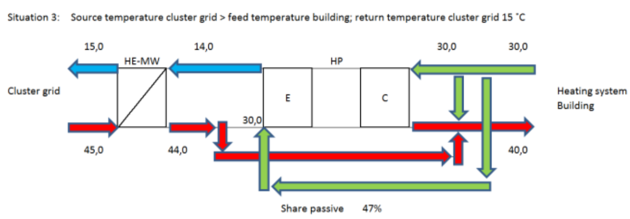

Figure 8. Temp cluster grid > feed temp building; return temp cluster grid 15 ˚C

Situation 4

In this situation no input of heat from the mine water grid is needed to supply the total heat demand in the cluster grid. Another heat source with a higher temperature, for example waste heat from industry or thermal solar heat, is available and a higher return temperature to the cluster grid is allowed. Then the heat pump installation can be fully by-passed with full passive use of the heat from the cluster grid. Then COP of the energy station is only determined by electricity consumption of the pumps for heat extraction out of the grid. It will rise up to 60 or more.

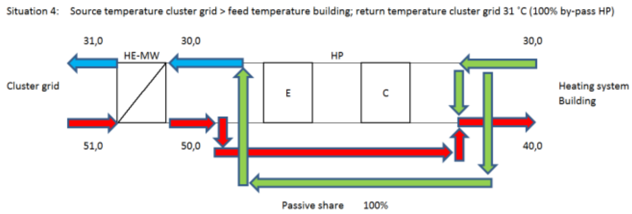

Figure 9. Temp cluster grid > feed temp building; return temp cluster grid 30 ˚C

3.3 Smart storage – Energy Carrousel

Smart storage is one of the key elements for future sustainable district heating and cooling networks to balance demand and supply in the most optimal way and a key element in the Minewater 3.0 development.

Three major storage functionalities can be distinguished:

- Seasonal buffering (long term);
- Peak shaving (mid and short term);
- Passive reuse (mid and short term).

The Mijnwater concept is based on all-electric (off-gas) energy stations. Peak loads have to be generated by heat pumps. With buffers it is possible to equalize demands over a longer period and so reduce the installed generation capacity and connection to the grid, which leads to a major reduction of costs (Capex and Opex) and maximizes the usage of the grid.

Passive reuse means that the stored heat or cold in the buffer generated during cooling or heating by the heat pumps or supplied by other sources through the cluster grid can be (re-)used without being upgraded again by the heat pumps.

The Heerlen thermal smart grid distinguishes three levels of control:

- Building;
- Cluster;
- Mine water (grid, wells and reservoir).

For each level, the storage functionalities, as mentioned above, are executed differently. In the next

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paragraphs the functionality for the building and cluster level are discussed.

3.3.1 Building level

In buildings only short term buffering, for a few hours within one day, is possible because of limited space. Seasonal buffering is not applicable, only peak shaving and passive reuse.

In the new built Maankwartier complex (50,000 m2; 1,300 kW heating; 1,800 kW cooling) a 65 m3 thermal buffer (see figure 10) is installed.

Figure 10. Thermal buffer Maankwartier

The capacity of the grid connection for heating could be reduced by 50% from 60 to 40 m3/h and for cooling by 15% from 70 to 60 m3/h. The reduction of the cooling capacity is less because the demand curve has a rather block profile with a steady peak demand in the afternoon (See also demand curves for heating and cooling during peak load in figures 11 and 12).

The heat is distributed to the end-users with 40 ˚C. The return temperature is 30 ˚C. During peak demands in winter (200 to 400 hours per year) the buffer temperature can be lifted to 60 ˚C. So the effective delta T for storage is 30K which results in a storage capacity of 8.2 GJ (2,275 kWh).

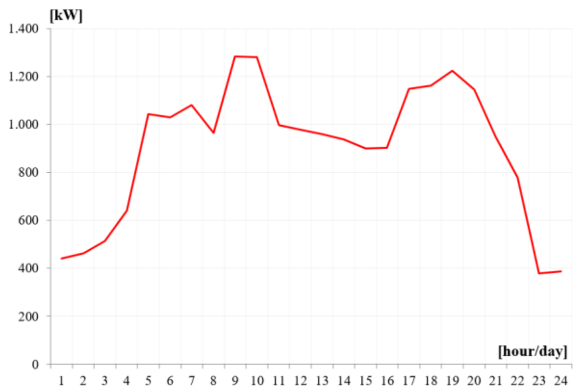

Figure 11. Heating demand curve peak

During peak demands of cooling in summer the buffer is used to store and discharge the produced waste heat gradually to the grid. The maximum temperature is 48 ˚C. With a cooling temperature of 18 ˚C from the grid the effective delta T for storage is also 30K.

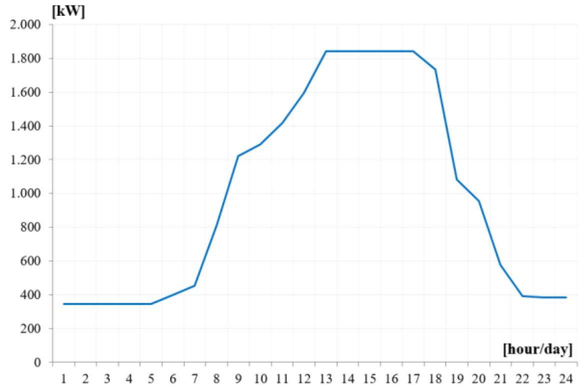

Figure 12. Cooling demand curve peak

During mid-season alternate demand of heat and cold occurs, for example heating in the morning and cooling in the afternoon. If the heating demand exceeds the cooling demand, the heat produced during cooling is stored to be reused passively at a later time and vice versa. For the Maankwartier a passive reuse factor of 30% for heating and 10% for cooling is expected. The factor for heating is higher because of a constant cooling demand (waste heat supply) of a supermarket for product cooling. It means an increase of the average COP for heating from 6.5 to 9.1 and for cooling from 5.7 to 6.3.

3.3.2 Cluster level

For the cluster level Mijnwater developed a new concept called Energy Carrousel, based on the Ecovat ([3]) application as shown in figure 13.

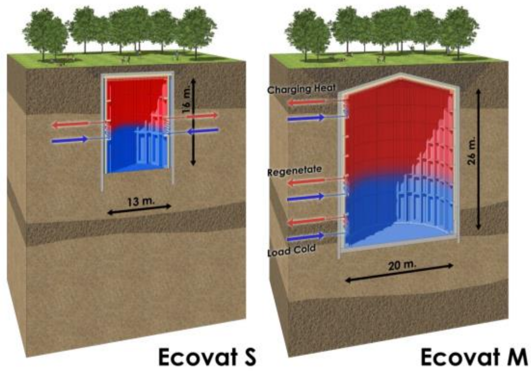

Figure 13. Impression of the Ecovat

The Energy Carrousel is a big multi-functional sub-surface stratified thermal buffer for mid and long-term buffering (weeks/month) with a capacitance between 2,000 and 20,000 m3 for supplying an area of 50,000 to 500,000 m2 renovated or new build floor area. The application is shown in figure 14 for the proposed OU Campus area.

The buffer is operated with temperatures between 10 and 90 ˚C. The energy loss is less than 10% in 6 months.

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The buffer can be supplied with heat (25 – 50 ˚C) or cold (6 – 18 ˚C) from the cluster grid and/or heat (40 - 60 ˚C) or cold (6 - 15 ˚C) generated by the heat pump and/or heat from high temperature sources (max 90 ˚C) e.g. solar thermal, biomass, high temperature heat pumps, high temperature waste heat from industry and/or (cheap) green electricity during overloads in the electricity grid.

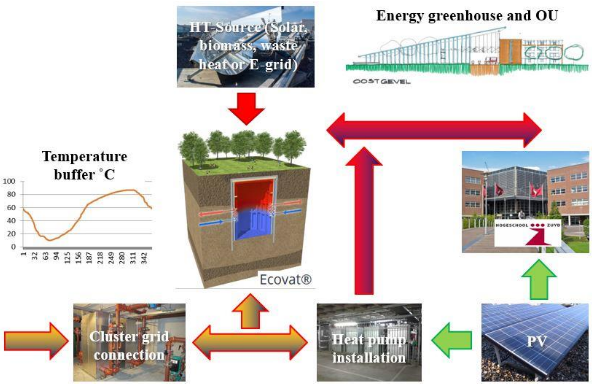

Figure 14. Energy Carrousel OU Campus area

In areas of dense housing, space for positioning these multifunctional buffers can be limited. Research is ongoing to find a solution with multiple pre-cast small buffers. The animation in figure 15 shows how smart thermal exchange grids provided buffers could look like.

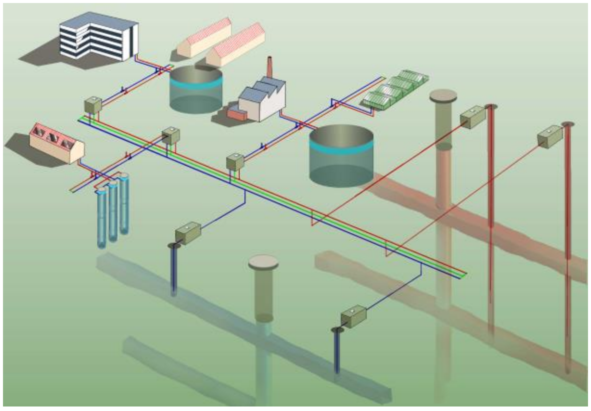

Figure 15. Animation thermal smart grid provided with smart storage buffers

3.3.3 Functionality Energy Carrousel

Peak shaving is the most important functionality for the business case, besides seasonal buffering and passive reuse.

Calculations for the OU Campus case show that the connection to the grid and the heat pump capacity can be reduced with 65% with a buffer big enough to cover a 3 month winter period (10,000 m3). The reduction of costs (Capex/Opex) of infrastructure and heat pump capacity is much higher than the costs of the buffer. So the buffer is a cost efficient application to increase the capacity of the network with a factor 3.0.

After the winter season the buffer is cooled down to a minimum temperature of 10 ˚C. The buffer will be recharged with low temperature heat by passive cooling in spring and active cooling with the heat pumps in summer up to a temperature of about 50 ˚C.

With additional high temperature heat sources the temperature can be lifted up to 90 ˚C, increasing thermal capacity with 100%. Depending on the business case additional storage can be put in place for these applications.

The heat input by high temperature sources will result in a further reduction of the required grid capacity up to 80%. Solar thermal will have the lowest impact because of the long period to bridge between summer and winter. The impact of heat input from a biomass plant or waste heat from industry is much higher, because this heat is also available to recharge the buffer in winter. Utilizing these sources a high contribution of the buffer to the energy balance is achievable even with limited storage capacity.

For OU Campus case the solar thermal and biomass options have been reviewed without additional storage for these applications. An amount of 900 m2 of solar thermal panels can provide 10% of the total heat demand. The capacity of the grid and heat pumps can be reduced from 35 to 30%. The extra costs for solar thermal are in line with cost reduction of heat pump and grid capacity. A small biomass plant of 100 kW (heat-only) would achieve the same reduction of the grid and heat pump capacity and the same contribution to the total heat demand. The investment costs for the solar panels are about € 300.000 higher. The annual energy costs are about € 16.500 lower. Thus the business case of the biomass plant is better. From the low-exergy point of view solar panels are in favor. Biomass should primarily be used for high quality application not for a low quality application like heating of buildings.

3.3.4 Operation modes Energy Carrousel

The different operation modes of the buffer are shown in the figures 16, 17 and 18.

Situation 1

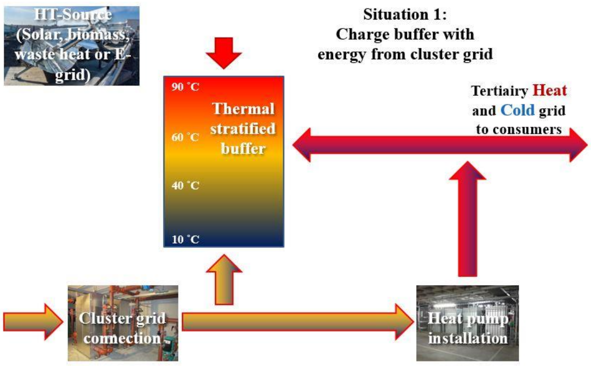

Figure 16. Charge with energy from cluster grid

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In this operation mode the buffer is recharged with heat or cold from the cluster grid, directly or by the heat pump installation during periods of reduced demands. During peak loads shortage of heat or cold is supplied by the buffer.

Situation 2

In this operation mode the buffer and area are switched off from the grid and self-supporting. The lower part of the buffer functions as source and is cooled down. The upper part of the buffer functions as production and peak buffer. During periods of reduced demands the buffer is recharged by the heat pump installation. During peak loads shortages of heat or cold are supplied by the buffer.

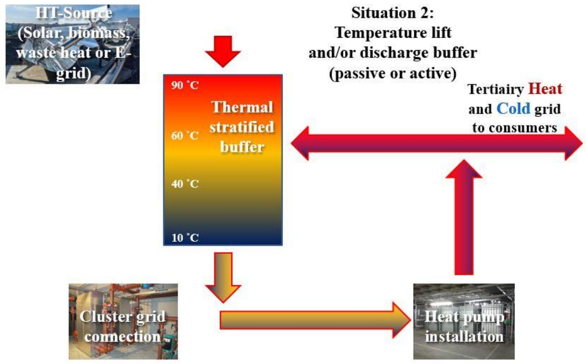

Figure 17. Temperature lift buffer by heat pumps

Situation 3

In addition to situation 2 the generated and stored heat or cold in the buffer are supplied back to the cluster grid, for example during peak loads or passive reuse of stored heat or cold. In this way stand-alone operation of the complete cluster grid is possible.

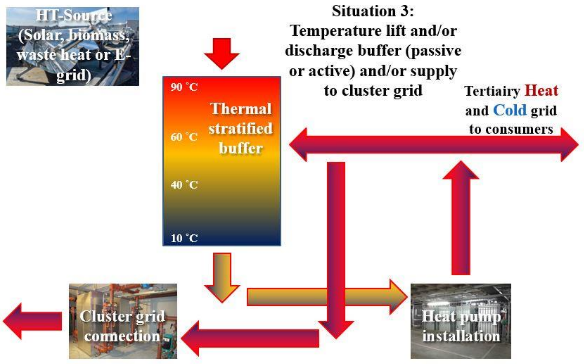

Figure 18. Discharge and supply to cluster grid

3.4 Smart local area grids for existing dwellings

One of the new initiatives in the Parkstad region is to preserve 20,000 existing dwellings by 2020 as part of the roadmap to energy neutrality in 2040 by connecting these dwellings to tertiary local area grids combined with reduction of demand by improving the envelope of the dwellings and the application of PV panels. Business analysis show that this is the most cost effective solution compared to other preserving options like Nearly Zero Energy Buildings (NZEB).

The local area grid is a 4-pipe grid for heating (max 40 ˚C) and cooling (min 15 ˚C) fed by a collective decentral heat pump station in an underground basement connected to and sourced by the cluster grid as shown in figure 19 and 20.

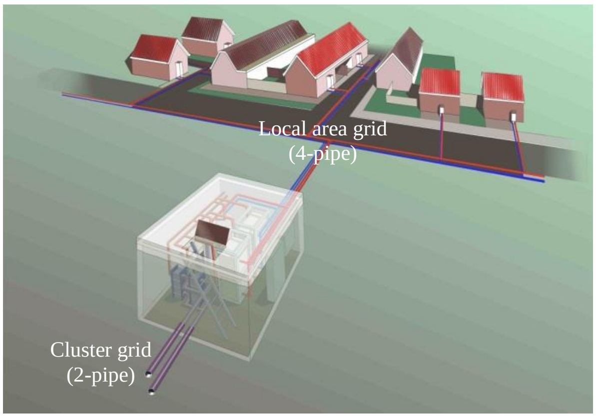

Figure 19. Local area grid for existing dwellings

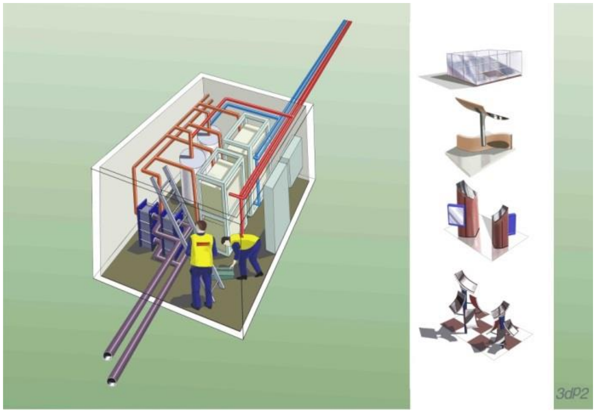

Figure 20. Collective decentral heat pump station in underground basement for local area grid

Figure 21. Energy Transfer Station (ETS) with booster heat pump for domestic hot water

The existing dwellings are provide with an Energy Transfer Station (ETS) in a box outside the dwelling as shown in figure 21. The ETS is provided with a

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booster heat pump for domestic hot water production as explained in paragraph 3.2.2.

4. OPERATION AND LESSONS LEARNED

In general the Mijnwater 2.0 system works very well as designed. Some parts operate even better than expected. Others failed initially during commissioning and needed improvement and/or mitigation. The following cases will be discussed:

- Production wells:
  - *Tuning productions wells and cluster installations;*
  - *Failure membranes pressurized buffers;*
  - *Leakage incident cold production well;*
- Behaviour cluster grid as a buffer;
- Hidden defects in system;
- Bio-fouling cluster grid A.

4.1 Production wells

The functionality of the production wells is explained in detail in [1]. Before discussing the lessons learned concerning the buffer and boosting system, a brief explanation of the operation is given. Figure 22 shows the scheme of the production well.

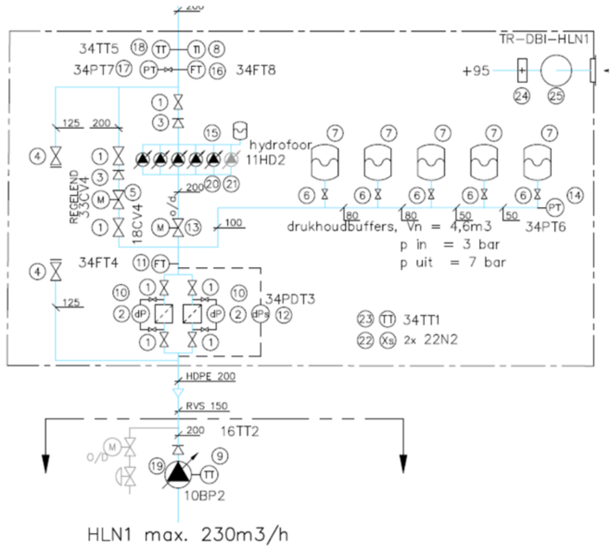

Figure 22. Scheme production well

The well pump brings the mine water to the surface with a minimum pressure of 3.5 bars at surface level and feeds the booster system ("hydrophore") which takes care of the distribution and provides a minimum pressure of 3 bars to the cluster installations of the cluster grids. The current distribution pressure varies between 5.5 and 8 bars. Between well pump and the booster pumps pressurized buffers are put in place for start/stop operation of the well pumps if the demand is below the requested minimum flow of the well pump. The switch-on pressure is 3.5 bars. The switch-off pressure is 7.0 bars. The pressurized buffer and boosting system is placed in an underground basement.

4.1.1 Tuning production wells and cluster installations

The booster pumps of the production wells provide a minimum pressure of 3 bars to the cluster installations of the cluster grids. This process is controlled by pressure. The cluster installations are provided with a control valve and parallel booster pumps to extract the necessary amount of mine water needed for cooling or heating. They push the mine water though the heat exchangers in the opposite mine water pipe. This process is controlled by flow. The booster pumps of the cluster installation operate in series with the booster pumps of the production wells. This requires a very careful fine tuning. The process control of the extraction by the booster pumps of the cluster installation is tuned very slowly to create enough time for the more quickly tuned booster pumps of the production wells to adjust to flow changes and prevent pressure drops, degassing of the mine water and fouling of the system. The slow tuning of the cluster installation can result in return temperatures to the mine water grid that temporary deviate from the desired values (cold return max 16 ˚C; hot return 28 ˚C). This is no issue for storage in the mine water reservoir if the yearly average injection temperatures are okay. This case shows that if properly designed, constructed and commissioned pumps can be put in series and work perfectly well. It only needs special attention and awareness of the application.

4.1.2 Failure of membrane's pressurized buffers

The pressurized buffers are filled with nitrogen. A membrane separates the process medium (mine water) and nitrogen. All membranes (in total 8 vessels) failed twice during commissioning of the installation. To prevent failure the buffers needs to be filled with mine water between a certain minimum and maximum. If the mine water filling drops below the minimum a fold may arise at the down side of the membrane near the mine water inlet which can lead to cracking of the membrane on the long term. If the fill exceeds the maximum, the load gets too heavy and the membrane can be ribbed of its anchors with cracking at the upside of the membrane. For the minimum filling the pre-set pressure of the nitrogen needs to be 0.5 bars below the switch-on pressure (3.5 bars). The maximum filling is about 70%. It can be exceeded if the pre-set nitrogen pressure gets too low. So the nitrogen filling is a very important factor to be watched during commissioning, sadly not recognized by the contractor and not well communicated by the supplier. During the first commissioning the pre-set pressure was set equal to the switch-on pressure, so too high. After the first failure occurred (the well pump exceeded its limit of 5 switches per hour) this was thought to be the cause. After disassembly it appeared that the membrane was ribbed of its anchors with cracking of the membrane at the upside near the anchors. This could only be caused by a too low nitrogen pressure due to nitrogen leakage. In our opinion no cracking of the membrane itself (if this was

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the case the cracking should be at the down side of the membrane) but because of a not properly sealed assembly. This was denied by the contractor, so it happened again. After the second replacement of the membranes the sealing of the membrane was done very carefully and the pre-set pressure was monitored, first daily, then weekly, then monthly and now twice a year. Now the buffers are working fine. This case shows a typical phenomenon: failure due to bad execution, poor awareness of the application and lack of communication between the supplier and contractor.

4.1.3 Leakage incident cold production well

In April 2014 a serious leakage incident occurred at the cold production well HLN1 due to lack of understanding of the application, bad execution and commissioning, cascade of failures and lack of safeguards.

The sequence of events can be derived by figure 23 which shows the progress of pressure and flow of the well pump and booster pumps before and during the incident. These monitoring values are 4 minute average measurements. It means that in reality values could have been higher or lower.

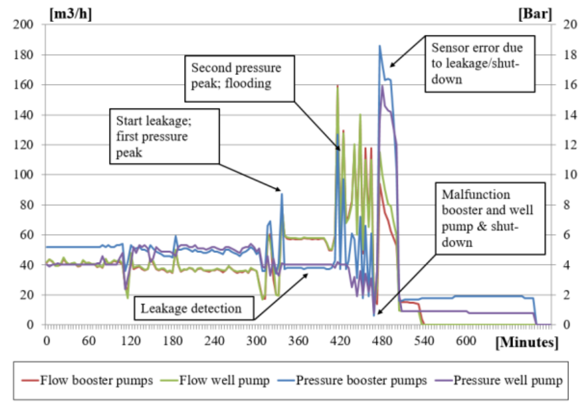

Figure 23. Flow, pressure and sequence of events during leakage incident cold production well April 2014

The ignition of the incident was a sudden pressure peak of 9 bars. At that moment a gasket in a junction of the distribution pipe just outside of the basement of the pressurized buffer and boosting system started to leak. The flow suddenly rose from 30 to 60 m3/h. 20 minutes later the leakage detection in the underground basement was activated. One hour later a second pressure peak up to 13 bars occurs, the gasket was blown out and the leakage increased dramatically. 40 minutes later the installation shut down due to an electricity short circuit. Result: a water level of one meter in the underground basement, almost all electrical equipment damaged, loss €100,000. See figure 24 and 25.

Figure 24. Flooding underground basement cold production well

Figure 25. Deformed terrain as result of leakage

What were the causes, what are the mitigations and lessons learned? We can distinguish four main aspects:

- Pressure peaks;
- Leaking gasket;
- Inflow of water in the underground basement;
- Lack of safeguards.

<u>*Pressure peaks*</u>

Several causes led to the pressure peaks:

- Damaged membranes of pressurized buffers;
- Damaged pressure sensor boosting system;
- Execution and commissioning boosting system.

Damaged membranes of pressurized buffers
At the time the incident occurred the membranes of the pressurized buffers were damaged (see paragraph 4.1.2). Start/stop operation of the well pump was not possible. A minimum demand of flow (30 m3/h) was created by a short circuit from the cold production well to the cold injection wells. The well pump and booster pumps were connected directly without the

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pressurized buffers to equalize and temper short term differences in flow and pressure, already a more sensible situation.

Damaged pressure sensor boosting system

The boosting system is a black-box. Two weeks before the incident some pressure fluctuation were monitored and it was determined that damage occurred to one of two pressure sensors of the black-box control unit. This was inadequately solved by the constructor, who at that time was still fully responsible for the operation and maintenance of the installation. In our opinion this was the main cause for the sudden pressure peaks.

Execution and commissioning boosting system

The boosting system was not executed and tuned in accordance with the application:

- Pressure head of the booster pumps was too high;
- Only the first booster pump in duty frequency controllable;
- Second and other booster pumps came in to fast;
- Retention time booster pumps too long;
- Booster pumps controlled by discharge pressure instead of the differential pressure between suction and discharge head.

Al these factors together caused pressure peaks. If the second pump comes in with full load this pump will cause a pressure peak and/or flow peak. If the pump comes in to fast, at low demands the peak will be higher and if the pump keeps running due to a long retention time it will last longer.

The first two points still have to be solved. They are part of the transformation of the production wells into bi-directional wells (see paragraph 3.1).

During evaluation of the causes with the consultant, contractor and supplier it became clear that the booster pumps were selected on a fixed operation point (10 bars) instead of operation curves (pressure/flow characteristics) for future scenarios, which were available but not discussed between the consultant and supplier during the final design phase and not added to the tender document by the consultant. Else it would have been clear that a wide range of operation points cannot be filled in with just identical large booster pumps, so at least one pump should be smaller and all individual pumps need to be frequency controlled. The tender document stipulated that the boosting system should be frequency controllable, but it was not explicitly mentioned that all individual booster pumps should have frequency control. Both can be seen as short comings in the tender document but the contractor who was responsible for the final and detail design (in accordance with the tender document) did not ask for details and implemented a standard solution based on the selection by the suppliers without delving into the application himself.

The above mentioned shortcomings also have caused pump damage and contribute to the bad performance of the production wells (see paragraph 5.1.2).

Leaking gasket

It is difficult to determine what exactly caused the leakage of the gasket as shown in figure 26.

Figure 26. Broken gasket

The type and design pressure of the gasket was equal to the existing gaskets, a soft gasket with a design pressure of 10 bars. The pressure curve shows that the design pressure was closely reached or even exceeded before the leakage occurred. Therefore it could also be caused by bad assembly of the gasket or a combination of both.

Resulting we learned afterwards that a soft gasket is not the right choice for a system with fluctuating pressures and that operating pressures close to design are too risky.

Replacement of all the gaskets in the mine water grid would be too expensive but gaskets were replaced at all critical locations near underground basements. The replacements are hard gaskets with a design pressure of 16 bars. No leakage has occurred since then.

Inflow of water

Figure 27. Flexible tubes

The leakage occurred outside the underground basement but entered the basement through wall penetrations due to poorly sealed and inappropriate pipes used by the contractor. All the flexible tubes as shown in figure 27 are replaced by fixed tubes and

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professionally sealed at all underground basements, so water from the outside can infiltrate no more.

Lack of safeguards

Despite all the failures, mentioned above, the damage would have been less disastrous if adequate safeguards would have been in place:

- Leakage detection with shut-down;
- Overpressure protection with shut-down.

In the tender document leakage detection and safeguards were prescribed but not in detail. That was the responsibility of the contractor. That was a major error. Safeguards have to be worked out in the design phase and prescribed in the tender document in detail. All the basements (production wells and cluster installations) are now provided with double leakage detection and overpressure protection.

Leakage detection

The first level leakage detection is a warning for detection of small leakages which can be easily pumped out by a submergible pump in the basement. Second leakage detection is mounted at a level of 20 cm above the floor that shuts-down all installations connected to the mine water grid (production wells and cluster installations) after being activated. The mine water system is an open pressure controlled system which means that only shutting-down the installation where the leakage occurs is not enough, especially if all production wells become bi-directional.

Overpressure protection

The booster pumps of a production or cluster installation are now shut-down if the discharge pressure exceeds 10 bars or if the pressure sensor is defected.

4.2 Behavior of the cluster grid as a buffer

One of the positive effects of a cluster grid (that were not taken into account during design) is its behavior as a buffer. The grid contains 100 to 150 m3 of water that enables equalization of short-term imbalances in demand and supply in the cluster grid. Imbalances result in temperature fluctuations in the cluster grid, but don't lead, in the short-term, to failure of energy stations and disruption of supply, for example due to temporary interruptions in supply of mine water (intentionally by control or unintentionally by failure). The temperature in the grid goes up or down which only leads to temporary reduction of efficiencies. This creates time for response and process control. Nice example is the use of the cluster grid in December 2014 to balance the available waste heat of the APG Pension fund and new build Arcus College during commissioning. Due to repair work in the cluster installation no supply of heat from the mine water grid was possible for several days. The heat demand of the Arcus College during the day was matched with the available waste heat of APG in 24 hours. At daytime (shortage of heat) the temperature in the cluster grid dropped and at night the temperature rose again (surplus of heat).

4.3 Hidden defects in the system

We experienced that hidden defects can occur in the cluster installations and exchange installations in the building that are not noticed quickly. These defects do not lead to failures but only loss of efficiency. For example if a 3-way valve in the cluster installation is not closing completely (although the pointer indicator says so) unwanted leakage of mine water to the old injection well (HLN3) can occur. The same can happen in the exchange installation of the building which will lead to unwanted cross flows and lower heating or higher cooling supply temperatures. These kinds of defects can easily be detected by check and balances in the process control system which will be implemented in 2016.

4.4 Bio-fouling cluster grid A

In late 2015 Mijnwater BV conducted a study of the quality of the water in cluster grid A. The research led to several alarming findings.

pH

The water in this cluster grid had a pH of 7.7 at the time of measurement. In order to keep the corrosion rate as low as possible, the pH of the water must be at least 8.0 in a water-filled thermal system. Because the cluster grid is operated at low temperatures a pH-level is required between 9.3 and 10. At a pH of 9.5 the rate of corrosion on steel, copper and stainless steel is the very lowest.

Oxygen

The cluster water also contained a high oxygen level. This results in corrosion of the steel pipes, parts and accessories. In addition it contributes to a decrease of efficiency, because the heat transfer capacity of oxygen is very low in contrast to water.

Bacterial activity

The piping system contained a very high presence of bacteria. These bacteria (bio-fouling) stimulate corrosion to a large extent. This kind of corrosion is local, takes place in secretions in the pipes and is difficult to prevent. This bacterial activity also allows for an increased presence of nitrite, sulphite and sulphide. In addition, these deposits of bacteria can result in glue creations and blockages in the system (mainly for pumps and valves).

The previously mentioned quality problems have multiple causes:

1. Due to the low temperature level of this system, the bacterial activity will be able to increase more rapidly than at a higher temperature system;

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2. The pipes in this cluster have been filled with demineralized water (demi water) with a too low required pH-value. This value was based on demi water systems with a higher temperature level than this LT-system;
3. The steel cluster system was connected with an older PE-piping system. These plastic pipes were filled with iron- and oxygen rich mine water. Through this connection a mixing of different qualities of water has occurred, which resulted in a degradation of the quality;
4. On top of this, oxygenated tap water has been supplemented in the system during leakages, by automatic filling systems and by connection of new (water-filled) pipes.

To improve these quality characteristics, a biocidal shot was administered into the water. In addition, an additive has been added to the cluster water to increase the pH in accordance with the required value for this low temperature system. A chemical dosing has ensured that the quality of the water improved within a month. Monitoring for the improvement progress took place through sampling of the water. In the future a biocidal shot will periodically be administered into the water in order to ensure that the bacterial activity is kept low.

4.5 General lessons learned

The cases show that new insights are obtained during operation which are not or can't be identified during the design phase, both positive and negative.

Especially the failures show that new innovative concepts like Mijnwater 2.0 need intensive assessment and guidance by Master of Concept, by own know-how and/or the capability to manage know-how, not only during concept design but in the entire process to realization. It is essential to prove by assessment that consultants and constructors understand the principles of the new concept completely so they make the right considerations and choices during final (by consultant) and detail design (by contractor) and to build in witness points during implementation and commissioning, not waiting till the end-product is delivered.

Safeguards require special attention. They have to be worked out in detail during the final design phase by the consultant, assessed by the principal and clearly and completely described in the tender document.

5. PERFORMANCE AND IMPROVEMENTS

In this chapter the performance of the network and energy stations of the APG Pension Fund and Central Bureau of Statistics (CBS) and the modification of minewater installations in the building are discussed.

5.1 Performance network

First the water and energy balance of the minewater reservoir is discussed, then the performance of the network.

For a good understanding of the situation a geographical overview of the Minewater 2.0 system with the different wells, as in operation between 2013 and 2015, is shown in figure 28.

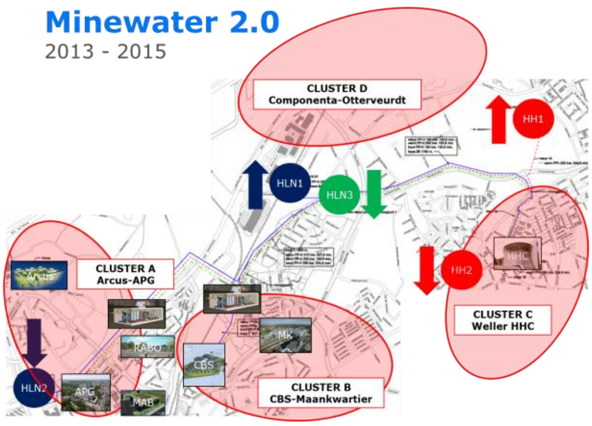

Figure 28. Overview Minewater system 2013 - 2015

HH1 is the hot production well; HH2 is the hot injection well; HLN1 is the cold production well; HLN2 is the cold injection well; HLN3 was the former central injection well for used minewater (hot and cold) during the Minewater 1.0 operation until June 2013 ([1]). In the Minewater 2.0 concept the HLN3 injection well is only needed for back-up during failure of the new injections well HH2 (hot) and HLN2 (cold).

5.1.1 Water & Energy balance mine water wells

Tables 1 and 2 show the water balance of the minewater reservoir with the extracted and injected water quantity of the different mine water wells per month for 2014 and 2015.

Table 1: Water quantities minewater wells in 2014

	Production			Infiltration			
In 1,000 m3	**HH 1**	**HLN 1**	**HLN 2**	**HH 2**	**HL N 2**	**HLN 3-H**	**HLN 3-C**
January	15.8	9.8	17.2	0	6.1	27.0	9.7
February	13.2	11.7	8.7	0	0.5	20.4	12.7
March	28.9	27.2	0	18.4	9.7	8.8	19.2
April	19.1	23.0	5.6	19.5	7.4	9.1	11.6
May	3.2	2.5	19.4	1.5	0	20.4	3.2
June	0.2	2.1	19.2	9.8	0	11.5	0.2
July	0	41.7	0	17.7	0	24.0	0
August	0	36.4	0	12.0	0	24.4	0
September	0.4	31.1	0	8.4	0	22.7	0.4
October	1.1	21.0	0	5.2	0.3	15.8	0.8
November	10.8	7.0	0	1.1	3.4	5.9	7.4
December	26.6	1.0	0	0	8.0	1.0	18.6
Total	**119.2**	**214.4**	**70.0**	**93.8**	**35.4**	**190.6**	**83.9**

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Table 2: Water quantities minewater wells in 2015

In 1,000 m3	Production			Infiltration			
	HH 1	HLN 1	HLN 2	HH 2	HLN 2	HLN 3-H	HLN 3-C
January	31.0	0	0	0	6.5	0	24.5
February	25.0	0.2	0	0	6.8	0.2	18.3
March	18.9	2.1	0	0.1	3.8	2.0	15.1
April	9.9	5.8	0	1.5	4.1	4.3	5.8
May	9.8	25.1	0	3.3	0.2	21.8	9.6
June	3.4	44.0	0	9.5	0	34.5	3.4
July	1.6	44.1	0	8.1	0	35.9	1.6
August	0.6	46.3	0	6.2	0	40.2	0.6
September	2.9	31.5	0	1.3	0.1	30.2	2.8
October	28.5	7.4	0	1.4	0.9	6.0	27.6
November	27.8	7.0	0	0.6	0.4	6.3	27.4
December	35.5	3.4	0	2.1	0.1	1.4	35.4
Total	**195.0**	**217.1**	**0**	**34.2**	**22.8**	**182.9**	**172.2**

In 2014 the cold injection well HLN2 was also used for production during the pump test and as back-up after the leakage incident of the cold production well HLN1 (see paragraph 4.1.3).

The water balances show that the hot mine water production increased by more than 60% in 2015 due to a higher heat demand. The cold mine water production reduced with 25% in 2015 due to operational problems and pumptest in 2014 and improvemend of the cooling efficiency in 2015.

They also show that in 2014 and 2015 the injection well HLN3 was still used mainly for injection of used minewater and even has been increased. This was due to four factors:

- Injection of used mine water from the Central Bureau of Statistics and the Heerlerheide Centrum Complex. The initial two buildings were still connected to the mine water grid in the former unilateral way based on the Minewater 1.0 concept. Both had to be modified first. Since April 2016 they are in operation as bilateral connections, in accordance with the Minewater 2.0 exchange concept;
- Failure of the new injections valves, mostly due to minor defects e.g. broken pressure sensor and printed circuit board. In the current situation the control unit is mounted in the pit of the well-head, which is a too humid environment. When the wells become bidirectional the control unit will be positioned in a separated dry pit;
- Pump test executed in January and February 2014. The cold well HLN2 was used as a production well and the mine water was injected in HLN3 without use of the cold;
- Major leakage incident in April 2014 at the cold production well HLN1 (see also paragraph 4.1.3). During rebuilt this cold well was not in operation and the cold injection well HLN2 was used as back-up with a fixed non demand driven production flow.

Tables 3 and 4 show the energy balance of the minewater reservoir with the extracted and injected heat and cold of the different mine water wells. The injection of heat and cold in HLN3 is split up.

Table 3: Energy balance minewater wells 2014

[GJ]	Production			Infiltration			
	HH 1	HLN 1	HLN 2	HH 2	HLN 2	HLN 3-H	HLN 3-C
January	990	412	0	0	361	412	629
February	686	613	0	0	33	613	653
March	853	869	0	351	95	518	758
April	469	814	110	312	25	612	444
May	110	0	894	14	0	880	110
June	3	0	898	459	0	440	3
July	0	1,101	82	884	0	300	0
August	0	1,519	0	884	0	635	0
September	12	724	0	459	0	265	12
October	29	577	0	340	12	236	16
November	373	118	0	14	155	104	219
December	713	25	0	0	344	25	369
Total	**4,239**	**4,155**	**1,984**	**3,717**	**1,026**	**5,040**	**3,214**

Table 4: Energy balance minewater wells 2015

[GJ]	Production			Infiltration			
	HH 1	HLN 1	HLN 2	HH 2	HLN 2	HLN 3-H	HLN 3-C
January	1,319	0	0	0	326	0	993
February	1,227	1	0	0	357	1	870
March	1,083	37	0	0	275	37	810
April	338	159	0	42	101	117	237
May	346	559	0	95	12	465	334
June	85	1,571	0	431	0	1,140	85
July	12	1,301	0	276	0	1,025	12
August	6	1,947	0	273	0	1,674	6
September	141	911	0	21	2	890	139
October	1,039	159	0	49	12	110	1,027
November	1,424	182	0	36	10	146	1,414
December	1,796	73	0	33	6	39	1,790
Total	**8,818**	**6,901**	**0**	**1,257**	**1,101**	**5,644**	**7,715**

The sum of produced heat is the same as the sum of injected cold and vice versa. It shows that the heat demand is significantly increased (108%) due to the new connections MAB and Maankwartier, conversion of the energy plant of Heerlerheide Centrum from bivalent to all-electric (increased heat pump operation) and less available waste heat due to higher internal reuse of waste heat by the datacenter of the APG Pension Fund. The cooling demand remained stable (HLN1 + HLN2). The increased cooling demand by the new MAB connection is compensated by a reduced cooling demand of the APG Pension Fund. Maankwartier did not have an impact on cooling because it was connected after the cooling season.

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In 2014 there was a surplus of heat (64%) and in 2015 a shortage of heat (22%). The average delta T for heating is improved from 8.5 K in 2014 to 10.8 K in 2015. The average delta T for cooling is improved from 5.8 K in 2014 to 7.6 K in 2015, both due to improved operation, settings and process control. The delta T for heating and cooling should be at least 12 K. This was not yet achieved due to the connection of the Central Bureau of Statistics (CBS) and Heerlerheide Centrum. The mine water installation of CBS was in 2015 still directly connected to the mine water grid and controlled by the building management system of the customer in a not optimal way, spilling water. Since April 2016 CBS is connected to the cluster grid B and heat and cold supply are fully controlled and optimized by Mijnwater. After Mijnwater acquired the energy station of Heerlerheide Centrum and started with the conversion to all electric and bidirectional exchange with the mine water grid a lot of shortcomings in the system and process control were discovered which had to be solved in 2015. This also resulted in a not optimal exchange with the mine water grid and spilling of water. So a further improvement of delta T up to 12 K is expected in 2016.

Table 5 and 6 show the average weighted temperatures of the production and injection wells.

Over the last 2 years the production of heat and cold, and as a consequence, the infiltration of cold and hot return water in well HLN3 have increased. During this same period, the temperature of the water produced from the hot production well HH1 has been stable at 27.5 ˚C, whereas the temperature of the cold production well has significantly increased by 0.5 °C, from 16.5 to 17.0 ˚C. These tendencies indicate that the geothermal potential of the hot part of the mine water reservoir has not been impacted during system operations while the cold part of the mine is showing the first signs of depletion.

Table 5: Temperatures minewater wells in 2014

	Production			Infiltration			
[°C]	HH 1	HLN 1	HLN 2	HH 2	HLN 2	HLN 3-H	HLN 3-C
January	27.5	16.3	18.5		15.3	21.4	10.9
February	27.5	16.4	18.4		18.0	24.4	14.9
March	27.5	16.6		26.9	15.2	18.7	23.1
April	27.5	16.9	18.3	27.0	17.2	20.3	24.6
May	27.0	16.8	18.7	22.8		28.7	18.8
June	23.4	15.9	18.7	30.2		26.9	20.0
July		16.6		31.0		17.7	15.9
August		17.0		31.0		25.0	
September	24.6	15.0		31.4	16.4	16.6	17.5
October	25.6	17.2		29.7	16.5	21.8	21.0
November	27.7	16.7		25.6	16.5	19.9	20.7
December	27.6	15.7			15.7	22.1	23.7
Total	**27.5**	**16.5**	**18.6**	**29.0**	**15.9**	**22.1**	**20.4**

Table 6: Temperatures minewater wells in 2015

	Production			Infiltration			
[°C]	HH 1	HLN 1	HLN 2	HH 2	HLN 2	HLN 3 -H	HLN 3-C
January	27.5				14.3	16.7	18.2
February	27.5	14.7			14.7	15.8	16.3
March	27.5	15.6			15.4	20.2	13.5
April	27.3	15.9		22.4	16.9	22.5	20.8
May	27.4	16.3		23.4	15.4	21.3	19.1
June	26.4	16.8		25.2		25.4	20.5
July	25.3	17.2		27.9		23.4	23.6
August	24.0	17.3		27.9		27.2	21.7
September	26.7	17.4		23.1	17.0	24.4	14.9
October	27.7	17.0		26.4	16.8	21.0	19.1
November	27.6	16.7		24.2	13.4	22.8	15.4
December	27.5	16.2		25.0		15.4	15.5
Total	**27.5**	**17.0**		**25.9**	**15.1**	**24.29**	**16.9**

Based on the combination of the data from Tables 1, 2, 5 and 6, the mean weighted temperature of the fluid infiltrated in HLN3 was 21.5°C and 20.7°C in 2014 and 2015, respectively.

Figure 29 shows the flow path (in green) between HLN3 and HLN1 in the Minewater EPANET model during production at HLN1 and infiltration at HLN3. The initial temperatures are given at each node of the model.

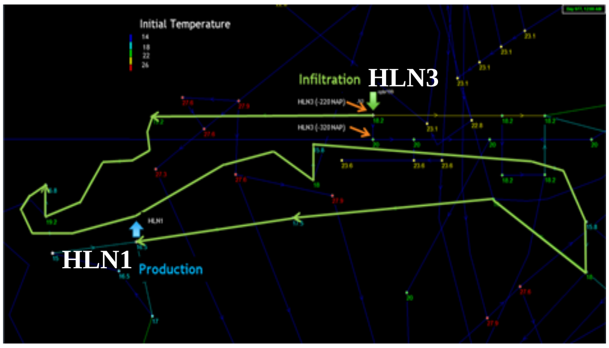

Figure 29. Minewater EPANET model

It shows that these temperatures are higher than the initial mean temperature of the galleries at the mine level at which most of the infiltrated water flows back into the mine galleries at HLN3 (-220 NAP). As a consequence the fluid that flows into the galleries heats up the surrounding rocks and creates a “hot region” along the flow path between HLN3 and HLN1 when both wells are in operation. Note that the rocks, surrounding the galleries into which the fluid flows between HLN3 and HH1, are also heated up but this has a positive effect on the heat production. As the increase in rock temperature tends to prevent any lowering of the temperature of the hot well. The warming up in the vicinity of HLN3 is less significant at HH1, as this well is further away from HLN3 than is HLN1. The fluid needs to travel 3.4 km to reach HLN1 from HLN3, whereas it is about 5.5 km to reach HH1.

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The observed depletion proves that the geothermal capacity of the reservoir is limited if the system is used as defined by the former Minewater 1.0 operation scheme; where HLN3 was used as the main infiltration well. It also shows that the geothermal potential of the hot part of the minewater reservoir is higher than the cold part if HLN3 is used for injection. One way to preserve the full capacity of the system is thus to use the reservoir in a smarter way such as the one in operation since February 2016, defined as the Minewater 2.0 operation scheme. In this new scheme, infiltration does not take place anymore at HLN3 but at HLN2 and HH2 (depending on the temperature of the return water). By doing so, much larger volumes of the minewater reservoir are activated and hot/cold balance is guaranteed as cold(hot) water is returned into originally cold(hot) regions. This way of operating the system will prevent depletion and homogenization of the system. Regeneration of the cold part of the mine water reservoir will also occur and the mine water temperature of the production well HLN1 shall gradually reduce again to the initial mean temperature.

5.1.2 COP network

The performance of the network can be expressed in a similar manner to heat pumps by using COP (Coefficient of Performance). It is the amount of energy (heat or cold) supplied to the buildings divided by the electricity of the pumps consumed at three levels:

- Minewater: Well pump and booster pumps at the mine water production wells;
- Clusters: Booster pumps in the cluster installations for exchange between the mine water grid and cluster grid;
- Buildings: Pumps for exchange between the cluster grid and the energy station in the building.

The COP can be determined per level of the system. Exchange between buildings reduces the supply of heat or cold from the minewater grid and use of the booster pumps in the cluster installation. Exchange between the cluster grids reduces the supply of heat or cold form the mine water production wells. This improves the overall COP related to the supplied heat and cold to the buildings. This effect is not yet taken into account.

Figure 30 shows the measured week average COP's of the hot (HH1) and cold (HLN1) production well and cluster installation of the cluster grid A in 2015.

It shows that the COP of the cluster installation with an average of 158 is much higher than the COP's of the well pumps. This is less than 15% of the total electricity demand of the mine water grid.

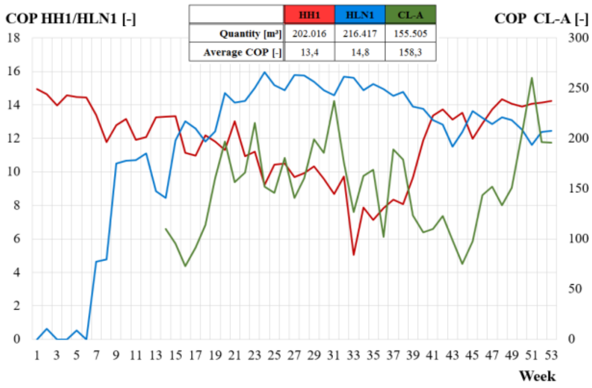

Figure 30. Average COP's production wells and Cluster A

The calculated design COP's for the mine water wells were about 25. The COP's in practice of the hot production well HH1 and cold production well HLN1 stay far behind. This was the incentive for an extensive investigation of the possible causes, executed for the hot production well HH1. It can be assumed that the causes are comparable for the cold production well.

<u>*COP HH1*</u>

The production wells are a cascade of a well pump and booster pumps [1]. The well pumps bring the mine water to the surface with a minimum pressure of 3.5 bars and the booster pumps supply the mine water to the mine water grid to keep up a minimum pressure of 3.0 bars at each cluster installation of the cluster grids. The discharge pressure at the production well at surface level varies between 5.5 and 8 bars.

For both the well pump and booster pumps the COP in practice is compared to the theoretical COP. The COP in practice is calculated by the supplied heat based on the measured distribution flow and fixed delta T of 12K, based on the cooling out of the hot mine water from 28 to 16 ˚C and the hourly measured electricity consumption. The electricity consumption of the theoretical COP is determined by the power consumption curve (power in function of measured flow & frequency) and pump curve (frequency in function of flow and pressure) based on the 4-minute values of the measured distribution flow and pressure. The pump curves deliver the frequency at each pressure/flow point. The power curves deliver the consumed (theoretical) power at each flow/frequency point. In figure 31 the COP's in practice and theory of the well and booster pumps are shown. The well pump and total COP is shown at the left axis. The COP of the booster pumps is shown at the right axis.

General conclusion is that the bad performance of the production well is mainly caused by the bad performance of the booster pumps. In the next paragraphs both are analyzed more in detail.

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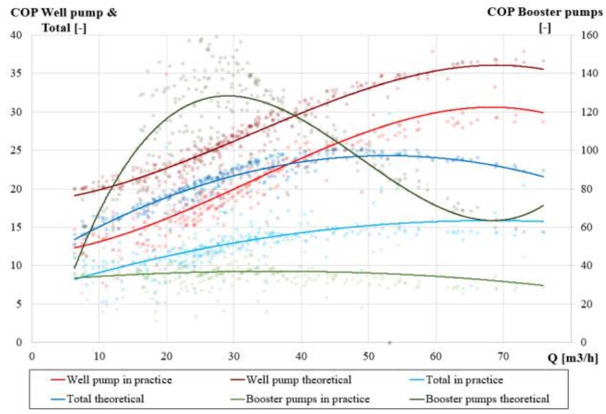

Figure 31. COP HH1: booster pumps, well pump and total

Well pump

The well pump is operated start/stop during distribution flows < 20 m3/h with a minimum flow of 20 m3/h (33.3 Hz) and 3.5 bars at surface level during start and 30 m3/h and 7 bars (37 Hz) during stop as shown in figure 32. For determination of the theoretical efficiency and COP of the well pump only the running period is taken into account based on the average energy consumption between these two working points.

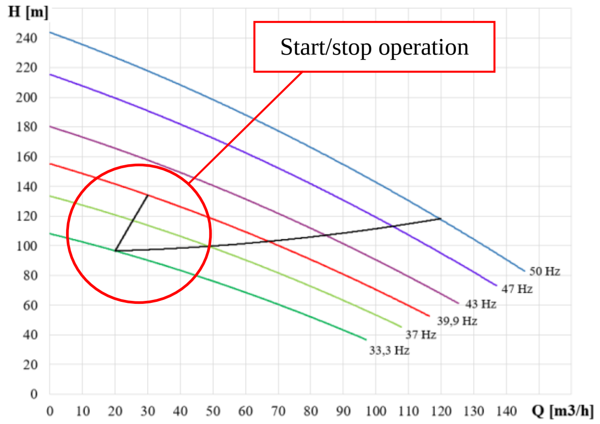

Figure 32. Start/stop operation well pump HH1

Figures 33 and 34 show the COP and efficiency of the well pump in practice and theoretically.

It is clear that the performance in practice is lower than in theory. Multiple aspects can be of influence:

- Start/stop operation during demand < minimum flow (20 m3/h);
- Efficiency motor and frequency converter;
- Accuracy of measurement;
- Process control.

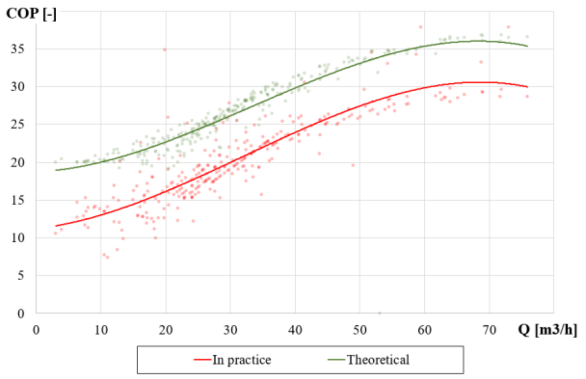

Figure 33. COP curve well pump HH1 in practice and theoretically

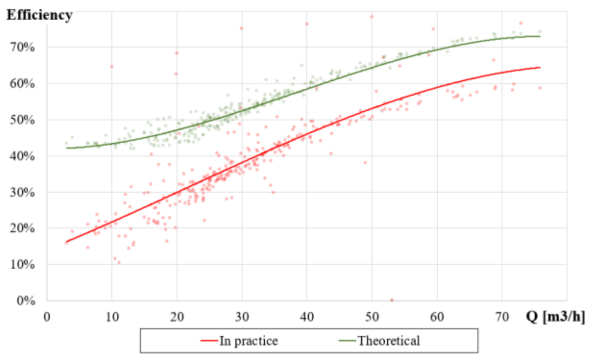

Figure 34. Efficiency curve well pump HH1 in practice and theoretically

Start/stop

The start/stop losses are not taken into account in the theoretical COP. The relative share of the start/stop losses increases with reduction of demand because the time for loading the pressure vessels reduces. Elimination of these losses is not possible.

Efficiency motor and frequency converter

The efficiency of the motor and frequency converter is not taken into account in the theoretical COP. Figure 35 shows a typical efficiency curve of a motor and frequency controller for different frequencies and loads ([4]).

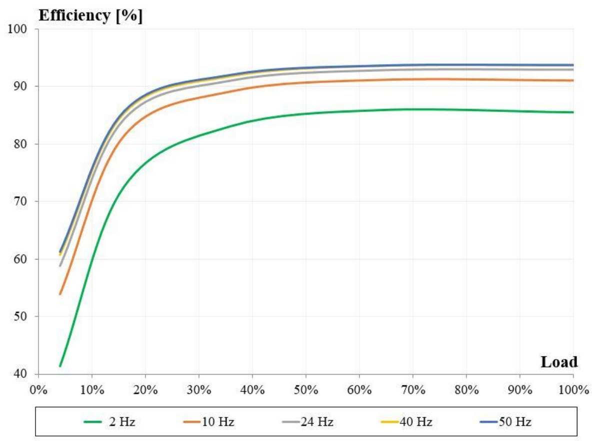

Figure 35. Typical efficiency curve motor and frequency converter

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Dominant factor is the load of the motor. At loads lower than 40% the efficiency drops strongly especially at low frequencies. This is not the case for the well pump. Even at the minimum operation point with a minimum frequency of 33,3 Hz at a flow 20 m3/h the theoretical power consumption is 38 kW. This is 50% op the maximum load (75 kW). The maximum efficiency loss caused by the motor and frequency converter will be about 7%.

Accuracy of measurement

During the monitoring period pressure and flow are measured on a 4 minute basis which means that the values are average values over a period of 4 minutes. Fluctuations during this period are equalized. This can result in too optimistic theoretical efficiencies also because efficiency losses due to change of operation point are not taken into account. The impact will be less during continuous flow beyond the start/stop modus (> min flow).

Process control

Even at flows (> 30 m3/h) beyond start/stop modus the difference between theoretical and practical COP is still 25% to 15%, whereof 7% can be explained by efficiency loss due to the motor and frequency converter. In practice we see that the well pumps are constantly adjusting to (quick) changes of flow. These constant adjustments result in pump efficiency losses. Process control can be an important factor to reduces these losses. A steady operation with a more gradual production and less fluctuations of demand introduced by the cluster installations (and indirectly by the mine water installations in the buildings) can improve the pump efficiency and COP of the system. This is part of the investigation and improvement to be executed in 2016.

The general conclusion is that the well pumps are functioning to an acceptable level. The differences between the practical and theoretical COP are explicable. Based on the above mentioned factors at least a 10% improvement of the COP must be possible.

Booster pumps

Figure 36 shows the efficiency of the booster pumps in practice, the theoretical efficiency of one frequency controlled booster pump and the actual operating curve based on hourly average values.

The possible causes for the significant discrepency between practice and theory are discussed on the basis of the following aspects:

- Pump selection and current operation;
- Efficiency motor and frequency converter;
- Accuracy of measurement;
- Process control.

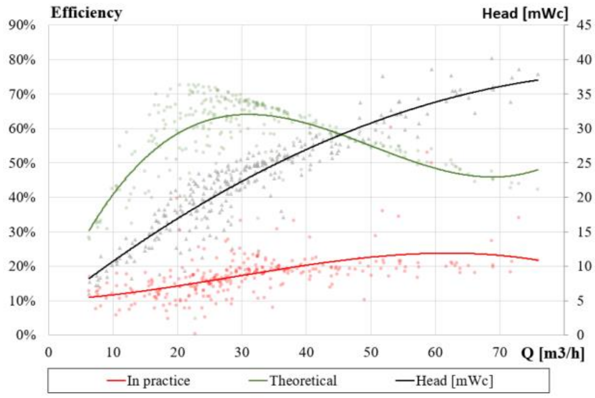

Figure 36. Efficiency of the booster pumps

Pump selection and current operation

Figure 37 shows the pumping curves of one booster pump for different frequencies and the actual operating curve based on 4 minute average values.

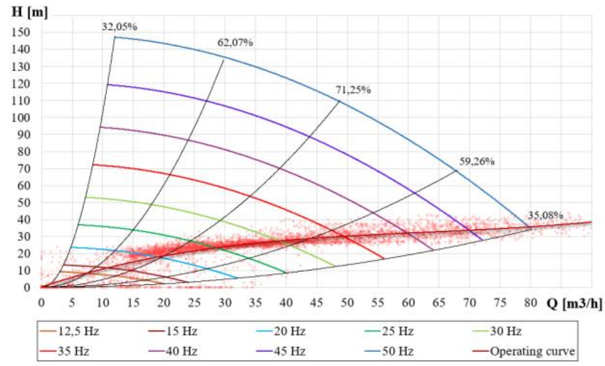

Figure 37. Frequencies and actual operating curve booster pump

As discussed in paragraph 4.1.3 the booster pumps were badly selected by the contractor and supplier on:

- Operation with a fixed pressure head of 10 bars instead of the (available) designed operating curves;
- All identical booster pumps instead of at least one smaller booster (jockey) pump during start/stop operation of the well pump;
- Only one frequency controllable booster pump instead of all.

These choices are mainly due to the bad performance of the boosting system. How these choices work out and can be mitigated is discussed below.

After the leakage incident at the cold production well (see paragraph 4.1.3) the control of the boosting system was modified. Control now takes place on differential pressure between requested distribution pressure (4.5 – 8 bars) and supply pressure of the well pump instead of the discharge pressure. During start/stop operation of the well pump, the supply pressure of the well pump can vary between 3.5 (start) and 7 (stop) bars. Above minimum flow the pressure is fixed on 3.5 bars.

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Operation booster pump during start/stop well pump (flow < min)

Two situations can be distinguished:

- Supply pressure well pump < requested distribution pressure: one frequency controlled booster pump on => boosting pressure 0 to 2.5 bars => frequency 10 – 25 Hz partly off-curve at left side with very bad pump efficiencies;
- Supply pressure well pump > requested distribution pressure: frequency controlled booster pump is off => Pressure is controlled by the pressure relieve valve in the by-pass of the booster pumps.

The conclusion is that the booster pumps are too large for start/stop operation to achieve a reasonable efficiency and durable operation. This can only be solved with a separate dedicated small frequency controlled booster pump (max 30 m3/h and 3 bars). One of the existing booster pumps has to be replaced.

Operation booster pump during continuous operation well pump (flow > min)

The required boosting pressure varies between 0 and 4 bars. At flows between 20 and 35 m3/h the requested differential pressures of the boosting pump can be very low due to available higher pressures in the pressurize buffer tanks (up to 7 bars) generated during start/stop operation of the well pump. In this situation the booster pump will run off the pumping curve with bad pump efficiencies and high wear. This can be solved by applying a minimum differential pressure of 1 bar.

In the current situation, the second pump is started if the frequency of the frequency controlled booster pump rises above 70% (35 Hz). In average based on the pump and actual operation curve this will be around 50 m3/h.

The second pump operates at full load. It creates a high pressure and flow and runs off its curve (50 Hz) which results in bad pump efficiencies. Meanwhile the frequency controlled pump reduces frequency and load drastically, also resulting in bad pump efficiencies. Because of the full load of the second pump, the desired distribution pressure will be reached quickly and the pump switches off again. Then the frequency controlled pump has to quickly speed up again and so on. Even with a steady demand this will lead to an instable operation of the booster pumps, bad pump efficiencies and high wear of the pumps, as observed in practice.

The conclusion is that all booster pumps should be equipped with frequency converters and operated with a minimum differential pressure of 1 bar. This also offers the possibility to optimized process control to achieve maximal efficiency.

Figures 38 and 39 show the improvement of the theoretical efficiency and COP if the second booster pump is also equipped with a frequency converter and operating with the same frequency.

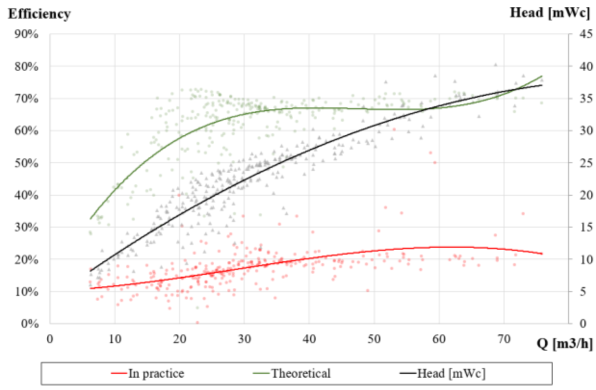

Figure 38. Efficiency booster pumps HH1

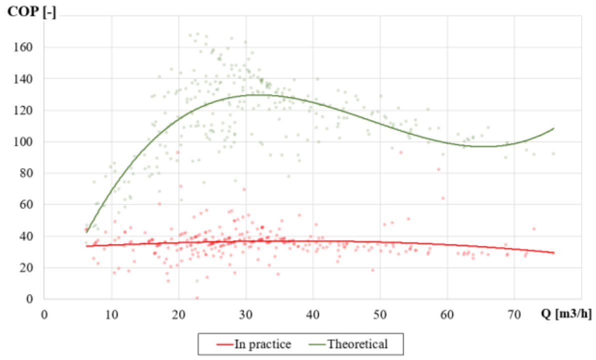

Figure 39. COP booster pumps HH1

It indicates that a much higher COP up to a factor of 2.5 to 3 must be possible for flows above the start/stop operation mode of the well pump (> 30 m3/h).

Efficiency motor and frequency converter

Figure 40 shows the power consumption of a booster pump.

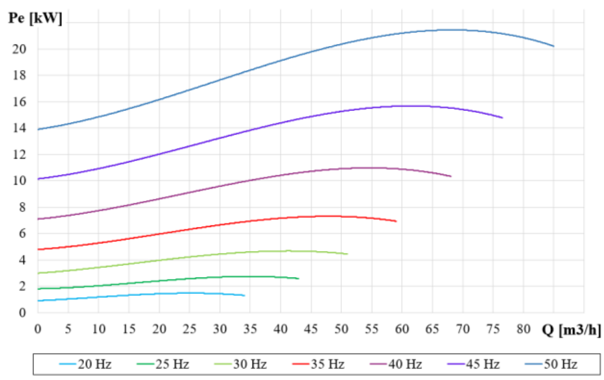

Figure 40. Power consumption of a booster pump

The maximum power is 22 kW. The selected motor is 30 kW. At maximum power the motor load is 73%. Relative to the maximum power the min load is about

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14/22 = 64%; a minimum load of the motor is 64% * 73% = 47%. So at each operation point, at each frequency, the efficiency losses of the motor and frequency converter are at normal levels between 5 and 10%. This can't be the cause of the poor efficiencies encountered in practice.

Accuracy of measurement
This aspect has a bigger impact for the booster pumps than for the well pump. Flow variations are almost equal to the well pump, but the pressure head fluctuations are much stronger and quicker. This leads to average theoretical efficiencies that are too optimistic, especially during start/stop modes of the well pump (< 30 m3/h) and at higher flows (> 50 m3/h) when the second, not frequency controlled booster pump is switching on and off.

Process control
Based on the analysis above, one would expect a better efficiency in practice between 30 and 50 m3/h, but this is not the case. There is no clear demarcation visible. The practical COP is almost a straight line until 40 m3/h and then declines; due to higher distribution pressures. The two specific situations of operation that cause bad pump efficiencies seem to flow over in each other. In addition, the constant adjustments to quick changes of demand as already discussed for the well pump will have its influence and should be optimized but is not the main cause for the bad COP of the boosting system. The influence is expected to be in the same range as for the well pump with a reduction of efficiency compared to theory between 35% for low flows and 15 % for high flows.

In general (not knowing all the factors exactly) it can be concluded that the COP of the boosting system can be significantly improved with more than a factor 2 from 38 to 100 by the following mitigations:

1. Replacement of one booster pump by a smaller booster (jockey) pump for operation during start/stop operation of the well pump (max 30 m3/h; 3 bars);
2. Providing all other (existing) booster pumps with frequency converters;
3. Control on maximal efficiency by frequency control;
4. A steady operation with a more gradual production and less fluctuations of demand introduced by the cluster installations.

Together, with the improvement of the well pump COP of 10% by above mentioned mitigation 4, the total COP can be improved with more than 60%, raising from a current average COP of 13.4 up to 22 or more.

5.2 Reuse waste heat and COP heat pumps APG Pension fund

At the APG Pension Fund the datacenter is cooled by a cascade of 8 small heat pumps with a total cooling capacity of 520 kW and a heating capacity of 620 kW. The cooling demand is reduced due to higher permitted temperatures in the datacenter, of up to 24 ˚C, and a shift of datacenter capacity from the Heerlen location to the APG location in Amsterdam. In the past 2.5 years it was stable at level of 40% of the available support capacity (waste heat production 260 kW; 8760 hours per year). It also means that a major part of the heat demand is still supplied by gas boilers.

In figure 41 the configuration of the heating circuit of the heat pump system is shown with its connections to the heating system of the building and cluster grid. The waste heat is first supplied to the building and the surplus heat is discharged to the cluster grid for reuse by other connected buildings.

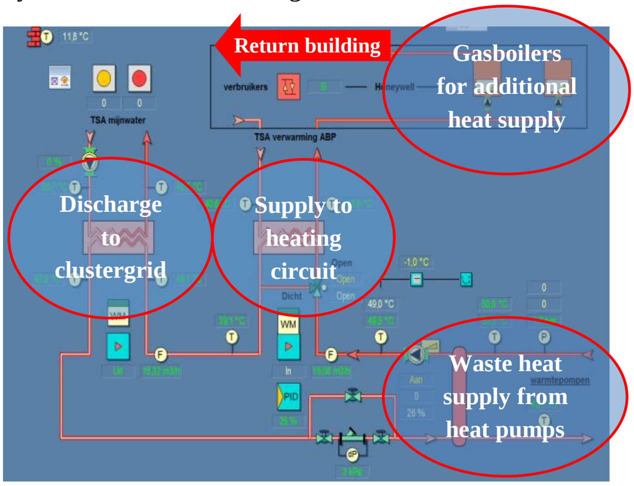

Figure 41. Configuration of the heating circuit of the heat pump system APG

The heating system of the building and cluster grid are hydraulically separated by heat exchangers from the heating circuit of the heat pump system. In the heating system of the building the return flow from the end-users is first heated up by the waste heat through exchange with the heat pump system and then topped up by the gas boilers to the demanded heating temperature.

The heat pumps are operating at a cooling temperature of 6 ˚C. During supply of the waste heat to the APG building the required heating temperature is 50 ˚C and the surplus of heat is discharged to the cluster grid at temperatures between 40 and 45 ˚C. During full discharge of the waste heat to the cluster grid in summer the heating temperature of the heat pump is reduced from 50˚C to a temperature of 32 to 37 ˚C depending on the available cooling temperature from the cluster grid (15 – 20 ˚C), to improve efficiency.

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Waste heat reuse

Tables 7 and 8 show the current and potential input of waste heat in the building for 2013/2014 and 2014/2015.

Table 7: Data APG period august 2013/august 2014

Waste heat production [GJ]	Reuse waste heat building [GJ]	Potential waste heat reuse [GJ]	Total heating demand [GJ]	Total degree days [-]
8,048	1,972	5,503	7,911	2,468
102%	25%	70%		
%total heat demand				

Table 8: Data APG period august 2014/august 2015

Waste heat production [GJ]	Reuse waste heat building [GJ]	Potential waste heat reuse [GJ]	Total heating demand [GJ]	Total degree days [-]
7,887	3,031	5,514	9,686	2,721
81%	31%	57%	122%	110%
%total heat demand			Comparison with 2013/2014	

The potential waste heat input is the amount of waste heat that could be used by the building; based on the total heating demand. If the heat demand is higher than the available waste heat capacity, then all waste heat should be reused. If the heat demand is lower than the available waste heat capacity, then the total heat demand should be supplied by waste heat. The tables 7 and 8 and figures 42 and 43 show that this is not the case. In 2013/2014 only 1,970 GJ of the waste heat potential of 5,500 GJ was reused. In 2014/2015 the reuse was significantly higher with 3,030 GJ of the waste heat potential of 5,500 GJ.

In the first year of operation (2013/2014) the heating system of the building was not tuned well enough to the new situation. The set point for the heating temperature to the building was set too high, even higher than the design set point of 50 ˚C, not aware of the consequences. This resulted in high return temperatures up to 45 to 50 ˚C from the building with a low input of waste heat. Another shortcoming was the tuning of set point of the room temperature in the building after business hours; it was not changed. The night reduction was about 3K. After 18.00 o'clock the heating system was more or less shut down and the waste was fully discharged to the cluster grid. In the morning the building was heated-up with peak load by the gas boilers in a short time with little input of waste heat. In consultation with APG the supply temperature of the heating system was reduced to 45 ˚C. Also the setback of room temperature after business hours was reduced to keep the building warmer during the night and to reduce the morning peak. By these measures the waste heat reuse was significantly increased in the period 2014/2015 from 36% to 55% of the waste heat reuse potential (See also figures 42 and 43 the blue line versus the black dashed line).

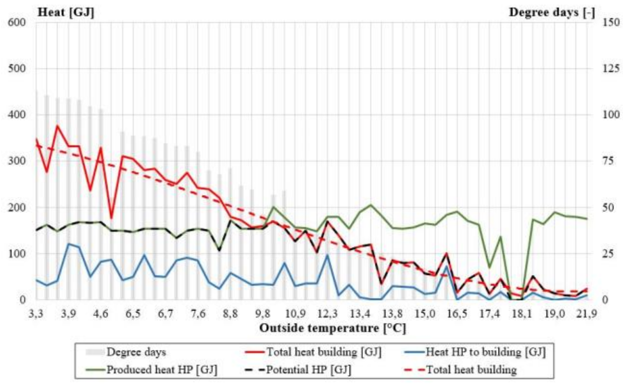

Figure 42. Heat demand, actual and potential waste heat reuse period august 2013/august 2014

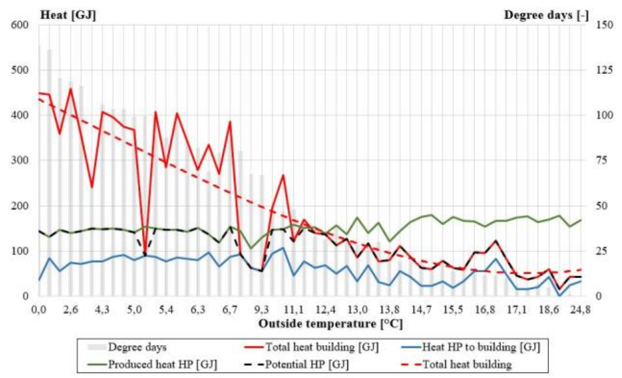

Figure 43. Heat demand, actual and potential waste heat reuse period august 2014/august 2015

COP Heat Pumps

Figure 44 shows the COP of the heat pumps during the season of 2013/2014 (November to August; green line), 2014/2015 (August to August; red line) and 2015/2016 (August to February; blue line).

Figure 44. COP Heat pumps APG Pension Fund period 2013/2014, 2014/2015 and 2015/2016

The design COP for the condition 50/6 ˚C is 4.2. The figure shows that a COP of > 4.0 is realized during the period 2013/2014 in winter and up to 6.0 in summer.

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In the period 2014/2015 the COP was lower (winter 3.8; summer 4.8) due to two major aspects:

1. "Hidden" causes in the heat pump installation (disturbed heat pump control and communication with overall control system) resulting in an increased number of start/stops of the heat pumps. The failure was observed by comparing the monitoring results of 2013/2014 and 2014/2015. Since November 2015 (week 48) this failure was solved and COP improved again;
2. Reduction of room set-temperature after business hours. More waste heat is supplied to the building at a temperature of 45 to 50 ˚C instead of full discharge to the cluster grid with temperatures of 32 to 37 ˚C.

Improvements
Further improvement of the COP and an additional increase of waste heat reuse will be realized by applying:

- A heating curve based on the outdoors temperature between 35 ˚C ($T_{outside}$ > 15 ˚C) and 50 ˚C ($T_{outside}$ < 5 ˚C);
- Frequency controlled pumps in the heating system of the building to increase delta T to 10K during base load;
- Modulating gas boilers, up to zero capacity.

In this way, the heating system of the building and heat pumps can be balanced in the most optimal way and adapted to the actual heat demand of the building.

In the current situation the heating circuit of the building has a fixed high flow of 60 m3/h based on peak load (700 kW) and a delta T of 10K. The delta T varies with the demand. The heating circuit of the heat pump system is designed and operating on delta T of 10K with a variable frequency controlled flow (average 22 m3/h) that adapts to the waste heat production (average 260 kW). The delta T is constant. For full input of waste heat to the heating system of the building the waste heat from the heat pumps has to be cooled down from 50 to 40 ˚C. This requires a maximum return temperature from the building of 39 ˚C. Then the fixed flow of the building's heating system of the building is lifted up to 42.7 ˚C (delta T max 3,7K). This temperature is insufficient to heat the building for a big part of the year, which leads to needless additional heat input by the gas boilers, higher return temperatures and less waste heat input are possible. Each degree more than 42.7 ˚C means 10% less waste heat input.

5.3 Heat pump performance Central Bureau of Statistics (CBS)

In Q4 2015 Mijnwater BV carried out an investigation into the efficiency of the power plant in the CBS building. The reason for this study was the limited contribution of the heat pumps to the total heating and cooling demand. The current heat pump set-up has a heating capacity of 275 kW and a cooling capacity of 175 kW. The total installed traditional capacity is 1.300 kW for heating (2 heat boilers) and 2.000 kW for cooling (2 chillers).

Table 9 and 10 shows the delivered heat versus the total demanded heat for respectively 2013 and 2014. Table 11 and 12 show the supplied cooling versus the total demanded cooling for respectively 2013 and 2014. In addition, these tables show the potential contribution of the heat pumps in relation to the total demand.

Table 9: Heating CBS 2013

	kWh	GJ	% Part	% Potential
Total	1,016,111	3,658	100%	
Heat pump	336,443	1,211	33%	47%
Potential	717,289	2,582	71%	

Table 10: Heating CBS 2014

	kWh	GJ	% Part	% Potential
Total	850,833	3,063	100%	
Heat pump	349,260	1,257	41%	57%
Potential	615,382	2,215	72%	

Table 11: Cooling CBS 2013

	kWh	GJ	% Part	% Potential
Total	541,111	1,948	100%	
Heat pump	161,111	580	30%	55%
Potential	292,870	1,054	54%	

Table 12: Cooling CBS 2014

	kWh	GJ	% Part	% Potential
Total	479,167	1,725	100%	
Heat pump	209,921	756	44%	72%
Potential	292,016	1,051	61%	

These tables show that the contribution of the heat pumps lags behind on the potential. The potential of the heat pumps in 2014 was 72% for heating and 61% for cooling.

Also, the heat pump contribution rose since the implementation of the demand-driven system (Minewater 2.0) in 2014 from 33% to 41% for heating and from 30% to 44% for cooling. This achieves the potency of approx. 60% for heating and approx. 75% for cooling. The contribution has increased because now heat and cold may be provided at any given time, while in the old situation (Minewater 1.0) only heat could be delivered in the winter and cold in the summer.

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Contribution heat by heat pumps

In figure 45 the power output of the heat pump (red) and the total demanded power (blue) are shown for 2014. The heat pump heating potential is shown with a black line.

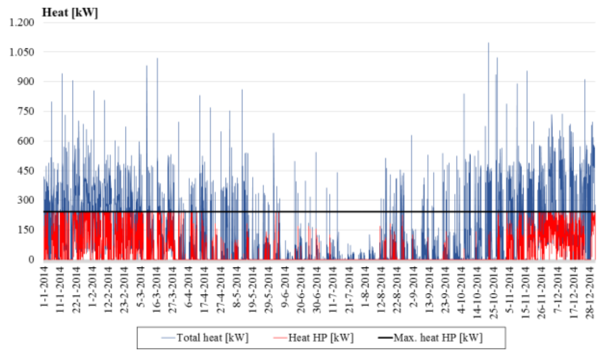

Figure 45. Heating demand CBS-building in 2014

The graph shows that the contribution of the heat pump is at its maximum at a total heat demand higher than 500 kW and is declining at a heat demand lower than 500 kW. The actual cause of this appears to be the minimum required power of the boilers (approx. 35% = 225 kW). Once the total demanded heat power is lower than 500 kW (minimum power boilers + maximum power heat pumps), then the boilers will reach their minimum power. This will produce these improper amounts of heat and will induce a rise in the supply temperature to the building. This results in a higher return temperature from the building, whereby the heat pumps can't add their full power. The heat demand is less than 500 kW for the greater part of the year, which results in a reduction of the heat pump contribution.

Contribution cooling by heat pumps

In figure 46 the power output of the heat pump (red) and the total power (blue) are shown for 2014. The heat pump cooling potential is shown with a black line.

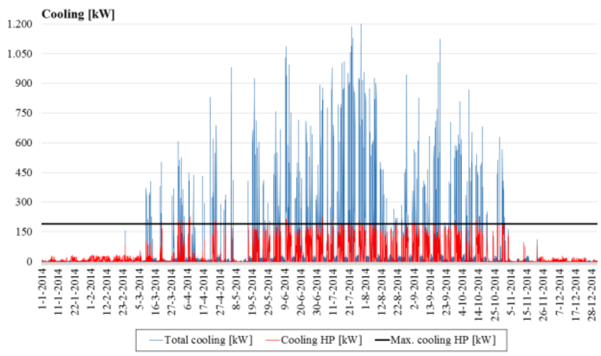

Figure 46. Cooling demand CBS-building in 2014

For cooling the effect is identical to heating, but not as strong. This is because the minimum required power of the chillers is lower (approx. 12.5% = 125 kW) than the maximum power of the heat pumps (175 kW). Besides that, the cooling demand has more peaks. When the demanded cooling power is lower than 300 kW (minimum power chillers + maximum power heat pumps), than the chillers produce an improper amount of cooling and the heat pumps will be pushed back. The contribution of the heat pumps of 44% is much closer to the potential of 61%.

Improvement contribution heat pumps

The reduction of the peak demand by a more gradual heat up and cooling of the building during the day, which normally ensures that the heat pumps are running longer and increasing the contribution of the heat pumps, now has little effect. This is because the period becomes larger in which the heat pumps are pushed away. There is a so-called dead-lock situation.

Further improvement is only possible by placing smaller central heating boilers and chillers or to increase the capacity of the heat pumps. The latter is part of the proposal of Mijnwater BV to CBS for acquisition of the total energy supply to CBS.

5.4 Modification minewater installations buildings

Every building connected to the cluster grid has its own pumping installation for extraction and injection of cluster water and transportation through the grid. The pressure loss in the grid is variable due to demand and exchange between buildings in the cluster grid. Mijnwater experienced that during very low flow and pressure losses in the grid, the frequency controlled pumps still have too much flow during minimum frequency. To avoid this pressure valves had to be throttled by hand, which led to efficiency loss during normal operation and excess wear of the pumps. To avoid this, an overflow is added which opens when pumps have reached the minimum capacity to reduce the net flow needed for capacity control of the heat exchange. This situation was already foreseen during design and provisions were already made to adapt easily. It has become part of the blueprint (see paragraph 2.4).

6. CONCLUSIONS

Mijnwater developed from a project into a business and became a private company in November 2013, fully owned by the municipality of Heerlen;

Mijnwater is a successful initiative with 175,000 m2 of building floor area connected to the grid and 30 million euros invested at the end of 2015;

Mijnwater developed and realized a replicable blueprint for future 4th generation DHC systems, not only for old mining areas;

A public owned utility company like Mijnwater B.V. can significantly contribute to realization of regional energy transition targets;

Ownership and operation not only of the grid but also of decentralized energy stations (heat pumps) in the connected buildings are essential to optimize

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the operation of the total energy infrastructure in low energy (exergy) areas;

Smart storage and an intelligent top level control frame-work (Mijnwater 3.0) with multiple control strategies to balance demand and supply are essential for minimizing infrastructure, to increase passive reuse and CO2-emission reduction up to more than 80% and for improvement of the business case;

A successful operation and business case is based on an integral demand driven approach from the heating and cooling systems and energy stations in the building back to the mine water wells and grids;

Future sustainable multiple sourced DHC grids need smart flexible hybrid energy stations, as designed, constructed and operated by Mijnwater, that can adjust to fluctuating temperatures in the grid and temperature demands in the connected buildings to prevent exergy losses, to improve efficiency and to maximize passive reuse;

The Mijnwater Energy Carrousel is a smart cost effective multifunctional storage concept for balancing demand and supply that enables to reduce the capacity of the energy stations up to a factor 3 and to increase the connected m2 of building floor area to grid by a factor 4 to 5, in combination with limited input of high temperature sources (solar thermal, biomass, HT waste heat or excess green electricity of the electricity grid);

Energetic refurbishment of the existing building stock will be most cost effective by utilizing area solutions like local green generation, storage, and exchange facilitated by a thermal grid linked to reduction of energy losses by improved envelope and individual PV generation;

The Mijnwater 2.0 system proofs that properly designed, constructed and commissioned pumps can be put in series and work perfectly well. It only needs special attention and awareness of the application;

New innovative concepts like Mijnwater 2.0 need a Master of Concept, controlling the entire process from idea to realization. Conventionally orientated consultants and constructors still miss the knowledge and skills to cope with this kind of high tech low energy/exergy concepts. A solid commissioning protocol is necessary to costly avoid failure and bad performance.

Monitoring of the mine water reservoir indicates that the geothermal potential of the hot part of the mine water reservoir has not been impacted during system operations while the cold part of the mine is showing the first signs of depletion due to fact that in the past two years the reservoir is still mainly used as a source (Mijnwater 1.0). It proves that the geothermal capacity of the reservoir is limited. Since February 2016 all provisions for the use of the reservoir as storage (Mijnwater 2.0) are in place and further depletion is prevented;

The performance of the Mijnwater network stays behind expectation due to bad performance of production wells, caused by lack of understanding and bad execution of the concept by the contractor. Investigations show that the COP of the hot production well (HH1) can be improved with more than 60% from a current average COP of 13.4 up to 22 or more by re-engineering of the boosting system (one small boosting pump, all pumps frequency controlled);

Performance of the bivalent energy stations of CBS and APG (operated and owned by the client) stays behind expectation due to (typical) shortcomings in the hydraulic and process control system of the energy stations and heating and cooling systems that lead to a low contribution and/or efficiency of the heat pumps and can easily be improved by simple low-cost mitigations. Clients are often are not aware of this due to lack of specialized knowledge and performance agreements with the contractor.

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ATTACHMENT 1: FIGURE 4. SCHEME CENTRAL HEAT PUMP STATION