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Mine water geothermal energy a source of energy for heating, cooling and storage - From status quo to challenges and monitoring of existing systems

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Abstract

Due to the Paris Agreement on climate change, it is essential to make the transition to renewable energies in the heating sector in order to achieve the climate targets. Abandoned mines can provide an opportunity for renewable energy supply. Based on the almost constant temperature level throughout the year and the large rock surfaces as a heat-transferring area, mine water is suited perfectly for heating, cooling and storage of energy with heat pump application.

In Germany, mine water geothermal plants have been built and put into operation in the last decades. Nowadays more plants are also being projected and implemented for example in the Ruhr area (hard coal field in west Germany). Furthermore, specific System locations, such as the "Reiche Zeche" in Freiberg and the "Schillerschule" in Aue-Bad Schlema, will be shown to illustrate technical requirements, designs and general conditions.

The correlation between the seasonal performance factor (SPF) and the temperature difference between mine water and the consumer temperature is a crucial factor—especially in relation to the integration of the system into an existing or new heating concept. Monitoring data from existing facilities shows that the combined supply of heating and cooling can result in high overall system efficiency, with total SPF values exceeding 7. In the case of a plant in Aue-Bad Schlema, various measurements were taken due to a noticeable decline in performance. The data from 2014 to 2019 indicate an average SPF of 2.2. However, due to several influencing factors, the system is capable of reaching a SPF of up to 2.8 without major modifications. With further optimizations, performance improvements up to a SPF of 3.5 or higher are possible, making the system more cost-effective and sustainable.

The monitoring parameters required for future systems and systems undergoing inspection are identified based on the findings. The required and recommended measurement data are central to evaluating functionality, analysing operational safety, and determining seasonal performance factor (SPF). Specific conclusions about system operation and possible environmental impacts for both heating applications and storage systems (MTES) can be drawn based on this data. These conclusions are the result of years of analysis.

Keywords: Monitoring, Construction, Performance, Efficency

1. Introduction

The transition to a greenhouse gas-neutral and climate-neutral energy supply is one of the most important challenges facing Europe and Germany in the 21st century. While the share of renewable energies in Germany is increasing, the focus is often on the electricity sector rather than the heating sector. Accordingly, there is significant potential and a pressing need for a switch to renewable energies in the heating sector to help achieve climate targets.

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These conditions explain why cities and municipalities want to use regional energy sources. In regions with former mines, underground excavations filled with water after decommissioning can serve as geothermal energy sources. This is the case in the Ore Mountains, where various municipalities have mines located directly beneath them. Some municipalities have already built small-scale plants in recent decades, which supply different types of buildings with heat and/or cooling in lower output classes. These plants can now serve as reference or learning facilities. This data can be used to improve knowledge and make enhancements to new large-scale plants in the megawatt range. Examples include the “Reiche Zeche” in Freiberg and the “Schiller School” in Aue-Bad Schlema. [1] see in Figure 1.

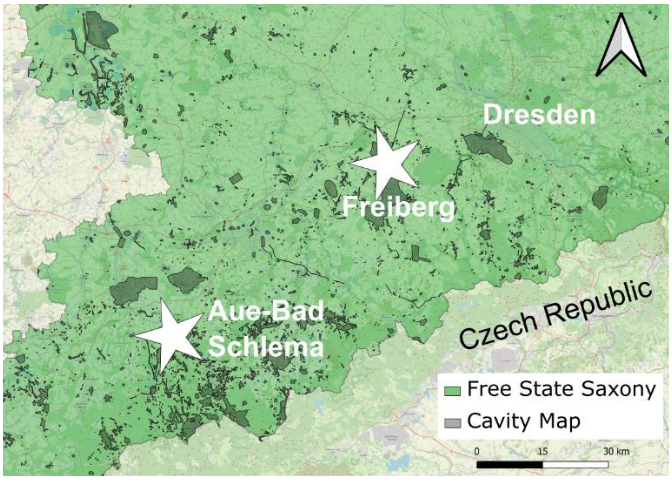

Figure 1 Locations of the two mine water plants in Aue-Bad Schlema and Freiberg

At the Reiche Zeche plant, geothermal energy from mine water is used to heat and cool offices, laboratories and server rooms. As can be seen in Figure 2, the geothermal energy plant has two possible water extraction points.

- The main shaft, 'Reiche Zeche' (RZ), provides access to deep water at a temperature of 19 °C throughout the year. This is mainly intended for heating in winter. (Winter operation)
- The cooler 'Rothschönberger Stolln' (RSS) drainage gallery, with water at 14 °C, is mainly used for cooling. (summer operation).

Depending on the heating and cooling requirements, the extraction points can be switched between according to the construction plans. In addition, water can circulate through the underground heat exchanger (the intermediate circuit) to the above-ground cooling/heating circuit, which is hundreds of metres long. This achieves a temperature difference for cooling/heating solely by transferring heat to or from the mountain. The system also has a cold storage unit which stores fluid that has been cooled in the heating circuit for reuse in the cooling circuit. As shown in Figure 2, the system comprises various feed pumps, two heat exchangers, two heat pumps and a cold storage unit. The system has a thermal output of 175 kW and a cooling capacity of 100 kW. [2,3]

Since 2020, the Rothschönberg gallery has been undergoing renovations, which have caused the upper section of the gallery to become dammed up. This has led to a temporary drop in water volume. [4] After the water has been drained, it carries particles and dirt with it, which has led to the plant being shut down as a precaution, since there was not enough clean water available.

At the Schiller School mine water geothermal plant, the mine water is mainly used to heat the classrooms. In addition to the classrooms, the school has a swimming pool, which is also heated. The Schiller School is located directly above the Schlema-Alberoda mine. [5] The mine water serves as a heat source and is lifted approx. 90 m via a production well using a pump, fed through heat exchangers and then discharged freely. As can be seen in the plant diagram in Figure 2, the mine water geothermal plant has two possible water extraction points, although only one borehole is operated with a pump.

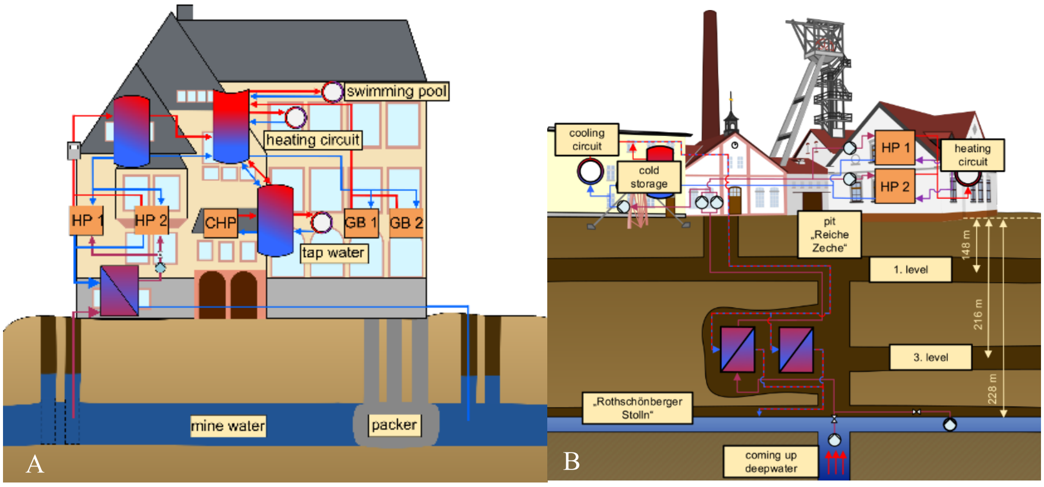

Figure 2 Schematic illustration of the Schiller School (Bad Schlema)(A) and Reichen Zeche (Freiberg)(B) plants

As shown in Figure 2, the geothermal plant is integrated into the heating system as one of several heat generators. The two heat pumps (HP1 and HP2), installed after the mine water intermediate circuit, have a thermal output of 53 kW each. In addition to the heat pumps, Schiller School has two gas condensing boilers (GB1/2) and a gas-powered motorised combined heat and power (CHP) plant. The two gas boilers have a thermal output of 160 kW each and operate at a flow temperature of 70 °C and a return temperature of 35 °C. Meanwhile, the CHP unit has a thermal output of 34 kW. Since 2019, the heat pump has been out of service due to an unknown fault; consequently, heat is only generated by the natural gas-fired condensing boilers. The school also has a ventilation system. [5]

The issue lies in the recommissioning of a generation plant, which is to be undertaken with a comprehensive understanding of the plant and its functionality, absent specific documentation, and based on measurement data. Any potential sources of error must be identified and analysed. Additionally, the plant's efficiency was evaluated mathematically to provide an objective basis for assessing its operating condition. Based on these results, potential for optimisation is to be derived to contribute to increasing the operational safety and energy efficiency of the plant. Furthermore, general requirements must be established for the planning and construction of plants with measurement technology. Therefore, it is necessary to clarify how existing geothermal energy plants that use mine water work, what optimisation options are available, and how these can be implemented in terms of measurement technology.

2. Approach

Reiche Zeche

As can be seen in [6] and [7] the Reiche Zeche plant can achieve a coefficient of performance (COP) of up to 10, depending on the operating point. Operating modes were defined to better evaluate and characterise plant behaviour based on its design. These differ depending on the intended use (heating, cooling, or heating and cooling), but the various water extraction points were not considered. Overall, it can be seen in Figure 3 that the mine water plant was primarily used for combined heating and cooling. Pure cooling operation accounts for an equally large proportion, primarily due to the use of colder water from the Rothschönberg gallery and the need to cool the server rooms all year round. While pure heating operation with the warm water from the shaft is possible, the cooling of the server rooms means that a basic cooling load must be provided almost continuously.

The full potential of the system could not be exploited during the period under review due to a defective shut-off valve. As automatic switching was not possible, cooler water from the Rothschöberg gallery had to be used for heating in winter.

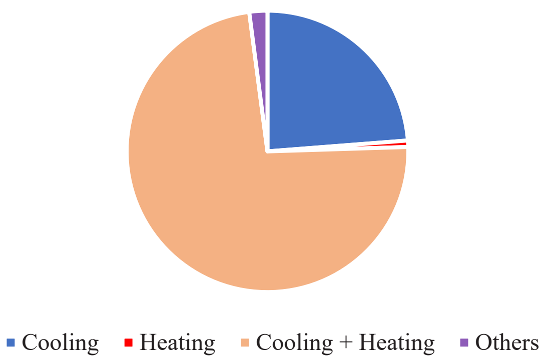

Figure 3 Share heating and cooling mode 3 years duration

The seasonal analysis of operating modes in Figure 4 shows that the heating and cooling mode is most prevalent in summer, with the cooling-only mode accounting for a significant proportion. This suggests that water from the Rothschönberg gallery was used for cooling purposes, or for cooling and heating in parallel. This is to be expected, given that the colder water (13–14 °C) is used for cooling purposes. It is also possible that heating and cooling only occur via the intermediate circuit when the heat transfer medium circulates in the shaft.

In winter, pure cooling declines and the combined supply to the building increases. This operating mode is geared towards using the Rothschönberg gallery and extracting cold air in conjunction with heat gains via the intermediate circuit, where further heat gains for the system can be recorded. Additionally, the shaft was able to provide a significant proportion of the heating energy.

During the transition periods, combined operation predominated, as did the use of the gallery and the heat gains from the intermediate circuit. Based on the monitoring data, the use of warm shaft water was reduced as it is seen in Figure 4.

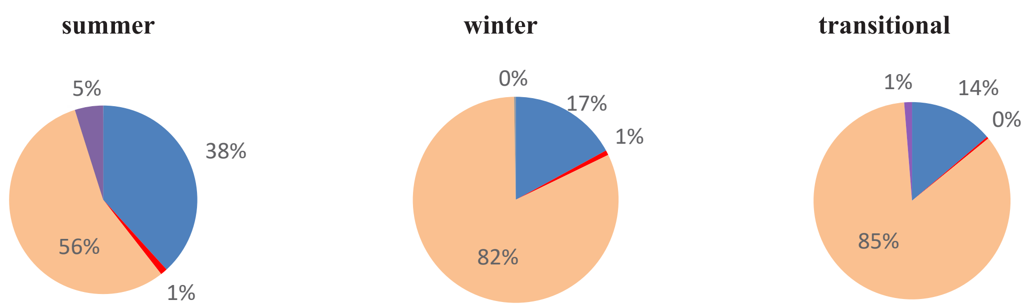

Figure 4 shows the temporal share of the heat pump runtime by season; two heat pumps are installed in the system (blue-cooling; red-heating; yellow- heating+cooling; purple-others)

Heat pump 2 and 1 had a heat output between 38 kW and 41 kW. Over the entire measurement period, the proportion is 26 % to 6 %. Both pumps are off for the most part in the transitional period and in summer. In winter, at least one of the heat pumps is in operation 70 % of the time. However, there is still a large potential here; only in 7 % of the cases are both heat pumps used at the same time, so there is still capacity available to supply more users with heating.

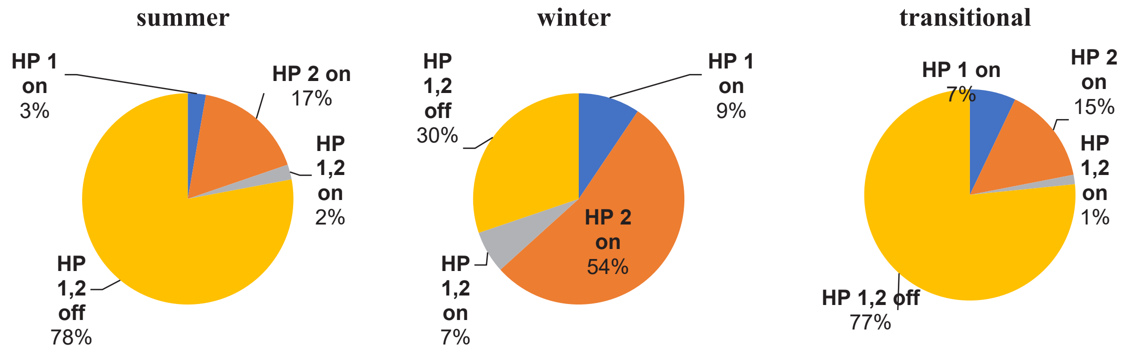

Figure 5 Proportion of heat pump running time by season (04/2015-12/2018)

However, the system also has room for improvement in many areas. Due to recurring defects in the automatic switching between the water extraction points, the warm water from the Reiche Zeche shaft could not always be used even when the demand for heating was high. In addition, the heat pumps often run at partial load, which reduces the system's efficiency. Here it is necessary to make better use of the system, e.g. by connecting additional consumers. This is also shown by the analysis of the heat pump running times. Even in winter, both heat pumps are very rarely used simultaneously (< 10%). The temperature spread of the mine water can also be increased, but the corresponding demand must also be available for this. In the end, the numbers show that it is better to use both heating and cooling together. This eliminates the need for a separate supply system for cooling, for example, and also increases the system's overall efficiency. Additionally, heat pumps can be operated alternately to increase total running time.

Schiller School

Several years of almost complete monitoring data for the system make it possible to analyse the efficiency of the heat pump system's operation. Various sensors with measurement data were available for this purpose and could be used for the evaluation. These include the inlet and outlet temperatures of the mine water, the volume of mine water pumped, and the flow and return temperatures of the intermediate circuit and heat pumps. In addition, a cumulative heat meter was available to provide the recorded thermal energy quantities for further evaluation.

The seasonal coefficient of performance is used to evaluate the efficiency of the heat pump. Since this system has meter readings for both the heat pump consumption and the mine water pump consumption, a second coefficient of performance can be calculated (comparable to the coefficient of performance of the "Reichen-Zeche" system). Both the seasonal coefficient of performance for the heat pumps installed in the heating system itself and the seasonal coefficient of performance for the complete 'mine water heat pump' system consisting of the heat pumps and the mine water pump can be calculated. This made it possible to calculate the key figures for the periods shown in Tabel 1. Two values are specified for the heat quantity of the heat pump in the existing monitoring system. The performance factors calculated using the heat quantity from the heat quantity meter are given an additional index 'HM'. The following variables are calculated for the evaluation:

$$.SPF_{HP} = \frac{Q}{W_{elektcHP}} \tag{1}$$

$$SPF_{MWHP} = \frac{Q}{W_{electrHP} + W_{electrMW}} \tag{2}$$

- "HP: Coefficient of performance of the heat pump according to equation (1), calculated using the heat quantity from the internal meters
- "MWHP: Coefficient of performance of the mine water heat pump according to equation (2), calculated using the heat quantity from the internal meters

- "HP, HM: Coefficient of performance of the heat pump according to equation (1), calculated using the heat quantity from the heating system's heat meter
- "MWHP, HM: Coefficient of performance of the mine water heat pump according to equation (2), calculated using the heat quantity from the heating system's heat meter

Tabel 1 Calculated working figures for the defined time periods

time periods	SPF_{HP}	SPF_{MWHP}	$SPF_{HP,heat\ meter}$	$SPF_{MWHP,heat\ meter}$
10-2014 till 02-2015	2.46	1.37	3.26	1.82
2015-2017 (Gap in meter readings)	2.40	1.59	3.25	2.15
02-2017 till 02-2018	2.26	1.10	2.72	1.31
02-2018 till 02-2019	2.49	1.41	3.14	1.78
02-2019 till 05-2019	2.38	1.43	3.07	1.85

From equation 2 of the basic equation for heat transfer and a calculated factor for electrical power with the mine water coefficient of performance (FPFMW), which is specified as a function depending on the temperature difference T extracted from the mine water.

$$SPF_{MWHP} = \frac{\dot{Q}}{P_{electr,HP}+P_{electr,MW}} = \frac{SPF_{HP} \cdot P_{electrHP}}{P_{electrHP}+\frac{SPF_{HP} \cdot P_{electrHP}-P_{electrHP}}{SPF_{MW}}} = \frac{SPF_{HP}}{1+\frac{SPF_{HP}-1}{SPF_{MW}}} \tag{3}$$

Figure 6 illustrates the relationship shown in equation (28), which is dependent on the SPF for mine water. The coefficient of performance of the mine water heat pump system is plotted against that of the heat pump itself. Here, the coefficient of performance of the mine water or the temperature difference resulting from heat extraction acts as the plough parameters. Even though no temperature differences can be added or removed, only heat quantities can be, the terms 'extracted temperature difference' and 'extracted temperature differences' are used throughout, since the extracted heat quantity can be reduced to a temperature difference ΔT at a constant density percentage, volumeflow and specific heat capacity c_p.

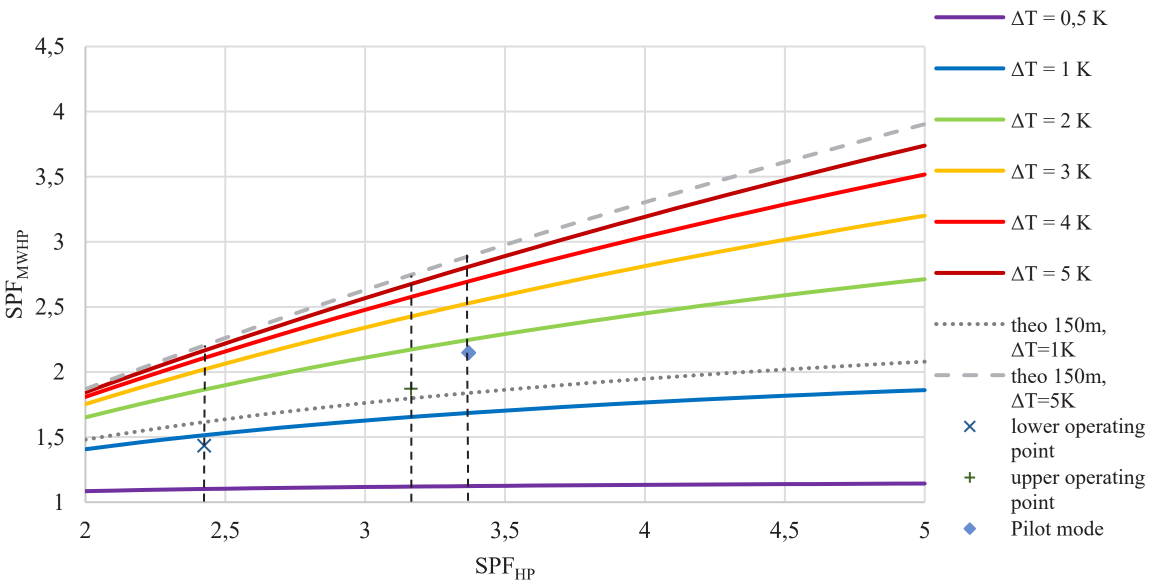

Figure 6 Potential for optimising the SPF of the mine water heat pump during recommissioning by adjusting operating behaviour

Figure 6 shows the dependencies for the existing system for temperature differences of 0.5, 1, 2, 3, 4 and 5 K. In addition, the diagram shows the two calculated operating points and the operating point of the pilot operation. Temperature differences greater than 5 K are not considered here, since it is not possible to cool the mine water by more than 5 K on a permanent basis at inlet temperatures of approximately 11 °C, in order to prevent the discharge of water colder than 6 °C. It can be seen that, at the lower operating point, the mine water is cooled by less than 1 K; at the upper operating point and the pilot operation point, cooling is

between 1 K and 2 K.
It is also evident that, with low heat extraction from the mine water (T = 0.5 or 1 K), the coefficient of performance of the mine water heat pump remains low, regardless of the heat pump's coefficient of performance. At higher temperature differences of 4 to 5 K, the mine water heat pump can achieve significantly higher coefficients of performance. This figure illustrates the potential of this system, always assuming that the volume flow can´t be further regulated, because 20 m³/h is the maximum as is currently installed. Nevertheless, further measurement data could support more detailed investigations.

The two heat pumps operate according to the master-slave principle. Heat pump 1 acts as the master machine, while heat pump 2 acts as the slave machine.
During the 4.5-year data period, heat pump 1 produced 79.6% of the heat, while heat pump 2 produced the remaining 20.4%. However, this does not reflect the intended operation, since the heat pumps are designed to run in parallel in master-slave mode and not to be redundant. Therefore, optimisation of the control and operation of the two heat pumps within the heating system is required to achieve proportions comparable to those at the “Reichen Zeche”.

Therefore, to ensure the mine water heat pump operates efficiently, the temperature difference extracted from the mine water must be increased. Cooling the mine water more effectively offers two significant advantages. Firstly, it enables a more precise analysis of existing systems in terms of their efficiency and mode of operation, allowing their strengths and weaknesses to be systematically identified. Secondly, the same amount of heat could be extracted while reducing the mine water volume flow. In this case, a smaller feed pump would probably be required, as even at maximum heat pump output, only around half of the current maximum volume flow is needed.

The school building under consideration has various heating and cooling systems installed. To date, these systems have only been partially integrated in terms of hydraulics and control technology. During periods when cooling is required, such as in summer or during the transition periods, integrating the mine water system would relieve or replace the existing air conditioning units. When using geothermal mine water systems for heating and cooling, heat is extracted from and supplied to the mine water. This approach can contribute to the regeneration of the geothermal system and can also be considered a form of thermal energy storage, either by deliberately introducing excess heat into the ground or by compensating for deficits.

3. Discussion

Reiche Zeche

During the ongoing renovation of the Rothschönberg gallery, the shutdown of the spring water supply caused the Reiche Zeche plant to fail, despite the availability of a second heat source (the Reiche Zeche shaft). This situation highlights the need for a different approach to restarting the plant. To ensure stable operation of the plant, it is therefore necessary to guarantee the water supply via the alternative source: the shaft water. This can be achieved by installing a controllable shut-off valve and a redundant system that can be operated manually, as the components can be accessed manually at the extraction point. Systems that are usually automatically controlled can be equipped with manual backup devices to circumvent malfunctions, such as those caused by defective valves. Where possible, these components should be installed in positions that allow for manual intervention. These measures can increase operational safety and ensure the plant's long-term resilience during recommissioning and operation.

Training and ongoing qualification of operating personnel is also important for the efficient future operation of the Reichen Zeche plant, as well as the Bad Schlema plant and others. Although the plant was intended as a pilot, it can technically supplement the existing gas-fired system, diversify the energy mix, and reduce CO_2 emissions and energy costs. Structured recording and evaluation of operational key figures will make these effects transparent in future. Compared to conventional systems, especially gas-powered systems or combined heat and power plants, operating renewable energy plants is more complex in terms of regulation and control because several operating parameters must be considered simultaneously. This requires clear communication and a shared technical understanding of the plant's functions.

Schiller-Schule

Improved performance coefficients can be achieved during recommissioning, given that the plant's performance coefficients are comparable to those of the 'Reiche Zeche' system in Freiberg, for example. Based on an inlet temperature of approximately 11 °C, cooling of up to 5 K seems feasible. The heat output extracted from the mine water could be doubled using the existing mine water pump. However, new heat pumps would be required to extract this increased amount of heat from the mine water. In this case, the installed capacity of the heat pumps would need to be roughly doubled, as the temperature spread of approximately 2.5 K at full load is half of what is realistically possible. This would enable the services identified during the planning stage to be utilised. Additionally, due to defects, the heat pumps must be serviced or replaced prior to commissioning.

The Figure 6 shows the relationship between the coefficient of performance of the mine water heat pump and the extracted temperature difference and the coefficient of performance of the heat pump. In addition to the representation in Figure 6, this figure also shows the coefficients of performance for the efficiency increase of the mine water extraction for comparison.

As can be seen here, raising the temperature difference by which the mine water is cooled can significantly increase the coefficient of performance, and thus the efficiency, of the mine water heat pump. For example, with a temperature difference of 5 K, the coefficient of performance can increase from 1.38 at the lower operating point to 2.15. At the upper operating point, the coefficient of performance can increase to 2.65 and even 2.8 at the pilot operation's operating point. Based on Figure 6, it can be assumed that the coefficient of performance of the mine water heat pump can be increased to at least 2.5 by raising the temperature difference.

In addition, the geothermal mine water plant should provide the option of cooling the air drawn in by the room ventilation system seasonally. Due to the mine water inlet temperature of approx. 10 °C, no refrigeration machine would be required for this purpose. With these mine water temperatures and the similar temperatures of the fluid in the intermediate circuit resulting from them, the heat from the air could be absorbed and transferred to the mine water for cooling.

As no refrigeration system is required to air-condition the room ventilation system in this proposed option, the coefficient of performance of this cooling would be the same as the coefficient of performance of the mine water, depending on the temperature difference transferred to the mine water. It can be assumed that the energy required to circulate the intermediate circuit is negligible for this purpose. The possible coefficients of performance of the mine water, and therefore the cooling system, are shown in Tabel 2 below, depending on the mine water temperature difference.

Tabel 2 Coefficient of performance of mine water depending on its temperature difference for cooling

ΔT	0,5 K	1 K	2 K	3 K	4 K	5 K
SPF_{MW}	1,19	2,37	4,74	7,11	9,48	11,85

Recommendations for monitoring mine water power plants

To assess and optimise the performance of mine water geothermal energy plants, reliable data on their operating behaviour is required. This data is generated through long-term monitoring. Parameters of primary importance in monitoring include energy input and heat transfer between the mine water and coolant. The latter can be characterised by the volume flow rate and the supply and return temperatures. [8]

In addition, the measurement data to be recorded can include the operating time of the circulation pumps and heat pump, electrical power, and outside temperature. Recording these parameters enables the system's effectiveness to be estimated and makes it easier to identify improvement opportunities. Only through metrological monitoring can it be determined whether, for example, the heat exchanger is dirty and transferring less heat. This may require the use of more fossil fuels to meet the constant demand for heat, resulting in additional costs and higher CO_2 emissions. However, by detecting contamination at an early stage through analysis of the measured values, the heat exchanger can be cleaned in good time.

By default, no additional storage of measurement data or evaluation of operating data is carried out. Although many software providers have already implemented the storage of parameters recorded in building management systems, the corresponding package is often not used by the operator. This is supposedly due to the higher costs involved in procuring and evaluating BMS expansion, which generally fall within the low four-digit range.

However, the relevant authorities often impose monitoring requirements to assess the impact of geothermal use on groundwater. This must be clarified in advance with the relevant state authority.

Requirements for measurement technology and data analysis

When constructing or renovating facilities, the general conditions must always be taken into account, particularly with regard to the measurement system. The system must be user-friendly for the employees who will use it. While large facilities with on-site technicians can be designed to be more complex, smaller local facilities must be designed to be easily operable by caretakers or other staff.

Experience shows that it is sensible to keep data collection as simple as possible. The new systems are designed to be user-friendly, enabling school staff to operate them without facing technical hurdles. For this reason, the measurement technology has been kept to a minimum and the control software has been limited to the essentials.

Functional requirements.

Deviations from the true value are caused by systematic and random sources of error. To at least partially counteract known systematic disturbances that distort the measurement results in a certain direction, requirements are placed on the disturbance compensation within the measurement technology.

→Knowing the true value and deviations is important.

This encompasses both the precision and accuracy of the measurement. In other words, a high degree of agreement between the results of independent measurements (precision) and between the true value and the mean of the measured values (accuracy) is required. [9]

→High repeatability and agreement of independent measurements.

In addition, the resolution of the measuring device is important; this is defined as the smallest change in the measured variable that the device can register and display. [10] These are the operating limits within which the device reliably displays measured values as accurately as possible, or as accurately as necessary. Therefore, the values to be measured in a mine water geothermal energy or mine water heat storage plant must lie within the predefined operating limits. Intensive coordination between all parties involved is required before and during the planning and installation of the plant. Retrofitting measurement sensors for monitoring purposes increases effort and thus costs. In addition, potential measuring points may then become inaccessible in certain circumstances.

→An appropriate resolution must therefore be defined.

Environmental requirements

The devices must be able to withstand climatic conditions, including temperature, pressure and, most importantly, humidity. They must also offer protection against these external influences. [11]

→Adequate shielding is required to protect the measuring device from external influences.

External influences also include the specific chemical composition of mine water, which can cause corrosion or deposits. [12] The resistance of operating equipment to the ingress of solid foreign bodies, dust and water is assessed and classified according to protection types in accordance with DIN EN 60529. In addition, equipment is classified into environmental classes according to usage conditions in accordance with DIN EN 1434. [13,14]

→The conditions of the variable to be measured on the technical equipment must be identified.

Economic requirements

Economic efficiency and cost-effectiveness are important factors in measurement technology. The aim is to strike a balance between the additional yield generated by the technology and its associated costs. While it is possible to optimise the measurement system by increasing the accuracy of the measuring instruments, this incurs unnecessary costs. [15]

→Measuring devices must be purchased for their intended purpose and be as accurate as necessary.

Figure 7 provides an overview of the measuring sensors to be installed. In addition to measuring heat flows directly or calculating them from the temperature difference and volume flow, it is also necessary to measure the pressure loss across the heat exchanger. This enables the system's efficiency to be monitored and any significant reduction caused by deposits in the heat exchanger to be quickly identified. The measured energy values can also be used to calculate parameters such as the coefficient of performance. These values can then be used to compare the system with others and estimate its effectiveness.

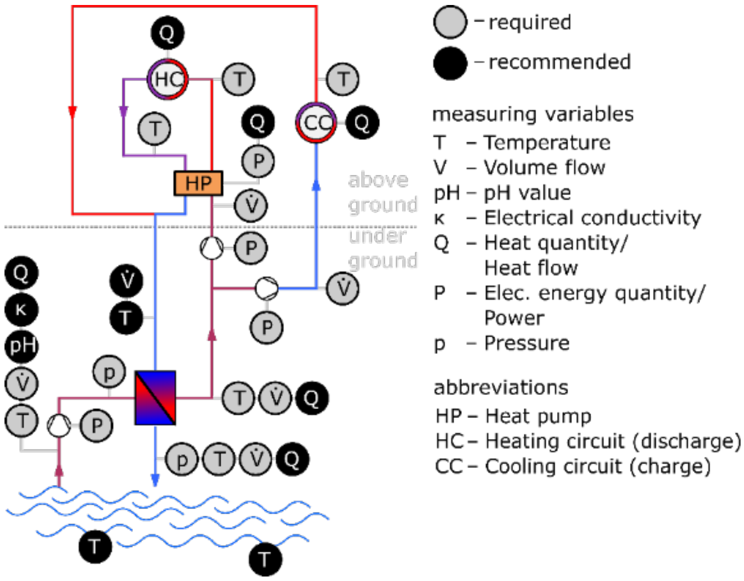

Figure 8 Overview of required and recommended parameters for monitoring a mine water geothermal plant

It is essential to take measurements at the inlet and outlet of the mine water. From an energy perspective alone, temperature and volume flow are sufficient. However, it also makes sense to record parameters that characterise the water chemistry, such as the pH value and electrical conductivity. To be able to make statements about the system's efficiency and profitability, it is also crucial to measure the supplied energy (electricity, gas) and benefits (heat, cooling).

Continuous measurement of the heat output of individual consumers would help with later plant optimisation and with purchasing new components, such as a heat pump, for dimensioning purposes. This additional data could also be used to create annual consumption curves at different temperature levels (for example, for different heating networks or flow temperatures), which could be used to optimise the system or dimension new heat pumps.

If the system is combined with above-ground energy storage facilities or other energy sources (e.g. CHP units), it also makes sense to record as many measured values as possible. The amounts of energy supplied and actually used are also necessary.

For systems that use mine water for storage, this can be expanded provided the storage facility was accessible prior to commissioning. This includes additional sensors in the surrounding rock to document the spread of the heat plume, for example. Additionally, multi-parameter probes or sensors can be installed to analyse the water chemistry and overall water quality, enabling changes caused by temperature effects to be detected.

4. Conclusions

The paper examined the ‘Reiche Zeche’ and ‘Schiller-Schule’ plants in Saxony in more detail. Several years of measurement data were evaluated for this purpose, with the risks associated with data collection being specifically highlighted. If both heating and cooling are required at the plants, this creates an optimal starting point for operation. It was found that combined operation in winter and during the transitional periods accounts for over 80% of operating hours, since both heating and cooling are required during this time. In summer, however, cooling requirements dominate, accounting for just under 40% of operating hours. These findings can also be applied to other systems with room air conditioning options. In this example, performance figures (SPF) of up to 10 could be calculated, which would significantly increase the system's efficiency.

Further efficiency gains can be seen in the operation of the heat pumps. Operating hours were recorded for the two systems under consideration and this data could be evaluated directly for the 'Reiche Zeche' system. It was found that, in some cases, alternating operation of the heat pumps worked. At the Schiller School, however, the data was collected manually, resulting in a greater discrepancy in the recorded running times 80% to 20%.

The relationship between the SPF and the temperature difference between mine water and the consumer system represents a decisive aspect, particularly concerning the integration of the technology into both existing and newly designed heating concepts. Observations from monitored installations demonstrate that the combined provision of heating and cooling can yield very high overall efficiencies, with total SPF values exceeding 7. At the installation in Aue-Bad Schlema, a series of measurements were conducted following a noticeable decrease in performance. Data collected between 2014 and 2019 revealed an average SPF of 2.2. Nevertheless, the analysis showed that, under favorable conditions and without significant structural modifications, the system can achieve SPF values up to 2.8. Further optimization measures could enhance performance to around 3.5 or more, improving both the cost-effectiveness and sustainability of the installation.

From these investigations, the necessary monitoring parameters for future systems and those under evaluation have been derived. The required and recommended datasets form the basis for assessing functionality, analyzing operational reliability, and determining the coefficient of performance. Over years of detailed analysis, these data have enabled specific conclusions regarding system operation and potential environmental impacts—both for heating purposes and for medium-temperature energy storage (MTES) applications.

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