14th IEA Heat Pump Conference
15-18 May 2023, Chicago, Illinois

Integration of heat sources for heat pump operation in the larger capacity range

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Abstract

In Switzerland, heat pumps (HP) in buildings with higher capacities still have lower market shares. The paper focuses on overcoming limitations of heat sources for HP capacities higher than 50 kW, e.g. for air-source due to noise problems or for borehole heat exchangers (BHE) due to space or drilling restrictions. By combining heat sources, a monovalent HP operation is enabled and due to synergies between the sources, also cost and efficiency benefits can result. By building and system simulations, it was found that the BHE size can be significantly reduced, if only winter peak loads are covered. This will circumvent both the noise limitations of the air-source and the space/drilling limitations of the BHE, and can even make dual-source operation more cost-effective. Regeneration can also result in smaller BHE design. For solar regeneration, favorable ratios regarding collector costs have been determined; while for air heat exchangers, special attention must be paid to the fan power and control. As conclusion, a dual source application does not only offer a monovalent HP application, but can also reduce cost and increase performance.

Keywords: Dual-source heat pump; peak load coverage; borehole heat exchanger regeneration; heat generator replacement; building renovation;

1. Introduction

Scenarios in many countries assume that heat pumps will be the predominant heating system in the future. In the Net Zero by 2050 report of the IEA of 2021 [1] it is evaluated that heat pumps will cover 50% of the global heat demand by 2045. While heat pumps already have a high market share in newly built, smaller residential buildings in Switzerland, their use in larger residential buildings and non-residential buildings with higher heat loads above 50 kW, especially in existing buildings, is still limited. One of the limitations regarding a higher diffusion of heat pumps for use in the higher capacity range are suitable heat sources, especially for heat generator replacements and renovations of existing buildings, where heat source limitations can be a major obstacle. In densely built areas of city quarters, limitations of air source heat pumps are mainly due to noise emissions, if many heat pumps are used on a small area and in a residential quarter with noise protection requirements. In Switzerland, the sound level is limited to 55 dB(A) at daytime and 45 dB(A) during the night to be approved for the installation permit [2]. On the other hand, also a ground source can be limited due to space restriction of the borehole heat exchanger, drilling limitation regarding depth due to ground layer structure and limitation due to the accessibility of the drilling area for the drilling machinery. Furthermore, the drilling density can also be a limitation, since with many borehole next to each other, the ground temperature is increasingly exhausted. One way to overcome the limitations of individual heat sources can be accessed by combining different heat sources, especially if synergies among heat sources can be exploited.

Thus, in this paper, combinations of heat sources are investigated with the aim of overcoming limitation on the source side and enabling a monovalent use of heat pumps despite limitations of individual sources. In this way, the market shares can be extended for larger capacities and renovation projects.

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The hypothesis is that synergies between the heat sources can be used for a better system performance and/or economic advantages compared to the use of only one single source, e.g. by using the heat source with the better temperature level or by exploiting design advantages. The project objective is to derive recommendations for the use of multi-source systems for higher capacity range applications.

2. Methodology

A literature review and market research delivered the result that so far hardly any commercial system solutions for multiple heat sources are available on the market from the relevant manufacturers. There are different examples for splitting the total heating capacity to different heat pumps, but only with the same heat source, which does not avoid problems in case of source restriction. This may be due to the several reasons:

- the retrofitting of buildings is emerging step by step
- currently, a peak load coverage by fossil fuels is still accepted in the market, which can relax the limitation on the heat source by downsizing the HP capacity
- multi-source systems are associated with a higher complexity and cost and thereby considered more error-prone and risky for the investor, designer and installer
- there are little reference systems with multi-source application

In research, there are several projects, but mainly covering solar assisted heat pumps, where solar energy is applied as regeneration source for the ground, e.g. [3], or a source storage, e.g. as ice storage, or also applied as heat source and/or in direct operation, e.g. for DHW production in summertime. However, since solar yield in winter cannot be guaranteed, either a source storage is required or the primary heat source has to be designed for the entire design heat load of the building. Natale et al. [4] investigate a dual source configuration of a ground and air-source regarding two control strategies. However, only switching between sources and no parallel operation of the two sources is considered. It was found, that even with smaller borehole design a similar performance can be reached, which enables a retrofitting for undersized borehole heat exchangers. Reum et al. [5] investigate control strategies for the air-source and horizontal ground collector, which also includes a parallel operation below a balance point temperature. The HP modelling is based on a black box model derived by test rig measurement. However, no implications for the design of the sources are given. A systematic evaluation of potentials that can be explored by different heat source integration is missing, though. Therefore, this project started with a characterization of different heat sources and combination options. Based on this characterization of heat sources, four strategies are considered for the integration of dual or multiple heat sources:

(a) peak load coverage by an additional heat source
(b) regeneration of the primary heat source by additional source(s)
(c) year-round base load operation by additional source(s)
(d) Preheating of the primary heat source by additional source(s) to increase the capacity output

Due to the higher practical relevance of the first two strategies, this paper will focus on evaluation of these two strategies. Typical applications for the third variant are e.g. an exhaust air or wastewater heat recovery for the DHW operation. The fourth variant can be interesting in cold climate regions with clear sky winter conditions, where the cold outdoor air can be preheated by solar energy use.

The variants for the above first two strategies were investigated by dynamic building and system simulation. The building and system technology has been modelled in Matlab-Simulink using the Carnot-Blockset [6]. The objective of the simulations is the investigation of the system configuration with respect to integration, design and control. Thereby, the main focus of the investigation is to enable the monovalent use of HP as sole heat generator without a peak load coverage by fossil energy or direct electric back-up heaters, in order to enable efficient and carbon free operation. Direct electric back-up heating for the space heating application is forbidden in Switzerland anyway. Thus, in this paper, the term "monovalent" refers to the heat generator and not to the heat source. It is thus understood as use without auxiliary heating, but possibly with multiple heat sources. The scope is set to the higher capacity range > 50 kW installed capacity of the HP, since for this capacity range the limitations of heat source are increasing, in particular for densely built environments in cities and heat generator replacement in existing buildings.

The investigations are carried out by means of simulations of generic residential buildings in the construction standard "new building" and "existing building" with a heat load of 60 kW (base variant) to 240 kW (upper limit for heat load variation). As a boundary condition for the design of borehole heat exchangers/ borehole fields, the design criterion according to SIA 384/6 [7] was always taken as a requirement for all calculated variants, where it is required that the mean fluid temperature must not fall below -1.5 °C after 50 years of operation, e.g. as -3 °C inlet and 0 °C outlet of the borehole heat exchanger.

Table 1. Building- and system parameters for the simulation studies in new and existing buildings

Parameter	New built	Existing	Variation/remark
Heat demand (SH & DHW)	45 kWh/(m^{2}yr)	160 kWh/(m^{2}yr)	No variation
Fraction SH/DHW	33% SH, 66% DHW	80% SH, 20% DHW	No variation
Design heat load	60 kW	60 kW	Varied up to 240 kW
Number of flats	36	12	At 60 kW
Supply temperature heating	35 °C	55 °C	Floor heating/radiators
DHW	55 °C	55 °C	No heating element, HP only
Weather data	Zurich Meteoschweiz	Zurich Meteoschweiz	Zurich Meteoschweiz cold year
Thermal conductivity ground	2.4 W/(mK)	2.4 W/(mK)	Standard Swiss middleland
Thermal conductivity grouting	2.0 W/(mK)	2.0 W/(mK)	0.8 W/(mK)

Legend: SH – space heating, DHW – domestic hot water

Thereby, effects of size scaling (e.g. probe spacing) as well as in the load profile (higher hot water share in new buildings) could be investigated. The different strategies can be compared according to energetic and economic criteria under the same boundary conditions (e.g. limited borehole depth). For this paper the key performance indicators of the seasonal performance factor (SPF) of the HP and the annualized life cycle cost are evaluated.

Table 1 gives an overview of the building and system parameters used for the simulation studies. The loads were used according to the standard use according to SIA 2024 [8] for multi-family houses. The site Zurich Meteoschweiz average year according to SIA 2028 [9] was used as weather data. To test the robustness of the design, variations including a cold year were also performed, both for the same weather data set of the cold year over 50 years and as a periodic variation of four normal years followed by a cold year. The heat pump was evaluated as a performance map based on manufacturer data for an air-to-water and brine-to-water heat pump. The higher loads are calculated by multiplying the load profile of the basic size of 60 kW.

The ground source model corresponds to a common approach of design programmes to have a finite difference model of the ground probe and the near surrounding and a step response function called "g-function" according to Eskilson [10] for the farer surrounding of the ground. The model has been validated by a cross programme comparison with the common design tool in Switzerland EWS [11] and also compared to monitoring data of a system in Feldmeilen, CH [3], which delivered feasible results. However, the validation does not cover the operation mode of a peak load coverage strategy investigated here, which is a future task within a demonstration project of a boiler replacement in two multi-family buildings, see chap. Conclusions. The upcoming demonstration project offers the opportunity to gather monitoring data of the peak load operation of the ground source field and is therefore well suited for further model validation work.

3. Results

The focus of this paper is on the first two integration options of the strategies "peak load coverage" and "regeneration". In the context of this publication, only the sole strategies are considered, although combinations of the strategies are also conceivable, which is particularly obvious for very high capacities in the range of the upper limit for the simulations of 240 kW and more, when the borehole field reaches a size, where regeneration is called for. The combination of the strategies can further improve the respective advantages of the individual strategies presented in the following.

3.1. Strategy (a) – Peak load coverage

For the integration variant (a) peak load coverage with borehole heat exchangers, advantages are offered in combination with capacity limitations of the primary heat source, as they may exist with the heat source outside air due to noise emissions. In the case of a sole ground source by borehole heat exchangers, on the other hand, space limitations may exist for the installation of a sufficient number of probes. Peak capacities, though, are often needed only for a rather short period, since in Switzerland HP are designed monovalently to the design outdoor temperature. Figure 1 shows the relative probe length compared to a 100% borehole heat exchanger heat source for the performed parameter variations with respect to new and existing buildings, different probe arrangements as line and compact rectangular field layout, different capacities of 60 kW and 240 kW, normal and cold weather and different thermal conductivity of the grouting of 2 W/(mK) and 0.8 W/(mK).

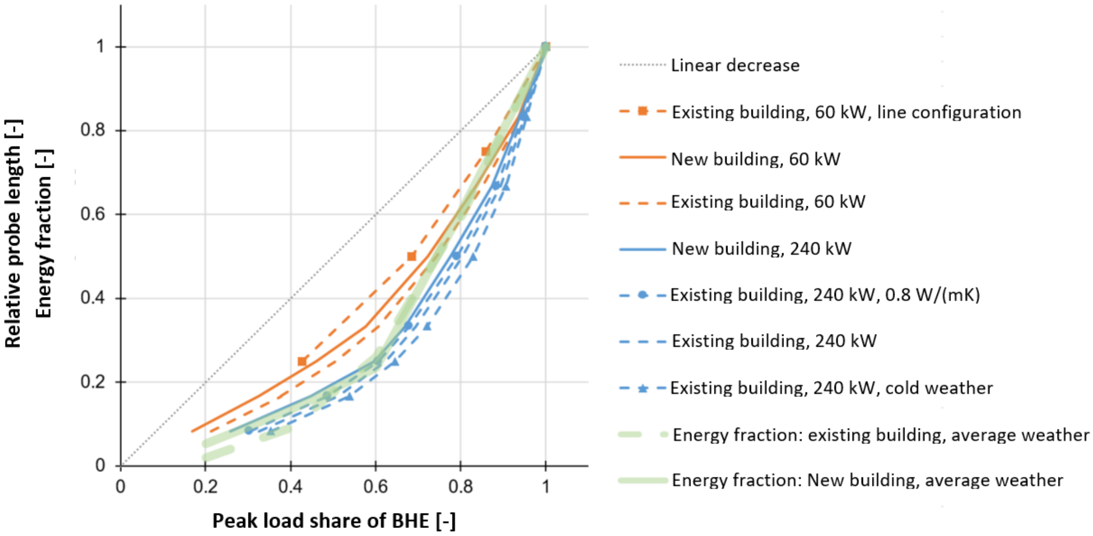


Fig. 1. Parameter variations for the strategy "Peak load coverage" by ground probes

The basic setting is a compact field layout as rectangular. For the 60 kW building also a line configuration has been evaluated, which is closest to the 45° line and thereby has the least saving potentials compared to a 100% borehole heat exchanger. In fact, most results show robust behavior regarding the performed variation, which simplifies the design for different boundary conditions. The biggest difference is found indeed in the probe arrangement between linear and compact field design. The compact field shows a more digressive behavior since natural regeneration is more limited by the field effect, i.e. the shielding of the inner probes in the center from the surrounding undisturbed soil, and therefore, a lower discharging of the field by the operation for peak load coverage has an even higher impact.

As conclusion of the results depicted in Figure 1, with the combination of air as primary source and the ground for peak load operation, significantly less energy is extracted from the ground than with a ground source only, e.g. about 20% of the total energy when designed for 50% of the total heat load. This corresponds to a much shorter probe length of only 20% of the ground source-only case, which can overcome space restrictions that exist in particular in existing buildings. Furthermore, simulations show that a slightly higher capacity in the range of up to 70 W/m can be temporarily extracted, since long "natural" regeneration times exist for the borehole heat exchangers.

The simulation results further confirm that peak load coverage with borehole heat exchangers, in addition to alleviating capacity constraints, can provide performance and economic benefits such as lower overall investment costs and can unlock additional benefits of borehole heat exchangers as a heat sink for summer cooling.

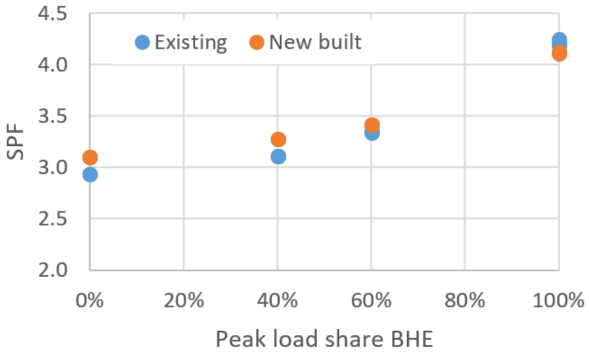


Fig. 2. Performance of the concepts "Peak load coverage" by ground probes

Figure 2 shows the SPF as a function of the peak load share by the borehole heat exchanger for peak load coverage. Compared to an outdoor air source only (0%), the efficiency also increases with increasing peak load share by the ground source. The difference between the new and existing building is relatively small, since the lower space heating supply temperature is compensated by the higher DHW fraction.

Fig. 3. Economical comparison of the concepts "Peak load coverage" by ground probes

This also explains the slightly better performance of the existing building for the 100% ground-source. Since the existing building is dominated by space heating, the supply temperature decreases, while the DHW stay constant for the entire year. For the air-source heat pump (0%) the performance in new built is better, since the higher DHW share can be provided very efficient due to the high outdoor air temperature during summer, which overcompensates the decreasing temperature in space heating in the existing building. For the ground source (100%), it is vice versa, i.e. the decreasing space heating temperature causes the better performance than the DHW temperatures.

The seasonal performance factor is averaged over the entire operating period of 50 years, since the system variants with higher ground fraction experience a cooling down of the ground and thereby lower source temperatures over the design period of 50 years.

Figure 3 shows an estimation of the cost structure for the case of the existing building depending on the peak load share by the borehole heat exchanger and in comparison to a bivalent solution with a fossil back-up boiler with natural gas as annualized life cycle cost (gas and electricity tariffs as of June 2022, see also Table 2). The used boundary conditions for the economic evaluation depicted in Figure 3 for the strategy "Peak load coverage" and Figure 4 and Figure 5 for the strategy "Regeneration" in section 3.2 are listed in Table 2.

Table 2. Boundary conditions for the economic evaluation in Fig. 3

Parameter	Specific cost/tariff	Variation/remark
Investment cost		
Air-source HP	1700 €/kW	
Ground-source HP	900 €/kW	
Gas boiler system (averaged)	300 €/kW	
Borehole heat exchanger	100 €/m	
Air heat exchanger (60 kW-240 kW)	1500 – 600 €/kW	
PV/T collector	750 €/m2	
Operational cost		
Electricity tariff	0.20 €/kWh	As of June 2022, strongly dependent on market
Gas tariff	0.15 €/kWh	As of June 2022, strongly dependent on market
Feed-in tariff	0.10 €/kWh	Dependent on site
Component lifetime/interest rate		
Ground probes	50 yrs.	
Heating system components	20 yrs.	
Interest rate (real)	1.5%	

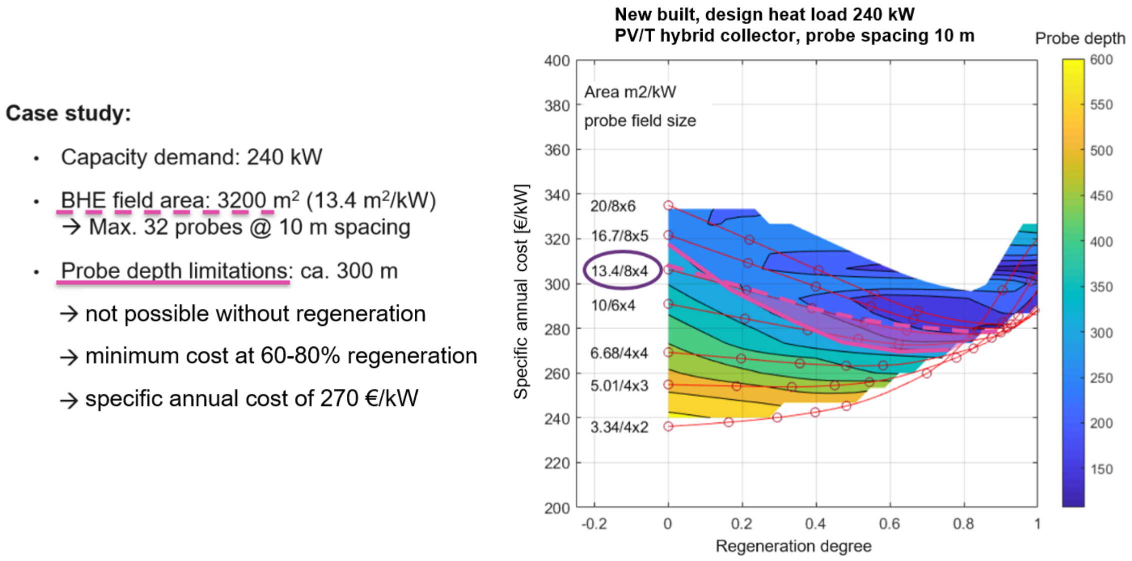
The costs of the monovalent solution only with HP can result in lower specific costs than the peak coverage by natural gas, which, however, is strongly dependent on the market prices. For the HP solutions, there are economic advantages of the individual sources ground probes-only or air-source-only for the smaller capacity range of 60 kW. The individual sources, however, may not be possible to realize in case of restrictions. Moreover, the additional costs for a dual source HP solution are moderate at 50 €/kW and allow a monovalent HP operation without back-up heater. For larger capacities, the cost advantages of the individual sources decrease or even show higher costs, in particular for the ground source. This is due to the effect depicted in Figure 1. Due to the significantly smaller design of the ground source in relation to the 100% ground source, larger cost saving occur for higher capacities, which can cover the additional cost of the second heat source. This can reach the cost of the 100% air-source, since the air source has also increasing cost for higher capacities and may not be possible due to restrictions, anyway. Furthermore, in new buildings and compared to air-source only, there may be additional freecooling potential by the dual source HP. If this is taken into account as cost benefit in the economic calculation, the differences to the individual source disappear for the lower capacities, as well (not depicted in Figure 3).

3.2. Strategy (b) - regeneration

For variant (b) with regeneration, it is known that large borehole heat exchanger fields are only insufficiently regenerated by natural heat inflows from the ground, which makes technical regeneration necessary. Furthermore, with regeneration the probes can be arranged with smaller distance to each other without cooling down the ground too much and it may be possible to reduce the total probe length, which opens up options for more probes on less space and thus can overcome space limitations. In the project, the control of the HP using solar absorbers and PV/T collectors as well as outdoor air heat exchangers as synergy to heating/domestic hot water operation was systematically investigated for different building sizes. The parameters that were varied include probe field sizes, drilling depth, probe spacing and probe placement in the field.

While many studies have already been conducted on the regeneration of mostly larger borehole heat exchanger fields, the focus has often been laid on 100% regeneration or even seasonal storage through so-called "active" regeneration, i.e. a higher heat regeneration amount than the heat extraction, so that the ground temperatures can be successively raised [12]. In this project, however, the evaluation is carried out for the investigated regeneration sources with respect to necessary area and possible drilling depth as a trade-off between costs and regeneration demand or degree of regeneration in order to evaluate, how and what extend of space and drilling limitations can be overcome.

The results show that both limitations in the possible field size/probe depth and space as well as economic advantages can be achieved by a shorter overall probe length. For solar regeneration, for example, the focus of the economic analysis is on a cost-effective design as the optimal ratio between the collector area and the probe length. From the results, a representation as a contour plot was developed, from which the cost-optimized degree of regeneration can be found, depending on the regeneration source and the boundary conditions.



Case study:

- Capacity demand: 240 kW
- BHE field area: 3200 m² (13.4 m²/kW)
  → Max. 32 probes @ 10 m spacing
- Probe depth limitations: ca. 300 m
  → not possible without regeneration
  → minimum cost at 60-80% regeneration
  → specific annual cost of 270 €/kW

Fig. 4. Evaluation of the concept "Regeneration" with PV/T hybrid collector

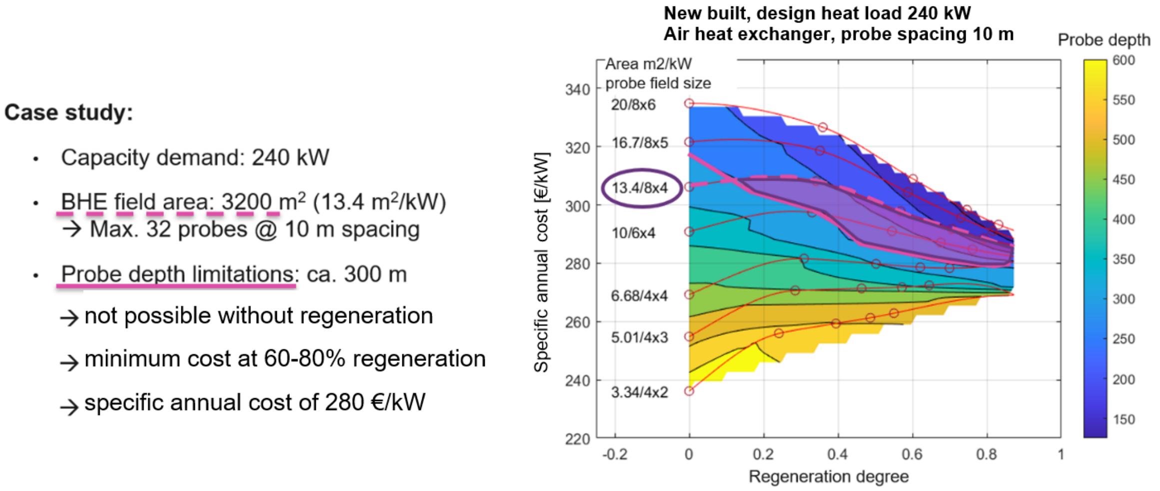
Figure 4 shows the results of the parameter variations for the new building with a fixed probe spacing of 10 m and a design heat load of 240 kW and a regeneration by a photovoltaic thermal (PV/T) system.

By means of a reading example, the statements of the graphical representation are clarified. The plot correlates the specific annual costs vs. the degree of regeneration. Parameters of the contour plot are the probe depth (color-coded contours) and the available area per kW of extraction power as parameter curves. If, for example, a heat load of 240 kW is based on a probe field area of 3200 m^2 (13.4 m^2/kW as dashed line), a maximum of 32 probes can be drilled at a probe spacing of 10 m. If additionally a drilling depth restriction of 300 m is considered (line along the middle blue contour), this results in the purple area in the diagram of possible solutions.

Since the area is only reached at a regeneration degree of almost 20%, the design conditions for the ground probes field of -1.5 °C after 50 years can only be achieved with regeneration under these boundary conditions. The regeneration degree with the lowest annual costs is found at regeneration degrees of 60-80%, i.e. clearly below 100%, with annual costs of 270 €/kW (costs for drilling and regeneration, including also the benefits of the electricity generation by the PV/T collector).

Compared to a PV/T system a solar thermal regeneration could offer certain advantages in summer operation, because the DHW operation can be provided directly by the solar thermal system. By the PV/T system, a double benefit with electricity production can be achieved, but for commonly available unglazed PV/T less heat is supplied than with solar thermal collectors systems without PV coupling. Thus, possibly the hot water storage temperature level cannot be reached with PV/T only operation.

However, especially in the case of renovation, the roof area may be limited or may have unfavorable conditions due to orientation or shading. Therefore, regeneration by an air heat exchanger can also be a good option, especially in the case of space limitation in the renovation case. Figure 5 shows the same diagram for the regeneration by an air heat exchanger, i.e. for the same limitations of the borehole heat exchanger as in Figure 4. The economic evaluation for the air heat exchanger is quite similar to the regeneration with the PV/T collector. The field of possible designs also starts at almost 20% of regeneration and the lowest system costs are reached at a regeneration degree of 60-80%. Therefore, also for the regeneration source different combination are available which enables an adaptation to restriction in the concrete situation. While the above limitations of the solar regeneration sources can be avoided, care has to be taken for noise issues and the positioning of the air heat exchanger similar to the use as primary heat source. Further criteria and potentials for a high energy efficiency of the air heat exchanger are the fan power and improved control strategies.



Case study:

- Capacity demand: 240 kW
- BHE field area: 3200 m^2 (13.4 m^2/kW)
  → Max. 32 probes @ 10 m spacing
- Probe depth limitations: ca. 300 m
  → not possible without regeneration
  → minimum cost at 60-80% regeneration
  → specific annual cost of 280 €/kW

Fig. 5. Evaluation of the concept "regeneration" with air heat exchanger

4. Discussion

The focus of the investigation was the larger diffusion of the use of HP as only heat generator without fossil back-up heating in the higher capacity range above 50 kW. One limitation for the higher capacity range can be limited heat sources, especially in the case of heat generator replacements in existing buildings. In order to enable a monovalent HP application also in the higher capacity range, combinations of heat sources and their integration and design have been investigated.

The hypothesis of the study was, that in particular for the higher capacity range, limitation of individual heat sources can be overcome and even benefits of higher performance and better economic values can be achieved due to the use of synergies between dual or multiple heat sources. In this paper, results of two investigated strategies entitled "peak load coverage" and "source regeneration" are reported.

It could be verified that with synergies between the heat sources, e.g. use of the better temperature conditions of the individual sources, i.e. the ground in winter time and the air in summer time, and adapted use of the ground, also performance advantages (compared to air source) and economic benefits (compared to ground-source) can be exploited.

For the conducted investigations on the strategy "peak load coverage", the combination of the heat sources "outdoor air" and "borehole heat exchangers", which are most frequently used in Switzerland, was considered. However, this does not limit the strategy of peak load coverage to these heat sources. The results can also be transferred to other heat source, where the "outdoor air" stands for a heat source that is limited in capacity, e.g. by noise protection requirements, and the ground stands for a heat source that can be stored, but which can also be subject to restrictions, e.g. by required space, drilling depth or other legal limitations. The combination allows a smaller dimensioning of both heat sources, so that both limitations can be overcome. Other possible combinations include groundwater or surface water with a limited pumping volume, or waste heat with a limited capacity in combination with air or geothermal probes. Depending on which source is considered as primary individual source, the performance may increase as shown in Figure 2 for the case of peak load coverage by ground source where air is considered as primary heat source.

In the strategy of "regeneration", the second source primarily serves to manage the storable primary heat source. In addition, though, the regeneration source can also take over e.g. the summer operation as only source, and thereby use seasonal advantages, in the case of solar thermal regeneration for instance the good summerly solar irradiation availability. In the case of air, heat exchangers the higher summer outdoor temperatures can be used, and thus further promote the regeneration of the primary heat source by a reduced use in summer.

The economic evaluation confirms that dual or multi-source system do not necessary have higher costs, since synergies between the sources may also decrease the cost. For the "peak load coverage" by ground probes, where a high peak capacity, but less energy is delivered by the ground probes, the decrease of the borehole heat exchanger size enables a cost decrease for the ground probes.

On the other hand, by regeneration of the ground, a cost optimized design can refund the investment in the second heat source for the regeneration and decrease the overall system costs. There is also a certain variability of regeneration sources, which can be designed according to respective on-site limitations especially in case of existing buildings. For the example outlined in this paper, the regeneration by PV/T collectors and by air heat exchanger lead to comparable overall system costs.

Moreover, the integration of a second source may also additionally enable further operation modes, such as a freecooling operation in case of additional use of geothermal probes as second source. However, the use of this freecooling option also depends on the installed emission system in the building. In the case of freecooling, larger surfaces for the heat transfer are required, which are classically installed in new buildings. Radiators in existing buildings are normally not suited for a freecooling operation, unless not supported by ventilators for enhanced convective heat transfer.

A drawback of dual or multi-source systems, though, is an increased system complexity. Results of this study should thus be elaborated to derive recommendations for an as far as possible simple and robust integration. However, further steps are required in order to derive more standardized guidelines for a dual or multi-source application.

Two other strategies of a "second source as base load" and a "source preheating" by a second source have not been discussed in this publication.

A "second source as base load" can typically be applied, if the one source has a more or less constant capacity and contributes to the overall coverage with this constant capacity throughout the whole year. As example, a wastewater heat recovery as second source is usually sufficient to constantly cover the DHW load throughout the year. In addition, waste heat from exhaust air can deliver a more or less constant heat source, which can help to overcome limitations of the primary source.

The strategy "source preheating" is particular promising in situations, where the temperature limitations during peak load hours is an obstacle. A situation can be cold days, which, however, have a high solar irradiation potential at clear skies, e.g. in northern or mountainous regions, where winter outdoor temperature can fall down to very low temperatures, even below the operating limit of the heat pumps, but are combined with high solar irradiation, which can be used to preheat the outdoor air source.

5. Conclusions and perspectives

Within the scope of the project, system solutions with the HP as only heat generator and dual source are investigated. However, in addition, the investigated strategies can also be useful for a combination with other heat generators or heat carriers. In combination with district heating, for instance, more buildings can be connected to the grid, if a decentralized coverage of the peak load with borehole heat exchangers is integrated. The load profile for the energy drawn from the grid shifts to a higher base load fraction due to the increase of the hot water share supplied by the district heating. Alternately, the district heat extraction can be better adapted to the application, e.g. existing grids can supply more buildings without increasing the pipe diameter/generator capacity, or more heat is available for high temperature applications, e.g. in existing buildings. These advantages can occur both for higher temperature grids, e.g. from waste incineration, or for low-temperature grids in terms of 5th generation district heating on waste heat level, such as waste heat from a waste water treatment plant.

The promising results both on the performance as on the economic evaluation can raise the question on cost and performance optimized combination of heat sources. Synergies for the individual heat sources in the combination can lead to more attractive multi-source systems than individual sources even in situations without the limitations of the sources. However, also the cost assumptions would need to be assured by practical applications. Furthermore, early adaptions and manufacturers or system developers as prime movers would be needed to enhance market extensions and knowledge to spread dual source systems. This could go hand in hand with an optimization and standardization of the systems for a certain capacity range.

A limitation of the results of the study is that they have been obtained by simulations only, so far. In order to approve their validity in practical application of a real system, monitoring of a system with respective limitations on the source side would be a fruitful verification which can promote the spread of the information on dual source HP applications by a best practice system and deliver further information and verification of systems models as well as on integration, design and control.

5.1. Demonstration project of dual source heat pumps for boiler replacement

In fact, in the course of the project, already a real case with the investigated limitations has been found. The project deals with the heat generator replacement of an old oil boiler, which supplies two existing multi-family buildings built in 1972 with 28 flats each and a heated area of totally 4180 m^2. The buildings have hardly been retrofitted and are mainly in their original state.

The total heating capacity of 200 kW is supplied by a common oil boiler and distribution line between the two buildings. The average annual heat consumption over the last 20 years was evaluated to 600 MWh/a.

The original concept aimed at the boiler replacement by a single-source ground-coupled HP, which significantly improves both the energy performance and the CO_2-emission reduction.

Due to the steep surrounding area, though, the space for the drilling of the boreholes is limited to the parking lot between the two buildings. The concept was detailed with ground probes in a depth of 295 m and an additional air heat exchanger for the regeneration of the ground probes. An air heat exchanger was chosen as regeneration source, since the retrofitting of the roofs of the two building is planned for the next years after the replacement of the heat generator. Therefore, the space on the roof was not available for solar regeneration.

However, during the drilling of the first three boreholes, artesian water has been found at 130 m, so the authorities defined an additional limit of drilling depth of maximum 120 m. With this new limitation, the concept with boreholes only is no longer sufficient to provide the whole source capacity for a heat pump operation and a dual source system of the ground and an extended air heat exchanger is now under consideration.

Since these boundary conditions correspond to the investigated limitations, the buildings are an ideal case study to gather further experience with a dual source combination of the ground heat exchanger and outdoor air heat source. A demonstration project has thus started in January 2023 and the monitoring data of the system can be used to verify simulation results, evaluate the real performance and cost of the dual source system and derive planning and design recommendation by a real monitored buildings.

Acknowledgements

Results outlined in this paper have been investigated in the project "HP-source – integration options for heat sources". The project supervision, support and funding of the Swiss Federal Office of Energy SFOE under the contract SI/502144-01 is highly appreciated and acknowledged.

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