Integration and use of manifold heat sources for brine/water heat pumps

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Abstract

Future heat generation systems require renewable and sustainable energy supply. Therein, heat pumps play a favourable role due to the ability to use renewable electricity efficiently and flexibly and to integrate fluctuating renewable heat sources or waste heat.
A heat source with a rather constant temperature level and hence interesting heat source during winter time is the ground, but heat transfer rates are limited. The most flexible heat source is the outside air, which is also the closed heat loop partner for the heat losses of buildings. In the focus of the paper are future heat pump systems that are able to integrate different heat sources flexibly and still efficiently.
Results from the SOFOWA project showed key facts for the integration of convective heat sources, solar heat, ground heat gains and ice storages connected via brine circuit. A project about the application of city-compliant air-source heat pumps for the replacement of fossil boilers in existing residential buildings shows potential application of brine/water heat pumps with mainly air as heat source. The results are summarised and interpreted from the point of view of using manifold heat sources for brine/water heat pumps.

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Keywords: heat pump; brine circuit; solar heat; ice storage; convective heat source; waste heat

1. Introduction

Two key points of a mainly renewable heat supply will be increased heat pump application and the use of waste heat. Therein, also integrated or combined heat supply solutions will play a significant role, which are able to adapt to the locally given circumstances. Hence, it is advisable to collect the required knowledge about the efficient and effective application of such system solutions.

Using manifold heat sources for brine/water heat pumps is not a completely new topic. A lot of work has been done for the efficient use of ground source heat pumps with additional heat sources or ground heat recovering. In this paper, the results from two finished research projects that focussed mainly on other topics shall be interpreted from the point of view of using manifold heat sources for brine/water heat pumps and some interim results of the actual project LEWASEF are shown. Therein, borehole heat exchangers are not considered and only solutions for situations without borehole heat exchangers are evaluated. In this sense, the paper is a mixture of results from previous research projects and an interpretation on what these results can tell us for the case of the future application of brine/water heat pump units.

Despite the trend to an increasing share of air/water heat pumps in central Europe, there are good reasons for brine/water heat pumps to find new, perhaps special application fields, because:

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- brine/water heat pumps are high efficient and flexible units
- they can help finding attractive solutions for a future heat supply with high renewable energy shares

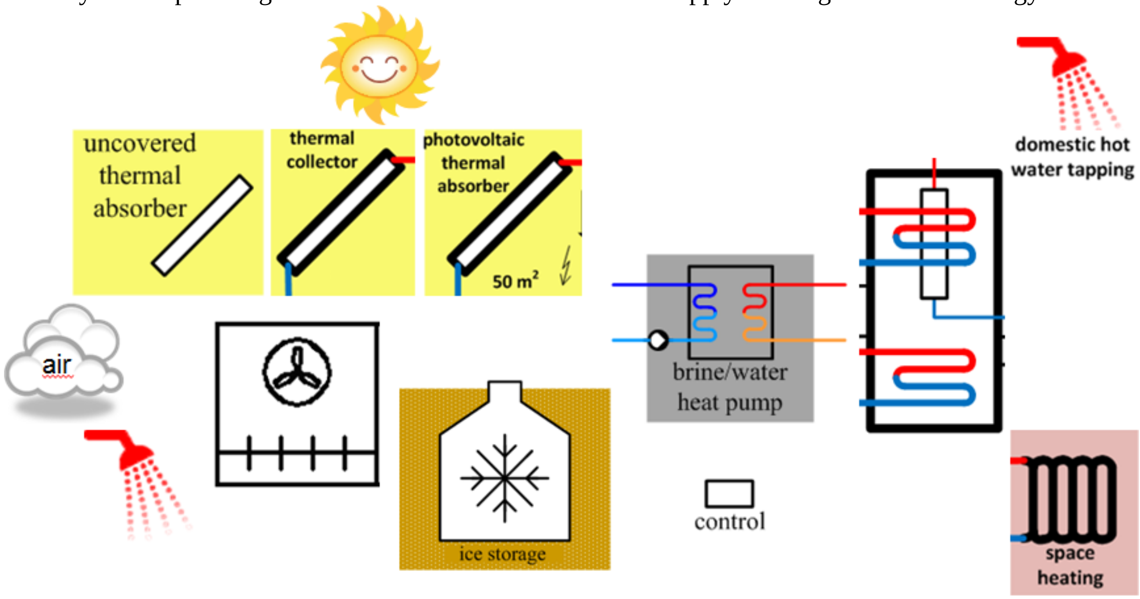


Fig. 1. Manifold heat sources for brine/water heat pumps applied in dwellings

The results shown and interpreted here are mainly from the following two finished projects:

1) SOFOWA - solar heat, fotovoltaics and heat pump system combinations including ice-storages [1]
This project has been conducted as one Swiss national contribution in the framework of the IEA SHC Task44 / HPT Annex 38 "Solar and Heat Pump Systems" [2]. Therein in a first step, a general view on heat pumps combined with solar technology shows advantages / disadvantages of technologies like solar thermal collectors (SC), photovoltaics (PV), combined photovoltaic thermal collectors (PVT) or ice-storages (ice-ST) as well as potential added value of combinations. In a second step, one solar-heat-pump-system, a solar-ice-storage-system, has been analysed in detail and has been one starting point for the discussion about usage of brine/water heat pumps. In the third step of SOFOWA, the aspect and influence of ground heat exchange of the buried ice-storage has been tested and validated in laboratory measurements with full-size scale.
2) Stadtverträgliche Luft/Wasser-Wärmepumpen als Hauptwärmeerzeuger [4]
(City-compliant air/water-heat pumps as main heat generators in the city of Zürich)
Air-source heat pumps have the potential to be easily applied and universal heat generators that can replace oil- or gas-boilers in future heat generation scenarios with the requirement of using only renewable energy sources. The energy strategy 2050 for the city of Zürich [5] shows in different scenarios the concept of the energy supply for the city of Zürich, fulfilling the requirements of the 2000-Watt-society with a high renewable energy share under the given local circumstances in Zürich. For every district the energy demand, energetic efficiency, energy density, existing energy infrastructure, local energy sources as well as the societal development are evaluated and an energy supply advice for 2050 is given. Therein, air-source heat pumps have the role of universal heat generators that can supply renewable heat and can be applied in almost every place with a very small demand for installation space and external infrastructure. The here referenced study [4] evaluated this universal application of air-source heat pumps for typical dwelling situations in existing buildings. In the following, the main findings are summarised and interpreted with a focus on the application of brine-source heat pump units using manifold heat sources.

as well as from the actually running project:

3) LEWASEF - capacity controlled heat pumps with solar-ice-storage and photovoltaics
The LEWASEF project takes the three most promising concepts of the SOFOWA project results to further develop these. One is the combination of heat pump with photovoltaics and the technical implementation of advanced direct PV-electricity consumption in the heat pump; second concept is the

use of brine/water heat pumps with manifold heat sources combined with air as main heat source; and the third concept focusses on combined solar heat and electricity generation with PVT-collectors.

2. Results from a model case with four heat sources

Previously finished project SOFOWA focussed on solar plus heat pump systems, considering solar heat and photovoltaic systems combined with heat pumps. One system concept that has been analysed more in detail is intended to use solar irradiation as additional heat source for the heat pump to improve the energetic efficiency. Hence, original intention of using a brine-circuit on the source side of a brine/water heat pump has been to facilitate the integration and use of solar irradiation as one heat source for the heat pump and an ice-storage as additional heat source where the latent heat gains secure a minimum source temperature.

Figure 2 shows the system hydraulics and main components of the solar ice-storage system. The solar ice storage heat pump system uses an uncovered thermal absorber and one buried ice storage as heat source for the brine/water heat pump. The uncovered solar absorber consists of two layers of parallel pipes which gain heat from solar irradiation and the ambient air by convection. The buried ice storage with 10 m^3 of water volume serves as secondary heat source in times when the absorber isn't able to deliver heat or if the use of the ice storage is more efficient. The absorber and the ice storage are connected in parallel to the source side of the heat pump and are in operation alternatively. There is a separate heat exchanger with hydraulic circuit to heat the ice storage from the absorber. Some results and details about the modelling of the system have been published at the last IEA heat pump conference 2014 in Montreal [6].

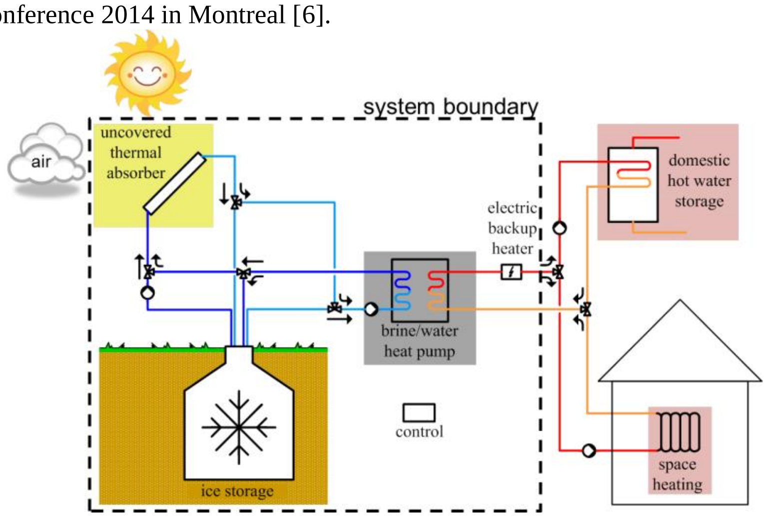


Fig. 2. Solar ice-storage system hydraulics and main components

In this case the system setup has to most extend been made by a clever combination of components but to some extend also by an unintended and lucky combination of components. Central questions during the evaluation of the system have been: Which heat source supplies how much heat under which operating condition? Which heat source is best in which operation condition? And for this special case: Where in fact does the heat come from over the whole year (solar irradiation, convection, latent heat gain, ground heat exchange)?

The question, "Where does the source heat come from?", is in a first step answered by figure 3 that shows an annual Sankey-diagram for a solar ice storage heat pump system with 8 kW heat pump capacity applied to a single family house with 250 m^2 living space and a space heat demand of 45 $kWh/m^2/a$ (SFH45*). It shows that the biggest part of the source heat comes, with 40.2 $kWh/m^2/a$, directly from the uncovered solar absorber, second biggest part is the electricity used in the heat pump and only third part is with 14.1 $kWh/m^2/a$ from the ice-storage. But, these numbers only show the heat supply related to components, not yet allocated to the heat sources. Therefore, further analysis had been done to allocate the heat flow to the heat sources.

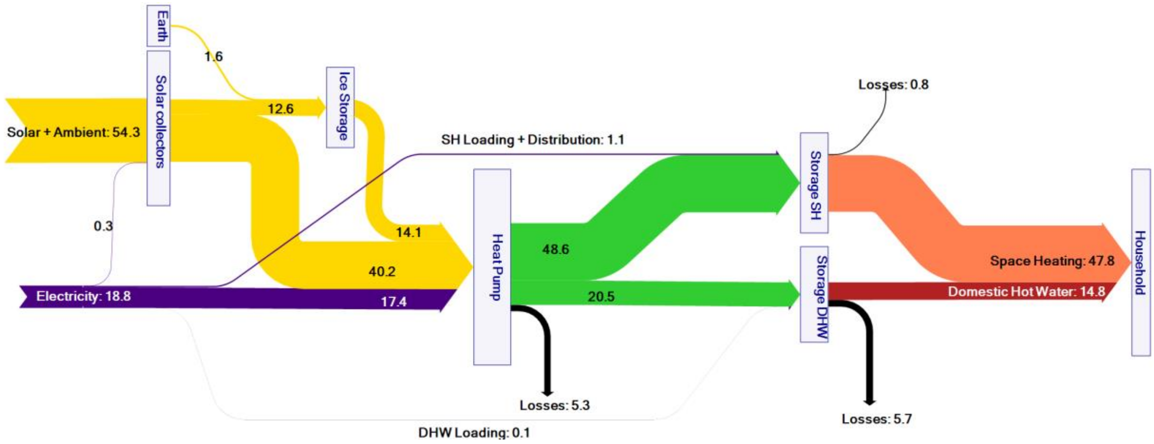


Fig. 3. Sankey-diagram for a solar ice storage heat pump system with annual energy sums

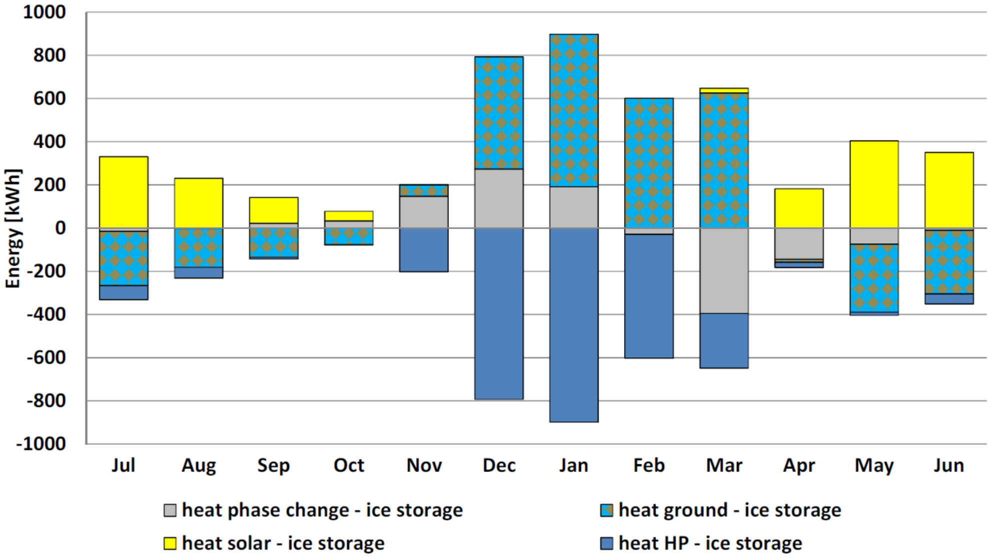


Fig. 4. Monthly energy balance for the ice storage system with SFH45*. Heat exchange is depicted on the ordinate axis, subdivided into the different energy ratios. Positive values indicate heat flow to the ice storage.
Phase change gains (losses) describe energy released (lost) through cooling (heating) or freezing (thawing) of water/ice.

Second step is then the analysis of the heat flows at the ice-storage. The heat balance between ground and ice storage in the Sankey diagram in figure 3 includes in the annual balance as well heat gains from the ground to the ice storage in winter time as also heat losses in summer time. Hence this part is not shown with its real impact in this picture. Therefore, in Figure 4, a monthly heat balance of only the ice storage is shown.

Between May and October the ice storage loses heat to the ground, which on the other hand is charged into the ice storage from the solar absorber. In the winter month November until March the heat pump draws heat from the ice storage which is supplied on the one hand from phase change heat gains and on the other hand by the surrounding ground. Here the importance of the ground heat gains is visible since in December to March most of the heat that is taken out of the ice storage comes from the ground. In fact, the latent heat gains of icing process secure a minimum inlet-temperature of the heat pump. Hence, the biggest amount of heat does not come from the latent heat transfer, but from the surrounding ground.

Third step then is the analysis of the heat flows at the solar absorber. Figure 5 shows the convective properties of the solar absorber by a comparison of the measured power curve without irradiation compared to the convective heat transfer at a plane wall. The main questions for the solar absorber are, "What are the most important characteristics of the absorber?" & "Where does the absorber gain heat from?". Since the mechanisms convective heat transfer and solar irradiation are strongly coupled at the solar absorber, the influence of these mechanisms is tested and shown by two failure cases in simulation with deteriorated properties.

In the first case the influence of the solar irradiation is tested by a total shading of the absorber so that no solar irradiation comes to the absorber and it can only gain heat by convection. This reduces the SPF_{bSt} for the SFH45* from 4.47 to 4.45 and hence shows a negligible influence.

In the second case the convective heat gains are tested. The first test reduces the wind speed at the collector to constant 1.5 m/s where the average wind speed in the climate data is 5.5 m/s. This reduces the SPF_{bSt} for the SFH45* from 4.47 to 4.18, a significantly higher reduction of 6.5%. In the second test of convective heat gains, a different absorber design is used, where the convective heat gain coefficient is approximately half of the original value. This reduces the SPF_{bSt} for the SFH60* comparatively strong from 4.12 to 3.66 or by 11%.

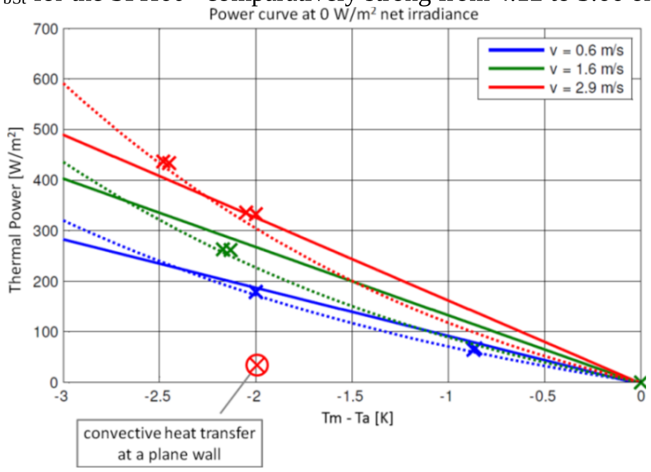


Fig. 5. Thermal power curves for absorber test without irradiance and three different wind speeds. Measurement points are marked with an 'x', dashed lines indicate a polynomial fit and the results from a simulation model are shown as solid line.
Tm - Ta = difference between medium absorber temperature and ambient temperature

The uncovered absorber of the solar-ice-storage heat pump system consists of two layers of parallel tubes. Hence, convective heat transfer is comparably high and much better than for a plane wall. For example, plane absorber plates or typical uncovered, plane PVT-collectors would require an area about five times larger to reach comparable results in system energetic efficiency in simulations. This means in the end that comparable results regarding the heat pump system efficiency can be reached by 10 m^2 of uncovered absorbers or 50 m^2 of PVT-collectors, as shown in figure 6.

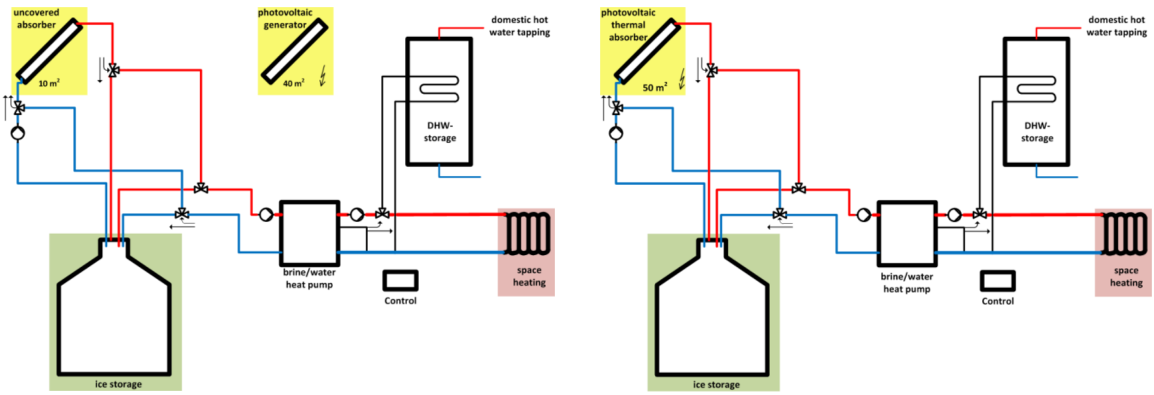


Fig. 6. Solar-Ice-Storage heat pump system
left: with 10 m^2 uncovered absorbers and 40 m^2 PV-modules / right: with 50 m^2 PVT-modules

The extended evaluation of ice-storage systems showed the following, summarised results, concerning the usage of manifold heat sources for brine/water heat pumps. Against first expectations, solar irradiation is nearly negligible as heat source and the by far most important heat source is convection from the outside air. Second biggest ambient heat source is the ground heat exchange. Only third biggest heat source are latent heat gains in the ice-storage, but they have an important effect on system efficiency due to the effect of securing a minimum source temperature.

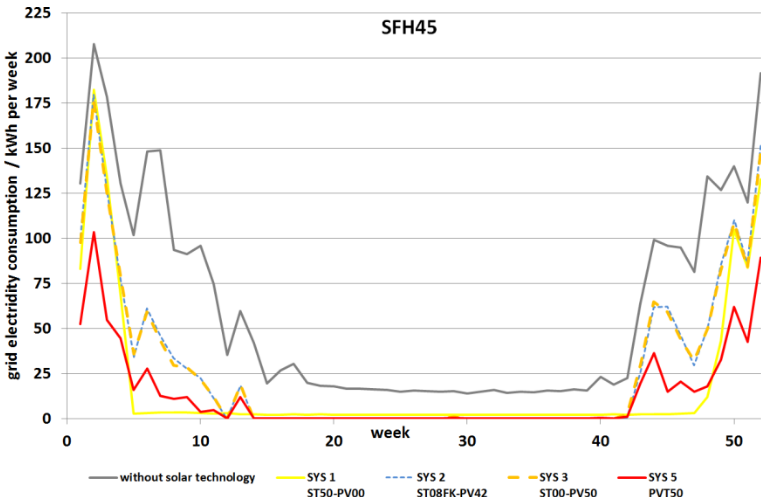


Fig. 7. Annual devolution of the electricity demand for four solar heat pump systems compared to an air/water heat pump without solar technology for SFH45

Why is this use-case exemplary for the integration and use of manifold heat sources with brine/water heat pumps?

As figure 7 shows in the comparison of the annual devolution of the electricity demand for four different solar heat pump systems compared to an air/water heat pump without solar technology, the summer situation is mainly the topic of cleverly using some solar technology and without much difference which. Biggest effect has the reduction of the electricity demand in winter or transition time. There, on the one hand storages can play an important role and on the other hand increased winter efficiency. From the authors' point of view, brine/water heat pumps using manifold heat sources can play an important role in increasing the winter efficiency. If you want to improve the annual heat pump system efficiency, that's much easier done with a brine/water heat pump, because you can much easier integrate manifold heat sources like solar heat, latent heat, ground heat or also waste heat from anywhere and, and that's also one thing I learned in the project, it's also possible to use air as universal heat source efficiently with a brine/water heat pump, especially since there are high efficient pump and fan solutions available nowadays, which may be the core difference to former projects trying to use air as heat source via brine circuit.

Now, next question from here has to be, where and how to apply these results. Because building an ice-storage heat pump system is more efficient compared to an air/water heat pump, but on a short view will be hard to pay off financially.

3. Application cases for brine/water heat pump with manifold heat sources

Brine/water heat pumps with manifold heat sources will probably not be the vast majority of heat pumps applied in future. Their strength is to easily adaptable to given surroundings and requirements. Application fields are more defined by the special situation, that a classical and easy solution like a single air/water heat pump or a brine/water heat pump with borehole are not fitting into the given situation or not fulfilling the given requirements. In the following some application situations shall be outlined, whereof one situation is described a bit more in detail because it was one starting point of these thoughts.

- The ice-storage system described above is one example where the aim of a higher seasonal performance factor is the driving reason to integrate several heat sources. In this case, every heat source can supply full capacity, but operation is linked to special boundaries. These boundaries are the seasonal variation of source temperature outside air on the one hand and limited energetic capacity of the ice-storage on the other hand. Nevertheless, these full capacity heat sources can be connected in parallel and used alternatively.

- If a heat source is limited and fluctuating in availability, like e.g. some waste heat sources, it has to be evaluated if this heat source can serve as booster function connected in series with limited capacity or as alternative, parallel heat source with limited operation time. One example could be outside air as basic heat source and the renovation of existing multi-family buildings with whether ventilation heat recovery or sewage water heat recovery which serve as heat source for the heat pump.

- Another case could be, that an existing borehole heat exchanger is too small, e.g. due to an increased heat demand of an older building or a smaller extension of a building and an air/brine heat exchanger could be used as additional heat source that improves the summerly efficiency and reduces the energetic load of the borehole heat exchanger so that afterwards the size is sufficient again.

- Last example is the integration of an air-source heat pump into an existing building, where the heating room and with this the connection to the heat distribution system is given and the air source has to be placed at a totally different place, e.g. due to sound level requirements.

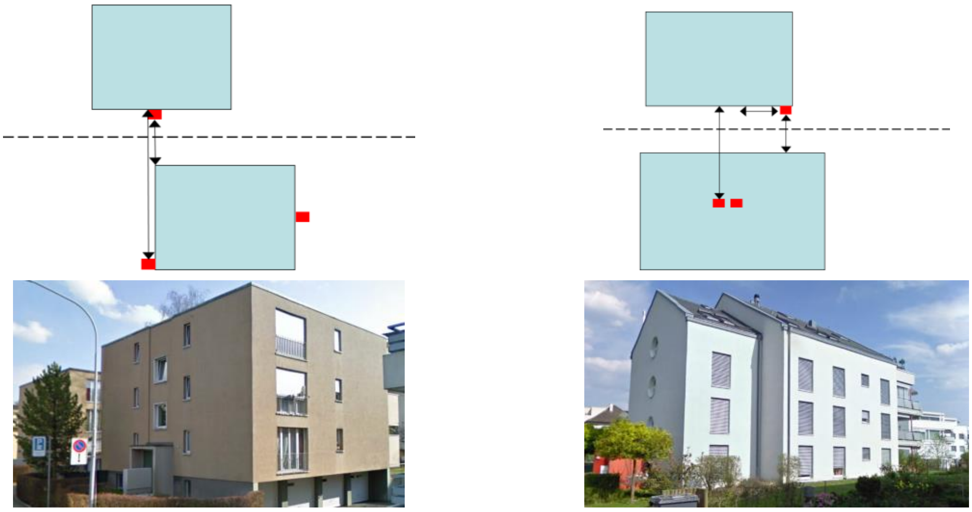
In a project for the city of Zürich, the extensive application of air source heat pumps had been evaluated, since they have the potential to be easily applied and universal heat generators, which can replace oil- and gas-boilers in future heat generation scenarios, with the requirement of using only renewable energy sources. An energy strategy scenario for Zürich in the year 2050 declares air-source heat pumps as being able to be applied in almost every place with a very small demand for installation space and external infrastructure. The main questions were if this is realistic and what is required to have city-compliant and energy efficient air-source heat pumps easily available for the most common application, replacement of fossil oil- or gas-boilers in existing residential buildings with up to about 1000 m^2 living space.

Four typical situations were defined for air-source heat pumps to be applied and were evaluated:

- Case 1 are single family houses (row house or small single family house) with
  100 - 150 m^2 living space,
  2.5 - 10 kW heat pump capacity,
  50 - 60 dB(A) typical sound power level of the heat pumps outside and
  3 - 8 m of typical distance for potential air-source placements to the next neighbour.
  For this case, there are simple and widely available solutions.

- Case 2 are detached single or double family houses with
  120 - 250 m^2 living space,
  4 - 20 kW heat pump capacity,
  55 - 65 dB(A) typical sound power level of the heat pumps outside and
  3 - 11 m of typical distance for potential air-source placements to the next neighbour.
  For this case, there are also simple and widely available solutions, but special attention has to be paid to the sound power level of the air-source heat pump to comply with noise protection regulation.
- Case 3 are smaller multifamily houses with
  250 - 500 m^2 living space,
  6 - 35 kW heat pump capacity,
  60 - 70 dB(A) typical sound power level of the heat pumps outside and
  3 - 15 m of typical distance for potential air-source placements to the next neighbour.
  For these smaller multifamily buildings air-source heat pump solutions showed to be available, but more complex to find a solution for fossil boiler replacement. Special challenges were that not always a planner is involved but to comply with noise protection regulation and realising an efficient heat pump operation with low flow temperatures is mostly not daily routine for the involved actors.

- Case 4 are medium sized multifamily houses with
  300 - 1000 m^2 living space,
  8 - 90 kW heat pump capacity,
  65 - 80 dB(A) typical sound power level of the heat pumps outside and
  3 - 15 m of typical distance for potential air-source placements to the next neighbour.
  Situation here is comparable to situation 3 but in addition, noise protection is even more challenging to comply with and the number of available and suitable heat pump units gets significantly smaller.



case 3 - smaller multifamily houses | case 4 - medium sized multifamily houses

Fig. 8. Case sketch with indicated land boundary (– – – – – –), possible heat pump location / sound source ■, distance between sound emission point and place of impact ⟷

Especially for the two bigger multifamily building types, main problems that planners announced were problems finding a place for the air-source that fulfils the noise protection requirements in the given surrounding and fulfils the visual demand of the owner, inhabitants and architect and furthermore has access to the existing heat distribution system. In densely built and already existing situations like in cities, sound power level of air/water heat pumps and visual integration are of key importance to overcome actual barriers that inhibit a more widespread application. In the case of more complex situations like in existing multifamily buildings, compact air/water heat pump units may be difficult to implement. Especially there, brine/water heat pump units with air/brine heat exchanger as main heat source, and where applicable additional heat sources, may help to overcome actual barriers concerning the placement of air-source and visual integration.

Hence, for a broad and numerous application of air-source heat pumps as replacement for fossil boilers in existing residential buildings, on the one hand easy to apply air-source heat pumps with low sound power level around 50 - 55 dB(A) are required especially for smaller houses and on the other hand flexible heat pump solutions to be easily adapted to a variety of existing situations in bigger multifamily houses.

4. Conclusions

Based on the results and work of three research projects a potential beneficial use of brine/water heat pumps with manifold heat sources can be outlined and also some positive experience with the integrative use of different heat sources can be shown. As pointed out in the beginning, this work was not explicitly intended to evaluate this type of heat pump systems, but evaluated and interpreted for this application. Hence, the presented work is neither extensive nor handles the topic in-depth. But, there is a potential use of such systems in future heat pump applications, like increasing system efficiency with air as first heat source using additionally other heat sources like ice storages, waste heat recovery, solar collectors or ground heat sources as well as the potential use of getting more flexible in choosing best heat source depending on actual operating conditions and adapting to local boundaries with intermediary brine circuit. There are also basic disadvantages like the additional heat transfer that is a drawback in principal. Hence, this is no universal solution but rather a niche solution, but if done right, there are potential benefits to solve future challenges with an increased renewable energy share and the demand to find more flexible system solutions and it is worth to keep an eye on it.

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References

[1] Dott R., Winteler C., Afjei T., Genkinger A. 2015. *SOFOWA - Kombination von Solarthermie, Fotovoltaik und Wärmepumpen - final report*. Institute of Energy in Building - FHNW for the Swiss Federal Office of Energy SFOE. Muttenz. CH.

[2] IEA Solar Heating and Cooling – Task 44 / Heat Pumping Technologies Annex 38: *Solar and Heat Pump Systems*, January 2010 - December 2013, CH (http://task44.iea-shc.org)

[3] Hadorn J.-C.. *Solar and Heat Pump Systems for Residential Buildings*, Wilhelm Ernst & Sohn., ISBN: 9783433030400, 2015.

[4] Dott R., Afjei T., 2014. *Stadtverträgliche Luft/Wasser-Wärmepumpen als Hauptwärmeerzeuger*, Report for the City of Zürich, Zürich, CH.

[5] Jakob M., Flury K., Gross N., 2014. *Kurzbericht Konzept Energieversorgung 2050 – Szenarien für eine 2000-Watt-kompatible Wärmeversorgung für die Stadt Zürich*; Report for the City of Zürich, Zürich, CH.

[6] Winteler C., Dott R:, Afjei T., Hafner B., 2014. *Heat Pump, Solar Energy and Ice Storage Systems - Modelling and Seasonal Performance*, Proceedings of IEA-HPC2014 conference, Montreal, CA.