AIR-SOURCE HEAT PUMP OPERATION

Technical Report of the IEA DHC TS3 "Hybrid Energy Networks", subtask A "Technologies and synergy potential", WP2 "Experiences with hybrid energy networks based on large-scale heat pumps": *Air-source heat pump operation*.

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Content

1 General experiences

1.1 Operation throughout the year

Something to consider for all type of heat sources is how they perform and handle non-ideal conditions. The expected daily and seasonal variations should be taken into account in the business case i.e., how the system is affected by real-life operation in the given case. Besides this, it is important to consider challenges affecting the performance and stability of the operation. In the following, selected key challenges are explained.

In general, examples from the significant number of air-source heat pumps installed in the past few years in Denmark show that the heat pumps are able to operate throughout the winter months. They are typically designed to expect downtime during the worst-case winter conditions simply due to the heat pumps being optimized to operate within a certain ambient air temperature span. The range could in principle be enlarged when designing the heat pump solution, but it would affect the performance for the worse during the remaining period of the year. To enable operation only for a rare case situation of extremely low outdoor temperatures (e.g., less than 1% of the time) is simply not feasible in a total system perspective, when the "cost" in terms of decreased performance and/or COP is taken into account. However, the DH company needs to take this into account and be prepared for such a situation with alternative capacity to ensure sufficient heat supply at all times.

1.2 Realtime monitoring of heat pump operation

The website www.heatpumpdata.eu does not only list and illustrate large-scale heat pumps for district heating in Denmark but also represents a data hub of monitoring the operation and performance of several of these. For the heat pumps connected with a data feed, the performance can be seen in real-time, illustrated in charts or downloaded for further processing. The data include thermal output, electricity demand, COP, temperature levels etc. To show only the systems with such a data connection, a filter option is applied in the top of the map as seen in Figure 1. Icons show the main heat source of the heat pump and a small lightning icon indicates a data connection.

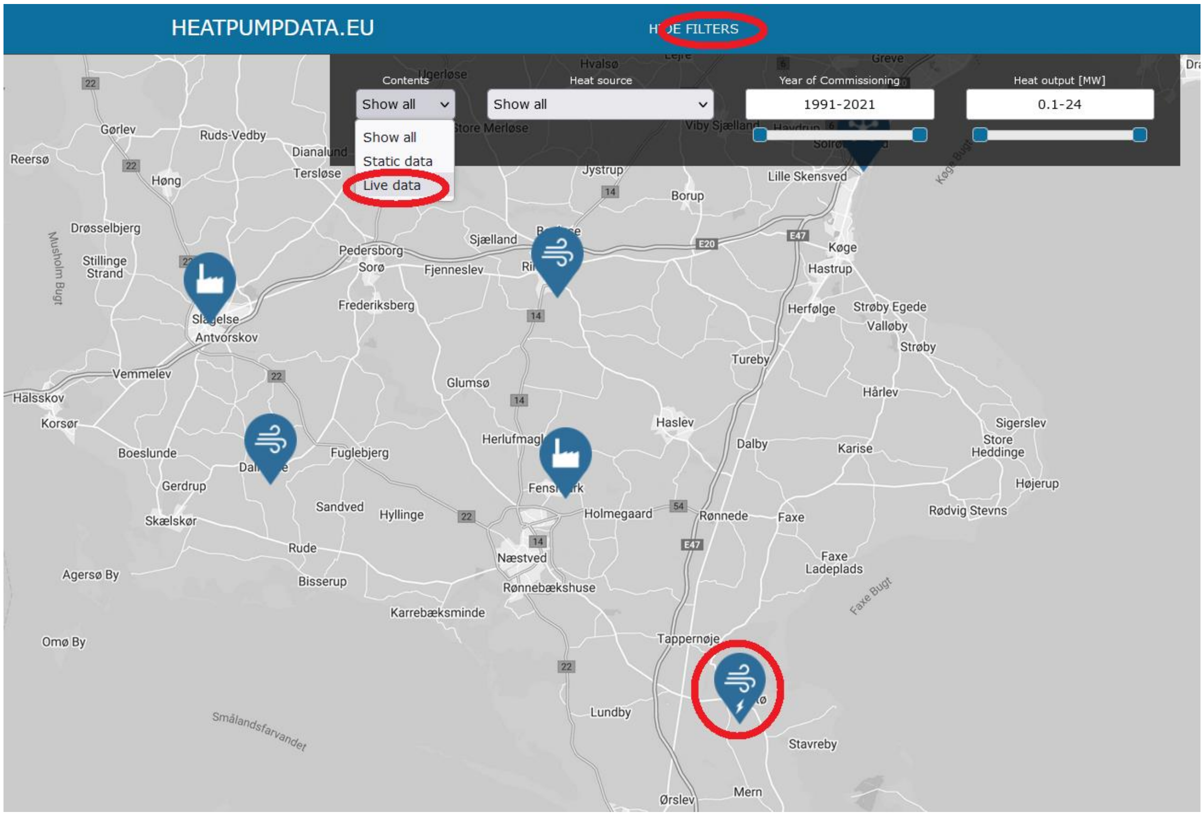

Figure 1. Section of heatpumpdata.eu website with indication how to filter for data connection (indicated with a small lightning in the bottom of the heat pump icon).

1.3 Condensate

The amount of condensed moisture can be substantial and it should be considered already in the planning phase how this is dealt with. In some cases, the water is simply absorbed by the ground below the evaporator unit (presuming the ground is prepared to handle it) whereas in other cases the water is led to a nearby sewer or even utilised for watering.

2 Defrosting

2.1 The need for defrosting

Air moisture condenses when the air is cooled by the evaporator unit. When the air temperature approaches 0 °C, this water will freeze on the evaporator unit. It should be noted that due to the cooling of the air, this happens already at ambient temperature *above* 0 °C.

To handle the build-up of ice on the evaporator unit, it is necessary to consider defrosting in the planning phase, control strategy and feasibility studies. Since the energy required for defrosting is not insignificant, this should be taken into account when evaluating the feasibility of different solutions.

2.2 The build-up of ice

Air source heat pumps operate with a temperature difference between the air and the refrigerant flowing inside the pipes, and the ΔT between these is usually 5-8 °C. Ambient air passing through the evaporator gets in contact with fins and pipes. These components are colder than the air. If the temperature is below the dewpoint of the air, then the humidity condenses on the evaporator. Drops start to accumulate on the surface, getting the evaporator wet.

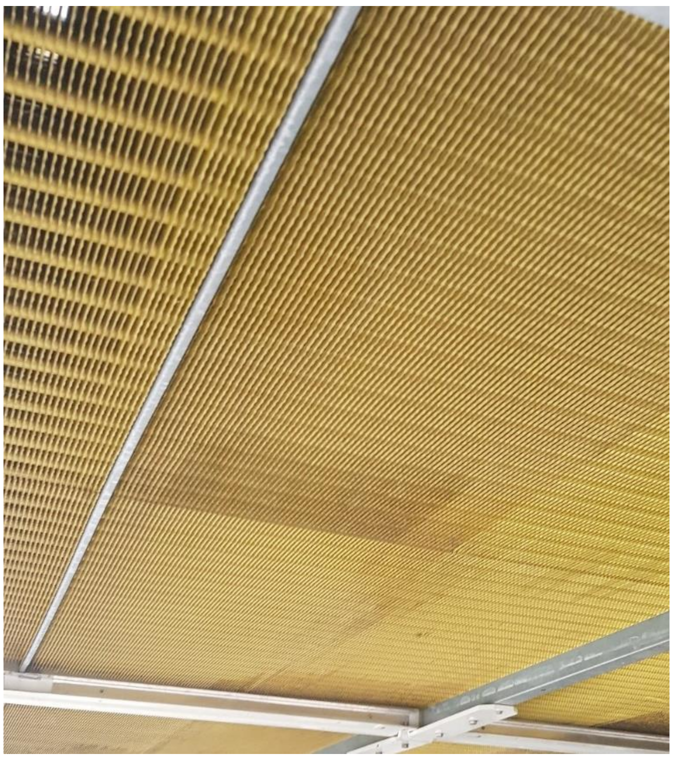

Figure 2. Flatbed evaporator fins seen from below.

Water deposition is beneficial for the operation of the heat pump since latent heat of condensation is released and used by the evaporator. The heat is then transferred to the refrigerant, and it is used for the operation. It accounts for approximately 25% of the total heat transferred in the evaporator.

When the ambient temperature drops below around 7 °C, the refrigerant temperature within the evaporator drops accordingly, reaching 0 °C and below. The water drops on the surface start to freeze, and a layer of ice grows. At first, the ice formation is beneficial in the same way of the water condensation: latent heat of solidification is released and transferred to the refrigerant.

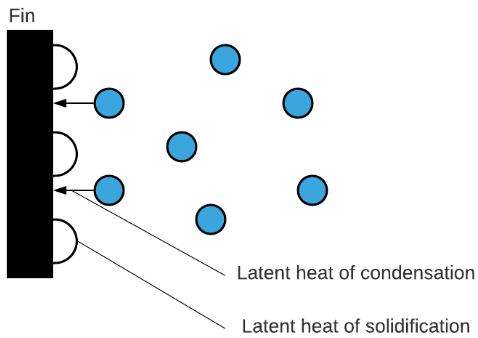

Figure 3. Condensation and solidification of air humidity.

The challenges start when the evaporation temperature stays below 0 °C for a longer period of time. The frost layer becomes thicker and thicker, and it starts to behave as a thermal resistance. The heat transfer coefficient between the air and the pipes reduces, and the amount of heat transferred to the refrigerant reduces as well. At the same time, as frost grows, the space between the fins reduces. Usually, the fin spacing is 3-7 mm to optimize the heat transfer surface and the compactness of the component. With increased frost thickness, the pressure drop throughout the component increases. At this point, the following two options are available:

Fixed fan speed

The fans are running at the same speed, regardless of the frost formation. In this case, since the pressure drop increases with increased ice thickness, the amount of air passing throughout the evaporator reduces, thus reducing the amount of heat transferred to the refrigerant.

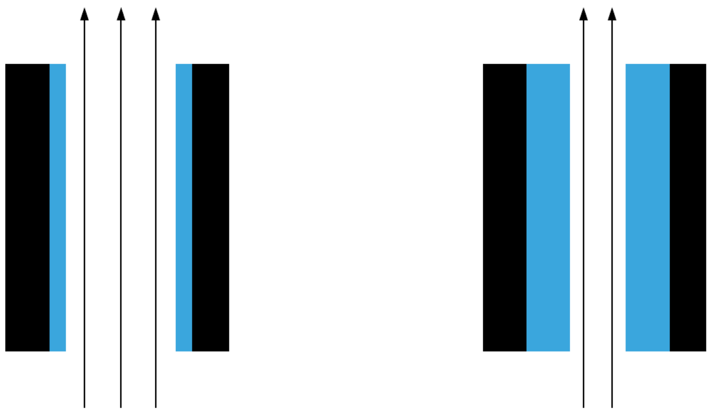

Figure 4. Fixed fan speed strategy.

Variable fan speed

Using a control system, a variable fan speed strategy can be set up in such a way that the fans increase their speed depending on the pressure drop to keep the heat load constant. This strategy ensures the normal operation of the components, but at the same time requires higher electricity consumption at the fans. The power consumption increases with an exponential trend, and it becomes very high when the fin spacing gets almost completely filled with ice. There might also be noise limitation for the maximum speed allowed.

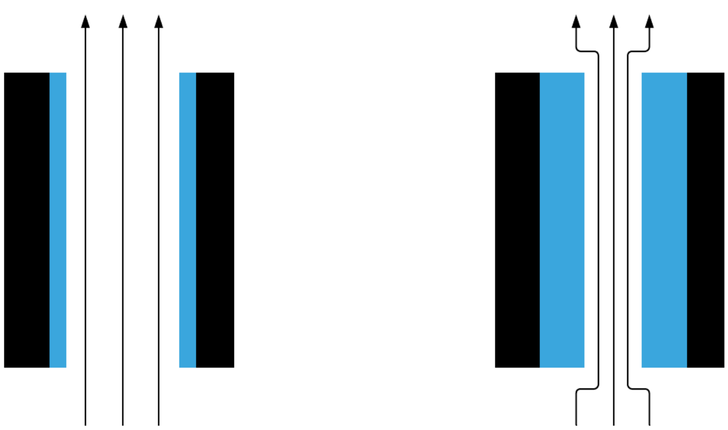

Figure 5. Variable fan speed strategy.

In both of these strategies, when the ice layer fills up completely the space between the fins, then the evaporators will stop working and no heat will be transferred to the refrigerant. Defrost is necessary to establish the correct functioning of the system before this happens.

2.3 Defrost strategies

Different defrost strategies are available to counteract the frost formation on the evaporator. They can be classified into different categories:

Upstream air treatment

This type of intervention aims to treat the air at the inlet of the evaporator to reduce the frost formation. Possible options are air humidity reduction at the fan inlet or preheating the air before it gets into the component. These interventions could have a beneficial effect on the operation since it would remove the frost issue, but on the other hand, it would increase the energy consumption and the initial investment since the components necessary to remove humidity or to heat up the air will be expensive and energy consuming.

Heat exchanger modification

The evaporator can be designed to get to the optimal configuration where frost formation is reduced at the minimum level and the heat pump operation optimized. The focus could be on:

- Increased fin spacing, to allow the maximum space between fins and extending the component operation by still keeping the component as compact as possible.
- Optimizing the tube geometry
- Selecting the right fin-type
- Coating of the fin since a cross-linked hydrophilic polymer coating can reduce the frost growth rate on a cold surface

None of these options prevent frost formation entirely. Every intervention should be balanced with economic considerations since the extra investment cost to include these modification does not necessarily lead to overall economic savings.

Defrost by cycle interruption

This category includes the most utilized and efficient techniques to perform evaporator defrost. To be able to remove the ice from the surface, the evaporator should be turned off. In this context, the large scale of the plant allows partial defrosting of the system since it is made of multiple evaporator sections running in parallel. One section at a time can be taken out of operation, defrosted, and then restarted. In this way, the system will always have enough evaporating capacity and keep a continuous heat production.

Different techniques are available such as:

- *Shutdown defrosting*, where the evaporator performing defrosting is shut down with the fans still blowing air on the surface. If the air is above the freezing point, the ice will melt.
- *Electric heating*, where electric devices are installed adjacent to the coil. Once frost is detected on the surface, the evaporator section is shut down and the heating elements are turned on with the fans still running. In this way the ice on the coil is melted by means of radiation, conduction, and convection.
- *Hot gas bypass*, where hot gases coming from the evaporators are bypassed into the evaporator section performing the defrost. Latent heat from the condensation of the superheated gas is released to melt the ice. This is a fast and the most common way to perform defrosting for commercial air-source heat pumps.

Regardless of the technique, the main goal is to optimize the operation. Depending on the location, on the number of evaporator sections installed, and on the size of the system, the defrost strategy should aim to minimise energy consumption. The analysis should focus on the maximum frost thickness allowed on the evaporator before defrosting is started, and on the defrost duration period.

2.4 Extraordinary occasions

What has been seen in specific winter conditions is that for downward air flow, a heavy snowfall at ambient air temperatures above 0 °C followed by sub-zero degrees may block the evaporators and freeze them over without the option of activating the normal defrosting. For upward air flow, the continuous operation blowing snow away from the fans may help to avoid this situation.

Under certain weather conditions it has been shown that the formation of an ice layer on the fans and inside the fan casing is creating a physical resistance for the rotating fans. Only a few cases of the occurrence have been gathered and research is ongoing as to how it is best avoided. One option is to include additional predefined circumstances where defrosting is activated in the heat pump control strategy. In case of supercooled moisture/water droplets, as seen in the rare occasion of freezing rain, ice is formed at the cold surface the droplets hit. When this surface is the protective grill/fan, it makes it difficult to defrost with a downward air flow. Further information on this is found in section 3.2.

3 Air flow

3.1 Type of air coolers

As a rough estimation, flatbed air coolers require approximately 100 m^2 of ground per MW of heat capacity. The air flow can be upwards or downwards.

Figure 6. Example of flatbed evaporators at Præstø Fjernvarme.

Another option is the V-shape evaporators as seen in Figure 7. With these, the air flow is always upwards. In some cases, it is more challenging to ensure sufficiently free flow of air around the evaporators compared to a flatbed solution.

Figure 7. Example of V-shape evaporators at Slagslunde Fjernvarme.

3.2 Direction of air flow

Advantages and disadvantages for both upwards and downward air direction are described in the following.

Downwards air direction

As shown in Figure 8, ambient air enters the evaporator from above and cools down, releasing heat to the refrigerant which evaporates. Cold air is denser compared to warm air, therefore the natural convection cooperates with the direction given by the fans. The air moves downwards. Once the cold air exits the evaporator, it stays on the ground level as it is denser than the surrounding air. In this way, the issues of mixing with warm air and short-circuits are averted.

For flatbed applications, the fans are installed on top of the coil. During their operation, the fans waste a considerable amount of energy (50% of their total use) as heat due to mechanical friction. With the downwards flow direction, the heat released from the fans is utilized within the evaporator component and it increases the capacity of the evaporator. However, this has a marginal impact, as it only increases the COP slightly.

Another positive impact of having downwards air flow is linked with the water condensation on the evaporator surface. When water condenses on pipes and fins, the fans blowing downwards will cooperate with gravity on getting rid of the water. The accumulation of water will be reduced during the operation and it will also reduce the amount of frost building up on the evaporator surface.

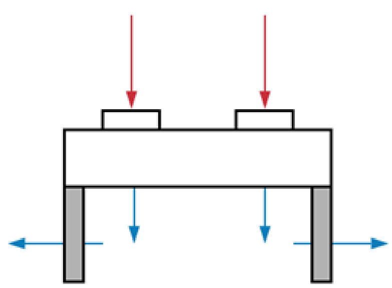

Figure 8. Downwards air direction of a flatbed evaporator.

Upwards air direction

As shown in Figure 9 ambient air enters the evaporator from below and cools down moving upwards. When cold air exits the evaporator, it may fall down due to increased density. This imposes a risk for short-circuits by recirculation of cooled air to the evaporator. The effect is reduced by the occurrence of wind blowing the cooled air away.

Hence, the risk, level and impact of recirculation are not fixed parameters, but varies along with the wind speed and direction.

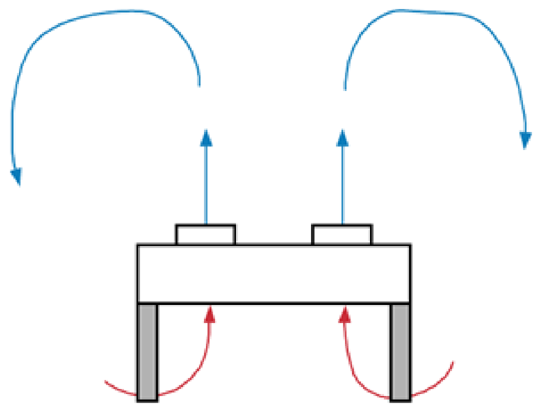

Figure 9. Upwards air direction of a flatbed evaporator.

With the installation of a diffuser at the outlet of the fans, cold air will be thrown further away, preventing recirculation and short-circuit.
On the other hand, the advantage of having upwards air direction is that instead of being pushed in, the air is sucked through the cooling surface, ensuring the best possible flow distribution and the best possible utilization of the cooling surface.

With an upwards air direction, the noise production is slightly reduced. The safety grill on top of the fans (see Figure 10) is placed at the outlet of the fan, ensuring higher efficiency and less noise.

Figure 10. Close-up of the protective safety-grill on top of the fans of a flatbed evaporator.

Regarding the distribution of cold air, with upwards direction improved mixing with uncooled air reduces potential inconvenience caused by the cold air. In contrast, with a downwards air flow direction, the air could lie as a duvet over the nearby area.

An important factor that should be considered is the temperature below the evaporators and the ice formation on the ground. During the operation, water condensation and defrost will occur and the water from the evaporators will fall to the ground. If the air temperature is below the freezing point of water, a layer of ice will grow below the evaporators until the temperature rises again to a sufficient level to melt the ice. For this reason, it is important to keep in mind to place the evaporators high enough to allow a gap between the evaporator components and the ground while ensuring sufficiently free flow of air.

3.3 Recirculation of air

In some cases, walls surrounding the evaporators are installed to mitigate an issue of recirculating air as seen in Figure 11. However, in the most common solution is for flatbed evaporators to be installed without such wall mount.

Figure 11. Evaporators with wall mount to reduce air recirculation at Karup Fjernvarme. (Credit: Morten Pedersen. https://viborg-folkeblad.dk/rundtomviborg/trods-gasprisernes-himmelflugt-lokalt-varmevaerk-styrer-flot-uden-om-prisstigninger#slide0)