New Heat Pump Concept for Temperature Flexible Low-Temperature Operation Used for District Heating

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This article describes the new approach to low-temperature district heating using a new type of heat interphase unit equipped with micro-heat pumps called Flex-Booster. The system will be demonstrated in a network with about 300 consumers. The network will use plastic pipes and a heat supply from a heat pump, partly powered by solar electricity. Concept and technology are described, as well as perspective on market potential. The special focus is on the benefits and problems solved with the Flex-Booster concept vs using traditional district heating systems.

Introduction

Approximately 350,000 homes in Denmark are still heated with natural gas. To reduce the emission of greenhouse gases, these homes must be converted to CO_2-neutral heat supply as soon as possible. A new innovative heat pump concept for low-temperature (LT) district heating (DH) has been developed, focusing on temperature-flexible operation on both primary and secondary sides. It will be based on a CO_2-neutral heat supply and tested as an attractive alternative to traditional district heating solutions.

The project is co-financed by EUDP, the Danish Development and Demonstration program for Energy Technology grant number 64021-2022, "Flex Temperature DH with local co-production and use of new Flex Booster units".

The project consortium consists of METRO THERM A/S (heat pump manufacturer), COWI A/S Energy International (consulting engineers), RUBRIK (communication bureau), EBO Consult A/S (district heating administrator) & Hvidovre Fjernvarmeselskab (district heating company).

The demonstration is located in Avedøre Landsby, situated about 10 km west of Copenhagen Centre in Denmark. It consists of mainly single-family detached and terraced housing, i.e., small and medium-sized consumers of 7-14 kW plus a few larger consumers up to 72 kW design load.

New hybrid heat pump assisted district heating system

The project innovates, demonstrates, and evaluates a new hybrid district heating system on full scale for a village district with 300 consumers. The demonstration includes the full energy supply chain from production over the distribution system to end-user installations and local co-production.

The system makes use of 3 new technologies:

1) Cost-efficient temperature flexible DH heat interface unit with built-in heat pump
2) Temperature flexible operation of district heating grid called Flex-Temperature District Heating
3) Flex-Energy Central with cascade coupled heat-pump system with a boiler modified for green fuels and a PV array – all installed in an energy community sharing the benefits.

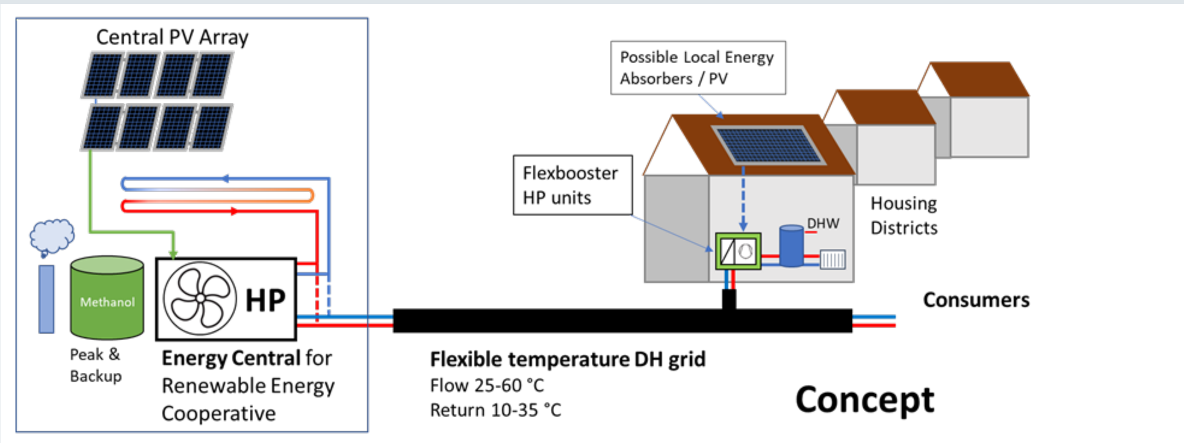

Figure 1: The new concept for temperature-flexible DH.

The purpose is to open up a wider use of 5th-generation District Heating systems in the green transition at lower cost and easier integration in existing buildings.

The purpose is also to demonstrate a zero-carbon energy system.

Low-temperature district heating areas - state-of-the-art

In recent years, DH companies have become more aware of the possibilities of lowering the temperature in the network down to the limit required for DHW production, where, in the past, they tended to run with a larger margin.

Furthermore, stronger competition in the heat market has arrived, where the main question is: "Should the future of heat supply be based on DH or decentralised heat pumps?". However, a new vision is now emerging in the industry, which is not "either / or" but rather a "both" with an optimised interaction between the different solutions. It is this realisation that the present article sets into scene. The use of electricity from solar and wind is increasing rapidly, and the electricity supply in Denmark and other countries is now getting green with much lower CO_2 emission – and in combination with a heat pump, the CO_2 emission related to the produced heat can get very low – hence heat pumps in DH systems have become interesting.

Advantages of low-temperature and ultra-low-temperature district heating:

- Lower heat losses in pipes and systems, as the temperature difference to the surroundings is reduced.
- Lower temperature provides better opportunities to integrate renewable energy sources such as, solar heat, geothermal heat, surplus heat, condensing heat etc. The lower temperatures ensure higher efficiency in the exploitation of these resources.
- The use of low operation temperature enables the use of plastic distribution pipes, which are easier to install than steel pipes, with no need for specialised steel welders and an expected life span of over 50 years.

Disadvantages of ultra-low temperature district heating:

- Existing housing supplied with natural gas most likely has heating systems originally designed for high temperatures, e.g. 80/60°C, but often still need about 70°C supply temperature under design conditions (depending on present insulation standard), so when LTDH is supplied, there is a need of installing bigger radiators and a need of rebuilding heating systems from single string to double string systems to reduce the return temperature to an acceptable level for DH supply.
- DHW systems with hot water tanks normally need a DH supply temperature above 60-65°C or 58°C with flow through heat exchangers.

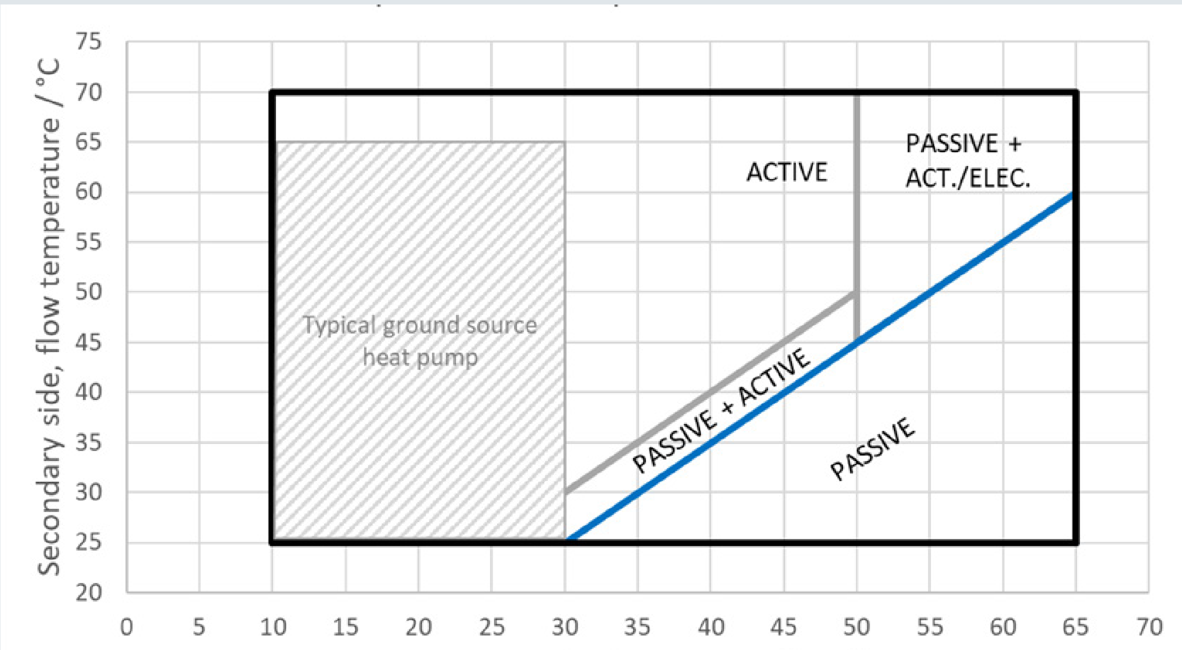

Figure 2: Operational envelope of the Flex-Booster Heat Interface Unit.

- With LTDH, the temperature difference between supply and return is often reduced, leading to bigger pipe dimensions and higher capital costs or less capacity in existing DH networks.
- The use of distributed heat pumps to boost the end-users' temperature needs normally comes with a relatively high cost when using normal ground source heat pumps, and the COP is relatively low as the evaporator temperature will be no higher than 15-20°C, as traditional heat pumps are not designed for high-temperature flexibility of the inlet temperature.

Advantages of the new flex-temperature district heating system and Flex-Booster heat interface units

- Flex temperature operation: Investigations from more sources have shown that the most economic DH grid is achieved with a design supply temperature of about 60-65°C under peak conditions, but during the rest of the year, the temperature could be lowered significantly to reduce heat losses. Calculations show that the optimum supply temperature is 40-45°C when all costs are considered under normal operation for the actual case in Avedøre raising until 63°C under peak load. The low supply temperature gives a good COP from the heat source as it is a central air-to-water heat pump.
- With the Flex-Booster HIU, DHW can be delivered under safe temperature conditions, and there is no need to rebuild the existing space heating installation. The Flex-Booster HIU is a combination of a passive HEX for LTDH and a micro heat pump where the heat pump covers the temperature needed at the end-user to the extent that the passive HEX can't meet the demand. This means that it is no longer the users with the highest temperature demand that defines the needed operating temperature of the DH grid.
- The Flex-Booster operates at higher COP (than traditional ground source heat pumps) as it can accept higher evaporator temperatures.
- The additional cost for the Flex-Booster HIU, all included compared to normal HIU's for LTDH, is of the same magnitude when the need for rebuilding the user's heating installation is also considered.

Figure 3: The houseinstallation with the Flex-Booster HIU to the left and DHW tank to the right.

- As the Flex-Booster refrigerant filling does not exceed 150 g propane, it is not required to have certified inspections every second year. The costs associated hereto are saved compared with normal heat pumps.
- Another major advantage of the Flex-Booster is that it sub-cools the return temperature by about 10°C. This means that the DH system can be designed for a design temperature difference of 30-35°C, which reduces pipe dimensions.

Test of prototype and configurations

With one Flex-Booster unit, it is possible to supply about 7 kW from the passive heat exchanger and 5.5 kW from the built-in heat pump with a COP of 4 for the heat pump and COP of 9.18 for the total unit when the DH temperature is 60/30°C. On top of that, a built-in 1.5 kW immersion electric heater can increase the peak capacity to 14.1 kW.

For apartment blocks, a Flex-Booster unit can be placed as a wall-hanged unit in each apartment. The sound level is comparable to a fridge.

How to deal with bigger single consumers?

When there is a higher energy demand, two Flex-Booster units can be combined in master–slave configuration, as seen in Figure 4. This doubles the capacity.

If the need for DHW is high, then a combination of one Flex-Booster and one Micro-booster VS unit. The Micro-booster has a built-in spiral for preheating and a micro heat pump for additional heating, similar to the Flex-Booster, but the hot water tank has an increased volume of 190 l, and it can serve 247 l hot water at 40°C. This option has the advantage that the Flex-Booster can operate at lower temperatures as it only needs to serve the space heating, which in many hours has a lower demand for service temperature than DHW.

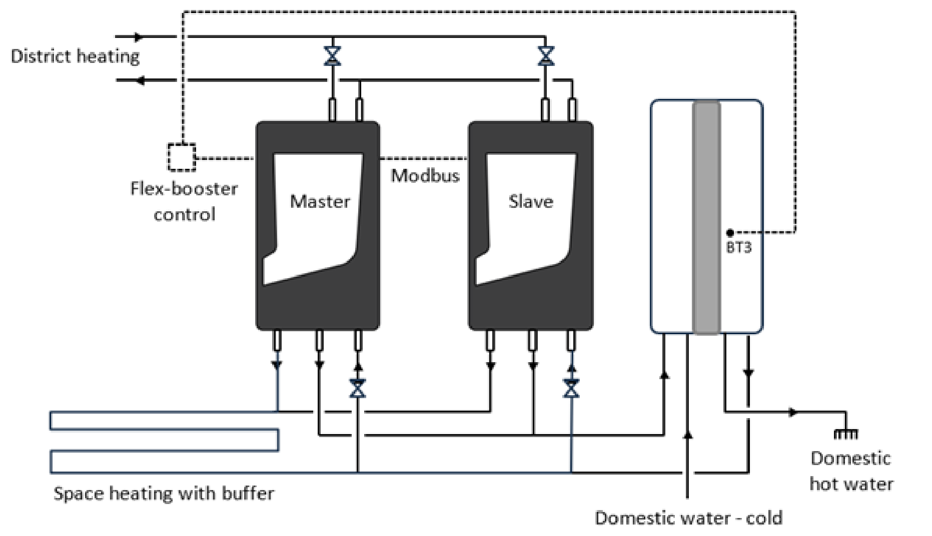

Figure 4: Modular master-slave configuration for larger consumers.

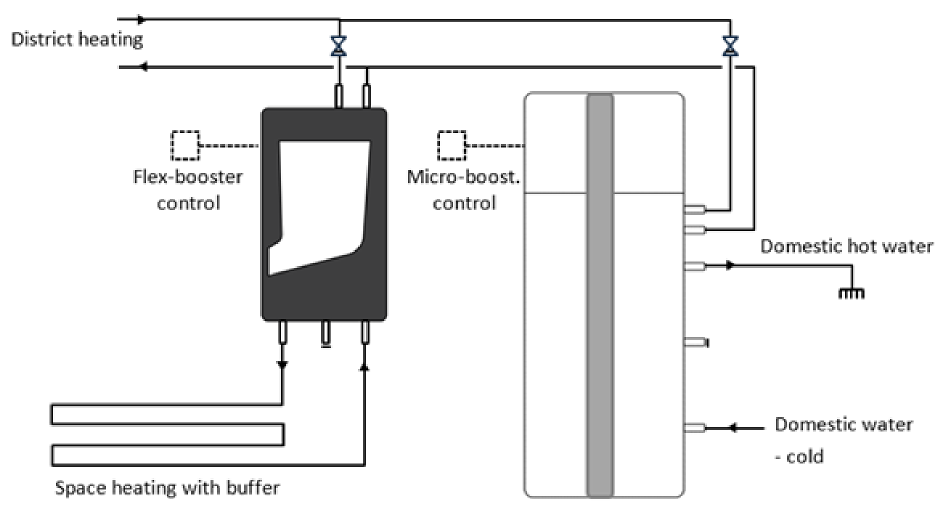

Figure 5: Configuration with large DHW consumption.

For the very large consumers

For large consumers up to 500 kW, it will be better to use a number of dual compressor Ground-Source heat pumps, but they are not optimised to use a DH as a source (they are normally only rated for 3-5 bars pressure on the primary side and usually do not allow inlet temperatures of above 25–30ºC. But with a heat exchanger and control, as shown below, it will be possible to operate well, especially if the system is serial coupled to the DH return, which will have a well-suited temperature for the heat pump. However, the COP for the heat pump will be lower due to the higher temperature lift compared with the Flex-Booster couplings.

The heat pumps can be owned and operated by the DH Company, ensuring optimal operation conditions and maintenance, and the electricity to the heat pump can either be supplied through a common purchase agreement with the DH Company or supplied by the private consumer, which may have a PV and battery system to run the decentral heat pump by solar energy to the extent possible.

Conclusions

With these new concepts introducing the Flex-Booster HIU together with heat pumps, it is now possible to operate u-LTDH grids with temperature flexibility independent of the end-user's higher temperature need. Further, it is not necessary to rebuild end-user radiator systems from single string to double string or install bigger radiators.

The new Flex-Booster HIU's increase the delta T by about 10ºC, reducing the need for pipe dimensions in new grids or increasing the existing grid's capacity. Further, it enables to use of the main DH return as a source in selected Flex-Temperature districts.

The system described is no "one-size-fits-all" solution, but it opens a variety of configurations with improved performance based on a detailed assessment of each individual case required to reach the best system design.

The system addresses the market of N-gas conversions of individual houses, DH districts where the return pipe can be used as a source, and individual houses that can be co-producers (prosumers).

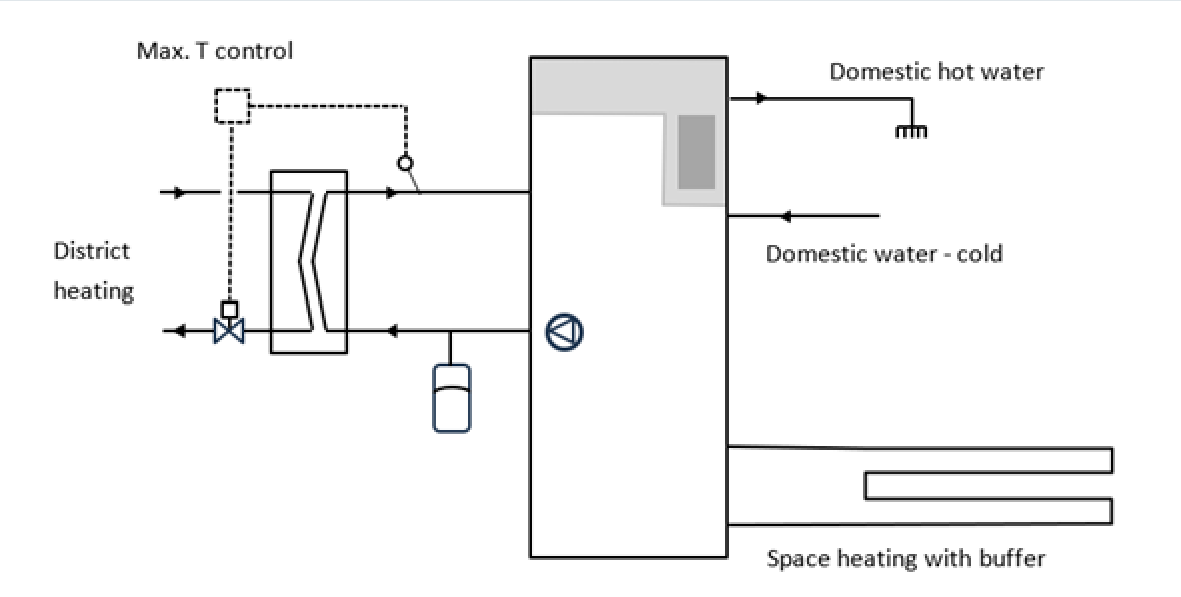

Figure 6: Configuration for very large consumer coupled on the main DH return pipe.

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For references see p. 30
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