EFFICIENT HEAT DISTRIBUTION IN SOLAR DISTRICT HEATING SYSTEMS

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Abstract – This paper contains a short analysis showing the main benefit for solar district heating when a novel heat distribution concept with low temperatures is applied. The analysis is performed by comparing the annual solar heat output from a solar collector field for current heat distribution temperatures in Sweden with the corresponding output for the novel heat distribution concept. The results show that the new low temperature concept provides 66% more solar heat for a typical solar collector. Hereby, the solar collector field can be reduced with 40%, giving a corresponding cost reduction for solar heat generated. Another result is that the cost gradient for lower costs from lower return temperatures is five times higher for solar district heating compared to current heat supply in Swedish district heating systems. One major conclusion is that high heat distribution temperatures in current European district heating systems are a major barrier for the competitiveness of solar district heating.

1 INTRODUCTION

Most current solar district heating systems utilise conventional methods regarding district heating technology for heat distribution. The present heat distribution technology has been developed over the course of a couple of decades. During this period, end users heat demand has been high, compared to what might be expected from future new and renovated existing buildings. Furthermore, heat has conventionally originated from high temperature sources, commonly by fossil fuels that can generate high temperatures with ease. These two conditions have of course had an impact on technology development over the whole period.

In the future, however, these conditions are about to change. According to legislation from the European Union, such as the energy performance in buildings directive (European Union, 2010), heat demand from buildings will decrease, and according to the renewable energy directive (European Union, 2009), less availability of high temperatures from fossil fuels is expected. A somewhat common feature of renewable energy sources is that they will not be able to deliver high temperatures at the same extent as fossil fuels have done. This is especially valid for solar district heating, since higher temperatures are more difficult and expensive to achieve. Hence, low temperatures are essential to improve system efficiency of solar thermal systems. This conclusion can also be expressed as: high heat distribution temperatures in current district heating systems are a major barrier for solar district heating.

Thus, there is a challenge for current distribution technology to change in order to cope with surrounding factors that are in motion. As when, buildings have low heat demands, heat supply is derived from low temperature sources (renewable, recycled, and stored heat), and lower system temperature levels will be required. As it seems apparent that a change towards lower temperature levels is necessary, the important question arises: what should this change or enhancement of current distribution technology consist of?

This question is essential in the development of the fourth generation of district heating (4GDH) technology, defined in (Lund et al., 2014). This definition implies that the current technology generation is called the third generation of district heating (3GDH).

2 THE CONCEPT

In previous research we have worked with a principal concept for future innovative heat distribution technology in order to obtain lower annual average return temperatures (Averfalk & Werner, 2018). In said research, we have identified three important paths to achieve lower temperature levels in future district heating systems. These are:

- Three-pipe heat distribution networks
- Apartment substations in multi-family buildings
- Longer thermal lengths in heat exchangers

One of the major drawbacks of current heat distribution technology is the embedded temperature error that occurs when no heat demands exist. At such times, supply temperature water needs to be by-passed into the low-temperature return pipe, causing considerable higher return temperatures. This happens because of supply temperature drop at a no flow situation. We refer to this as temperature degradation. In current distribution technology, the operational strategy is to mix supply and return water, we refer to this as temperature contamination and we consider this a bad utilisation of exergy. And especially so, since the situation will occur more hours of a year when buildings thermal performance increase. Thus, the extent of this problem issue will grow by time.

We suggest three-pipe distribution networks as a strategy to avoid temperature contamination. By doing so we introduce a second return pipe in the distribution network, this additional return (recirculation) pipe should only be used to at times when it avoid temperature contamination, as seen in Figure 1.

We suggest apartment substations to eliminate domestic hot water circulation in multi-family buildings. This facilitates control of flow separation into ordinary (delivery) return and the new recirculation return, since domestic hot water circulation is a constant source of delivery flow. Furthermore, due to temperature requirements of domestic hot water circulation with regard to the Legionella issue, it also a source of high return temperatures (at least when compared to the ideal of the 4GDH systems).

In addition to this, we suggest heat exchangers with increased thermal lengths in order to decrease the logarithmic mean temperature difference between flows in a heat exchanger, with the purpose to decrease temperature levels further.

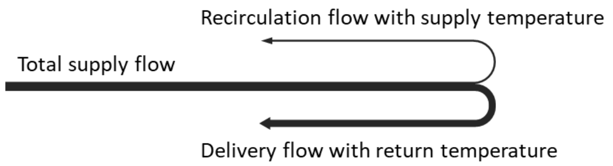

Figure 1. Denotes a conceptual depiction of the separation of total supply flow into a recirculation return flow and a delivery flow return.

In previous simulation work we have achieved results that indicate that these three changes achieve annual average return temperatures of around 20 °C for a small single-family house area, which is in line with ideal return temperatures of the 4GDH systems, as seen in Figure 2. Whereas, the ideal supply temperature is about 50 °C without requiring any auxiliary local heat supply. Various simulated annual average distribution temperatures from (Averfalk & Werner, 2018) are presented in Figure 3.

Simulation of heat losses, when comparing the situation in Figure 2, indicates that steady-state heat losses are equal. Currently, our research is still on a desk research level. However, we are interested to establish relationships with anyone that might be interested to take these ideas into a demonstration level project.

Figure 2. Presenting a standard configuration of twin-pipe (DN65 insulation series 3), to the left alongside with corresponding conceptualisation for a triple-pipe, to the right. The numbers are represented as annual averages temperatures for a single-family house area.

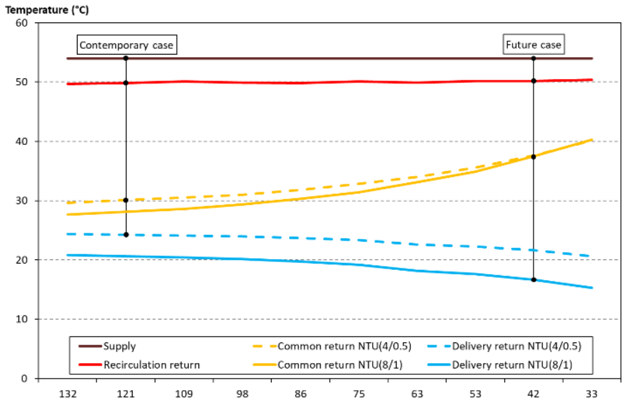

Figure 3. Annual simulation results regarding the case area temperature levels at the starting point to the distribution area. Horizontal axis displays the variation of heat power signatures, expressed as corresponding specific heat demands in kWh/m2, year. The two vertical lines point out two different simulation cases: one contemporary case with high heat demands to the left and one future case with low heat demands to the right. According to (Averfalk & Werner, 2018).

3 THE BENEFICIAL OUTCOME

The main economic value of lower annual average supply and return temperatures concerning solar district heating is higher conversion efficiencies in the solar collectors.

Other future economic benefits in 4GDH systems are:

- Lower heat distribution losses since lower temperatures than 3GDH systems
- Geothermal wells with higher capacities
- More easy access to low-temperature excess heat without heat pumps
- Higher COP in large heat pumps
- Higher recovery from flue gas condensation when using wet fuels, such as biomass and waste
- Higher power-to-heat ratios in steam CHP plants using biomass or waste
- Higher capacities in heat storages that also have access to high temperature heat sources

As an example, the economic difference for a solar collector field between different generations of heat distribution temperatures can be estimated in an analysis. The required input parameters for this analysis are the annual heat output with respect to mean fluid temperature, the installation cost for solar collectors, annual average network temperatures, the efficiency for the heat exchanger between the solar collector circuit, and the financial parameters of lifetime and hurdle rate.

The following input information has been used in the analysis:

- Annual heat output concerning Stockholm (Sweden) for Arcon-Sunmark HTHeatBOOST 35/10 solar collectors according to documentation in (Technical Research Institute of Sweden, 2016) and presented in Figure 4.

- Installation cost for solar collectors from Silkeborg, Denmark 2016 (225 euro/m^2 solar collector area).
- Annual average network temperatures of 86-47°C for a typical Swedish 3GDH system, according to (Frederiksen & Werner, 2013).
- Annual average network temperatures of 50-20°C for a new 4GDH system with novel heat distribution technology.
- Heat exchanger between the solar collectors and the district heating network with thermal length (NTU = number of thermal units) of 6.
- Annuities for lifetime of 20 years and 4% hurdle rate.

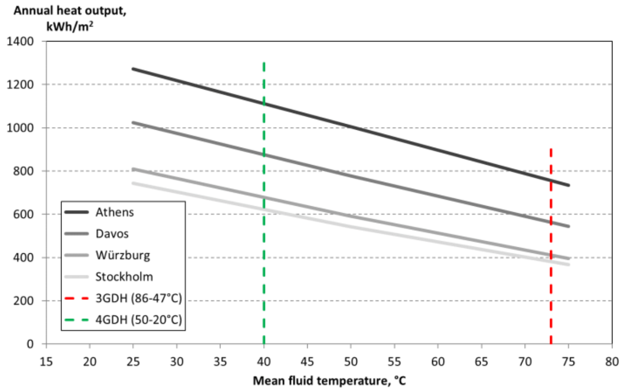

Figure 4. Annual heat output for four different locations from a typical solar collector with respect to mean fluid temperature, according to (Technical Research Institute of Sweden, 2016).

4 RESULTS

For the 3GDH system, the mean fluid temperature in the solar collector circuit becomes 73°C, since the temperature difference becomes 6.5°C from the thermal length of 6. The annual heat output from the solar collectors in Stockholm will be 379 kWh/m^2, according to Figure 4. The corresponding heat generation cost will be 43.7 euro/MWh from a collector investment of 594 euro per annual MWh.

For the 4GDH system, the mean fluid temperature in the solar collector circuit becomes 40°C, since the temperature difference becomes 5°C from the thermal length of 6. The annual heat output from the solar collectors in Stockholm will be 627 kWh/m^2, according to Figure 4. The corresponding heat generation cost will be 26.4 euro/MWh from a collector investment of 359 euro per annual MWh.

Hence, the considerable lower 4GDH temperatures increase the annual output from the solar collectors with 66 percent compared to current 3GDH temperatures. This gives a cost reduction of 17.3 euro/MWh or 40 percent. The cost gradient for a reduction of the return temperature with 27°C in a 4GDH system becomes then 0.64 euro/MWh,°C. The corresponding average cost gradient for Swedish 3GDH systems has been estimated to be about 0.13 euro/MWh,°C according to (Frederiksen & Werner, 2013). Hereby, solar collectors are five times more cost sensitive than traditional heat supply in district heating systems. This is an illustrative example of the main driving force for implementation of 4GDH systems in areas with new buildings.

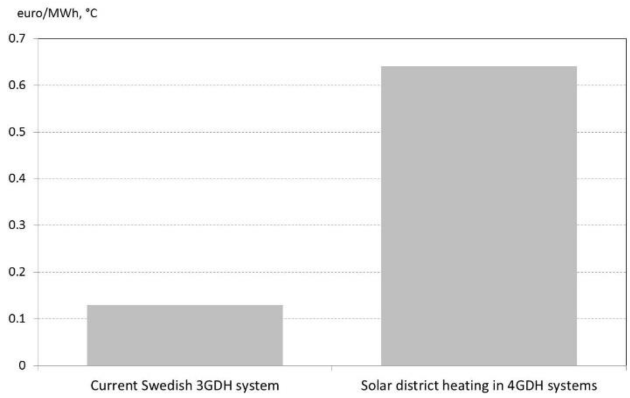

Figure 5. Examples of cost gradients for lower heat supply costs at lower return temperatures for 3GDH system based on conventional heat supply and 4GDH system based on solar district heating.

The total cost reduction of 17.3 euro/MWh obtained from the combination of solar district heating and lower heat distribution temperatures is considerable when comparing with the average price of district heating in Europe that is about 65-70 euro/MWh, according to (Werner, 2016).

The estimated cost reduction has also about the same magnitude as the total annual capital cost for distribution pipes in a district heating system. This cost can be estimated to be 14.7 euro/MWh for a distribution network with an average investment cost of 400 euro/m and linear heat density of 2 MWh/m.

5 DISCUSSION

This short analysis has been performed by comparing the novel heat distribution concept with current heat distribution temperatures in Swedish district heating systems. Many district heating systems in Europa apply higher temperatures (Averfalk et al., 2017). Hence, the identified benefit with the novel heat distribution technology will be higher when comparing with these higher network temperatures.

On the other hand, network temperatures are somewhat lower in Denmark than in Sweden (Gong & Werner, 2015). In these cases, the expected benefit with the novel heat distribution technology will be somewhat lower.

6 CONCLUSIONS

The following three main conclusions can be obtained from this short analysis:

- High heat distribution temperatures in current European district heating systems are a major barrier for the competitiveness of solar district heating.
- Considerable less solar collector area is required when the novel heat distribution technology with lower network temperatures are applied in new district heating systems.
- Solar district heating has a cost gradient for lower temperatures between 3GDH and 4GDH systems that is five times higher than the average cost gradient for current Swedish 3GDH systems.

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