EuroSun2026

SYSTEM-COP AND OPERATION STRATEGIES FOR LARGE-SCALE SOLAR THERMAL & HEAT PUMP COMBINATIONS

Summary

The ideal operation mode for the combination of solar thermal systems and heat pumps depends on a number of case-specific parameters as well as external factors such as electricity prices and weather conditions. Where the focus is often intuitively on maximising the solar yield per m^2 of solar collector and the COP of the heat pump, this analysis evaluates the overall system performance to minimise the electricity consumption and need for auxiliary energy. It is shown how unconditional operation using solar heat as heat source for the heat pump can lead to an increased primary energy demand, whereas sufficient evaluation of options in a "level playing field comparison" can reveal options to both energetic and financial improvements compared to standard operation of solar thermal systems and heat pumps.

Keywords: Solar district heating, heat pumps, system-COP

Field of application for the findings: Large-scale systems, district heating, design and operation optimisation

Addressed audience: System designers, decision makers, operation managers, system simulation researchers

1. Introduction

While solar thermal systems are well-known and, in some countries, widely used, large-scale heat pumps are becoming an increasingly important component for district heating. Optimising operation in the combination of both technologies – possibly using the solar thermal system as heat source for the heat pump – involves a potential for energetic and economic improvements but at the same time risk of a hidden unnecessary electricity demand if the control strategy is oversimplified.

Recommendations for the operation strategy of large-scale solar heating systems in combination with heat pumps are described, and the concept of system-COP is introduced. The system-COP calculation represents the extra heat output when using the solar thermal production as heat source for the heat pump, divided by the extra electricity consumption needed for that process. This becomes a useful tool to identify the real value of such "solar cooling" taking into account the electricity cost enabling the extra solar yield.

The results can benefit companies investing in and/or operating the combination of solar thermal systems and heat pumps – especially in systems involving multiple choices to define the most suitable control strategy.

2. System-COP example

It is shown that when a heat pump is used to cool down the solar collector fluid, the solar heat production increases by an absolute amount independent of the solar radiation. The extra solar heat gained is thus independent of the solar radiation while, with relatively high solar radiation levels, more solar heat must be cooled using the heat pump, and thus more electricity is needed to achieve the extra solar heat. Hence, a correlation can be defined between extra heat output and electricity consumption to enable this. The correlation can be considered a COP for the whole system process – a "system-COP". The figure below shows an example of such a system-COP. For comparison, a typical level of a heat pump's COP is shown in normal operation ("Standard COP"). While the exact values are both case-specific and depend on weather conditions, there is a trend represented by the light orange shaded area on the figure defined by a typical operation range of 5-20 °C ambient air temperature. The example is based on a solar collector typically used for large-scale systems and an air-source heat pump used for district heating.

Since the system-COP is a calculation comparing two states (i.e. possible operation modes), the value depends on the relevant alternative operation. In winter and shoulder seasons when the total heat demand is relatively high, standard solar thermal systems can benefit from delivering an intermediate temperature since the solar heat can be mixed with a higher temperature from a heat pump or boiler to achieve the desired resulting district heating supply temperature. In the example in Figure 1, this period of the year is represented by the ambient air temperature (T_a) of 5 °C indicated in dark purple colours. Using the solar heat as heat source for the heat pump should in winter months be compared primarily with an alternative representing solar heat at intermediate temperature (indicated with a fully drawn dark purple line). Similarly, the ambient temperature is typically higher in summer (represented by T_a = 20 °C in Figure 1) when the solar thermal system often covers a relatively large share of the heat demand. In this case it may not be possible to mix a relatively large share of district heating water flow at intermediate temperature with sufficient flow at higher temperature to reach the target supply temperature. Hence, the relevant alternative to "solar cooling" is standard operation delivering solar heat at the district heating network supply temperature level. This is represented by the fully drawn light purple line in Figure 1. Hence, though the orange shaded area representing other temperature combinations are possible, the fully drawn lines represent the most relevant trends for the system-COP in the example.

It is seen how the system-COP is low when the irradiance is high and vice-versa. This indicates that operation using solar heat as a heat source for the heat pump is mainly relevant at low irradiation levels. However, it also depends on what other heat sources are involved in the overall supply mix, and the costs associated with displacing these.

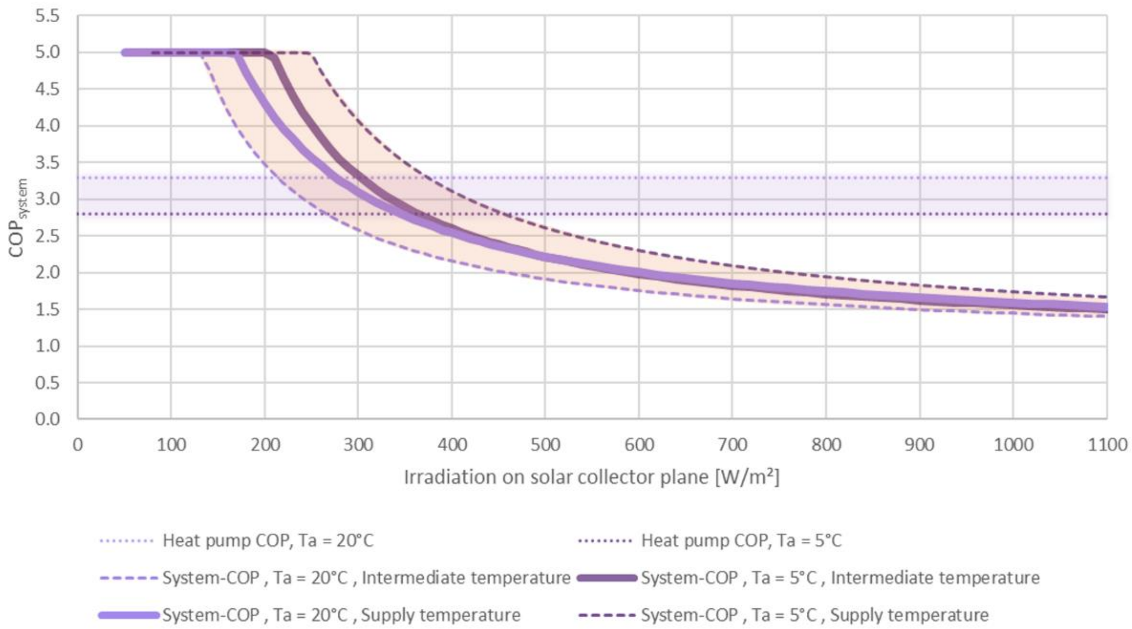

Fig. 1: System-COP related to irradiation on solar collector plane depending on the reference condition of either solar thermal production at intermediate temperature level or district heating supply temperature level. The range of possible system-COP values in this example is indicated with shaded orange. COP for normal heat pump operation is indicated between dotted lines for comparison.

In many cases, the higher temperature of the heat source when using the solar collector loop (indirectly by cooling or storage water) compared to the regular heat source (e.g. ambient air) will result in an increased heat capacity of the heat pump. When additional heat is needed beyond what the heat pumps and solar collectors can deliver, even a low system-COP (e.g. of 2.0) may still be relevant, e.g. if the alternative is an electric boiler for peak load. On the other hand, if there is an overcapacity of the solar heat in the storage/from the solar collectors and the regular heat pump operation combined, then solar heat used as a heat pump heat source would simply displace the regular heat pump operation. If the system-COP is lower than the COP of regular heat pump operation, the result is increased electricity demand even if both the solar yield and measured COP of the heat pump are increased. An example of such increase in electricity consumption though the solar yield is increased, is seen below for an irradiation level of 500 W/m^2.

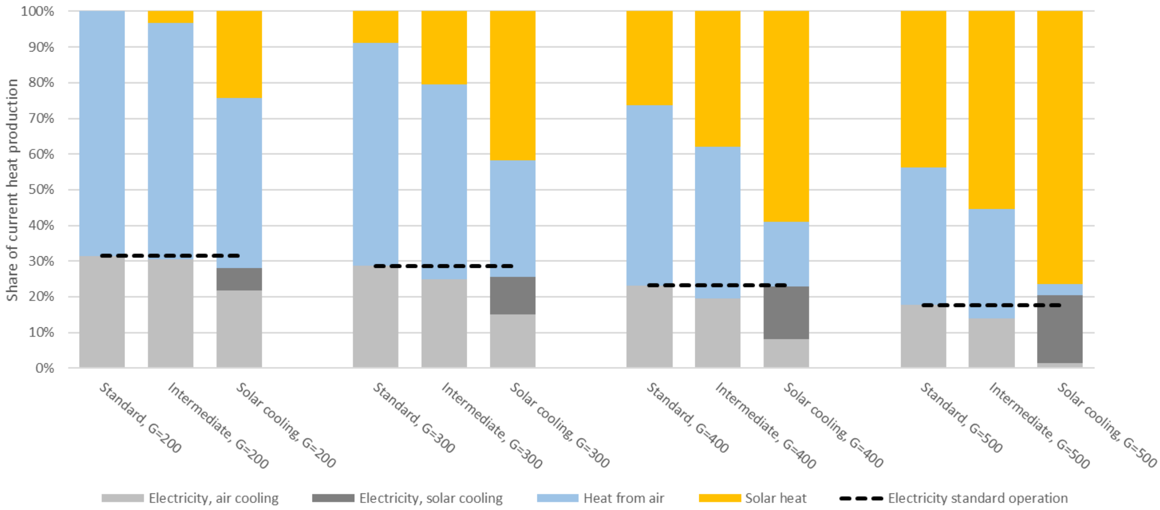

Fig. 2: Example calculation of the distribution of heat production in a situation with solar irradiation (G) of 200, 300, 400 and 500 W/m^2, respectively, where the solar collectors must supply the flow temperature in the district heating network ("Standard"), an intermediate temperature ("Intermediate", i.e. a temperature between the return and flow of the district heating network) or where the solar collectors are cooled by the heat pump and deliver a low temperature ("Solar cooling").

3. Yearly simulations and recommendations

System-COP calculated hourly over a year show how the values follow the trend in Figure 1 above. It can be seen from the annual simulations that if solar cooling is activated at times when it is feasible (with the chosen assumptions), about 7-11% higher solar thermal output is achieved than a reference situation without solar cooling though this requires extra electricity consumption for the heat pump.

The calculations show a potential for financial savings by optimising the combined operation of the solar thermal and heat pump systems, e.g. in the form of cooling the solar collectors with the heat pump under certain conditions. This applies even if such an opportunity requires an additional investment. However, the total economic value depends on assumptions such as electricity prices and the price of the auxiliary heat production which can be displaced by increased solar heat production.