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| Chapter: | System |
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| Description: | The energy output of the solar district heating system is highly dependent on the conditions on which it is operated. In order to get the most out of the plants potential, it is necessary to consider what the optimum control strategy will be for the given system, i.e. pros and cons for every control setting. |
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## Contents

## Introduction

The control of the SDH plant is a very important parameter in terms of getting the most out of the systems potential. Several parameters should be considered carefully in order to utilize as much of the solar energy as possible. One example is the temperature level in the solar collector loop. As described further in fact sheet 7.1 *"Solar collectors"* the efficiency of the collectors are highly dependent on the solar collector fluid temperature.

Several partly contradicting targets have to be met by an effective control of a solar district heating plant:

- provision of required temperatures for grid operation
- avoidance of stagnation of the solar system
- optimal use of heat storages
- minimization of heat losses in collectors, pipes and storages
- minimal wear of the solar plant, i.e. reduction of changes in temperature and pressure
- minimal electricity consumption of pumps
- minimum requirement of human intervention
- optimal use of other heat sources like heat pumps, boilers, waste heat

The flow temperature often has to be at a certain required level:

- It could be 90 °C for charging a heat storage. However – depending on the storage – it might also be possible to charge the storage at different temperature and height levels.
- It could be 70-80 °C if the solar heat is directly connected to the flow pipe of the DH network (depending of course on the DH network supply temperature)
- It could be 50-60 °C if return temperature of the grid is <40 °C and solar thermal is used for pre-heating of condensation heat recovery of a boiler's exhaust air.

Normally the supply levels are kept below 95 °C because of the boiling point of water and because of temperature limits in several devices of a solar thermal plant.

## Normal operation control

### Effect of chosen flow rate

The mean temperature of the solar collector fluid is determined not only by the inlet temperature, the ambient temperature and the solar radiation, but also the flow rate. The faster the flow rate, the less time for the fluid to heat up as it flows through the collectors, and the lower the outlet temperature (for given weather conditions and inlet temperature). Lower outlet temperature means lower heat loss from the collectors and thereby higher collector efficiency (to a certain extend). However the flow rate should be within a reasonable range in order to have evenly distributed flow throughout the collector as described in fact sheet 7.1 *"Solar collectors"*.

On one hand you could say that the flow rate should only be kept just high enough to supply the heat to the DH network at the desired temperature level. On the other hand a high flow rate will increase the electricity consumption of the pump. Choosing a low flow rate for the typical operation will even make it possible to have smaller (and thereby cheaper) pipes since the pressure losses are lower.

For large solar plants, pumps and controls for variable flow proved to be very efficient.
Experiments at Marstal District Heating, Denmark, showed, that variable flow results in electricity savings of about 75 %. Electricity consumption for pumps dropped from over 16 $kWh_{el}$ to 3-5 $kWh_{el}$ per MWh of solar thermal heat.

The combination options are numerous and it is the task of the consulting engineers to include all variables in both the designing of the plant, and the operation strategy to calculate the optimum overall SDH plant solution.

### The effect of storage type and size

For storages with daily charging and discharging, high charging temperatures up to 80-90 °C are possible at moderate heat losses in the storage. These high temperatures should only be chosen in case of limitations in storage size or if there is a demand for high temperature in the DH grid in order to avoid the need for auxiliary heating. Lower charging temperatures, 5-10 K above flow temperature of DH grid, are more favorable for collector efficiency in cases of sufficient buffer storage volume.

For seasonal storages it might be desirable to have high inlet temperatures in order to avoid destroying the thermal stratification of the storage. The thermal stratification makes it possible to concentrate the insulation on the top part of the storage. If the storage has inlets at several height levels, it is possible to utilize solar heat at a wider temperature range since the heat can enter the storage at the corresponding temperature level thus maintaining the thermal stratification. When the temperature of a seasonal storage reaches a certain lower level, the heat cannot be used directly in the DH network. If the solar collector outlet temperature were matched to be exactly equal to the minimum temperature required by the DH network, the heat loss of the seasonal storage would result in a decrease in temperature thus making the stored heat useless in terms of *direct* heating (without auxiliary heating). Hence the auxiliary energy supply plays a role in the choice of operation strategy as well. A (widely used) option is to use auxiliary boilers to boost the temperature to the required DH temperature. Another option is to use a heat pump to accumulate heat in the top of the storage. This way heat at a moderate temperature can be used i.e. the solar collector outlet temperature can be reduced.

### Flow rate control by collector temperature measurement

With this control mode, collector temperatures at several points in the SDH plan are measured continuously and the needed pump speed is calculated from these values. Normally one temperature sensor per 1000 m² is sufficient for solar system control. Additional temperature sensors are often installed for checking hydraulic balance of the system.
Control by collector temperature has the advantage of using rather cheap sensors for measurement of the actual temperatures in the collector array. This is especially useful at cloudy conditions, when parts of the solar plant have irradiation and other parts do not. In this case, having many sensors is useful for calculation of appropriate pump speed. However in very large SDH plants the thermal inertia is high enough to cause a delay of the system control which may cause fluctuating pump regulations lagging behind the optimum pump setting. Therefore optimal control algorithms and control parameters are to be found during commissioning phase of the solar plant.

### Flow rate control by irradiation measurement

By measurement of irradiation at the solar plant, pump speed can be controlled by calculation with collector efficiency, temperature levels and fluid volume and heat capacity (eq. 6.3.1). Measurement of irradiation makes quick reaction of the control possible, as there is no thermal inertia as with measurement of collector temperature. Pyranometers which are used for irradiation measurement at high accuracy cost more than 500 € including signal amplifier. Thus normally only one pyranometer is installed per collector array and partial clouding of the SDH plant can be hardly detected.

To avoid adjustments of the pump speed for very small deviations in the weather conditions (e.g. if a small cloud passes by the sun) mean values for short periods (e.g. 2 minutes), are used to calculate the flow rate.

In equation 6.3.1 the flow rate is derived by combining the formula for a) the solar collector energy* output and b) the energy required to provide the increase in the collector fluid temperature.

$$\dot{V}_{prim} = \frac{\eta_c \cdot G \cdot A_c \cdot 3600}{\rho_{prim} \cdot c_{p,prim} \cdot (T_{c,out} - T_{c,in})} \qquad \text{(eq. 6.3.1)}^{\dagger}$$

* *See equation 7.1.2 in fact sheet 7.1 “Solar collectors”.*
† *The factor 3600 is seconds per hour which is used to convert the unit from $m^3/s$ to $m^3/h$.*

where

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| $\dot{V}_{prim}$: | Flow rate on primary side of the heat exchanger | [m$^3$/h] |
| $\eta_c$: | Actual solar collector efficiency (for the given time step) depending on temperature level (eq. 6.3.2) | [-] |
| G: | Solar irradiance on collector plane | [W/m$^2$] |
| $A_c$: | Total collector area | [m$^2$] |
| $\rho_{prim}$: | Density of the solar collector fluid | [kg/m$^3$] |
| $c_{p,prim}$: | Heat capacity of solar collector fluid | [J/(kg·K)] |
| $T_{c,out}$: | Collector fluid outlet temperature | [°C] |
| $T_{c,in}$: | Cold fluid inlet temperature | [°C] |

The collector efficiency used in eq. 6.3.1 is calculated by the following equation:

$$\eta_c = \eta_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 \frac{(T_m - T_a)^2}{G} \quad \text{(eq. 6.3.2)}$$

where

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| $\eta_c$: | Collector efficiency | [-] |
| G: | Total (global) irradiance on the collector surface | [W/m$^2$] |
| $T_m$: | Mean collector fluid temperature | [°C] |
| $T_a$: | Temperature of the ambient air. | [°C] |

The flow rate on the secondary side is calculated and controlled to maintain an equal capacity flow on both sides of the heat exchanger. See fact sheet 7.4 *"Heat exchanger"* and 7.1 *"Solar collectors"* for more information.

## Start up

In some systems the fluid is circulated in the primary loop without starting the secondary pump which transports the heat from the solar collector field to the DH network. This is done in order to heat up all the pipes which are naturally cooled down during the night, thus being ready to provide heat at a given (chosen) minimum temperature when the secondary pump is started.

The minimum irradiance for starting up the primary pump may vary depending on the storage temperature. If the storage temperature is low, even small irradiances may be acceptable whereas a high storage temperature means that a higher (minimum) irradiance level is required to charge the storage. [1]

## References

[1] Planning & Installing Solar Thermal Systems, 2. ed., p. 159, Earthscan, 2010.

*The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.*

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