Simulation of Large Collector Fields

Subject:	Simulation of large collector fields for system design and optimization
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Description:	How to simulate large collector fields. Recommendations for selection of load data, weather data, component models and input parameters for large collector fields.
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Download possible at:	http://task45.iea-shc.org/fact-sheets

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Introduction

Simulation is a very useful tool for design and sizing of a solar collector field. To get a good accuracy it is important to start with a load analysis and secondly to find accurate enough local weather data. Also a time resolution of at least hourly weather data is needed. The split into beam and diffuse radiation is also very important, to derive a good all-day simulation accuracy. Then of course the component models and accuracy of the input data is very important too. Below some hints are given to make a good collector field simulation.

Load analysis

This is often the most forgotten and unsure input for an accurate solar simulation work. This is also the reason for lower than expected measured performance. When a collector field is oversized compared to the load distribution over the year the operating temperature will be higher and the performance reduced. A wrong load analysis can also lead to that the collectors design is optimized for a lower demand temperature, than in reality. Then also a lower annual output will be the result.

For an existing district heating network these facts are fortunately often well known. The most important information is monthly average forward- and return temperatures and the total load in MWh of the network each month. If available measured hourly load data can be used, but the value of this is limited as it can change from year to year.

Also near future plans for extension of the district heating network and connection of new houses or industries is important to consider before starting design simulations. Many industries demand higher forward temperatures and give higher return temperatures.

In a network also a few badly adjusted substations can give high return temperatures in the whole network due to short circuiting between the forward and return pipes. This should be checked first and adjusted especially if return temperatures are higher than normal. Otherwise the system design will be based on a bad operating situation for the network and the collector performance will be low.

Normally the minimum summer load is determining the maximum collector array size, if no seasonal storage is present in the system, or if no dumping of energy is planned for shorter periods of extreme sunshine and low load. Also strategies for operation of cogeneration plants will affect this summer situation. Many collector fields are prepared for dumping of energy at night. This possibility of dumping of energy at night in the collector array might be part of the simulation control too to prevent overheating and boiling in the collector field.

Check list Load analysis:

-Monthly load temperatures

-Monthly load energies

-Near future plans for extension of the district heating grid.

-Plans for new customers like industries demanding higher temperatures in summer.

-Check for badly adjusted substations first if the return temperatures are unusually high.

-Plans for larger storage size.

-Plans for change of rules for auxiliary power production in the network.

-Strategies for overheat protection of the collector field by dumping of energy in summer.

Weather input data

It is uncommon that accurate measured climate data are available for the location of a collector field. Also the split of solar radiation into beam and diffuse and tilted surface radiation is very uncommon in long term measured data. The most practical ways to solve this is to use synthetic weather data from a software like Meteonorm http://meteonorm.com/

These data are based on measured monthly data, as complete as possible for each site. Sometimes weather data has to be interpolated from different nearby locations, if the collector field is not close to a weather station with measured data.

Normally hourly mean values are produced but recent versions of Meteonorm can also create data with higher time resolution down to 1 minute data. This can be an advantage if control algorithms are going to be tested out by simulation.

In Meteonorm it is possible to produce the solar radiation in a tilted plane. But the best is often to create DNI direct normal beam radiation plus global radiation (total radiation on horizontal surface) as then the errors at low solar altitudes at sunrise, sunset and winter months can be minimized when otherwise large numerical errors due to division by zero can happen. This is a common hidden error in solar simulation.

Check list for weather data:

-Look for as good weather data as possible. Preferably split into beam and diffuse radiation.

-Be aware that weather data vary from year to year and that this affects collector output more in %. A typical variation range is +-10% in solar radiation, leading to typically +-15% in collector field output.

-Be aware that different solar radiation processor algorithms to calculate solar radiation on a tilted plane can be quite inaccurate and give significant errors (+-10%) in collector output. This can happen both in the simulation tool but also in a software producing the weather data used.

Component Models and Parameters

Normally a system simulation model for a collector field is set up of already validated component models. The total accuracy of the simulation can be very good if the sub models are correctly used.

To program and use detailed theoretical component models based on fundamental physics is not recommended for engineering purposes. It is very time consuming both in running time, but also to write the code and find all the input data needed with good accuracy for the local situation.

Collector model

Preferably a collector model that is directly compatible with the collector test standard EN12975/ISO9806 should be used. Then also parameters derived from a standard test can be used directly without conversions or adaptations. The very long and large area collector rows in a collector field, may seem difficult and advanced to model but as the flow rate per m² through each collector is high it closely operates like a small collector under test with the same solar collector fluid and collector tilt, just increased in size.

Collector array shading

The collector array shading by rows in front has to be additionally modelled. This will reduce both beam and diffuse solar radiation in the collector plane. The importance of shading depends on the time of day and year and fraction of diffuse radiation.

Pipe modelling in the collector field

Normal pipe models can be used but in some cases long transition pipes between the collector field and district heating system need extra care, as the thermal inertia can be huge. This should also be considered in the control modelling as a lot of energy can be regained by discharging such pipes in the evening.

Flow distribution in the collector field

Bad flow distribution in an installed collector field will easily give boiling in collector rows with a too low flow rate. This is by experience often caused by air in the collectors or pipes. This is normally not possible to treat by simulation. Also smaller variations in flow distribution due to different pressure drop will affect the performance, as collector rows with lower flow per m² than average will work at unnecessary high mean collector temperature. Then extra heat losses will reduce the performance. Probably flow distribution is best to simulate separately in detail and take action in the collector field hydraulic design and follow up by regular outlet temperature measurements and adjustments.

It should also be remembered that in a well designed collector field, the rapid viscosity reduction for the fluid with temperature rise, will help to self-balance the flow. Collector rows with lower flow will get higher fluid temperatures and therefore lower viscosity and a tendency to increased flow that balances automatically.

Collector field control

In the Danish collector plants constant collector array output temperature is controlled by variable flow according to solar radiation, ambient temperature and inlet temperature. Here the actual control algorithm has to be known to have a realistic simulation. It is also possible to just have a temperature difference control with fixed flow. In systems with long transit pipes also a special control is applied to discharge these long pipes in the evening. Also in the morning the control can start the collector flow very early to preheat these pipes at low radiation levels that otherwise could not be used to feed into the network.

Solar Radiation processor

This is a bit forgotten modelling need, but very important for the accuracy of results. Depending on which model is used, the collector output can vary by up to 10 % with exactly the same input data. It is mainly the way diffuse radiation onto the tilted collector plane is calculated based on horizontal plane solar radiation. On top of this comes the collector array shading modelling that is still to be worked on in detail.

Storage models

The storage model can be very important as the return temperature to the collector field depends on how well the stratification works in the storage.

Check list for component models

-Try to use models validated against measurements

-Try to use models where input parameters can be derived from standard tests.(like for collectors).

-Complicated advanced component models are not always more accurate, as they need much more input data and settings that adds to uncertainties if they are not exactly known.

-Do not forget the solar radiation modelling accuracy to get beam and diffuse radiation onto the collectors as accurate as possible.

-Collector array internal shading needs attention too.

-Uneven flow distribution in a inaccurately designed or badly adjusted solar plant can give a large performance reduction. But this is difficult to simulate.

System model setup

This part can be done on several levels of detail. Here experiences of simulation and especially previous system model validation, is very advantageous. It is important to find a balance between complexity and accuracy as high accuracy also requires a lot of extra inputs. Often the exact pipe runs, all diameters, bends and valves do not have to be modelled in detail. Instead some effective pipe lengths, diameters and insulation level can be enough, as the heat losses in the solar collectors are often much larger and dominates the picture of the whole collector array.

But if storages, heat pumps and cogeneration plants are present, the system model can get quite complex especially including the necessary control. If also consideration of electricity prices is taken into account it can be very complex but at the same time valuable, as the control strategy can be optimized for the whole plant.

System optimization by simulation

There are many detailed design considerations that could be investigated by simulation. Especially, if the system layout is complex with storages, heat pumps and cogeneration components etc.

Some simulation software can be run together with an optimization software to make multiple runs and successively find minimum in cost or maximum in performance or lowest cost/performance ratio. The goal function is important to decide in advance.

Simulation for collector field performance evaluation and follow up

Simulation with measured operating data as input, is a very powerful tool for the system operator and evaluator, that makes it possible to optimize the control and also get very early warnings if something is wrong in the collector field, like flow distribution. Also errors of sensors are quickly discovered. Also degradation for the collectors, due to soiling or moisture inside for example.

Good experiences for this exist from Swedish plants for example, where the procedure was called “on-line” simulation. Also “off line” simulation can be very effective using stored measured operating data as input to the simulation. This is very close to model validation and can be very useful for development of simulation tools and gain confidence for coming plant design work too.

Recommendations for the use of Simulation Tools

-Adapt the simulation for the end user of the result. Simulation work never ends otherwise.

-Do not forget to define the goal function carefully when optimizing a system

-Simulation can also be used for check of plant operation

Examples of simulation tools for solar collector fields

The most common detailed simulation tool for collector fields is TRNSYS http://www.trnsys.com/

TRNSYS is a general solar and renewables system simulation software. It includes also building simulation. Boiler plants and district heating networks can also be simulated in TRNSYS.

TRNSYS comes with a large library of validated component models and also possibilities to handle input weather and load data. The possibilities to plot and present results during a simulation are important features.

Other solar system simulation tools that might be quicker to get started with than TRNSYS are Polysun http://www.velasolaris.com/ and T-Sol http://www.valentin-software.com/en but they are presently mainly developed for domestic and multifamily system sizes.

The European SDH (solar Distric Heating) programme also present four tools for simulation or calculation for prefeasibility studies. The sofwares presented are: F-Easy, Fjernsol II, SDH Online Calculation Tool and Sunstore 4 Feasibility Evaluation Tool. http://www.solar-district-heating.eu/ServicesTools/SDHcalculationtools.aspx

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