DESIGN AND RECOMMANDATIONS FOR DECENTRALIZED SOLAR DISTRICT HEATING SYSTEMS IN FRANCE

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ABSTRACT

The development of solar district heating is experiencing a booming. In some case the space available for the integration of solar panels is limited and the use of decentralized systems is necessary.

For decentralized solar district heating systems different hydraulic schemes at the substation level, with or without local use of solar energy, is possible.

The present paper detailed an advanced study on decentralized solar district heating system using dynamic simulation software. Initially different hydraulic schemes of substations are studied, and then integrated in a complete district heating including 12 substations. All these configurations are compared and some recommendations are done for designing decentralized solar district heating systems.

INTRODUCTION

Solar District Heating is becoming more and more popular in European countries especially in Denmark where dozens of systems are already installed since many decades (Dalenbäck, 2010).

In France, the interest for Solar District Heating is new, but is growing quickly (Paulus, 2012), especially with the development of new districts with low-energy buildings. In such context, solar thermal energy can achieve significant fractional energy savings for both space heating and domestic hot water preparation.

As these areas are densely populated, solar collectors cannot be implemented on the ground, but should be installed on the roof of the buildings. Such implementation offers many options for hydraulic connection of the solar collectors to the district heating network as well as for the implementation of thermal energy storage.

Within the SDH+ project, and based on “Quartier Villeneuve” a new district of 480 housings under construction close to Chambery, a case study was conducted to select the most appropriate solution based on an extensive simulation work with TRNSYS software.

DESCRIPTION OF THE SYSTEM

Substations for decentralised solar district heating system

Within this project, 9 basic system layouts have been selected in collaboration with ITF engineering office and investigated. They are characterised by:

- The use of solar thermal energy locally for DHW preheating, referred as E1 (no preheating), E2 (preheating with a DHW heat exchanger) and E3 (preheating with a DHW storage tank)
- The possible local use of solar thermal energy feed in the district heating, referred as R1 (no local use), R2 (solar energy feed in the DH is used for preheating the DH return line) and R3 (solar energy is used to preheat the return line of the DH after the solar/DH heat exchanger)

Figure 1 to Figure 3 illustrates three of the nine systems studied.

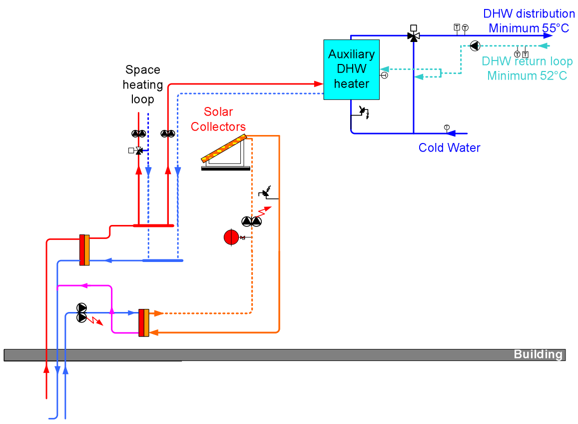

Figure 1 : E1R1 hydraulic scheme

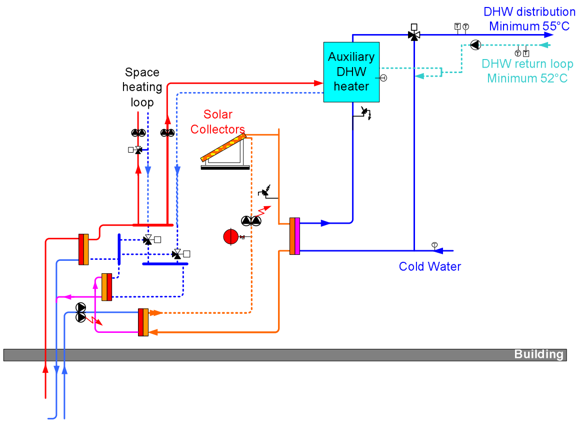

Figure 2 : E2R2 hydraulic scheme

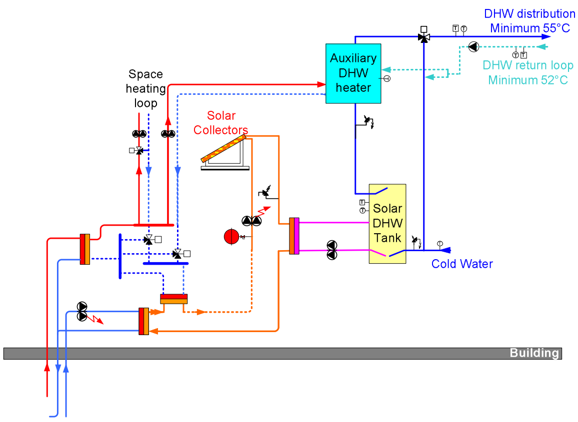

Figure 3 : E3R3 hydraulic scheme

Regarding the "feed-in" principles of the solar thermal energy to the district heating network, the option referred as "feed-in return -> return" has been selected. With this principle, the flow is picked from the return line of the DH network, then heated through the solar heat exchanger and injected in the return line of the DH network.

District heating network

A new low temperature district heating network should be built in order to provide energy to each building for domestic hot water production and space heating.

Two different concepts of network have been evaluated:

- Normal two pipes network
- Three pipes network with a common return

Two pipes district heating network

Each substation unit of the 12 buildings are connected to a two pipes district heating network as shown on the Figure 4.

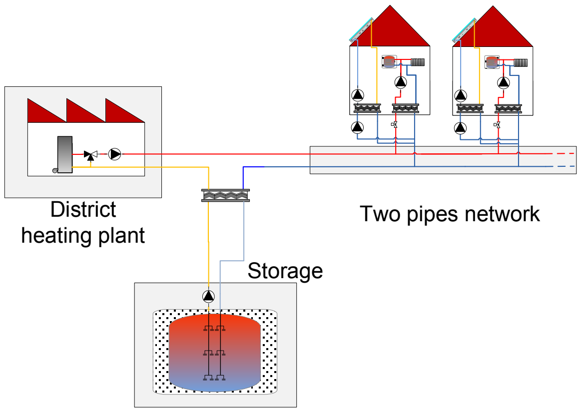

Figure 4 : Block diagram of a two pipes decentralised district heating network

The solar collectors are distributed on the roof of each building and connected to the return pipe of the district heating. The excess of solar heat is stored in a big storage tank connected on the main return pipe.

In this configuration, each solar system has an influence on the next one as they are connected in series on the return pipe. The temperature increased progressively further injections of substations. The solar production of the last solar installation is lower than the first one (in the return direction).

Within this configuration, the district heating flowrate should have a minimum value necessary for supplying the solar substation. For low consumption district during some low consumption period of buildings and high solar production it could be necessary to increase the district heating flowrate that caused an increase of the return temperature.

Three pipes district heating network

Another configuration of district heating network using three pipes has been evaluated. The substation unit are connected to the district heating as detailed on the Figure 5.

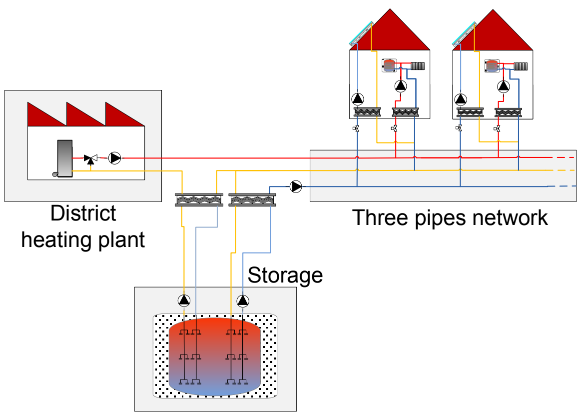

Figure 5 : Block diagram of a three pipes decentralised district heating network

This configuration is a variant of a four pipes network that separates completely the solar installation from the district heating network. In the three pipes network the return pipe is the same for the solar (hot) and district heating network (cold) : it saves the additional investment for the 4th tube.

Within this configuration, the solar flowrate and the district heating are separated.

The solar installation has a lower working temperature and could work only for charging the storage if necessary.

Each substation has the same inlet temperature that allows obtaining the same solar collector productivity for each installation.

On the other hand the controlled of a three pipes solar district network is more complex especially for the control of the solar pump.

SIMULATION

Environment of simulation

This study was carried out using the dynamic simulation software TRNSYS 17.

The buildings connected to the district heating are low consumption:

- Space heating needs : 25 kWh/m²
- Domestic hot water needs : 20 kWh/m²

These buildings were modeled with TRNSYS and an external file has been generated (Jezequel, 2012). These files are used as an input for the unit in order to simplify the simulation and focus on the hydraulic part.

All the hydraulic installation has been modeled with TRNSYS. The network feeds 12 substations.

The weather station used is Chambery (France).

Substations modelling

In a first approach, the substation has been modelled with standard TRNSYS components (flow mixer, diverter…) and equations to be able to deal with the nine basic systems.

Due to some difficulties to extend to 12 substations, it has been decided to develop our own component which is able to simplify the hydraulic connections but also the control strategy of the various hydraulic loops. This component is thus the only one component between the DH network, the solar collector loop and the two different loops for heating and DHW preparation in the building.

Additionally, within this new component referred as Type5004, heat exchangers have been modelled with heat transfer coefficients on the primary and secondary sides that are dependant of the mass flowrate.

The others components used for this substation are the solar thermal collectors (Type 832), two DHW storage tank (Type 340), a thermostatic mixing valve (Type 5915) and pipes (Type 31) for the solar collector loop and for the DHW loop.

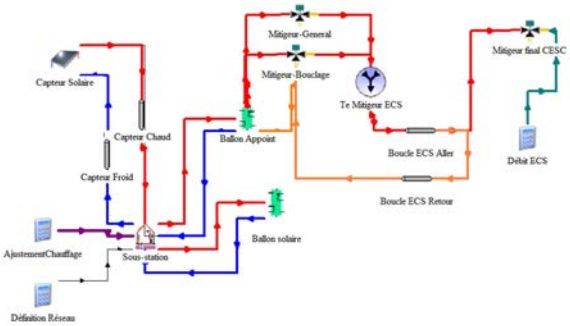

Figure 6 : Overview of the substation in TRNSYS

To simplify the design of the complete district heating system, all the previous components have been merged in a macro.

District heating network modelling

District heating network

The network is modeled using pipes (type 31) with an environment temperature of 10°C.

The control of the district heating loop and the general solar loop for the 3 pipes network is done by a specific controller. They have both a variable speed pump to adjust the flowrate to the needs.

Connection between buildings and district heating network

The TRNSYS macros including the substation unit, the solar collector, the DHW production and space heating of each building are connected to the district heating through a specific type. This type permits to connect the flow and return pipe of the district heating and the flow and return pipe of the substation.

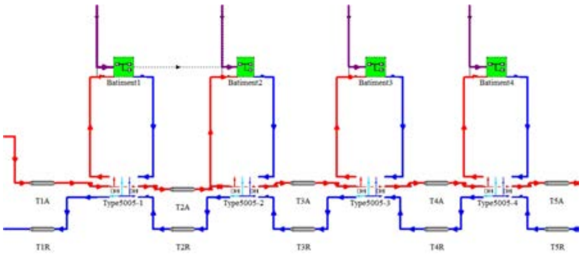

Figure 7 : Overview of the connection between the substation and the district heating in TRNSYS

Storage tank and heat exchanger

The storage is modeled using a stratified storage tank (Type 340) with a stratified charge and discharge.

The storage tank is installed outside (not buried) with an environment temperature equal to the ambient temperature. It has an insulation of 300 mm of a material with a conductivity of 0.04 W.m^{-1}.K^{-1}.

The energy between the storage and the network is transferred through dynamic heat exchangers compatible with the variable speed pump of the network and the storage loop.

Summary of TRNSYS types used in the model

The main TRNSYS type used to model the district heating are described in the Table 1.

Table 1 : TRNSYS type used in the model

TYPE	DESCRIPTION	LIBRARY
31	Pipe duct	TRNSYS
832	Solar collector	SERC
340	Multiport storage tank	TRANSSOLAR
5915	Thermostatic mixing valve	INES
5004	Substation unit for decentralized solar system	INES
5005	Hydraulic collector for 2 pipes district heating network	INES
5008	Hydraulic collector for 3 pipes district heating network	INES
5006	District heating controller	INES
5218	Dynamic heat exchanger for storage tank discharge	INES
5219	Dynamic heat exchanger for storage tank charge	INES

Issues and key factors for the simulation

A first difficulty is about the number of components in the model. More than 300 of components are used in the simulation. The parameterization of the entire component is quite long and tedious and a lot of outputs are available. It is important to be methodical and to first analyze each part of the model to validate it.

In order to make the model run it is necessary to adjust the component order in the control cards respecting the resolution loop. It is important not to use the function optimize.

Due to the storage capacity it is necessary to perform simulations over several years. In our case and due to the low interaction between the storage and the soil, the simulation time was two years.

DISCUSSION AND RESULTS ANALYSIS

Substations

As a first approach, simulations have been performed only for a single substation, in order to evaluate the influence of the hydraulic layout and of the DH return line temperature on the thermal efficiency.

Two kinds of solar thermal collectors have been investigated:

- Flat plate solar collector (LT) (η_0=0.8 , a_1=3,5 W.m^{-2}.K^{-1}, a2=0.015 W.m^{-2}.K^{-2})
- Double covered flat plate solar collector (HT) (η_0=0.817 , a_1=2,205 W.m^{-2}.K^{-1}, a2=0.0135 W.m^{-2}.K^{-2})

Figure 8 illustrates the influence of the DH return line temperature for LT collectors with regard to the hydraulic layout: it can be seen that the hydraulic layout has very little influence on the solar thermal productivity when the DH return line temperature is low (40°C). Hydraulic layout without local preheating of DHW (E1R1) is thus to be preferred since the investment cost, as well as the maintenance cost, is reduced. When the DH return line temperature increase, the solar productivity is decreasing, but the decrease rate is lower when there is some local use of solar energy. Having an increase of the temperature from 40 to 90°C results in 60% decrease of the solar productivity for E1R1 and is limited to 40% for E3R1.

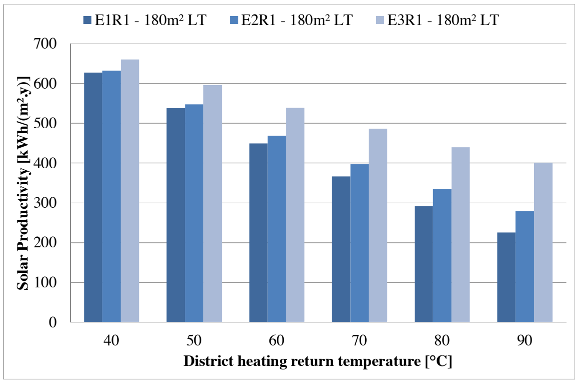

Figure 8 : Influence of the DH return line temperature on the productivity for LT collectors and for various configurations for DHW preheating

When using HT collectors (Figure 9), the effect of an increase DH return line temperature is lower: from 48% reduction of the solar productivity (E1R1 layout) to 31% (E3R1).

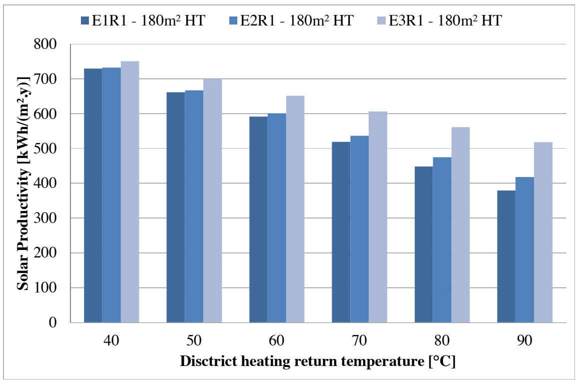

Figure 9 : Influence of the DH return line temperature on the productivity for HT collectors

Regarding the local use of solar energy feed in the DH network, it has been shown (Figure 10) that R2 configuration offers no improvement of the solar productivity with regard to R1 configuration. For R3 configuration, the improvement is not significant for low temperature (less than 1%), but has an impact with high temperature (27%). Once again, the most significant parameter is the DH return line temperature which is the key parameter regarding the choice of the hydraulic scheme at the substation level.

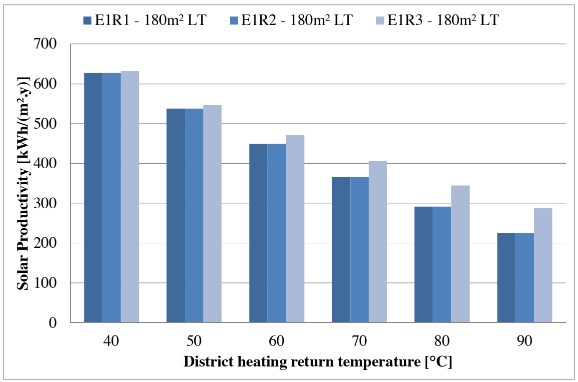

Figure 10 : Influence of the DH return line temperature for LT collectors and for different local use of solar energy

Based on this first approach, it can be concluded the most important parameter is the DH return line temperature. As a consequence, focusing on the substation only is too far limited and the whole system including the 12 substations and the district heating network should be investigated.

District heating

Assumptions

In this part the choice of using a total feed-in substation has been made.

The auxiliary heater is a heat exchanger connected to a high temperature district heating network and the flow temperature of the district heating is 70°C. Due to the space available on the roof of the building, we decided to implement 4.5 m² of solar collector par apartment.

A parametric study is done for different volume of storage and type of solar collector in order to optimise the system.

Indicators

Some indicators are used in order to describe the performance of each system.

The solar collector production:

$$Q_{sol,year}\ [\text{MWh}]$$

The solar collector productivity:

$$Q_{sol,m^2} = \frac{Q_{sol,year}}{A_{solar}*1000}\ [\text{kWh/m}^2]$$

The fractional energy saving compared to a reference case without solar energy:

$$f_{sav} = \frac{Q_{aux,solar}}{Q_{aux,ref}}\ [\%]$$

Reference case

The reference case is a district heating network without any solar installation.

The annual consumption of the 12 substation is 1944 MWh.

Table 2 : Consumption of the 12 substations for the space heating and domestic hot water production

Month	$Q_{space\ heating}$ [MWh]	Q_{DHW} [MWh]
January	277.4	89.8
February	204.2	83.3
March	84.1	92.0
April	21.7	83.5
May	2.0	80.9
June	0.0	66.2
July	0.0	59.9
August	0.0	61.9
September	0.0	60.5
October	18.7	71.6
November	164.9	75.2
December	261.9	85.4
Total	1034.8	910.3

The annual consumption of the district heating including the heat losses of the network is 2168 MWh. These values are used to calculate the fractional energy savings of each case study.

Table 3 : Detailed consumption of the district heating network for the reference case

Month	$Q_{aux,ref}$ [MWh]	$Q_{substation}$ [MWh]	$Q_{loss\ DH}$ [MWh]
January	384.6	367.1	17.8
February	303.7	287.5	16.4
March	194.9	176.1	18.8
April	123.8	105.3	18.6
May	102.6	82.9	19.7
June	85.3	66.2	19.1
July	79.7	59.9	19.8
August	81.7	61.9	19.8
September	79.6	60.5	19.1
October	109.6	90.3	19.3
November	257.6	240.1	17.5
December	364.9	347.2	17.9
Total	2168.2	1945.1	223.7

The flow temperature of the district heating is 70°C and the return temperature is variable. The Figure 11 describes the hourly distribution of the return temperature.

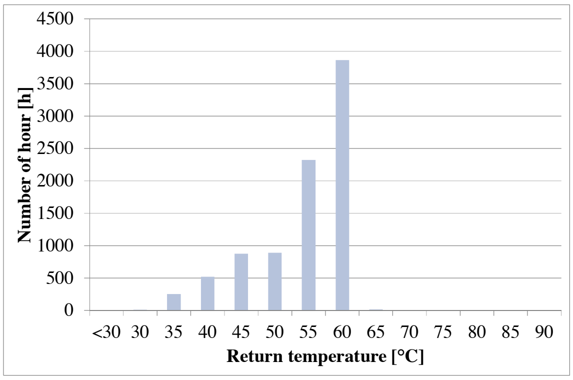

Figure 11 : Hourly distribution of the return temperature for the reference case

Two pipes district heating network with solar

Simulations have been performed for two types of solar collectors: Low temperature (LT) and high (HT) temperature flat plate collector ; and different volume of storage.

Table 4 : Results of the simulation for the two pipes network

Solar collector	Storage [m^3]	$Q_{sol,year}$ [MWh]	Q_{aux} [MWh]	Q_{sol,m^2} [kWh/ m^2]	f_{sav} [%]
LT	500	593.4	1616.2	275	25.5
LT	1000	613.6	1608.3	284	25.8
LT	2000	613.7	1624.5	284	25.1
LT	4000	616.7	1652.1	286	23.8
HT	1000	771.5	1458.0	357	32.8
HT	2000	813.7	1441.7	377	33.5
HT	4000	895.7	1388.3	415	36.0
HT	6000	908.4	1405.2	421	35.2

The f_{sav} of all case studies are quite high and the share of solar energy in the network is important. This means that the solar system has a real influence in the operation of the network.

As detailed in the Table 4 , there is an optimum storage volume for each type of solar collectors that have both a total area of 2160 m². The storage tank stored the excess of solar energy in order than it can be used later. When the storage volume is too big compared to the excess of solar energy there is more thermal losses. The useful solar energy is then lower. It is necessary to adapt the volume of the storage to the excess of solar energy.

For the LT and HT solar collector the optimum storage size are respectively approx.1000 m^3 and 4000 m^3.

The LT solar collector has a low productivity (<300 kWh/m²) even if the district heating network is design to work at low temperature. The Figure 12 shows the return temperature of the district heating for the case LT solar collector and 1000m3.

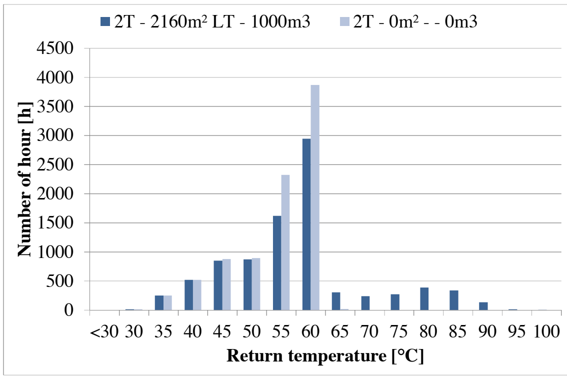

Figure 12 : Hourly distribution of the return temperature for the LT solar collector and 1000 m3 of storage compared to the reference case

The return temperature of the district heating is higher than for the reference case and especially during working time of the solar installation. This is due to the solar energy injected in the return pipe of the network. But also due to the necessary increase of the flowrate of the network to carry the solar energy during sunny period and low consumption of energy the buildings. This phenomenon appears for low energy needs of buildings and quite an important solar fraction of the district heating needs.

For the same amount of energy if the flowrate increase the delta T of the network decrease. This means that for the same flow temperature, the return temperature increase. The increase of the return temperature influence the working temperature of the solar collector that work at quite high temperature.

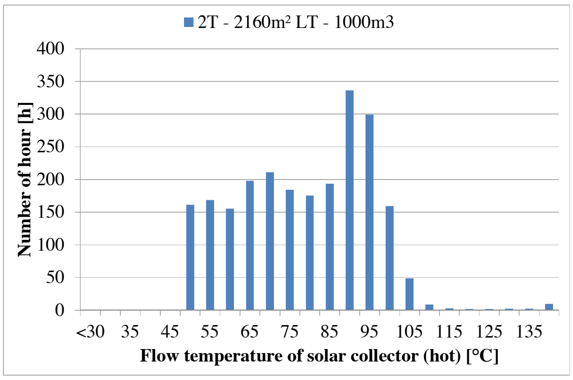

Figure 13 : Hourly distribution of the flow temperature of the solar collectors (hot temperature) for a 2 pipes network, 2160 m² LT solar collector and 1000m^3 of storage

For low consumption buildings in the climate of Chambery and a quite high solar fraction it is necessary to use high temperature solar collector or to separate the solar and district heating network. The study of a 3 pipes district heating network has been done.

Three pipes district heating network with solar

The same simulations for 2160 m² of LT and HT solar collector and different storage volume have been performed for a three pipes district heating networks.

Table 5 : Results of the simulation for the three pipes network

Solar collector	Storage [m^3]	$Q_{sol,year}$ [MWh]	Q_{aux} [MWh]	Q_{sol,m^2} [kWh/m^2]	f_{sav} [%]
LT	500	803.4	1489.9	372	31.3
LT	1000	825.3	1480.1	382	31.7
LT	2000	854.6	1469.6	396	32.2
LT	4000	893.7	1464.5	414	32.5
LT	6000	919.6	1471.1	426	32.2
HT	1000	992.8	1331.5	460	38.6
HT	2000	1037.4	1311.1	480	39.5
HT	4000	1118.4	1270.9	518	41.4
HT	6000	1171.2	1238.6	542	42.9
HT	8000	1205.8	1245.3	558	42.6

For the LT and HT solar collector the optimum storage size are respectively approx.4000 m^3 and 6000 m^3.

The three pipes network increases the fractional energy savings for both LT and HT solar collector. For the LT solar collector the f_{sav} increase from 0.258 to 0.325 (+26%), and for the HT solar collector it increases from 0.36 to 0.429 (+19.1%).

Even if the solar production or the solar productivity increases the most important figure is the consumption of the auxiliary which is representative of the useful solar energy.

The third pipe allows to provide the same temperature to each substation and also to separate the necessary flowrate for the building needs network and the solar installation.

The working temperature of the solar collectors is lower for the three pipes network.

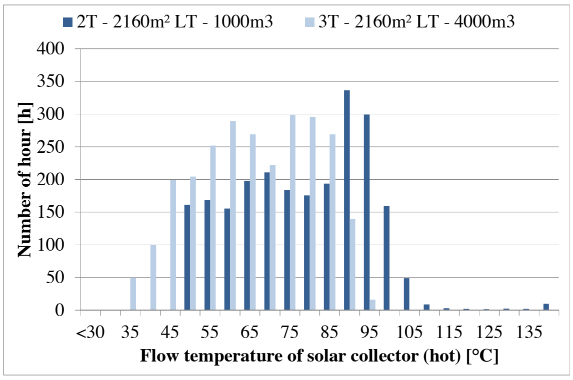

Figure 14: Hourly distribution of the flow temperature of the solar collectors (hot temperature) for a 3 pipes network, 2160 m² LT solar collector and 1000m^3 of storage compared to a 2 pipes network

The level of temperature is quite too high for a LT solar collector and it might be necessary to use HT solar collector.

The working temperature of the solar collectors is lower for the three pipes network in order to obtain a higher f_{sav}.

Detailed analyses of a 3 pipes network with 2160 m² of HT solar collector and a storage tank of 6000 m^3

The use of 2160 m² of HT solar collector combined to a 6000 m^3 of storage tank has an f_{sav} equal to 42.9%.

Table 6 : Results and detailed consumption of the district heating network for the 3 pipes networks with 2160 m² of HT solar collector and a storage tank of 6000 m3

Month	$Q_{sol, year}$ [MWh]	$Q_{aux,ref}$ [MWh]	Q_{lossDH} [MWh]	f_{sav} [%]
January	40.2	354.5	21.6	7.8%
February	62.1	277.8	20.5	8.5%
March	117.0	156.9	24.6	19.5%
April	133.3	47.0	26.2	62.1%
May	144.2	24.9	28.4	75.8%
June	154.5	0.3	28.6	99.6%
July	158.1	0.0	31.3	100.0%
August	133.9	0.0	32.1	100.0%
September	99.7	0.0	30.1	100.0%
October	57.2	0.0	27.7	100.0%
November	42.0	66.5	22.1	74.2%
December	29.0	310.8	21.9	14.8%
Total	1171.2	1238.6	315.2	42.9%

The solar installation is autonomous from June to October.

Table 7 : Results for the solar and storage part of the installation

Month	Q_{rad} [MWh]	$Q_{sol,ye}$ [MWh]	$Q_{char\ stor}$ [MWh]	$Q_{dischar\ stor}$ [MWh]	$Q_{loss\ stor}$ [MWh]
January	112.9	40.2	38.0	31.7	-9.1
Februar	158.3	62.1	59.3	27.6	-8.2
March	268.3	117.0	107.2	35.2	-9.5
April	319.3	133.3	105.7	58.4	-10.6
May	350.6	144.2	105.0	49.3	-10.5
June	366.2	154.5	112.2	54.3	-11.0
July	389.5	158.1	109.8	45.4	-12.3
August	359.8	133.9	84.3	46.8	-13.4
Septem	289.7	99.7	60.5	53.6	-14.1
October	193.2	57.2	32.7	95.2	-14.1
Novem	121.0	42.0	37.3	191.5	-11.1
Decemb	95.8	29.0	25.0	54.3	-9.5
Total	3024	1171	877	743	-133

CONCLUSION

The detailed study on 9 configurations of substations for decentralized solar district heating system highlighted the influence of the return temperature of the network on the solar thermal efficiency for the choice of the substation. In all cases, it is important to promote a low operation temperature for the district heating. If this is not possible some configurations of substation can limit the performance degradations of solar systems.

The operation and the choice of a typology of substation cannot be limited at the level of the substation but it is necessary to think across the complete network, especially if the share of solar energy in the network is large or the temperature of the district heating is highly variable.

A thorough study on the complete network with a high share of solar energy (25-45%) has been done.

When many substations are connected and feed in on the return line, performances of decentralized solar system are linked and decrease with increasing return temperature. This is particularly the case for a network supplying low energy buildings where the flowrate required to supply buildings became during some period lower than the required flowrate of the solar circuit.

In this case it is interesting to add a third pipe to the network in order to dissociate the necessary flowrate for the solar and the district heating loop. The thermal performances are thus improved.

To conclude, even if improvements could be done at the substation level, it is important to optimize the complete system and to design the system in order to have the lower return temperature of the district heating network.

NOMENCLATURE

Q_{sol,m^2} = Solar collector productivity [kWh/m²]
$Q_{sol,year}$ = Annual solar production [MWh]
A_{solar} = Total solar collector area [m²]
$Q_{aux,solar}$ = Auxiliary comsumption of the system with a solar installation [MWh]
$Q_{aux,ref}$ = Auxiliary comsumption of the reference system without any solar installation [MWh]
f_{sav} = Fractionnal energy savings [%]
$Q_{space\ heating}$ = Energy for the space heating of the 12 buildings [MWh]
Q_{DHW} = Energy for the DHW production for the 12 buildings [MWh]
$Q_{substation}$ = Energy delivered to the 12 substations [MWh]
$Q_{loss\ DH}$ = Energy loss of the network [MWh]
Q_{rad} = Total solar energy on the collector plane [MWh]
$Q_{char\ stor}$ = Energy charged in the storage tank [MWh]
$Q_{dischar\ stor}$ = Energy discharged in the storage tank [MWh]
$Q_{loss\ stor}$ = Thermal losses of the storage tank [MWh]

ACKNOWLEDGEMENT

This work is supported by Intelligent Energy Europe program through SDH+ project (project IEE/11/803/SI2.616372).

The authors also extend their thanks to the engineering company ITF (Georges B. and Jezequel A.) and the operator of the district heating of Chambery SCDC subsidiary of COFELY (Mortier C. and Lecocq J-L.) for their participation in this analysis.

REFERENCES

Dalenbäck J-O, CIT Energy Management AB, December 2010, Success factors in solar district heating

Paulus C., 9-10 October 2012, Solar District Heating in France: developing and innovating – The Next DHC Generation Conference, Brussels, Belgium

SDH+ website : http://www.solar-district-heating.eu/

TRNSYS 17 – a TRaNsient SYstem Simulation program – Solar Energy Laboratory, University of Wisconsin-Madison, 2012

Jezequel A., 2012, Building modelling of the Ecodistrict Villeneuve, ITF