CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 3*. Department of Civil Engineering, Aalborg University.

Introducing distributed solar thermal power in small-scale district heating systems

Fabio Zanghirella[1], Jonata Canonaco[2], Giovanni Puglisi[3], Biagio Di Pietra[4]

ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development)
Via Anguillarese 301, Roma, 00123, Italy

[1]fabio.zanghirella@enea.it

[2]jonata.canonaco@enea.it

[3]giovanni.puglisi@enea.it

[4]biagio.dipietra@enea.it

Abstract
District Heating Systems (DHS) connected to distributed solar collectors may contribute in reaching, especially in areas with high population density, the target of 50% of the heat demand for domestic hot water, space heating and cooling provided by renewable sources, which will be mandatory in Italy, from January 1, 2017, for new and deeply renovated buildings. By means of a software platform, developed by the Energy Efficiency Department of ENEA, a small-scale district heating system located in a suburb in the Municipality of Bologna (Italy) and including residential buildings, schools, public buildings and a commercial building and heated by gas boilers was simulated. The introduction, in the simulated DHS, of one or more solar thermal fields integrated on the roofs of the buildings was studied, and sensitivity analysis on the effect of the number and the size of the solar fields on the energy and economic performance of the DHS was carried out. The energy performance of the DHS integrated with the solar fields reaches its optimum in the configuration that maximizes the local self-consumption of the produced solar energy. Using the DHS as a vector to share solar energy, the increase in the thermal losses of the DHS can be considered acceptable in the configurations with a solar production equal to or lower than the domestic heat water loads plus the heat losses of the whole DHS in summer.

Keywords - District heating, Solar thermal, Distributed generation

1. Introduction

As a consequence of the transposition of the European Directive 2009/28/CE, the Italian regulation on energy efficiency will require, from January 2017, that thermal energy plants for new buildings or for buildings subjected to a deep renovation, will have to be designed and built to ensure that at least 50% of the heat demand for domestic hot water, heating and cooling will be met by renewable sources. This target could be particularly ambitious, especially in areas with high population density, where the installation of technologies to produce the required heat demand from renewable sources might be difficult due to lack of space or for integration problems. These difficulties could drive designers to invoke the presence of technical constraints. District Heating Systems (DHS) connected to distributed solar collectors could contribute in reaching this target, and especially in urban and densely built areas, could contribute to solve the possible technical constraints: the DHS can act as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later and/or to share the renewable source production with the whole thermal network.

2. Methods

To evaluate the introduction in an existing DHS of one or more solar fields installed on the available building roofs, a numerical tool, described in [1], was used. A small-scale DHS located in a suburb in the Municipality of Bologna (Italy) was simulated.

2.1. TheAnalyzed Small-Scale District Heating System

The analyzed DHS consists of: 13 customer substations supplying 27 residential buildings, for approx. 88650 m^2; 2 customer substations supplying 3 schools and 1 gym, for approx. 8950 m^2; 1 customer substation supplying 2 public buildings, for approx. 7750 m^2; 1 customer substation supplying 1 commercial building, for approx. 4200 m^2 heated. The heat plant consists of 5 gas boilers with a total installed rated power of 14.5 MW, which can be modulated in 10 steps of 1.45 MW each. The energy thermal loads of the buildings are available by means of their energy signatures calculated in [2], based on a multi-year evaluation of the actual thermal energy consumptions of the buildings.

Fig. 1 Scheme of the DHS: supply scheme, gas boiler heat plant, substations

The set-points of the working feeding temperature during winter and summer are, respectively, 85±2°C and 60±2°C. The total extension of the DHS is approx. 1800 m. A scheme of the system is shown in Fig. 1. Further details on the analyzed DHS can be found in [2] and [3].

2.2. The Simulated Layouts

The connection of each solar plant to the DHS is thought by means of a thermal storage, part of each customer bi-directional substation, which collects the heat fluxes from the solar plants which supply the substation, and from the DHS (when the heat request of the buildings is not satisfied by the solar production), and that delivers the heat loads to the supplied buildings or to the DHS. For the present case-study, the considered connection of the solar with the DHS is “supply to return” [4] and the energy is fed to the DHS when the temperature of the thermal storage in the customer substation exceeds the DHS supply temperature of at least 2°C. The regulation strategy of the bi-directional substation is described in [5].

The solar collectors can be potentially installed on the roofs of 33 buildings, supplied by 16 customer substations. The surface of solar collectors which can be potentially installed is approx. 3070 m^2, corresponding to a peak power of approx. 2200 kW. 77% of the potentially installable surface is facing south, the remaining 23% is facing South-East. The following solar plant layouts were simulated:

- *Layout 0 – Baseline*: the actual DHS without solar plants.
- *Layout 1 – 25% Sol*: DHS with installed 25% of the solar potential, corresponding to 765 m^2 and a peak power of 550 kW.
- *Layout 2 – 40% Sol*: DHS with installed 40% of the potential, corresponding to 1240 m^2 and a peak power of 890 kW.
- *Layout 3 – 50% Sol*: DHS with installed 50% of the potential, corresponding to 1530 m^2 and a peak power of 1100 kW.
- *Layout 4 – 60% Sol*: DHS with installed 60% of the potential, corresponding to 1855 m^2 and a peak power of 1335 kW.
- *Layout 5 – 75% Sol*: DHS with installed 75% of the potential, corresponding to 2300 m^2 and a peak power of 1655 kW.
- *Layout 6 – 40% Conc. Sol*: DHS with installed 40% of the potential, corresponding to 1240 m^2 and a peak power of 890 kW, installed on a lower number of roofs (17 over 33).

In the layouts from 1 to 5 a share of the maximum installable solar surface was considered. The solar collectors were placed on all the 33 available roofs and their surface distribution among the roofs was, as far as possible, proportional to the energy consumption of the buildings, in order to maximize the self-consumption of the energy produced locally and to minimize, ultimately, the heat losses caused by the solar energy fed to the DHS. Based on the results of the layouts from 1 to 5, a further layout (*Layout 6*) was considered: the share of solar power which better fit the needs of the

DHS without significantly increasing the heat losses was considered as installed on a number of roofs which minimizes the number of solar plants and, ultimately, the installation costs. The simulated period was one year.

2.3. Energy Performance Indicators

The most commonly used indicator to assess the performance of a DHS is the Primary Energy Factor (PEF), as defined in [6], but this indicator does not give a complete insight of the whole energy use of district heating networks [7] and it equates renewable and non-renewable primary energy. The characterization of the energy performance of the simulated layouts was therefore performed using the following energy indicators:

Non-Renewable Primary Energy Factor (PEF_{NR})

PEF_{NR} is defined according to [6]:

$$\mathrm{PEF_{NR}} = \frac{\text{Non Renewable Primary Energy for Thermal Production}}{\text{Delivered Energy}} \quad [-] \qquad (1)$$

Where “Delivered Energy” is the energy delivered to the buildings by the thermal storage of the customer substation. This indicator PEF_{NR} takes into account only the fraction of fossil primary energy, therefore it considers indirectly the supply of thermal energy from non-fossil sources.

Non-Renewable Equivalent to Nominal Power Duration (H_{eq_NR})

This indicator expresses the equivalent number of operating hours at full load of fossil fuel generators in a year. It is defined as:

$$\mathrm{H_{eq\_NR}} = \frac{\text{Thermal Energy Produced from Fossil Fuels}}{\text{Rated Gas Boiler Heat Plant Power}} \quad [h] \qquad (2)$$

Renewable Equivalent to Peak Power Duration (H_{eq_R})

It expresses the equivalent number of operating hours at peak load of the solar plants in a year. It is defined, as:

$$H_{eq\_R} = \frac{\text{Thermal Energy Produced from Renewable Sources}}{\text{Peak Power of Solar Fields}} \quad [h] \qquad (3)$$

Renewable Utilization Factor (UF_R)

It’s the ratio of the energy produced from renewable sources minus the losses caused by the installation of solar plants (this loss is calculated as the thermal losses in the considered layout minus the thermal losses in the baseline layout) and the energy produced from renewable sources. It is defined as:

$$UF_R = \frac{\text{Thermal Renewable Energy Produced} - \text{Increase in Th.Losses}}{\text{Thermal Renewable Energy Produced}} \quad [-] \qquad (4)$$

It indicates the percentage of "useful" thermal energy from renewable sources or, rather, the percentage of the total produced renewable energy, reduced by the increase in the energy losses for dispersion introduced in the DHS by the energy supplied to the network by the installed solar fields.

Usable Equivalent to Peak Power Duration of Renewables (UH_{eq_R})
It is defined as:

$$UH_{eq\_R} = UF_R \cdot H_{eq\_R} \;\; [h] \tag{5}$$

It's the product of UF_R and H_{eq_R}. This index represents the equivalent number of useful operating hours at peak load of the solar plants in a year, namely the total renewable energy produced, reduced by the increase in losses for dispersion introduced in the DHS by the installation of the solar fields.

2.4. Economic Indicator

The economic performance of the introduction of distributed solar plants, with respect to the actual DHS (baseline) was assessed using the net present value, defined as:

$$NPV(i, N) = \sum_{t=0}^{N} x_t * (1+i)^{-t} - I_0 \tag{6}$$

Where: t is the year of the cash flow, x_t is the cash flow during the year t, i is the discount rate, N is the total number of years, I_0 is the total initial investment cost.

The NPV was calculated assuming $i = 5\%$, $N = 10$ years, considering an average present price for natural gas in Northern Italy (approx. 0.40 €/Sm^3) and an average selling price of the thermal energy provided by DHS in the area of the Municipality of Bologna (approx. 0,118 €/kWh). The initial investment cost was assessed considering an average price for evacuated tube collector plants: approx. 555 €/m^2 for the layouts from 1 to 5 and, as far as the layout 6 in concerned, the halved of the installed solar plants was evaluated with a decrease in the price of 20% (approx. 443 €/m^2).

3. Results and Discussion

The simulation of the DHS in its actual layout shows that the heat load request of the buildings reaches a peak of approx. 9.5 MW during the heating season and of approx. 500 kW during summer (Fig. 2).

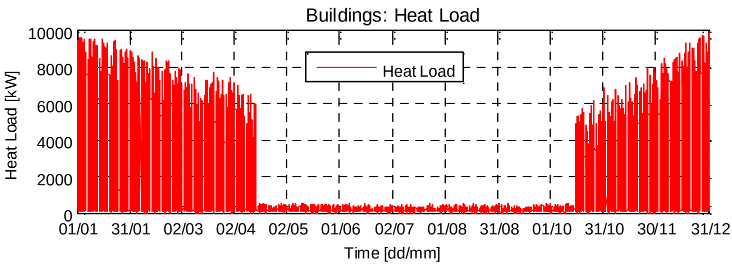

Fig. 2 Buildings Heat Load

The energy request during summer for domestic heat water (DHW) is 459 MWh, the thermal energy produced yearly by the gas boiler heat plant is approx. 16’500 MWh. The energy delivered to the buildings is approx. 15’400 MWh, in this case totally produced by the gas boilers. The total yearly thermal losses are approx. 1’100 MWh and the sum of DHW loads and thermal losses during “summer” (indicating with “summer” the period when the space heating system is off) is 920 MWh (Table 1).

Table 1. Main energy results for the different layouts, data given in MWh

	Baseline	**25%**	**40%**	**50%**	**60%**	**75%**	**40%C**
E_Gas_Boiler	16’462	15’899	15’581	15’420	15’315	15’226	15’602
E_DHS To Buildings	15’372	14’862	14’746	14’696	14’644	14’579	15’026
E_Sol_Prod	-	553	887	1’076	1’249	1’390	877
E_Sol_Prod Summer	-	438	700	846	970	1’046	689
E_Sol Self-Cons.	-	322	424	474	523	578	273
E_Sol To DHS	-	52	258	397	514	586	529
Heat Losses	1’146	1’146	1’153	1’181	1’249	1’300	1’163
Heat Losses Summer	461	461	466	495	563	613	478
DHW Loads + Heat Losses Summer	920	920	926	954	1’022	1’072	937

With the introduction of the solar plants, the energy produced by the gas boilers decreases of a value ranging between -3.4% for layout 1 and -7.5% for layout 5. In the layouts from 1 to 5, in which the self-consumption of the solar energy is advantaged, a reduction in the energy delivered by the DH network (E_DHS To Buildings) can be observed, ranging from -3.3% for layout 1 up to -5.2% for layout 5. The self-consumed share of the solar production reaches its peak with the smallest solar surface, 58% for layout 1, and it decreases with the increase of the installed solar: 42% for layouts 4 and 5. On the contrary, the share of the solar fed to the DH network increases with the installed surface: it ranges from 9.5% of the total solar production for layout 1 to 42% for layout 5.

As expected, the wider the installed solar surface is, the bigger the reduction in the energy produced by fossil fuel is observed. This is clearly shown in Fig. 3, where the thermal output of the gas boiler, during two summer days, for the different layouts, is plotted: in the baseline layout 11 outputs of the gas boiler can be observed, these are reduced to 5 outputs in layout 1 and to only 1 output for two days in layout 2; in the remaining layouts, the solar production seems to be sufficient to satisfy the thermal load request of the DHS in summer.

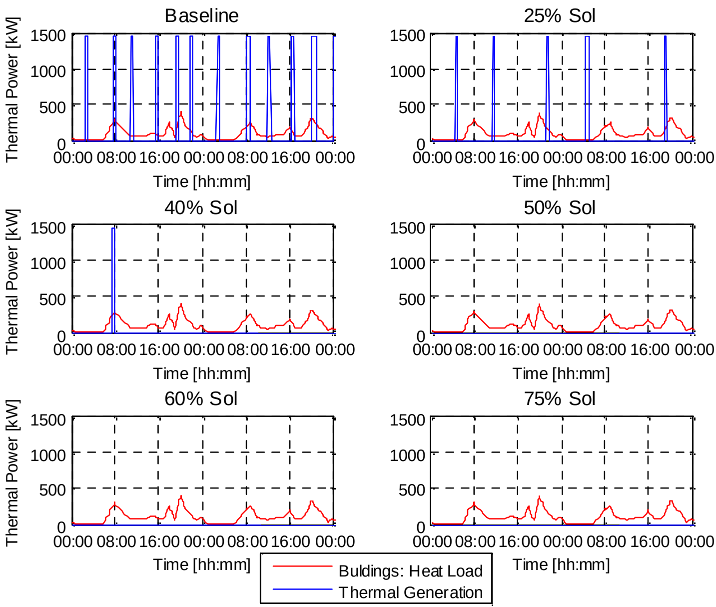

Fig. 3 Buildings' heat load and thermal output of the gas boiler for different layouts during two summer days

The reduction in the production by fossil fuels is also shown by the PEF_{NR} and H_{eq_NR} indicators (Table 2), whose decrease confirms the trend.

Table 2. Energy performance indicators for the different layouts

	Baseline	**25%**	**40%**	**50%**	**60%**	**75%**	**40%C**
PEF_{NR} [-]	1.176	1.137	1.113	1.100	1.088	1.078	1.114
Heq_{NR} [h]	1135	1096	1075	1064	1056	1050	1076
Heq_{R} [h]	-	1007	996	980	937	840	984
UF_{R} [-]	-	0.999	0.992	0.967	0.917	0.889	0.981
$UHeq_{R}$ [h]	-	1005	988	948	859	747	965

However, bigger installed solar surfaces introduce two different problems: a limit in the solar production of the solar plant with respect to its potential, and an increase in the thermal losses in the overall DHS. The limit in the solar production is clearly shown in Fig. 4, where the thermal power produced by the solar plants, the self-consumed share and the share supplied to the DHS, for the different layouts in a summer day are plotted. For the layouts with an installed surface up to 50% of the maximum (layouts 1, 2, 3 and 6), no reduction in the solar production can be observed. For the layouts with the biggest installed surfaces, a decrease in the solar production can be observed. This happens when some of the thermal storages in the customer substations reach the upper temperature limit (approx. 95°C), stopping the production of the connected solar plants. In the same figure, the increase in the thermal power supplied to the DHS in accordance with the increase in the installed surface can be seen. The thermal power produced by the 25% Sol layout (layout 1) is almost totally self-consumed and stored in the local thermal storage: the heat flux supplied to the DHS is limited and is present only in the afternoon.

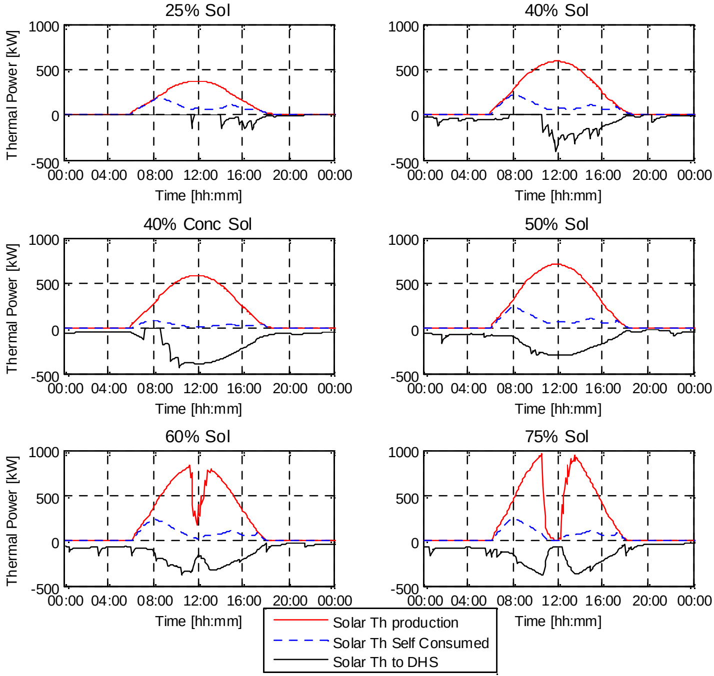

Fig. 4 Components of the solar thermal production for the different layouts, summer conditions

The same Fig. 4 shows the difference between a fully distributed and a more concentrated layout: the two 40% layouts (2 and 6) present the same solar production, but in the concentrated one (layout 6) the self-consumed share is much lower (since only half of the buildings are equipped with solar plants) and the thermal power supplied to the DHS is bigger in amplitude and duration. On a yearly basis, layout 6 produce 99% of the solar production of layout 2, but the self-consumption share is 31% instead of 48%, and its share supplied to the DHS is 60% instead of 29% (Table 1).

The second problem is the increase in the temperature of the DH network during summer, and consequently in the heat losses. This phenomenon is shown in Fig. 5. Layouts 1 and 2 have practically no effect: the increase in the heat losses is lower than 1% (Table 1). Whereas for the remaining layouts the temperature of the network is raising accordingly with the installed surface and remains higher for a longer period. The yearly heat losses are 1.5%, 3.5%, 9.0% and 13.5% higher, with respect to the baseline, respectively for the layouts 6, 3, 4 and 5.

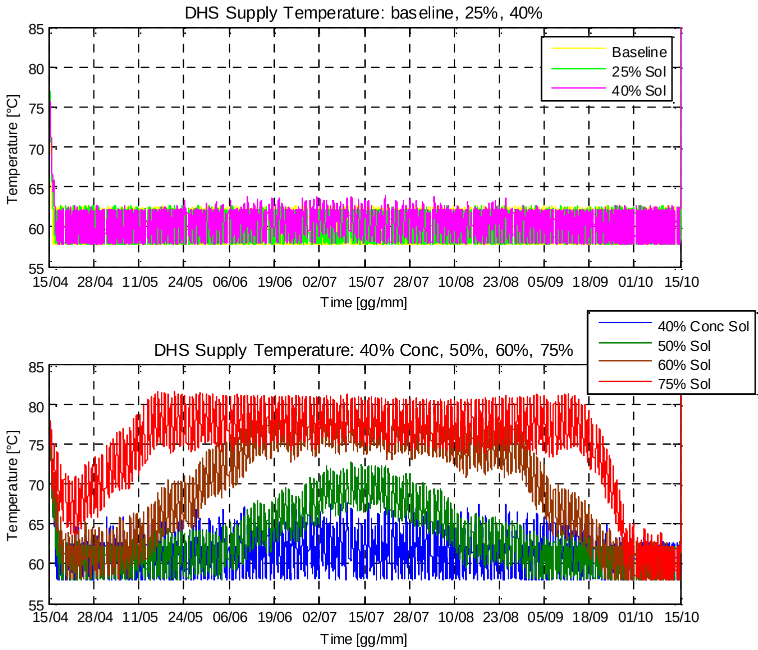

Fig. 5 DHS Supply temperature for different solar plant layouts

The limit in the solar production, particularly evident in layout 4 and 5, increasing with the installed surface, is shown also by the renewable equivalent to peak power duration: the highest value (1007 h) reached by layout 1, goes down by 1.1%, 2.3%, 2.7%, 6.9% and 16.5% with layout 2, 6, 3, 4 and 5 respectively. The renewable utilization factor, on the other hand, shows the share of produced solar energy which remains usable by the DHS, being its complement the solar energy lost in increased heat losses.

For layouts 1 and 2 more than 99% of the produced solar remains usable by the DHS. The UH_{eq_R} is the indicator which includes both the limit in the production and the solar energy lost for the induced increased heat losses. Considering acceptable, for this indicator, a decrease lower than 5% with respect to the best performing layout (layout 1), and in order to minimize the limit in the production and the increased losses, but at the same time installing the biggest surface, the most interesting layout can be considered Layout 2, whose solar production is the closest to the sum of the DHW loads and the heat losses of the whole DHS in summer. A more “concentrated” layout was simulated (Layout 6) in order to evaluate the influence of reduced installation costs. The reduction in the installation costs (-20%) makes the more “concentrated” layout the only one with a positive net present value at 10 years (Table 3).

Table 3. Net Present Value for the different solar plant layouts, data given in thousands of euro

	Baseline	**25%**	**40%**	**50%**	**60%**	**75%**	**40%C**
NPV (5%, 10)	-	-42.4	-65.0	-96.2	-160.6	-268.2	65.1

4. Conclusions

Introducing distributed solar thermal power in a small-scale DHS and using the DHS as a vector to share the heat produced by solar, the limit in the solar production and the increase in the thermal losses of the DHS can be considered acceptable in the configurations with a solar production equal to or lower than the DHW loads plus the heat losses of the whole DHS in summer. The economic performance can be considered acceptable only for the layouts with a lower number of installed solar fields, with a consequent reduction in the installation costs.

References

[1] B. Di Pietra, G. Puglisi, F. Zanghirella and F. Bonfà. “Simulating a small scale polygeneration thermal network: numerical model and first results”, In: Book of papers of the 2nd International Solar District Heating Conference, 3-4 June 2014, Hamburg, Germany, 2014.
[2] M. Spanu, “Analisi dei consumi energetici del comprensorio Corticella di Bologna, alimentato dalla rete di teleriscaldamento”, M.Sc. Thesis, Facoltà di Ingegneria, Alma Mater Studiorum - Università di Bologna, 2011. (in italian)
[3] F. Zanghirella, J. Canonaco, G. Puglisi and B. Di Pietra. “Analisi energetica di un'ipotesi di trasformazione di reti di teleriscaldamento esistenti in reti poligenerative con presenza di scambio attivo”, Report RdS/PAR2014/015, ENEA, 2015. (in italian)
[4] M. A. Ancona, B. Di Pietra, F. Melino, G. Puglisi and F. Zanghirella. “Utilities Substations in Smart District Heating Networks“, Energy Procedia, vol. 81 (2015), pp. 597-605.
[5] B. Di Pietra, F. Zanghirella and G. Puglisi, An evaluation of distributed solar thermal "net metering" in small-scale district heating systems, Energy Procedia, v. 78 (2015), pp.1859-1864.
[6] UNI EN 15316-4-5:2007. Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, the performance and quality of district heating and large volume systems.
[7] P.E. Pacot and S. Reiter, “Quality indicators for district heating networks”, Proceedings of the International Conference CISBAT 2011 - Clean Tech for sustainable buildings - From Nano to urban scale, 2011.