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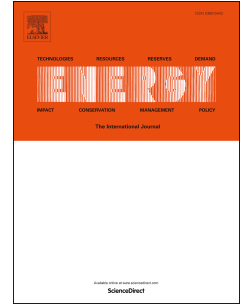
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OPTIMAL SET OF

ANTICIPATIONS

IN ORDER TO

MINIMIZE THE PEAK LOAD
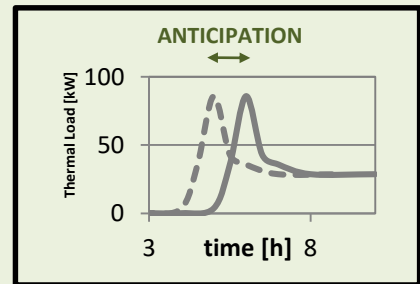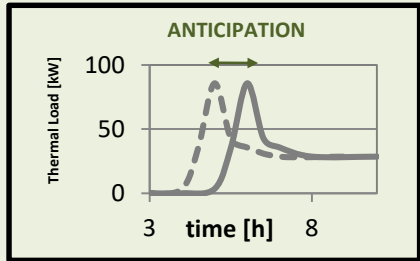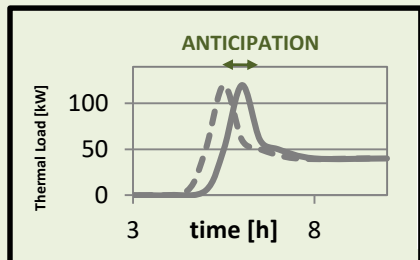
USERS

THERMAL

LOAD

TOTAL

THERMAL

LOAD

PHYSICAL MODEL
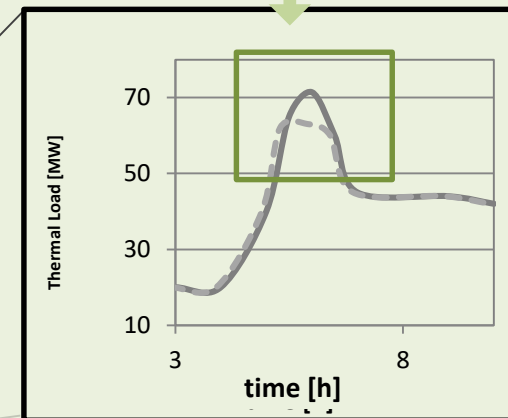
THERMAL PEAK SHAVING FOR:

- Minimization of the boiler production

- Increase potentials for new user connection

Peak-shaving in district heating systems through optimal management of the thermal request of buildings

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Abstract:
This paper aims at analyzing the opportunities for peak load shaving in district heating systems using a physical simulation tool. Using the proposed approach it is possible to examine the effects on the total load that can be obtained by adopting management strategies such as variation in the thermal request profile of the buildings or installation of local storage systems. The model is applied to the optimization of start-up time of the heating system in the buildings located in a selected distribution network. Proper constraints are introduced in order to avoid significant effects on the indoor temperatures of the buildings, so that acceptable comfort standard can be guaranteed. The primary energy consumption at the thermal plants is considered as the objective function to be minimized. An application to a portion of the Turin district heating network, which is the largest network in Italy, is presented. Results show that even in the case only small changes are applied, reductions in annual primary energy consumption up to 0.4% can be obtained without any additional investment cost. This opens the door larger positive impact through implementation of more complex operating strategy.
Keywords:

District heating model, peak shaving, primary energy savings, optimization, thermal request variation, virtual storage

1. Introduction

District Heating (DH) technology allows one to reduce the primary energy consumption for domestic heating in urban areas through the integration of industrial waste heat, high efficiency cogeneration plants and renewable energy plants [1]. As an example we report the Turin district heating network, which is largest network in Italy and constitutes the case study analyzed in this paper. This network is primarily fed by heat produced in cogeneration plants. The simultaneous production of thermal energy and electricity allows a significant reduction of primary energy consumption; it also leads to a reduction of carbon emissions. As a consequence, district heating allows reducing primary energy consumption and carbon emission of about 50% with respect to the use of condensing boilers [2].

A literature review shows that, in the last years, a particular attention has been focused to the connection of networks with sustainable energy sources such as biomass plants [3], like solar plants [4] and geothermal heat pumps [5] and to the use of heat recovered from industrial processes [6,7].

A major problem in district heating system management is the presence of a peak request in the mornings particularly in Mediterranean regions. In these areas, the house heating systems are typically switched off during the night and the thermal request dramatically increases early in the

morning ~~in~~ because of the low temperatures on the secondary side of the heat exchangers. In general, there are two main drawbacks in the thermal peak occurrence.

The first regards the unfeasibility of an optimal cogeneration exploitation. Indeed, when a thermal peak occurs it is not possible to cover the entire request through cogeneration. This leads to a reduction in the overall system performances and consequently an increase in primary energy consumption. As an example the global thermal request of the Turin DH system in a winter day is shown in Fig. 1. The plot shows that the global thermal load during the morning peak, at around 6 am, is almost double than the average request during the day. Turin DH system is fed by three cogeneration plants able to produce about 350 MW in full electricity mode (η_{el}= 59%) and about 320 MW electricity and 245 MW heat in full cogeneration mode and three boiler plants (η_{th} = 90%). In the case of a thermal request smaller than about 735 MW heat, it is completely provided through cogeneration plants. If the request exceeds this value, the storage systems installed along the network are discharged. When the request exceeds ~~about~~ 1000 MW boilers have to be used to provide the correct amount of heat to the users.

A second issue is that the mass flow rate at peak in some branches of the network can reach the upper limit. This means that the thermal peak occurrence impedes further expansions of the district heating network in some areas of the town, therefore connecting additional buildings becomes impossible.

In such scenario, it is worth investigating possible opportunities for thermal peak shaving such as the variation in the thermal request profiles for some of the connected buildings or the installation of local storage systems. Recent works in the literature demonstrate the interest for larger exploitation of cogeneration, renewable sources and storage technologies. In [8], a model for optimizing integration of boilers, heat pumps and cogeneration is proposed. The possibility of using a dynamic simulation tool with the aim of studying interactions of CHP/DH network, with a particular emphasis on the network to heat storage capacity, is examined in [9]. In [10], the use of storage systems charged during the night and used during the start-up transient are examined in order to reduce the morning peak. This is shown to be a very effective measure for reducing the boiler utilization and enhance cogeneration use. In [11] and [12] the opportunities to modify the thermal request profile of some buildings in order to maximize heat production from cogeneration or renewable plants are examined using numerical models.

Investigations on systems responses to configuration variations or user request variation, aiming primary energy reduction, can be achieved using models and simulation tools. This is the reason why district heating modelling has been largely applied both at design [13] and management stages [14].

In this paper, a physical optimization tool is presented and applied to ~~the analysis of~~ analyse the possibilities for peak shaving through changes in user thermal request profile of buildings. The tool allows one to obtain the best start-up schedule of the heating systems in order to minimize the effects of the two problems previously cited. In fact, the energy fraction produced through boilers and the maximum heat load are the objective functions that are alternatively minimized. The first one allows to better exploit the cogeneration technology while the second one allows to increase the buildings connected with the network. The effects of the heating system start-up time changes on the request evolution of a distribution network have been simulated using a physical model. This is necessary because the long distances involved in the network cause a temperature evolution at the barycentre (the point that connect the distribution network with the transport network) significantly different than that at the users.
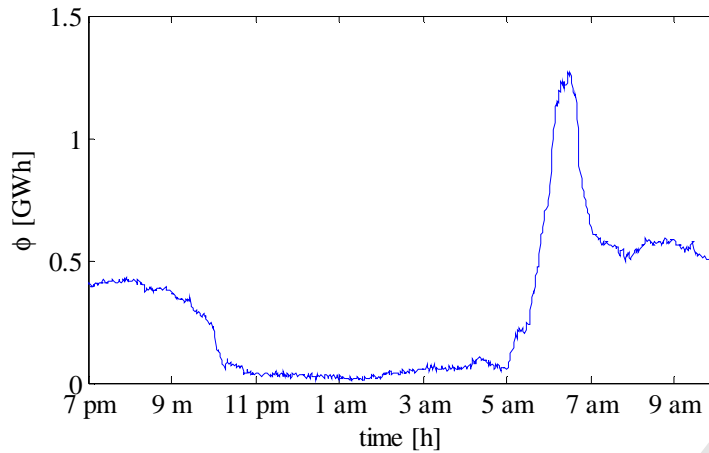
Fig. 1. Global thermal request in a typical winter day in the Turin DH system

2. Methodology

The optimization tool elaborated in this work aims at finding the best set of start-up time for the heating systems connected to a distribution network of the Turin network.

In particular, the goal is to find the best set **x** of anticipations that allows to minimize the objective function. Changes in the thermal request profile produce variations in the indoor temperature evolutions, which should be checked through proper building models. Here only small positive (i.e. anticipation) changes have been investigated in order to avoid further checks on the indoor temperature. Such changes in fact produce only small increases in indoor temperatures. This assumption is made in order to keep the analysis simpler but obtain proper estimation of the impacts. With these results, experimental investigations can be easily conducted and then more complex and ambitious strategies can be analysed.

The variables in **x** can assume only discrete values, since the time demand modification is performed considering slots of 10 minute multiples. This assumption is related with the structure of the ICT system which commands the rescheduling. Therefore each profile start-up time modification can be chosen among the following value: 0 minutes, 10 minutes, 20 minutes. The building thermal request generally increases with respect to the current operation due to the an extra 10 or 20 minute operation. Nevertheless, a global benefit is expected due to a reduction in the primary energy consumption, despite the additional energy consumption.

A genetic algorithm, set for integer-values, has been used to perform the minimization. Both the selected population members and generation number are 100.

Different objective functions can be considered in order to select the desired optimization criteria.

1. In the first case the set of optimal values x allows one to minimize heat produced through boilers in order to increase the cogeneration exploitation. The objective function that has to be minimized is the time integral of the thermal power when the thermal power exceeds the maximum heat flux that can be supplied by cogeneration plants.

$$Q_{Non\_cog\_hp} = \int_{t_a}^{t_b} \Phi_{th_{tot}}(t)dt - \Phi_{maxCog}(t_b - t_a) \tag{1}$$

where t_a is time when the heat request exceeds the maximum cogeneration power, t_b is time when the system starts requiring only cogeneration power. 1. The objective function is detailed in Figure 2.

In the case of the application to a single distribution network i.e. a distribution network instead of a full network, the maximum heat flux produced in cogeneration mode is calculated as proportion of the nominal request of the distribution network with respect to the total request. The current request of the ~~barycentre~~ distribution network is:

$$\Phi_{th_{tot}}(t) = G_{TOT\_BCT}(t) \, c_p \, (T_{supply} - T_{ret\_nodeBCT}(t)) \tag{2}$$

where $T_{ret\_nodeBCT}$ is the temperature of water exiting the distribution network and $G_{TOT\_BCT}(t)$ is the circulating mass flow rate. In this case, the set of optimal values included in **x** guarantees a very low fraction of heat produced through boilers, maximizing the cogeneration exploitation.
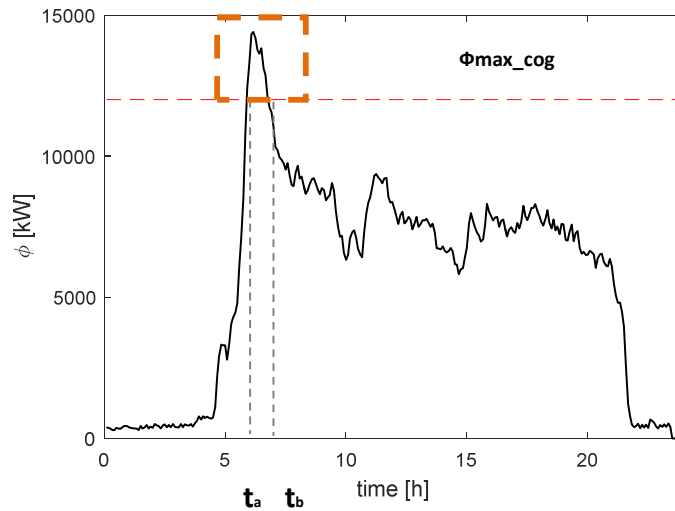
Fig. 2. Thermal power evolution and, in evidence, the objective function

2. In the second case the optimizer allows one minimizing the maximum peak value. It can be used when the thermal peak does not necessarily exceed the cogeneration maximum production and the goal is to check the possibilities to connect additional buildings to the network. It can also be useful when the cogeneration fraction is not fixed in advance and the aim is to guarantee a thermal profile as flat as possible. The objective function is:

$$\Phi_{max} = max(\, \Phi_{BCT}(t) \,) \tag{3}$$

where

$$\Phi_{BCT_{414}}(t) = G_{TOT\_BCT}(t) \, c_p \, (T_{supply} - T_{ret\_nodeBCT}(t)) \tag{4}$$

In all the cases $T_{ret\_nodeBCT}$ is evaluated through the thermal fluid-dynamic model.

The network model is used in order to take into account the long distances involved in the network; in fact, water exiting the heat exchangers in the buildings flows in the return distribution network and mixes with the various streams coming from the users located in the other areas. These streams are at different temperatures, due to the different distance of the users to the barycentres. As a result, temperature evolution at the barycentre is significantly different than that at the users.

A one dimensional model has been used as the network physical model to study the thermal fluid-dynamic behaviour of the distribution network. The topology of the network has been treated with a graph approach [15]. Each pipe of the network is considered as a branch that starts from a node, the inlet section, and ends in another node, the outlet section. The incidence matrix A describes the network topology by expressing the connections between nodes and branches. Matrix A has as many rows as the number of nodes and as many columns as the number of branches. The general element A_{ij} is equal to 1 or -1 if the branch j enters or exits the node i and 0 otherwise. The fluid-dynamic model considers the mass conservation equation applied to all the nodes (Eq. 5) and the momentum conservation equation applied to all the branches (Eq. 6).

$$\mathbf{A} \cdot \mathbf{G} + \mathbf{G}_{ext} = 0 \tag{5}$$

$$\mathbf{G} = \mathbf{Y} \cdot \mathbf{A}^{T} \cdot \mathbf{P} + \mathbf{Y} \cdot \mathbf{t} \tag{6}$$

These equations are here considered in steady state, since fluid-dynamic perturbations travel the entire network in a period of time smaller than the time step adopted for calculations (60 s). Further details on the method are available in [16].

The thermal model is expressed in transient form since thermal perturbations travel the network at the water velocity, which is the order of few meters per second, depending on the request and the portion: velocity is typically small at night and in the distribution networks. Therefore, temperature variations take a lot of time to reach the thermal plants. The thermal model is expressed by Eq. 7.

$$\mathbf{M} \cdot \dot{\mathbf{T}} + \mathbf{K} \cdot \mathbf{T} = \mathbf{g} \tag{7}$$

Mass flow rate and water temperature at the outlet of each heat exchangers is imposed as a boundary condition in the return distribution network model. The ~~return distribution~~ network model applied to the return distribution network gives the temperature values of all the water flows entering the return main pipeline.

3. System description

3.1 District heating system

The system analyzed in this paper is a distribution network of the Turin district heating network. The Turin district heating network is the largest in Italy and one of the largest in Europe. The system is linked to about 56 million m^3 of buildings (more than 5000 users). The network is connected to six thermal plants and storages located in different areas of the city; the thermal plants and the storages provide heat to the network.

The water supply temperature is constant at about 120°C while the return temperature is between 65 °C and 45 °C. It varies with mass flow rate flowing in the network and the thermal load.

The entire network can be considered as composed of two interconnected parts: a transport network and a distribution network. The transport network, including the pipes with large diameter, (usually larger than 200 mm), links the thermal plants to the distribution networks. The latter's provide water to groups of buildings that are located in the same area of the city. In the Turin

network there are 182 distribution networks. Fig. 3 depicts the transport network and, in detail, the considered distribution networks.
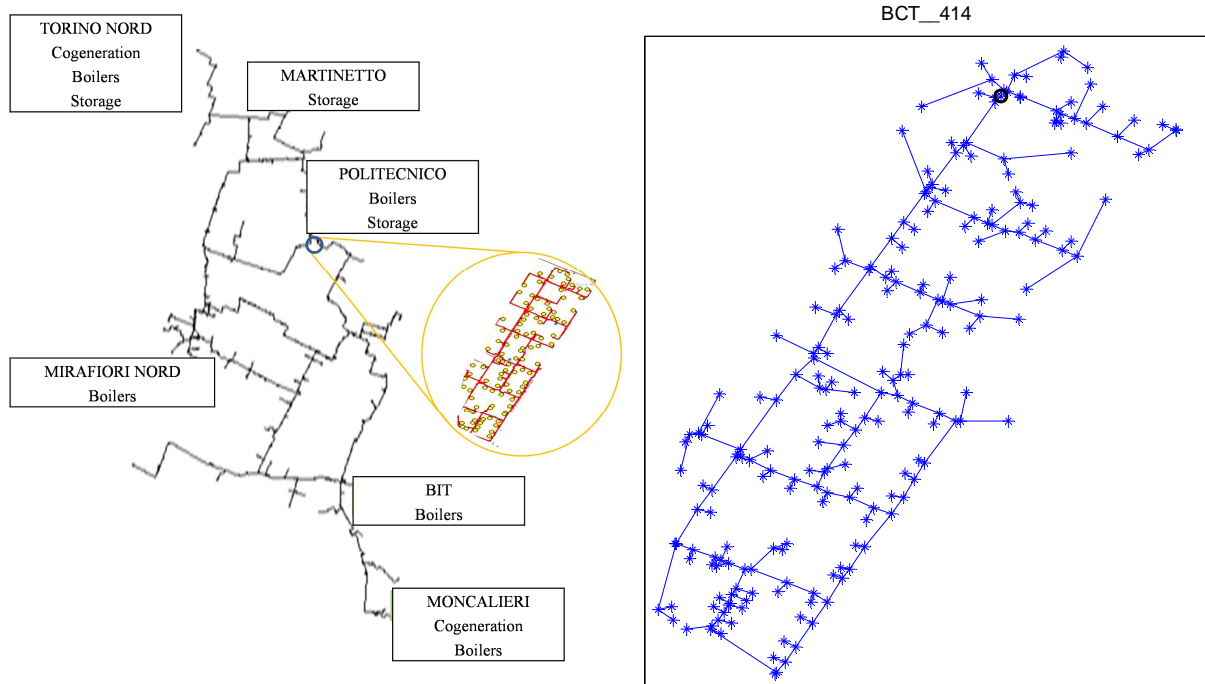
Fig. 3. Schematic of Turin District Heating Network: the transport pipeline and in evidence the thermal plants and the analyzed distribution pipelines.

The selected distribution network is indicated in the full network topology as BCT_414.This is 4.7 km long and links the transport network to 103 buildings. The network is shown in the circle in Fig. 2. The BCT_414 has been selected because of the large number of users linked to this network that are monitored using a data gathering system.

The thermal demand of a limited number of buildings connected through the BCT_414 can be modified, due to technical reasons. In fact only public buildings and some buildings with specific agreements with the company can be currently considered for the change of the switching on time. Due to this reason, the total number of independent variable that can be considered nowadays is 32. Therefore, for the study related to the current condition **x** is a vector 32x1 (TEST 1). As regards the analysis related to future potentials, two other cases have been studied: the first includes 60% of the buildings with variable schedule (TEST 2) and the second 90% (TEST 3). The thermal request evolution of all the users (thick line), the variable users (plain line) and the non variable users (dashed line), for the three considered cases are reported in Fig. 4. It is clear from the figure that in the TEST 1 most part of the thermal power request cannot be modified through rescheduling; in TEST 2, more than a half of the users can be modified while in TEST 3 most of the thermal power request can be modified.
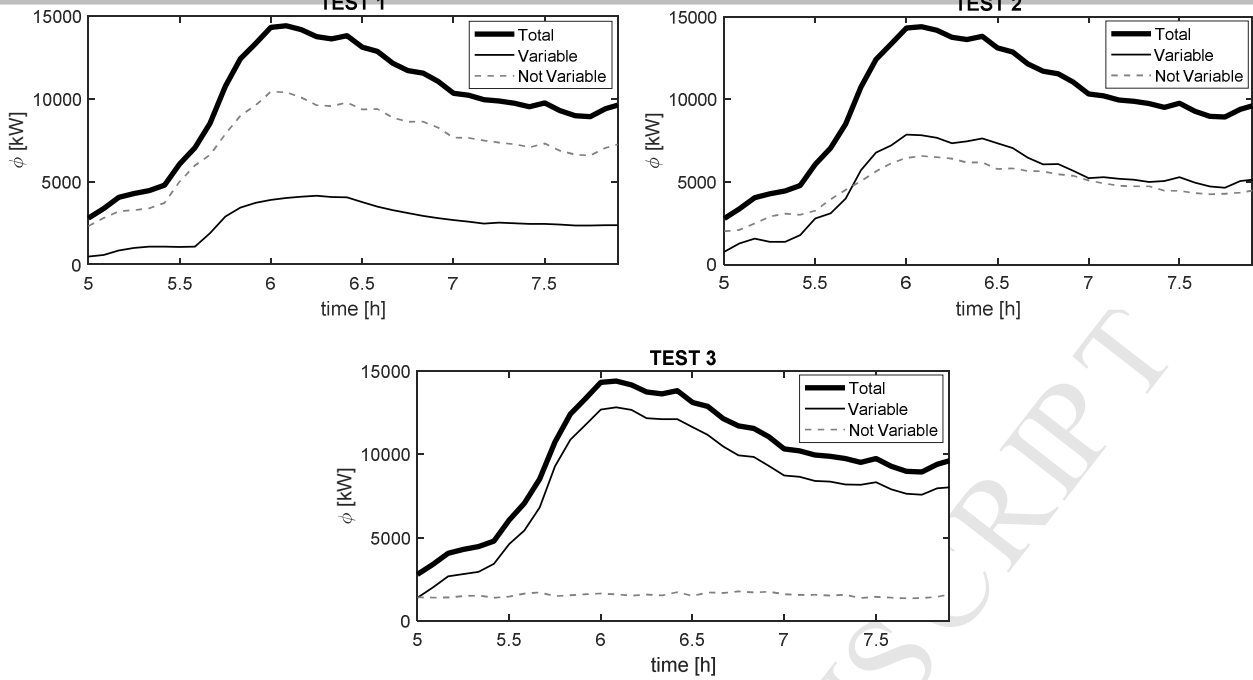
Fig. 4. Schematic of Turin District Heating Network: the transport pipeline and in evidence the thermal plants and the analyzed distribution pipelines.

3.2 Data gathering system

In order to obtain an optimal set of rescheduling, the knowledge of the expected thermal profile of each building is necessary. For this reason, a system for monitoring the thermal request of the buildings has been installed in most thermal substations over the past years. Temperature sensors and mass flow meter collect temperature at the inlet and at the outlet section of the heat exchanger and the water mass flow rate at the primary side. These data can be used in order to evaluate the heat request evolution with different external temperatures in weekdays and weekends. It is therefore possible to estimate the heat load profile at the user for different level of external temperature. In Fig. 5 the data collected in the BCT_414 are shown with the goal of highlighting various aspects:

- the various buildings present significantly different evolution in the request profiles. Most of them present a peak at about 6 am, but this is not exactly at the same time. In other buildings the heating system operates continuously while in others it is stopped various times;
- the requested mass flow rates are quite different and so the heat flux levels;
- the temperature of water exiting the heat exchangers is very similar at certain times (e.g. between 7 am and 9 am)
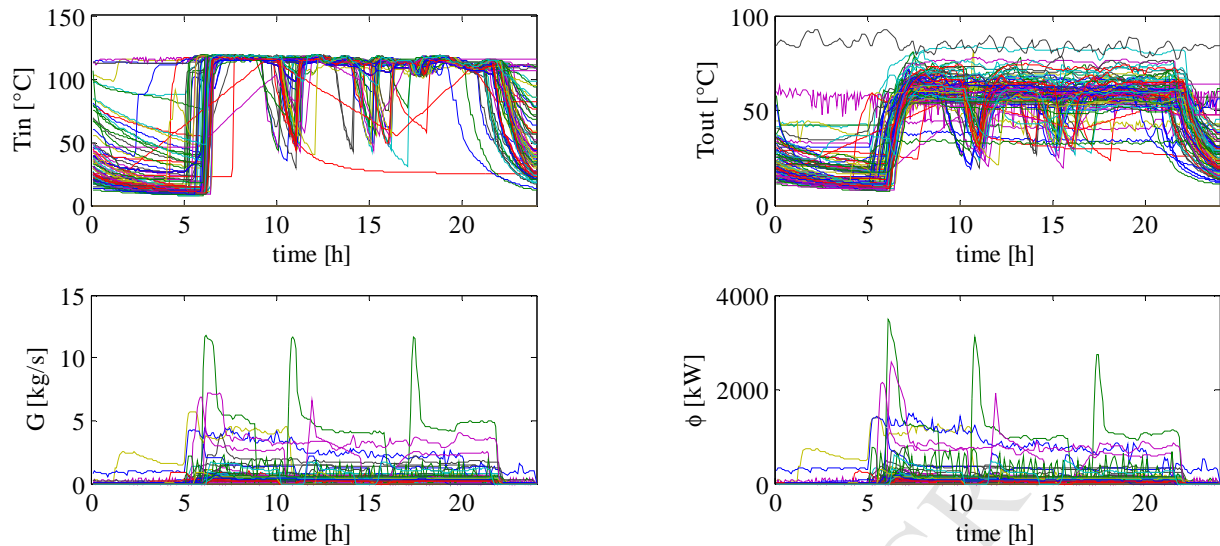
Fig. 5. Data collected at the heat exchangers of users in the BCT_414

When all the systems are on, the values of temperature at the inlet section of the heat exchanger are between 118 °C and 113 °C. The difference of these values is due to the different distances from the barycentre, i.e. the link between the distribution and the transport network. In fact, the larger the distance between the user and the thermal barycentre, the larger the thermal losses and the lower the inlet temperature at the heat exchanger. At night, temperatures drop when the systems are switched off but the slope is different due to the different thermal capacity. The outlet temperatures are very different; values at steady state are between 55θ °C and 70 °C. These considerations reveal the necessity of detailed information about the buildings in order to implement energy savings policies in a proper and effective way.

In Fig. 5 it is also possible to notice that most users activate the heating system in the morning and keep it switched on until evening, while some of them switch on and off the heating system 2 or 3 times which causes 2 or 3 peaks. Nevertheless, while the morning start-up time occurs at about the same time in almost all the users, the following start-up occurs at different time. Finally the morning thermal peak is often higher than the other peaks. For these reasons the attention has been focused on the morning that is much more relevant respect to the other peaks (as shown in Fig. 2).

These pieces of information are also used in order to monitor the various heat exchangers with respect to possible fouling. The ratio between steady-state heat flux (i.e. in the afternoon) and mean logarithmic temperature difference is calculated for each thermal substation. These values are compared with historical data corresponding with similar outdoor temperatures. In the case a systematic decrease is observed this is symptom of fouling, therefore no strategies are applied and a maintenance is scheduled.

4. Results

4.1 Boiler production minimization

In this section, the optimization results obtained using the total boiler production as the objective function are described. Fig. 6 depicts the total thermal power required to the BCT_414, for different percentages of buildings, with flexible schedule. The external temperature considered for this case is 0 °C. For each percentage, the thermal request evolution obtained through the genetic algorithm

optimization is compared to the current one. In all the 3 cases, the load curve obtained with the modified strategy is slightly shifted with respect to the current one because of the anticipations. The horizontal line represents the maximum cogeneration power assigned to this distribution network according to criterion formulated in the previous section; the value is 10 MW. The integral over this value represents the quantity that has been minimized. Fig. 6 shows that in all the cases this area is reduced with respect to the one obtained with the current strategy. Clearly the higher the number of users with flexible schedule, the lower the boiler production.

As regards the maximum peak value, a negligible reduction occurs, especially when the percentage of flexible users is small. Actually, in the first of the considered cases the maximum peak value is higher than to the one obtained with the current condition.
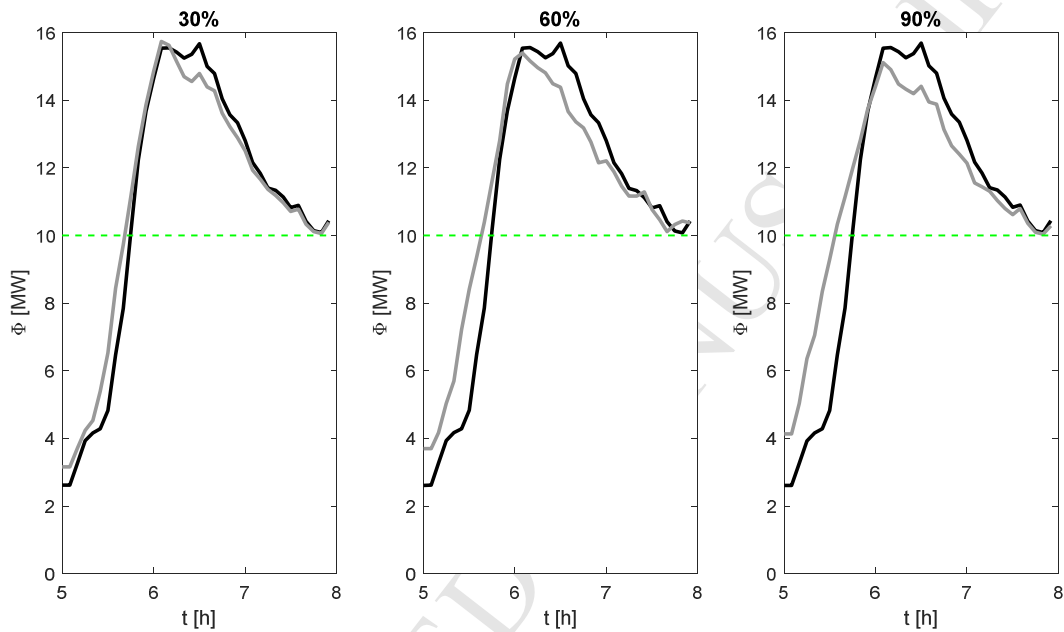

Fig. 6. Optimization results for different variable users -Objective Function 1-

In order to quantify the effect of the anticipation on the amount of the energy required, the amounts of energy produced through boilers, cogeneration and the total primary energy consumed have been calculated. The results are shown in Fig. 7 compared to the current strategy.

This figure reports the increase of thermal energy covered by cogeneration and by boilers, by turning to the optimized strategy. Cogeneration in all the cases increases at the expense of the boiler production, which decreases. The higher the percentage of buildings which schedule can be modified, the higher is the cogeneration exploitation. The total thermal consumption corresponding with the optimized cases is clearly higher than in the current case, due to the additional consumption associated with anticipated starting of the heating system (in this analysis no energy recovery associated to additional or longer stops during the day has been considered). Nevertheless, this additional request is mostly covered through cogeneration, which presents a much small primary energy factor than the boilers. The boilers have a performance of about 90%.The cogeneration plants allow exploiting low exergy source and therefore the thermal performances are very high; the electric performance is 0,59 and the thermal power (ΔW_{th}) that can be produced in place of electricity (ΔW_{el}) is about 210%. The costs of a unit of energy produced through boilers and a unit of energy produced through cogeneration are reported in Eq. 8 and 9.

$$c_{cog} = \frac{1}{\eta_{el}} \frac{\Delta W_{el}}{\Delta W_{th}} = 0.35 \tag{8}$$

$$c_{boil} = \frac{1}{\eta_{th}} = 1.1 \tag{9}$$

~~In fact t~~Therefore the ratio between primary energy consumption and heat produced is about 1.11 for the boilers and about 0.36 for the cogeneration system [17]. For this reason even though the energy request increases, the primary energy consumption decreases, as shown in Fig. 7. The boiler energy consumption is reduced of about 5% in TEST 1, 9 % in TEST 2 and 12 % in TEST 3.

Considering 60% of users with flexible schedule, instead of 30%, an extra 35% of primary energy saving can be obtained. A further increase of less than 1% can be achieved passing from 60% to 90%. Therefore it is very important to augment the number of flexible users. The analysis shows that applying the mild strategy considered here, 60% is a sufficient value to obtain satisfactory results. The primary energy consumption reduction obtained during the peak is more than 1%. The amount of the primary energy saving in TEST 1 and TEST 2 are 0.46 MWh/day and 0.62 MWh/day, which represents about 0.79% and 1.07% of the consumption of this distribution network. Flexibility becomes even more important in the case the freedom to modify the schedule profiles increases.
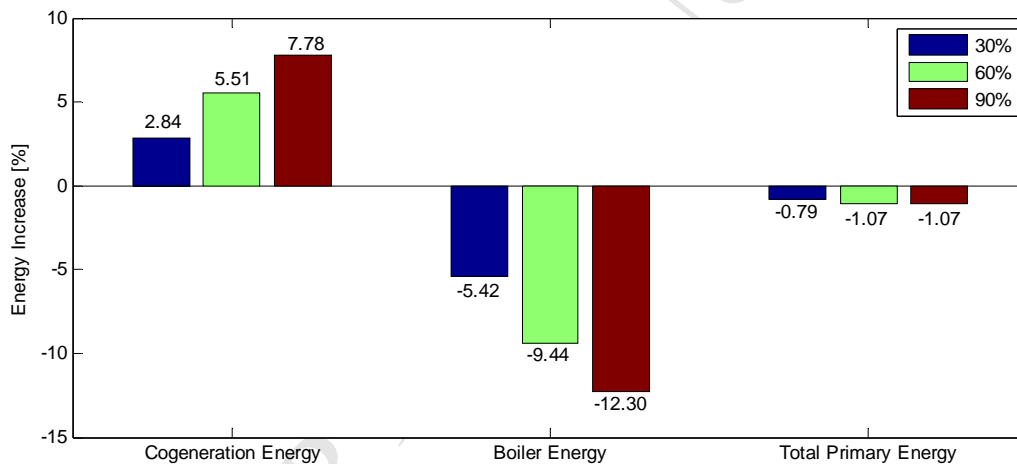
Fig. 7. Optimization results for different variable users -Objective Function 1-

In addition, it should be observed that results significantly depend on the external temperature. Fig. 8 reports the profiles corresponding with an outdoor temperature of 5°C.

In the case of 30% of flexible users a primary energy savings of about 2.1% can be reached (more than the double with respect to 0 °C). The energy saved in this case is larger, in percentage, because the total thermal request during the peak is smaller. In TEST 2 and TEST 3 the area above the cogeneration limit is even smaller and the primary energy consumption in both cases is reduced of about 3.5%. Also in this case 60% of users with a flexible schedule is sufficient in order to reach a satisfying result.
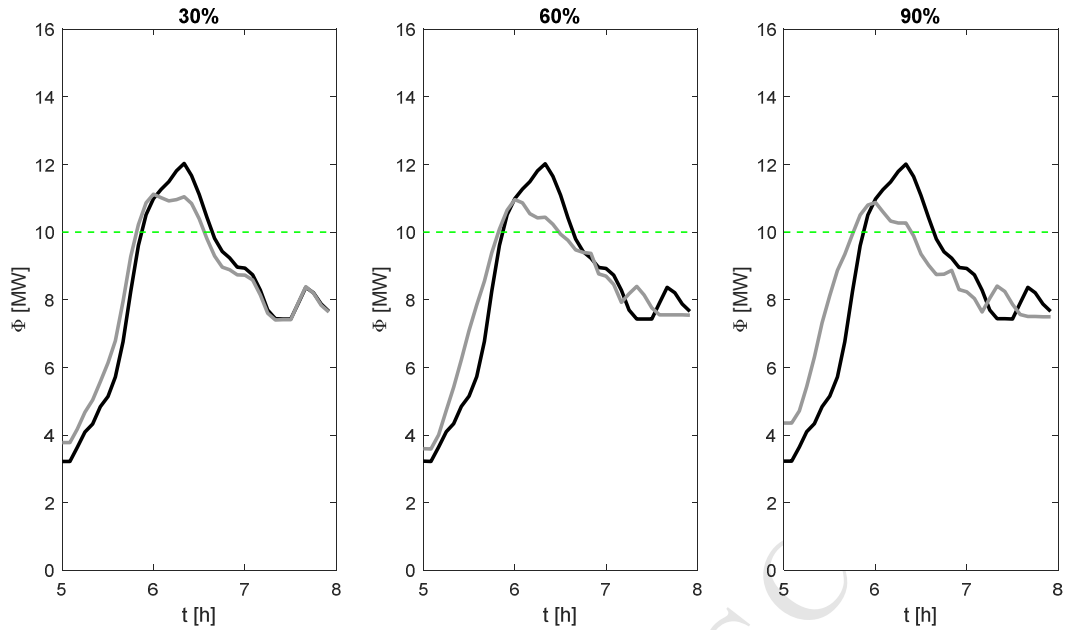
Fig. 8. Optimization results with external temperatures T= 5 °C -Objective Function 1-

In TEST 1 a primary energy reduction of about 60 MWh/year can be achieved with respect to the current strategy, while the primary energy saving in TEST 2 and TEST 3 is about 100 MWh/year. The percentage reduction of the overall primary energy consumption in one year is more than 0.4%, assuming 60% of variable users.

4.2 Maximum request value minimization

In this section the results obtained when the second optimization approach is used are reported and commented. As shown in Fig. 9 the maximum value of the peak is reduced in all the considered cases. When only 30% of the users can be modified, a peak reduction of 2% is obtained (corresponding to 320 kW). The peak reduction significantly increases when a higher fraction of variable scheduling is considered. In TEST 2, a reduction of 685 kW in the peak power is obtained, which corresponds to about 4.4 %, while a reduction of 5.7% of the peak (900 kW) is possible in TEST 3. Fig. 9 also shows that using such objective function the benefits significantly increase when TEST 3 is considered instead of TEST 2.
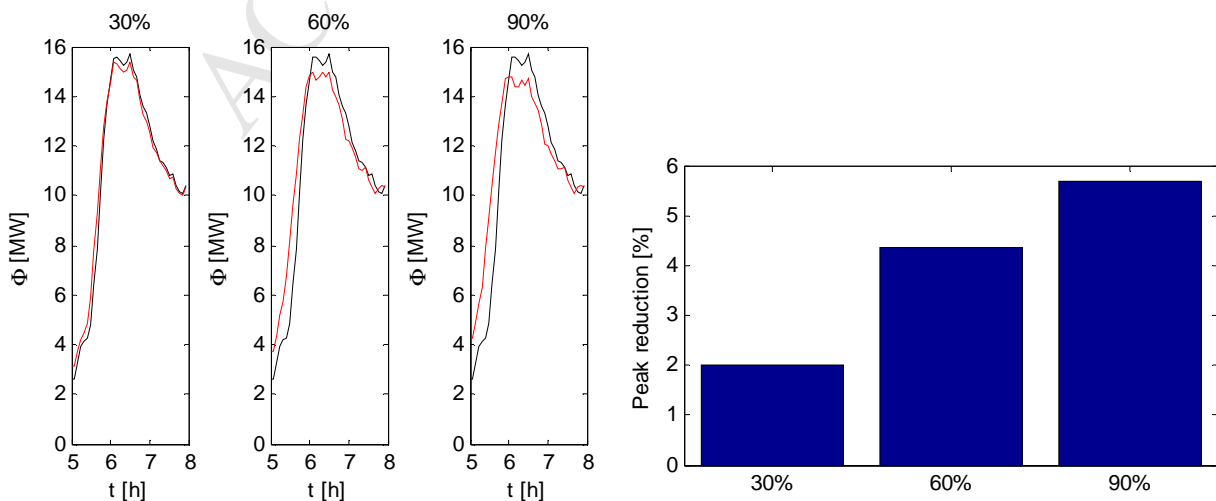
Fig. 9. Optimization results -Objective Function 2-

This result can be used to make the connection of additional buildings to the network possible without the installation of storage systems or new pipelines. In particular, about 12000 m^3 of buildings can be connected in TEST 1, 28000 m^3 in TEST 2 and 36000 m^3 in TEST 3. When new buildings are connected to the DH network the primary energy consumption decreases, due to the higher efficiency that can be obtained producing heat in cogenerations plants and large boilers with respect to independent heating systems based on boilers. Assuming a primary energy cost of about 1.25 for these independent heating systems about 0.35% primary energy reduction can be achieved in TEST 1, 0.75% in TEST 2 and almost 1% in TEST 3.

This leads to a significant fossil fuel saving with a consequent reduction of CO_2 emission of pollutant substances; furthermore pollutant emission from central plants are easier to be controlled with additional global benefits for urban areas.

4.3 Discussion

The selection of the objective function is an important aspect and should be performed depending on the specific goal of the energy saving strategy. In fact, results show that, when the maximum value of the thermal request is selected as objective function, the boiler production is not significantly different than in the current state. On the other hand, when the minimization of boiler production is used, it is possible that the maximum thermal power request increases.

It is important to remind that in the analysis conducted in this paper various strong limitations have been imposed in order to:

    a)   Make the system suitable to test the potential advantages of rescheduling even in the case of small changes

    b)   Do not affect the comfort level inside the buildings.

Such limitations are:

1. The maximum allowed anticipation is 20 minutes.
2. No thermal recovery is applied.
3. Only the first thermal peak has been shaved.
4. Only a single distribution network has been considered for the analysis.

Authors consider that it is appropriate and possible to relax such limitations. An increase in the anticipation time can be performed through the use of a model of buildings [18] that allows to simulate the effects of rescheduling on the indoor temperatures. Such model would also allow to consider delays in the switching on time or multiple pauses and attenuation.

In addition it is possible to consider the full network in the analysis, including the transportation pipeline and all the distribution networks. In such case the effects of the complete optimization in terms of primary energy savings is expected to be larger. The distances involved when the overall network is considered are very large and a properly selected anticipation for each building, or distribution network, can leads to a considerable energy savings.

Furthermore, when the thermal demand evolution presents more than one peak, proper modifications for can be introduced in the current model to achieve the reduction of every peak.

However through this approach it is possible to reduce the mass flow rates in the pipes during the peak period and primary energy consumption without any other investment costs.

As regards the computational cost, the optimization tool provides the optimum set of anticipation using a single 3.3 GHz CPU in about 2 hours. This is a crucial feature to allow optimal operation in real networks.

In Table 1 the best schedule for the heating systems subject to changes can be seen. The current schedule are reported and both the best sets of start-up time obtained with the first and the second objective function, for the TEST 1. In such test 25 user schedules out of 32 have been modified; in particular, there are 13 user schedules that have been handled in the same way. From Table 1 it is possible to notice that in most cases when the schedule are varied, the variation required is 20 min. This means that, when a system is suitable for anticipation, it is usually anticipated as much as possible. This result also suggests that larger anticipation ranges would be achieved.

CURRENT STRATEGY	1st OBJIECTIVE FUNCTION	2nd OBJIECTIVE FUNCTION
5:00	4:40	4:40
6:00	6:00	5:40
6:10	6:10	6:00
6:00	5:40	5:40
6:00	5:40	5:40
6:00	5:40	6:00
6:00	5:40	6:00
6:00	5:40	5:40
6:00	6:00	5:40
6:00	6:00	5:50
6:10	6:10	5:50
6:00	5:50	5:50
6:00	5:40	6:00
5:50	5:30	5:30
6:00	5:40	5:40
6:00	5:40	5:40
6:00	5:40	6:00
6:10	6:00	6:10
5:30	5:10	5:10
5:30	5:10	5:10
6:00	5:40	5:40
6:00	5:50	5:40
5:50	5:50	5:30
6:00	5:40	5:40
6:10	6:10	5:50

Table 1. Best schedule obtained for TEST 1

5. Conclusions

In this paper, a tool for optimal energy management of district heating networks is presented. The tool is applied to the reduction of the thermal peak request occurring in the morning in order to minimize the total primary energy consumption. This is performed through variation of the thermal request profiles of the buildings acting on the scheduling of the heating systems of each building but without affecting the comfort conditions of the users. This peak does not allow full exploitation of the cogeneration plants that are typically sized to cover just a portion of the maximum load.

Furthermore the presence of a peak limits the opportunities for network enlargement, because of the limitation on the mass flow rates in the existing pipeline. For this reasons peak shaving represents a major challenge in DH system management. The tool includes a physical model of the network which allows one taking into account properly the effects of the different distances of the buildings in the considered network. An application to the Turin district heating network is presented. Two different objective functions have been investigated: minimization of the boiler production and minimization of the maximum peak value. The first objective function allows one to reduce heat request during peak hours not covered by cogeneration. Currently only about 30% of the of the users in the selected distribution network have a variable time schedule. With this constraint, the optimization allows a reduction of about 5.5% in the boiler use and primary energy reduction of 0.8% when the environmental temperature is 0 °C and 2.1% with 5°C. It leads to a total primary energy savings of 60 MWh/y. In order to evaluate the potential primary energy savings that can be obtained for the selected distribution network, the optimization tool has been also applied to the analysis of a scenario where the 60% and 90% of the users have flexible schedule. When the variable schedules are more than 60% of users a primary energy reduction of 1% is verified when the environmental temperature is 0°C and 3.5% when it is 5°C. Results also show that in this case a primary energy reduction of 100 MWh/year is reached.

In case the objective function is maximum peak reduction, results show that a reduction of 2% can be obtained with 30% of flexible schedule, 4.5% reduction with 60% of flexible schedules and 5.8% reduction when the percentage of users with variable time schedules is 90%. This makes it possible to increase the number of buildings connected with the distribution network from 2% to 5.8%. A corresponding primary energy savings from about 0.35% to 1% can be thus achieved.

Results obtained using both the objective functions are very promising, in particular considering that no extra investment costs are required. Results can be further enhanced by considering larger anticipation rages or changes in the profile shapes, nevertheless this would require the use of building model to check the acceptability of internal temperatures as discussed in [18].

Nomenclature

A	Incident matrix	-
cp	Specific Heat	kJ/kgK
G	Mass flow rate	kg/s
Q	Thermal Energy	kJ
T	Temperature	K
t	time	s
Φ	Heat power	kW

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Highlights

- A method for the optimal management of District Heating (DH) Systems is proposed.
- Peak shaving is performed acting on the thermal request profiles of buildings.
- The method is applied to the distribution network of a large DH network.
- Significant reductions in primary energy without any investment cost are achieved.
- It increase the possibilities of connecting additional buildings to DH network.