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Real operation data analysis on district heating load patterns

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ABSTRACT

District heating networks play an important role in the heating and cooling sector, serving up to 60% of the citizens in some countries. The availability of a thermal network supplying multiple users allows producing heat from different sources and multiple technologies. The possibility of relying on different solutions allows the system manager to optimize the heat generation by choosing the best unit for each operation condition. This choice is based on a deep knowledge of heat load profiles, that are related to users' behavior, network performances and control logics.

This paper provides an analysis of a DH system operation over ten heating seasons, with the aim of highlighting the main characteristics of the heat load variations and finding the fundamental drivers for heat load prediction. Although the system has seen a significant development throughout the years, the specific energy consumption has been found to be comparable on the whole duration of the analysis. Two main patterns are highlighted, based on the different operation settings along the hours of the day and the outdoor temperature as the main weather driver for building's heat demand.

1. Introduction

District heating systems have been developed in last decades as an effective way to supply heat to final users, especially where combined heat and power plants provide a high conversion efficiency. Within the current European targets on energy efficiency [1] and energy production from renewable sources [2], DH systems can play a major role through sustainable and efficient thermal energy production, within the Smart Thermal Grids concept framework [3–6].

DH systems have a wide field of applications, ranging from large systems supplying heat to the major metropolis to small systems tailored on mountain villages or isolated communities. The heat production comes from different sources, depending on the size of the system and on the location. Large DH systems usually rely on CHP production from fossil fuel-based plants, exploiting the higher efficiency provided by cogeneration with respect to separate production of heat and power. In some cases, the heat is produced from waste incinerators or from large biomass plants, especially in northern Europe. Medium and small DH systems show a wider variety of energy conversion technologies, ranging from fossil CHP production to biomass heat or CHP production [7,8], waste heat recovery from industrial sites, heat pumps, energy generation from geothermal sources [9,10] and solar energy [11,12].

Many literature works addressed the development of simulation models and tools for the design and optimization of DH systems, considering both energetic aspects and economic aspects (among others, [13–17]). These models provide different approaches to increase the energy efficiency of the DH systems, comparing technologies, system layouts and configurations. Some works are focused on the role of energy storage systems, which provide an effective way to help decoupling the energy production and the energy demand, with the aim of increasing the DH system efficiency [18–20]. The increase of CHP share can become in some cases the crucial aspect for a multi-objective optimization of a given DH system [21].

In the last years, demand load assessment and management has become more and more important, as the users' behavior can have a significant impact on the global efficiency of the system. In particular, the heat load pattern of the single substations is a major concern for a correct and effective DH operation and management. Multiple studies address the forecast of DH heat loads, by considering ensemble weather predictions [22], Machine Learning techniques [23–25] and analysis of heat loads diversity [26]. These applications point out the importance of a tailored forecast for an operational optimization of the DH systems, which includes the scheduling of multiple production units and the choice of network temperatures. The DH load analysis has also been used in some

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cases to improve the quality of the piping diameter design [16].

In addition, environmental aspects need to be taken into account, as the development of DH systems should provide environmental benefits together with the increase of energy efficiency. While a decrease of CO_2 emissions can generally be obtained, the emissions of other pollutants could need a dedicated analysis [27–29].

While much attention has been paid on the design and optimization of future networks, few works address the operation analysis of existing DH systems considering actual data and detailed time steps [30–33]. The results of these works show that the operation and control settings can have a significant impact on the primary energy consumption of the DH system, as over the year the system operates in different off-design conditions, especially at partial loads.

This paper provides an analysis of an existing large-size DH system, supplied by natural gas CHP units and integration boilers. The possibility of considering several years of operation with a narrow time step gives the opportunity to perform a statistical analysis over various operation conditions. A correlation is proposed between the DH system consumption in different operation conditions with respect to the outdoor temperature of the site, by applying the energy signature methodology.

2. Methodology

2.1. Description of the case study

The DH network considered in this work is supplying the city of Turin (about 900,000 inhabitants), in the north-west of Italy. The DH system has been continuously evolving in last decades: the first users of the DH system were connected in 1982, when a CHP unit started to produce electricity and heat in a northern district of the city. In the following years, different production sites were connected to the grid, and the size of the network and number of users have continuously increased. Turin DH network currently serves about 56 million cubic meters of buildings (almost 60% of the total buildings in the city), with a network extent larger than 500 km of dual piping (as of 2014). The total amount of heat produced in 2014 was 2.0 TWh, and 1.7 TWh of energy was supplied to the final users, resulting in about 16% of thermal losses of the network [34]. The main part of the connected users are residential buildings (about 75%), while the remaining part is composed by public administration offices, schools, hospitals and commercial buildings. The total area served by DH network is shown in Fig. 1. The heat production is provided by multiple generation units, both CHP and integration boilers. The newest CHP units are combined cycles with natural gas turbines, while a gas turbine, a steam turbine and a natural gas engine are no longer in operation. The DH system is also equipped with heat storage units: 5000 m^3 of tanks are installed in Torino Nord site, 5000 m^3 in *Martinetto* site (near Torino Nord) and 2500 m^3 in *Politecnico* site. The first HSS have been installed in 2005/2006. Their main purpose is the storage of the excess of CHP production at night in order to match a part of the morning peak request without the need to activate integration boilers.

2.2. Description of the dataset

The data used in this paper have been obtained from the monitoring system of the generation plants, and have been collected during some previous works [35,36].

2.2.1. Available operation data

The operation data are available from October 2001 to April 2011, representing the energy consumption of ten heating seasons. The data have been collected separately for each unit of the system, i.e. CHP units, integration boilers and heat storage systems. As of April 2011, the Torino Nord site was not in operation. Therefore, the operation data considered in this paper are currently limited to the other sites. The availability of updated data could lead to an extension of the analysis, with a comparison between the old and new DH system layout. For each generation unit the thermal energy production supplied to the DH grid is available, with a time step of 6 min. The operation data refer to a wide-ranging period, in which the DH system has significantly evolved, both on supply side and on demand side. Considering the latter, the amount of connected buildings has almost doubled from year 2001 to year 2011, reaching almost 41 million m^3 from an initial value of about 22 million m^3. Considering the supply side, some generation units have been decommissioned, and other started their operation. In particular, the heat storage systems in *Politecnico* site have been in operation since the summer of 2006, and before 2006/2007 heating season the heat was provided only by CHP and integration boilers. In 2007 two diesel CHP engines in the Mirafiori Nord site have been decommissioned, and they are now available only for emergency operation. The CHP units in Moncalieri underwent two different refurbishments. Two CHP natural gas combined cycles have been installed, the first in 2005 as a substitution of a gas turbine unit and the second in 2009, replacing a steam turbine power plant.

In addition to DH operation dataset, some weather data have been collected. The outdoor temperature has been recorded with the same time step of the heat data, and will be used for the calculation of the energy signatures. Other weather data have been obtained with a daily time step, by aggregating different measuring stations in the city of Turin [37]. The daily data available are the minimum and maximum outdoor temperatures, the total rain, the snow level, the average wind speed and the global horizontal radiation. These data will be used to investigate possible correlations with heat consumption of the DH network.

2.2.2. Data gathering and corrections

The dataset considered in this research contains data over about 840,000 time steps for 16 generation units. For each unit, the Distributed Control System (DCS) of the generation plants has stored the thermal power, the mass flow and the supply and return temperatures. This research has been focused on the heat demand on the network, and future works will consider the mass flow and temperatures analyses. The data have been collected from two different DCS systems, depending on the generation sites, and therefore a preliminary activity required a merging of the data to a single dataset. This huge amount of information had some gaps, caused by sensor failures or other database recording problems. The gaps are mainly related to single values, but in some cases the error affects a longer period of time (up to some days in few cases, mainly in summer months). The majority of the gaps are related to a single unit or a production site.

These gaps have been repaired with value interpolations with the previous and following available data. The electricity production of the CHP units has been measured by a different system: therefore in some cases it has been possible to check the power load to have some additional information for the heat production estimation. This approach is justified by the irrelevant number of data errors with respect to the total amount of measured data (lower than 0.1%).

The data have been collected from different data management systems, depending on the type of generation unit. The total heat supplied to the DH network has been calculated as the sum of the production from each generation unit at the same time-step.