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ASSESSING FLEXIBILITY IN SOLAR BASED DISTRICT HEATING AND COOLING SYSTEMS: A SIMULATION-ASSISTED CASE STUDY

Summary

The performance of a complex multi-energy district heating and cooling system was assessed and optimized. This system relies heavily on locally produced solar energy and comprises multiple pieces of thermal equipment based on different technologies, whose operation was optimized to increase overall system efficiency. The optimization was carried out by means of a series of dynamic simulations for various scenarios. This way, several improvements for increased energy flexibility and efficiency were assessed. Results show potential to increase the utilization of solar energy taking advantage of the appropriate climate conditions, maximizing local generation, as well as minimizing thermal losses and shaving peak loads by using thermal energy storage. The proposed adjustments improve the energy flexibility, efficiency and independence of the facility, contributing to its decarbonization and resilience, while also reducing costs and emissions.

Keywords: District heating and cooling, solar energy, decarbonization, resilience, energy efficiency

Field of application for the findings: Sustainable and Efficient District heating and cooling

Addressed audience: district heating and cooling facility management, energy service companies, planners

1. Introduction

The building sector covers a good share of overall global energy consumption both for cooling and heating. As a result of the transition toward low carbon centralized heating and cooling infrastructures, there is an increasing demand for heating and cooling networks that can actively adapt to fluctuating renewable energy supplies and varying thermal loads to take advantage of the renewable energy (Kim, et al., 2026). Recently, the integration of diversified energy sources to cover thermal demand for residential and public buildings and district heating and cooling (DHC) networks has been proved to stabilize the system while following variable electricity prices. This paves a direction towards optimal solutions from energy, environmental and economic point of view (Jacopo, et al., 2022).

To achieve diversified energy sources in centralized heating and cooling the use of large-scale heat pumps, solar thermal plants, waste heat recovery and utilization and thermal energy storage tanks both for cold and hot water showed to have a positive impact, significantly reducing or even completely phasing-out the use of fossil fuels (Kalina, et al., 2025). Additionally, since new-generation DHC systems consume a significant amount of electricity due to the implementation of heat pumps and chillers, they can be further supported by solar photovoltaic (PV) panels, which could (partly) cover the base energy load. This reduces the electricity imported from the grid and thus its corresponding energy cost, resulting in overall savings in the operation of centralized heating and cooling networks (Marta, et al., 2019).

2. Methodology

2.1. Case study description

This study presents a detailed, simulation-assisted case study analyzing the operational flexibility of a solar based DHC system supplying the thermal demand of a large hospital complex located in Southern Europe. The local climate is hot summer continental mediterranean (Csa in Köppen classification) (Beck, et al., 2018), characterized by summer temperatures surging up to 40 °C and mild winters. For this reason, the cooling demand is dominant. Also, there is a good availability of solar resources and thus a considerable amount of locally produced solar energy. Increasing its share is crucial, not only to decarbonize the installation and reduce its costs, but to ensure its energy security. Reducing dependence on the power grid and other external energy sources is of vital importance for critical infrastructure, such as hospitals, as it prevents disruptions caused by blackouts or similar incidents that could have catastrophic consequences for their operations.

This DHC installation is characterized by being a complex multi-energy system, comprising various energy sources (solar, electricity, natural gas) and multiple generation technologies and units (PV, solar thermal, heat pumps, chillers, dry coolers, cooling towers and boilers). Due to the nature of the activity of the building, there are simultaneous thermal demands for different services: heating, cooling, domestic hot water (DHW) and steam. These demands vary depending on weather conditions, occupancy, use of installations, etc.

The goal of the study is to propose technical measures that can be applied to the DHC installation to improve its energy efficiency, sustainability and resilience. To this aim, modifications are proposed both for equipment and controls. More specifically, the following improvements are assessed:

- Increase in the installed PV generation capacity
- Addition of a cold storage tank
- Optimization of distribution temperatures to minimize thermal losses

These modifications are tested by series of dynamic simulations, in which relevant parameters (such as equipment sizing or control settings) are optimized to find the most appropriate implementation specification.

2.2. Model description

For the assessment of improvements through simulations, a model of the installation is developed in Dymola, a dynamic modelling tool based on Modelica language. This software is well-suited for modelling multi-energy systems because of its Multiphysics capabilities and the availability of dedicated libraries that include thermal and electrical components. The resulting model can be observed in Fig.1.

In this case, the existing solar thermal field is prioritized as a primary heat source, complemented by a water-to-water heat pump which takes heat from the cooling loop and puts it into the heating loop, hence covering simultaneously the base loads of both heating and cooling demands. When the combined solar thermal and heat pump output is insufficient to meet the peak heating demand, a gas boiler is dispatched as a fast response back-up. As for the cooling demand, it is primarily covered by free cooling through dry coolers when outdoor temperatures are low (<12 °C). With ambient temperatures in the range of 12-25 °C, chillers kick in to meet demand, while dry coolers act as condensing units. Finally, when ambient temperatures exceed 25 °C, cooling towers are used as condensing units for the chillers. Regarding cooling capacity, there are four chillers of different sizes that operate in cascade adjusting production dynamically to the load. There is also a relevant PV installed capacity (>2 MW) that partially covers the demand for electricity of the whole facility.

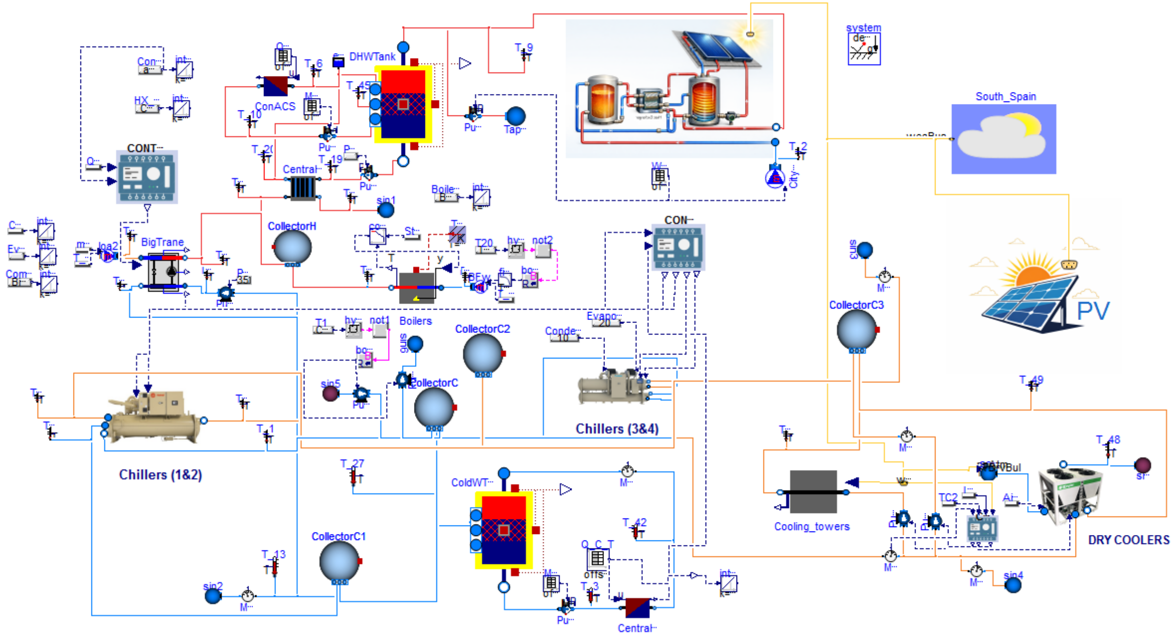

Fig. 1: Model of the multi-energy DHC installation

3. Results

By comparing the results of simulations for each measure against the baseline (validated with data from the existing installation in its current state) the impact of each improvement can be quantified for different KPIs. These KPIs include flexibility value (Zhou, et al., 2022), defined in eq.1, and flexibility energy (Maitanova, et al., 2024), in eq.2.

$$Flexibility\ value = \frac{Annual\ savings}{Energy\ shifted} \qquad \text{(eq. 1)}$$

$$E_{flex} = P_{flex} * H_{flex} \qquad \text{(eq. 2)}$$

Where: E_{flex} = *Flexibility energy (MWh/year),* P_{flex} = *Flexibility power (MW) and* H_{flex} = *Flexibility hours(hours/year)*

The existing PV panels cover around 70 % of the total electricity consumption in the facility. Increasing the installed PV capacity to cover around 90 % of the total demand results in a reduction of the electricity imported from the grid of approximately 430 MWh/year, corresponding to yearly savings of around 40,000 € and 50 tons of CO_2, with a flexibility value of 90 €/MWh per year added to the facility operation.

Regarding thermal energy storage capacity, results show that the addition of a cold buffer tank can shave peaks by up to 17 MWh per cycle, which leads to approximately 1700 MWh per year of thermal energy and translates into yearly savings of approximately 85,000 € and 230 tons of CO_2. This measure would contribute to around 50 €/MWh flexibility value.

As for the distribution temperature optimization, current cooling circuit water supply temperature ranges between 3-12 °C, while the heating circuit supply line stays between 60-80 °C. Taking advantage of the cold storage tank improvement measure mentioned above, it is possible to adjust distribution temperature setpoints to 6-12 °C for the cooling supply. And by optimizing controls, heating supply temperatures can be reduced to 55-65 °C. As a result, a COP improvement of about 10 % could be obtained, resulting in electricity savings of 100 MWh/year which translates to approximately 9,000 €/year, reducing emissions by about 12 tons of CO_2/year.

Similarly, improved smart control strategies optimizing the operation based on load, weather, solar production and electricity prices, resulting in optimal equipment sequencing, leads to peak reductions up to 60 kW, which entails around 170 MWh/year savings and approximately 20 tons of CO_2/year.

4. References

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