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Research Paper

Optimal DHC energy supply harnessing its thermal mass

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HIGHLIGHTS

- DHC thermal mass and heat losses in energy supply are studied.
- An Energy Management System is proposed to provide optimal supply strategies.
- DHC thermal mass is used as energy storage increasing power plant benefits.
- Heat losses are reduced by the use of an optimal supply temperature.

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ABSTRACT

Optimal supply strategies are a promising and inexpensive way to improve energy efficiency and to reduce expenditure in district network energy supply. These strategies aim to reduce heat losses by modifying the supply temperature within its working boundaries. Through supply temperature adjustment and network's thermal mass it is possible to modify the energy stored in the network and to use it as an active energy storage. In this work, scenarios with variable and fixed supply temperature are compared during four weeks representing the different seasons. The simulations are carried out using an energy management system. Results of both scenarios for a district heating and cooling network placed in the Mediterranean region are presented and discussed.

1. Introduction

District Heating and Cooling (DHC) infrastructures have been developed in the last decades as an effective way to supply thermal energy. DHC systems distribute energy to users spread in a neighborhood, area or city through a pipe network. DHC connect the users to a centralized power plant or a number of distributed plants providing heating and/or cooling [1].

A centralized generation system uses large generation units with higher efficiency and more advanced air pollution control methods. Moreover a central power plant allows working together with a variety of energy sources easing the integration of Renewable Energy System (RES) [2].

Furthermore, DHC energy supply networks are attracting attention for their low carbon potential enhancing energy efficiency [3]. In addition, the usage of energy storage may improve the performance of the whole system [4] and provide an effective way to decouple energy production and energy demand [5].

District Heating systems (DH) and District Cooling systems (DC) systems development have gone through 3 generations improving several factors such as supply temperature and energy integration seeking to improve their performance [1].

DH system delivers hot water or steam from a central plant to energy users using a pipe network. Analogously, a DC system delivers chilled water from a central power plant to energy users. The main difference between DH and DC is the delivery temperature which in DC systems is normally below 10 °C [4]. The temperature drop between supply and return in DC is much lower than in DH. This means that the pipe size is much bigger in DC to carry the same power than in DH, leading to a more expensive investment in DC network [6].

As previously mentioned, DHC systems are an efficient way to supply thermal energy to the customers, but these systems must be planned carefully in order to perform properly [7]. The planning phase needs to address features such as: pipe layout, insulation and size, underground depth, soil conductivity and operation strategy.

The district network may be designed using different topologies. Pipe layout is arranged in one of these three forms: branched, looped and branched-looped network. Branched network is simple and

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Nomenclature

A_0	annual amplitude of the surface soil temperature (°C)
A	cooling power produced by absorption chiller (kW)
A_{in}	heating power feeding the absorption chiller (kW)
B_t	thermal power produced by boiler (kW)
C_f	price of the fuel feeding the CHP or Boiler (€/m^3)
C_p	price of electricity purchased from the grid (€/MWh)
C_s	price of electricity sold to the grid (€/MWh)
D_{in}	internal diameters of the pipe (m)
D_{out}	external diameters of the pipe (m)
D_t	thermal power wasted in the environment (kW)
E_c	cooling power produced by electric chillers (kW)
E_{TM}	energy stored in thermal mass (kWh)
EG	energy generated by the plant (kWh)
E_s	energy supplied to the network (kWh)
$P_{ele,p}$	electric power consumed by pumping system (kW)
P_p	electric power purchased from the grid (kW)
P_{res}	thermal power produced by RES (kW)
P_s	electric power sold to the grid (kW)
P_t	thermal power produced by CHP (kW)
L	length of pipes (m)
T_a	ambient temperature (°C)
T_f	supply temperature in the district network (°C)
T_r	return temperature in the district network (°C)
T_s	soil temperature (°C)
U	overall heat transfer coefficient (W/m^2 K)
U_d	thermal power demanded by the network users (kW)
U_c	cooling power demand (kW)
U_t	heating power demand (kW)
V_{DHC}	volume of water in the DHC (m^3)
ΔT	temperature difference between supply and return (°C)
c_p	specific heat (kJ/kg K)
c_{pm}	specific heat of material (kJ/kg K)
c_{pw}	specific heat of water (kJ/kg K)
d	damping depth (m)
k_B	ratio of heat losses depending on supply temperature
k_{ele}	ratio of pumping electricity consumption to mass flow
k_ϕ	ratio of heat losses depending on supply temperature
$\dot{m}$	mass flow of water (m^3/h)
z	depth of pipe burial in a DHC (m)
ϕ	heat loss on distribution network (kW)
ϕ_f	heat loss on supply pipe (kW)
ϕ_r	heat loss on return pipe (kW)
ϕ_B	base heat loss on a network for a given return and supply temperature (kW)
λ_s	soil heat conductivity coefficient, (W/m K)
ρ	density (kg/m^3)
ρ_m	density of material (kg/m^3)
ρ_w	density of water (kg/m^3)
γ	binary variable
CHP	Combined Heat and Power
DC	District Cooling systems
DHC	District Heating and Cooling
DH	District Heating systems
EMS	Energy Management System
ESS	Energy Storage System
HL	Heat Loss
KPI	Key Performance Indicator
LCOE	Levelized Cost of Energy
MILP	Mixed Integer Linear Programming
O&M	Operation and Maintenance
RES	Renewable Energy System
TM	Thermal Mass
TPL	Target Pressure Loss
UIB	University of Balearic Islands
VFD	Variable Frequency Drives

unreliable. Looped is more reliable but on the other hand it has higher investment cost. Branched-looped is a combination on both designs [4]. As pointed out in [8] it is necessary to design the network with an efficient layout, otherwise the DHC expected performance is not achieved.

Another factor influencing DHC performance is the piping. Pipe size should be considered together with pumping consumption and insulation thickness to achieve the shortest payback time [9]. Whether to select single or twin pipe is an important decision affecting both the initial investment and Heat Loss (HL) in operation along the useful life of the installation. Significant energy savings could be provided using twin pipes instead of classic pipes with a minor increase of investment [10]. Equally important is the insulation used for the pipes which plays an important role in the network cost-effectiveness [11].

A general method to size the pipe section in a DHC considers the pressure loss per unit of length or Target Pressure Loss (TPL) on the network. This maximum TPL is used to size of the smallest pipe diameter in the network and the rest is selected in accordance [9]. The selection criteria for TPL values vary in many European DHC, a review of them is shown in [12].

In DHC network constructions the location of the pipes varies on the following types: overhead, aboveground and underground. Being the last one the most common construction [13]. In such construction an important design parameter is the soil around the pipe and the depth where it is placed. The soil composition and moisture is important in order to estimate the thermal transmittance the network is subjected to. In large networks soil estimation and its thermal conductivity is not easy since it is subjected to composition, structure, moisture content and varies with time [14].

Moreover, the depth of pipe burial has a direct impact on the soil temperature around the pipe. The temperature undergo daily and annual cyclic variations. The amplitude of such variations gets damped with depth, being at the same time, dependent to thermal conductivity [15]. It is considered that the mean soil temperature at an infinite depth, where there is no temperature variations, is equal to mean ambient temperature. Furthermore, the daily variations are small and negligible below 0.25 m and may not be even observed at 1.0 m depth [16].

An optimal operated DHC should take into account the operation of pumps and supply strategies. The pumping system has to be able to overcome the network flow resistance including pressure losses in clients heat exchangers. The study conducted by [12] shows that variable flow and variable supply temperature operating strategy is beneficial in all cases.

Moreover, a slight change in the network's flow temperature can effectively enhance the performance of the whole system, either through the improvement of efficiency on the generation units or through the decrease of HL in distribution [1,17,18]. Therefore, it is important to study and optimize the energy supply parameters in order to avoid a poor delivery quality in the network [19]. Some studies approach the optimization of DHC supply but mainly from the design point of view [20,21]. Despite its importance not much attention has been placed on the evaluation and study of energy supply strategies in DHC. The study in [22] proposes a new distribution concept based on mass flow control. Vertelund and Dahl [23] proposes an optimization method for meshed grids and [24,25] present a model which takes into account the thermal inertia of the pipe. Only lately the studies carried on by [26–29] thermal inertia of the DHC and buildings are considered