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Key energy and technological aspects of three innovative concepts of district energy networks

Samuel Henchoz [a], Patrick Chatelan [a], François Maréchal [a], Daniel Favrat [b, *]

[a] Industrial & Process Energy Systems (ex-LENI), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 9, CH-1015 Lausanne, Switzerland
[b] Energy Centre, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 5, CH-1015 Lausanne, Switzerland

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ABSTRACT

Energy needs in urban areas are heterogeneous by their nature, spatial distribution and temperature level required. Three concepts of district energy networks that could provide the energy services efficiently to a city centre are compared. The focus is on the energy and technological aspects. These networks are characterized by similar temperature levels; between 9.5 °C and 18 °C, rely on free cooling for most of the cooling services and use a combination of centralized and decentralized heat pumps to provide the heating services. Two of these concepts exploit the latent heat of evaporation/condensation of CO_2 and of the refrigerant R1234yf to store and transfer heat. The third concept is more conventional and uses the sensible heat of liquid water, however with a small temperature spread. The proposed networks allow the waste heat emitted by the users requiring cooling to be transferred and valourised by the users requiring heating, thus reducing the load on the central plant. For the area considered, where the annual heating and cooling demand are 53.1 GWh and 49.4 GWh respectively, the annual electricity required to supply the thermal services amounts to 10.87 GWh for CO_2, 10.52 GWh for water and 9.60 GWh for R1234yf.

1. Introduction

Urban areas represent an ever increasing challenge in term of energy use and environmental impact associated with it. According to the World Bank [1], the share of the world population living in urban areas rose steadily from 34% to 53% over the period 1961–2013, and projection from the United Nation expect this number to reach 66% by 2050. In Switzerland the current figure is 73% which is on parity with the value in Europe. According to URBACT [2] the building sector in the European Union accounts for 40% of the final energy consumption and 36% of the emissions of greenhouse gases. It also considers that energy efficiency in buildings located in urban areas represent one of the greatest potential to cut down greenhouse gases emissions and reduce the impact of the European society on climate. According to the Swiss Federal Office for Energy [3], the final energy consumption associated to thermal energy services in the sectors of households, services, industries are 87.6%, 71.5% and 68% respectively. Therefore, in order to realize the potential of energy savings in urban areas, it appears crucial to develop efficient energy conversion technologies dedicated to the thermal services. Obviously, other measures have to be taken jointly in order to reach the full potential of savings in the urban building sector. Measures such as improvement on the buildings envelope, management of solar and internal gains, better integration of electrical and thermal energy services, etc … will also contribute.

The basic concept of using a CO_2 network for both district heating and cooling was described in Ref. [21] based on theoretical demands. A second paper [23] illustrated its application to a real district.

The present study compares three concepts of district energy network for the same real district as in Ref. [23] on an energy basis and also from a technical point of view. Two of such networks are based on the use of the latent heat (refrigerants including CO_2) while the third one refers to “so-called anergy networks” with water [18–20]. The goal is to provide a valuable insight on the potential of such networks, as well as on the technological similarities/particularities that characterize them. Note that bulky 4 pipe networks (two hot and two cold) have not been considered in the comparison since they would hardly allow the synergy between users that was looked after.

* Corresponding author. Tel.: +41 79 3349785; fax: +41 216930000.
E-mail address: Daniel.favrat@epfl.ch (D. Favrat).

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Nomenclature

Acronyms
COP coefficient of performance (heat pumps)

Symbols
$\dot{E}$ electric power, W
E electricity, Wh
$\dot{m}$ massflow, kg s^{-1}
P pressure N m^{-2}
$\dot{Q}$ heat rate, W
T temperature, °C

Greek symbols
ΔP pressure drop, Nm^{-2}
ΔP_{h-c} pressure difference between hot and cold water lines of the water network, Nm^{-2}
ΔT temperature change, K
$\Delta T_{cooling}$ temperature difference between inlet and outlet water of cooling hydronic loops, K
$\Delta T_{heating}$ temperature difference between inlet and outlet water of heating hydronic loops, K
ΔT_{h-c} temperature difference between hot and cold water lines of the water network, K
ΔT_{min} minimum approach temperature difference, K
ΔT_{sc} subcooling, K
ΔT_{sh} superheat, K
η electrical efficiency
ρ mass density, kg m^{-3}

Subscripts
a atmosphere
airCond air conditioning
comp compressor
data data centre cooling
$H+C$ heating + cooling (requirements)
liq state in the liquid line
LL liquid-liquid (heat exchange)
LR liquid-refrigerant (heat exchange)
N network
refrig refrigeration
RR refrigerant-refrigerant (heat exchange)
RR refrigerant-refrigerant (heat exchange)
vap state in the vapour line

2. Historical and current trends in district energy networks

District heating network have been used to provide thermal energy services to buildings in densely populated area for over a century. In fact, the first mentioned use of a heat distribution network dates back to 1332 where geothermal water was provided to houses in the village of “Chaudes-Aigues” (France) via a piping network. This system is still partly used today. However, modern district heating networks only date back to the end of the nineteenth century. In 2011, member countries of Euroheat and power [4] had over 482000 km of district heating in operation, 2/3 of which for Russia and China only, they provided 3276 TWh of heat to the final users. The share of the population connected to district heating networks in all these countries is in average 28.6%. Two major technological shifts have occurred over the twentieth century with regard to the technology of district heating. The first shift concerns the supply temperature that gradually decreased as new networks were being built. Networks built in the early 1900's typically distribute steam at ~300 °C, while those built between 1930 and 1970 rely on superheated water above 120 °C and more recent networks operate with water at ~80 °C. The trend toward lower supply temperatures continues as networks at ~50 °C are considered for the supply of energy efficient building areas [5–7]. For instance, since 1985 space heating is delivered to the campus of EPFL by two networks one with a supply temperature of 65 °C (at $T_a = -10$ °C) feeding the oldest buildings and one at 50 °C for the newer constructions. The second shift concerns the conversion technologies used in these networks. Initially, fossil fuelled heat-only producing boilers were the only technology, but over the years, and especially after the oil crises of 1973 and 1979, steam cycle based cogeneration plants became widespread. In 2011 and for the OECD countries the share of district heat provided by cogeneration plants reached 79% [8]. One has also to mention the successful integration in district heating of biomass fired and municipal solid wastes fired boilers and CHP plants, of gas turbines either in single or combined cycles, of electric and absorption heat pumps and of solar thermal collectors [9–13].

Since the 1980's, district cooling networks have also been in use [14], they consist in distributing cold water to the customers through a network of pipes, either in a closed or open loop. The cold water can be directly pumped from a river, a lake or a sea and sent trough the network or it can also be used in a heat exchanger at the central plant to cool down the water from the network. Finally, if the water from the source is not cold enough, centralized water cooled chillers are used.

Where both district heating and cooling networks coexist, heat pumps at the central plant are sometimes used to provide both services simultaneously [14]. Another trend of development is the use of a single network to provide heating and cooling services. It has been proposed to use a district heating network to deliver heat to the hot source of absorption chillers installed at the users end, allowing the delivery of cooling services which reduce the relative thermal loss during the hot season. The use, at the user end, of absorption heat pumps and/or small cogeneration units based on ORCs is also a mean to increase the energy efficiency when an existing high temperature district heating networks is used to provide heat to modern buildings equipped with low temperature hydronic loops [15,16]. In some cold water networks, essentially built for cooling purposes, decentralized electric heat pumps are sometimes used to deliver heating services [14]. The major interest of using decentralized heat pumps is to supply heat at a temperature adapted to each user, thus reducing the electricity consumption when the buildings stock is heterogeneous as compared to a centralized solution with a single supply temperature fixed by the most demanding consumer. There is a maximum limit to the use of decentralized heat pumps in networks where the users are connected in series (no return line) to avoid freezing in the pipes. For a network with the users connected between a supply and a return line, there is no such limit, the maximum amount of decentralized heat pumping being mostly linked to the maximum flowrate and the supply temperature. For instance, at the time of writing, a 28 MW district heating network relying on a cold water loop feeding decentralized heat pumps is under construction in “La Tour-de-Peilz” (Switzerland) with its operation that started in 2016

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