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Performance and profitability perspectives of a CO_2 based district energy network in Geneva's City Centre

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ABSTRACT

A new type of district energy network providing simultaneously heating and cooling services is being investigated. It is based on the use of CO_2 as a heat transfer fluid by taking advantage of the latent heat of vaporization, to store and transfer heat across the network. The goal of the present study is to determine the performance of a CO_2 network when applied to a real urban area. It focuses first on determining the requirements for the various thermal energy services for a part of Geneva's City Centre. The final energy consumption is first computed for the energy conversion technologies now in place in this area – namely heating oil boilers and air cooled compression chillers. Then the new final energy consumption is computed considering that a CO_2 network is used instead of boilers and air cooled compression chillers. For the area considered the CO_2 network's variant leads to a final energy consumption of 10,968 MWh of electricity. It represents a reduction of 84.4% when compared to the boilers and chillers case. A comparative profitability analysis of the two cases is also presented. The analysis takes into account investment, heating oil and/or electricity, equipment replacement, operation, and maintenance costs, as well as the sales of energy services.

For an interest rate of 6%, a price of the delivered heating/cooling services at 0.108 € kW h^{-1} and a lifetime of 40 years, the conventional technology does not reach profitability while the CO_2 network achieves a profit in present value of 69.59 million € and the break-even point is reached after 5.5 years of operation.

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1. Introduction

District heating and cooling networks have been used to deliver energy in urban areas for many decades. Generally, these networks rely on centralized and efficient energy conversion technologies supplying heating and/or cooling to the users through a water network. In most of the cases, the supply temperature of such a network is selected according to the most demanding consumer connected. Thus all the other users are supplied at a temperature beyond their needs – often far beyond their needs. Furthermore, when heating and cooling have to be supplied, two independent water loops are needed. Finally, most of the time, heat discharged by the cooling users in the district cooling network is not transferred to the district heating network, and thus not recovered. A new type of district energy network is being investigated. It is based on the use of refrigerant as a heat transfer fluid. It uses the latent heat of vaporization, instead of sensible heat, to store and transfer heat. The pressure of the network is selected such that evaporation/condensation takes place at a desired temperature – usually around to 15 °C, but potentially up to the critical temperature of the refrigerant chosen. The level of temperature should be selected so as to allow for free cooling in most of the cooling applications, while decentralized heat pumps transfer heat from the network to each user at the specific required temperature level. Furthermore only two pipes are required by the network, thus allowing the waste heat from the cooling users to be recovered by the heating users. Obviously, the heat required by the heating users may, most of the time, not be strictly equal to the waste heat discharged by the cooling users. Hence, a central plant is needed to balance the overall network by taking or releasing heat into the environment, for instance a lake. A schematic view of a refrigerant based network using CO_2 as a working fluid is provided in Fig. 1 and

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Nomenclature

Acronyms

ERA	Energy reference area
HX	Heat exchanger
LMTD	Log mean temperature difference
MDAC	Mechanical draught air-cooler
PLC	Programmable logic controller
YDD	Yearly degree days

Symbols

A	Area, m^2
$\dot{E}$	Electric power, W
h	Specific enthalpy, J kg^{-1}
$\dot{m}$	Massflow, kg s^{-1}
$\dot{Q}$	Heat rate, W
s	Specific entropy, J kg^{-1} K^{-1}
T	Temperature, °C
U	Overall heat transfer coefficient, W m^{-2} K

Greek symbols

Δh	Specific enthalpy difference, J kg^{-1}
ΔP	Pressure drop, N m^{-2}
ΔT	Temperature change, K
ΔT_{min}	Minimum approach temperature difference, K
ΔT_{SC}	Subcooling, K
ΔT_{SH}	Superheat, K
ε_n	Boiler first law efficiency at part load
ε_n	Boiler first law efficiency at nominal load
η	Efficiency
λ_0	Boiler consumption at idling condition relative to nominal load
ρ	Mass density, kg m^{-3}
τ	Load factor

Subscripts

a	Atmosphere
air	Cooling air
AirCond	Air conditioning
cond	Condenser
data	Data centre cooling
ERA	Energy reference area
evap	Evaporator
H	Space heating supply
heating	Space heating
HotWater	Hot water preparation
in	Inlet condition
liq	State in the liquid CO_2 line
N	Network
out	Outlet condition
refrig	Refrigeration
s	Isentropic
sat	Saturation state
vap	State in the CO_2 vapour line
W	Water

a more detailed description of the concept is given by Weber and Favrat in Refs. [1,2]. Finally, a list of possible energy services and associated conversion technologies that can be included in a refrigerant based network was done by Henchoz et al. in Ref. [3]. The objective of the present study is to determine the benefits that a refrigerant based district energy network, using CO_2 as a working fluid, could have over a fully decentralized conversion technology using a combination of boilers and compression chillers. The comparison is done with respect to the final energy consumption and the economic viability of both systems. The present study

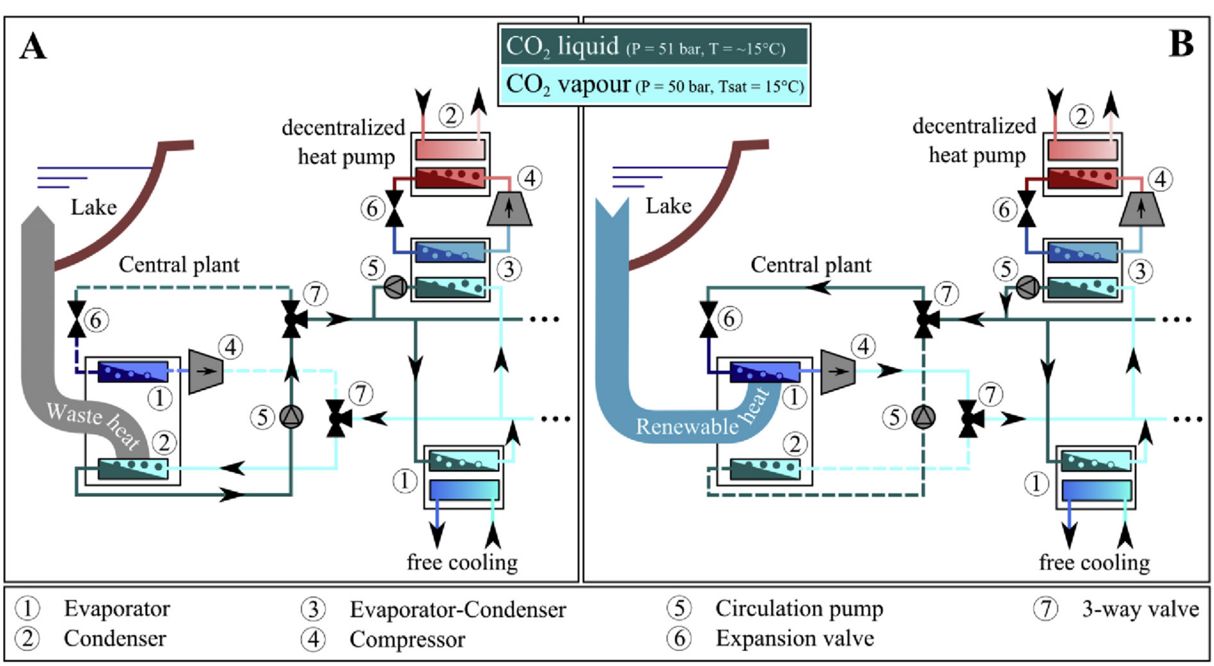

Fig. 1. Schematic representation of a CO_2 based district energy network. Side A – net cooling operation. Side B – net heating operation.

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