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Global and local environmental and energy advantages of a geothermal heat pump interacting with a low temperature thermal micro grid

E. Marrasso[a], C. Roselli[a], M. Sasso[a], F. Tariello[b,*]

[a] DING, Department of Engineering, University of Sannio, P.zza Roma 21, 82100 Benevento, Italy
[b] Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

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ABSTRACT

Urban heat island affects cities climate and results in higher air temperature with respect to the surrounding rural zones. Anthropogenic heat released by human activities exacerbates this phenomenon which impacts on environmental and energy fields. Air conditioning is commonly used to achieve comfort indoor conditions in the warmer urban climate but it is also one of the serious cause of the urban heat islands. The heat rejected by the condensers of air conditioning systems, increases the air temperature next to the buildings in which they are installed. In this paper a system consisting of a ground-source heat pump, a low temperature thermal network and a series of electric heat pumps, is analysed. The thermal grid is the heat source/sink for the water to water electric heat pumps that are installed at each end-user of a multi-purpose six floors building located in Naples (Southern of Italy). In cooling mode the condenser heat is discarded in the ground by the ground source heat pump that operates between the lower temperature thermal grid and the borefield. In the heating period the thermal network is heated by the ground source heat pump, that draws energy from the ground. The models simulating the energy conversion systems, the low temperature thermal network and the building, are implemented in the dynamic simulation software TRNSYS 17. A first advantage of the proposed configuration is the avoided interaction with the outside air and the corresponding mitigation of the urban heat island phenomenon. A second one is the higher coefficient of performance of the water to water electric heat pumps, operating with a lower temperature gap with respect to the case in which the electric heat pumps interact with the outside air. Furthermore, the interaction with thermal grid allows high seasonal performance due to the low fluctuation of the temperature with respect to the air. Finally this energy efficient system could be simply installed not only in the new buildings, but also in refurbishments. The proposed system is compared with a conventional one installed in each dwelling consisting of an air to water air conditioner for cooling operation and a boiler for heating. Interesting global and local environmental advantages are obtained.

1. Introduction

In the 2016 the energy demand of the civil sector amounted to about 41% of the total final energy consumption in Italy [1]. Over 70% of residential energy requests are due to air-conditioning [2]. In particular, during last decade, the increase of the electric energy requests for cooling purpose in buildings caused the summer peak loads instead of winter ones. The maximum electric demand for 2015 was in July and was about 60 GW [3]. The massive use of air-conditioning systems, highlighted by these data, is changing the climate especially of urban areas.

Air temperature of urban or metropolitan areas is higher than the air temperature of the neighbouring rural areas. This is the well-known Urban Heat Island (UHI) phenomenon observed in many large urban centres in the last decade.

The Authors in [4] calculated the Urban Heat Island Intensity (UHII) in Rome. This indicator expresses the average air temperature difference between urban area and the rural one in a certain reference period. During summer 2011 the maximum value of UHII registered in Rome, was equal to 4.5 °C. Data from climatic stations in Manchester, showed a summer maximum UHII of 8 °C in recent period [5]. In [6] a summer maximum UHII of 2.8 °C and 3.7 °C was measured in Osaka and Tokyo respectively, using air temperature near of the coast as reference temperature of the surrounding urban area. Memon et al. [7] reported the maximum UHII for several areas of the world, calculated using different methods. The maximum value of this indicator, calculated on the base of the annual outdoor air temperatures, was equal to 10.5 °C for Hong Kong, 5 °C for Mexico City and New York and 8 °C for Paris.

* Corresponding author.
E-mail address: francesco.tariello@unimol.it (F. Tariello).

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Nomenclature

$CO_{2,eq}$	equivalent carbon dioxide emission [$kgCO_2/y$]
E	energy [kWh]
FESR	Fuel Energy Saving Ratio [%]
HDD	heating degree days [K]
HHV	higher heating value [kWh/m^3]
k	increasing factor of air temperature [K/MW]
PE	primary energy [kWh/y]
Q	thermal power [MW]
UHII	Urban Heat Island Intensity [°C]

Greek symbols

α	emission factor for electricity [$kgCO_2/kWh_{El}$]
β	emission factor for natural gas [$kgCO_2/kWh_{PE}$]
$\Delta CO_{2,eq}$	avoided equivalent CO_2 emissions [%]
ΔT_{Max}	maximum increase of urban air temperature [K]
η	efficiency [%]

Subscripts

BOR	borehole
Co	cooling
cp	cooling operation period
El	electric
hp	heating operation period
Max	maximum
off	referred to office users
P	primary
rej	rejected heat
res	referred to residential users
Th	thermal
tot	total

Superscripts and Acronyms

AUX_CS	Auxiliaries equipment of Conventional System
AUX_PS	Auxiliaries equipment of Proposed System
B	boiler
CH	chiller
CS	Conventional System
COP	Coefficient Of Performance
EER	Energy Efficiency Ratio
EHP	Electric Heat Pump
GHG	greenhouse gas
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HVAC	Heating and Ventilation Air Conditioning
LTTG	Low-Temperature Thermal Grid
PP	Power Plant
PS	Proposed System
PV	photovoltaic
ST	Storage Tank
TEWI	Total Equivalent Warming Impact
UHI	Urban Heat Island

The UHI phenomenon is mainly related with the disappearance of the natural land replaced with constructions built up with high thermal capacity materials which collect the incident solar radiation causing the increasing of temperature nearly building surfaces. As a consequence, the facades, the roofs, all the components of building envelope and of the urban infrastructures, release slowly long wave thermal radiation to the surrounding environment during the night, determining high night temperatures in areas affected by UHI phenomenon. The warmer climate in urban areas depends also by anthropogenic activities, such as the combustion of fuels in industry or transport, the rise of comfort expectations in buildings and the energy consumption (in particular cooling demands supplying by the air conditioners), and the related greenhouse gas (GHG) emissions [8].

The UHIs impact dramatically on human health. Baccini et al. [9] carried out an epidemiologic study about the correlation between the high urban air temperatures and the mortality, analysing the occurrences in 15 cities during warm season. They found that the increase of 1 °C of urban air temperature upon a fixed threshold, influenced the variation of mortality rate for 1.84% and 3.12% in North continental regions and Mediterranean areas, respectively. In Cyprus the heat related annual mortality rate for the warm months April-September in the years 2004–2009, was estimated around 3.8 per 100,000 population. It doubled, if an increasing of 1 °C with respect to the daily summer air temperature baseline was considered [10].

Urban warming has impacts not only on social domain but also on energy and environmental field. Because of the increasing of air temperature in urban areas, a rise of the cooling demand and a corresponding reduction of the heating requirement, is observed. Santamouris [11] collected several studies that investigate the energy impact of the UHI. He found that the increase of the summer energy demands grows more than the decrease of winter energy demands, in cooling dominant zones. In these areas the cooling load percentage difference between similar buildings of urban and rural region was equal to 13%. Since the cooling demand is commonly satisfied by electric driven air conditioners, the rise of summer requests results in peak electricity loads and consequently blackout risk, treating the stability of the power grid. Radhi et al. [12] quantified the domestic electricity consumption for air conditioning due to UHIs in Bahrain. They developed a linear regression equations to predict the variation of electricity consumption as a function of air temperatures. It was observed a growth up to 10% of electric demand for air conditioning due to the urban warming. In Beijing during 2005, the 28.8% of the electricity consumption of air conditioning is imputable to UHI. Besides the urban warming contributed to the increase of the electricity demands for cooling purpose. The Authors estimated this rise in 54.26% upon the total air-conditioning consumption for Beijing [13].

The air cooled conditioning systems increase air temperature in urban area themselves promoting UHI phenomenon. In Paris the increase in temperature was estimated equal to 0.5 °C in the current scenario, but it could enhance to 2 °C if a doubling of air conditioning systems were considered [14]. The urban air temperature growth due to the heat rejected from the air conditioners was estimated for several towns. The waste heat from the air conditioners has caused a temperature rise of 1–2 °C or more on weekdays in the Tokyo office areas [15]. In [16] the Authors have introduced a model to quantitatively determine the rise in outdoor air temperature caused by using domestic air conditioners in Wuhan (China). The results have demonstrate the rise degree is 2.56 °C. Furthermore in [17] the heat rejection from condensers of the Cheng-Kung public houses (in Tapei, Taiwan),

Table 1
Rated data for air to water EHP and condensing boiler.

	Condensing boiler [31]	Air to water chiller [30]
Capacity	25 kW_{Th} [a]	6.15 kW_{Co}
Energy input	25.5 kW_P [a]	2.06 kW_{El}
Efficiency/EER [–]	0.98	2.98

[a] Referring to the HHV of natural gas.