Energy 145 (2018) 79–87

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Urban water networks as an alternative source for district heating and emergency heat-wave cooling

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ARTICLE INFO

Article history:
Received 5 August 2017
Received in revised form
6 December 2017
Accepted 20 December 2017
Available online 28 December 2017

Keywords:
Urban water cycle
Thermal energy recovery
Urban heat island
Heat-wave
Central heating supply

ABSTRACT

Urban water networks can contribute to the energy transition of cities by serving as an alternative source for heating and cooling. Indeed, the thermal energy potential of the urban water cycle is considerable. Paris is taken as an example to present an assessment of the field performance of a district-scale waste water heat recovery system and to explore potential techniques for emergency cold recovery from drinking or non-potable water networks in response to heat-waves. The heat recovery case study was found to provide significant greenhouse gas emission reductions (up to 75%) and limited primary energy savings (around 30%). These limited savings are found to be mainly due to the performance of the heat pump system. Three emergency cold recovery techniques are presented as a response to heat-waves: subway station cooling, ice production for individual cooling, and "heat-wave shelter" cooling in association with pavement-watering. The cold generation potential of each approach is assessed with a special consideration for mains water temperature sanitary limitations. Finally, technical obstacles and perspectives are discussed.

1. Introduction

Concentrating 60%–80% of the world's energy consumption [1], cities are at the heart of the energy transition challenge facing humanity over the 21st Century. This challenge is made more difficult by the changes in climate expected over the course of the current century, which will gradually and inevitably affect the way energy is used to heat and cool buildings.

As climate change continues, cities will witness a decrease in their heating demand and an increase in their cooling demand. While the decrease in Heating Degree Days (HDD) forebodes energy savings, these may likely be compensated by the sharp increase in cooling demand [2]. This trend can be observed in many major cities across the globe and present a major challenge for the world's successful energy transition [3]. In Paris, as can be seen in Fig. 1a), building energy demand is clearly heating-dominated. This is reflected by its average 2352 °C.day of HDD, while cooling demand remains small with a total 17 °C.day of cooling degree days (CDD) (the threshold values used are 18 °C for heating and 24 °C for cooling) [4]. At the end of this century, climate change is expected to decrease HDD by 30% to 1622 °C.day, while CDD should increase seven-fold to 127 °C.day [4]. This shift is already visible over the last few decades [5].

In addition to the local climate, which is the main determinant for building heating and cooling demand, cities are also subject to the urban heat island (UHI) effect. This localized warming phenomenon is the result of a combination of radiative trapping, increased heat storage, wind obstruction, low vegetation presence, low surface permeability and high concentrations of human activity along with corresponding heat release [6]. One should also mention the increase of individual, air source air-conditioning systems that intensify the UHI. These mechanisms cause higher air and surface temperatures in city centres relative to the surrounding rural areas, in the order of 1°–3 °C [7]. In terms of its impact on energy consumption, UHI tends to increase cooling demand and reduce that of heating.

Parallel to the global climate shift and UHI effect, the frequency of extreme weather events, in particular heat-waves, is expected to increase [8]. In Paris, heat-waves are expected to increase from 1 heat-wave day per year to as many as 26 days per year [4]. Combined with the UHI effect, these events pose a serious public health concern, as witnessed during the 2003 heat-wave [9]. Although

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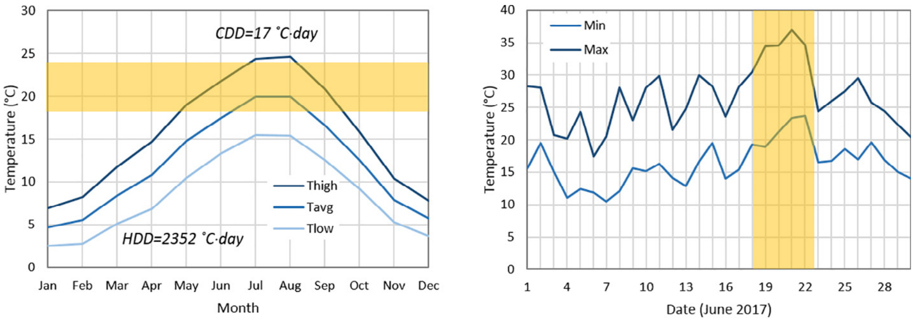
https://doi.org/10.1016/j.energy.2017.12.108
0360-5442/



a) Historical monthly temperatures for Paris

b) Maximum and minimum daily temperatures during the June 2017 heat-wave

Fig. 1. Air temperature data at the Montsouris weather station in Paris. The yellow band shown in the left gives the human comfort zone between 18 °C and 24 °C; The vertical band on the right outlines the peak of June 2017 heat-wave.

infrequent, such events are characterized by high temperatures during more than 3 consecutive days, as shown in Fig. 1b), and merit active cooling techniques. How to deal with short but intense emergency cooling needs in traditionally heating dominated regions is more of a public security issue than an energy efficiency concern.

In recent years, energy recovery from urban water networks has gained increasing attention from urban planners as well as water utility companies. To date, urban water networks, especially sewer systems, have been seen as potential sources for heat recovery [10,11], while cold recovery has been considered more recently [12,13]. In Paris, industrial applications of both heat and cold recovery have been built recently [14–16]. However, the field performance of actual recovery systems has only rarely been evaluated. Furthermore, cold recovery has never been considered as a means of responding to heat-waves.

In this paper, the Paris metropolitan area is used as a case study for evaluating different possibilities of using water as heating and cooling alternatives. For the heating supply from sewage water heat recovery, the field performance of an existing heat recovery system is assessed. Regarding cold supply from water mains during extreme heat, a potential assessment is conducted for three cold recovery configurations designed as an emergency response to heat-waves.

The rest of the paper is organized as follows: first, the global urban water cycle is described with special attention to temperature level and thermal energy recovery potentials in each step. Then, annual running data from a waste water heat recovery project in Paris is analyzed. Greenhouse Gas (GHG) emissions and primary energy savings are used as evaluation criteria. The third part gives innovative concept descriptions of three cooling productions from potable or non-potable water mains. These concepts are expected to provide real active solutions during heat-waves in high density urban centers.

2. Thermal energy recovery in water networks

The overall water cycle in an urban area begins at a river or underground water source and ends at the outlet of waste water treatment plants (WWTP). As shown in Fig. 2, after being pumped from the source, treated water is transported to its end-users through urban water mains. After being used, sewage is carried to a WWTP via the sewer network. Certain cities, such as Paris, are equipped with secondary water networks dedicated to non-potable uses such as green space irrigation or street cleaning. This water may also come from a similar water source with less intensive treatment or may also be treated waste water, the source being the WWTP outlet. Regardless of the specifics, its cycle remains similar to that depicted in Fig. 2.

Considering the whole urban water cycle, domestic hot water (DHW) preparation is by far the highest energy consumer, representing approximately 85% of total energy needs [17]. The other two main energy uses are found at the supply and sewer disposal ends of the cycle. As a means of comparison, raising water temperature by 1 °C is already equivalent to the energy needs of those two processes. Generally, DHW is heated to 60–65 °C to combat bacterial hazards, particularly *Legionella spp.* Given that the water inlet is between 10° and 15 °C [18], the temperature must be raised by 45–55 °C on average throughout the year, not accounting for seasonal variations.

Temperature levels in the whole water cycle range from 1 °C to 65 °C, as shown in Fig. 2. In the cycle, two thermal energy recovery potentials can be possible: cold recovery in the water mains where temperatures are below 25 °C, as well as heat recovery in the sewer systems where temperatures are between 13 and 35 °C.

For heat recovery, the sewer water must remain above 13 °C to meet the operational needs of WWTP processes. For cold recovery, water mains temperature must remain below 25 °C to ensure that bacterial growth remains limited [19]. Therefore, in the case of closed loop systems (sewage or potable water), where water remains in the water network, a maximum temperature difference is permitted. However, in the case of an open loop system (introduced in section 4.3), higher temperature changes are allowed.

While the flow rate fluctuation feature of water networks could be a difficulty for recovery projects, its application at the district level is less intermittent. As long as the connecting population is sufficiently dense and diverse, a continuous flow rate is maintained almost all through the day. Particularly in the case of waste water heat recovery, sewer networks can temporally hold high effluent inlets since their volumes are generally over-dimensioned. Consequently, they can serve as buffers to stable waste water flowrate. In this paper, we focus our attention to the collective utilisation of water thermal resource, i.e., by supposing stable flow rates during heat recovery processes.

3. Heat recovery from sewage water system

3.1. Principle

Waste water effluent has a temperature range of 35–27 °C at the outlet of buildings. In France, the temperature level decreases along sewerage channels until 13 °C before entering WWTPs. Lower temperatures should be avoided as most treatment processes require a warm environment for efficient nitrogen removal [20],