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Heat recovery from urban wastewater: Analysis of the variability of flow rate and temperature

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ABSTRACT

Heating, cooling and domestic hot water supply represent the biggest share of energy demands in residential buildings. Usually for these demands fossil fuels are used, however in the last years international energy policies recommended the use of less valuable energy. This paper investigated the possibility to use sewer water as alternative source of heat. Wastewater deriving from buildings is characterized by higher temperature than clean water because inside the buildings 60% of water is heated. The amount of energy that can be obtained from wastewater and the optimal design of heat recovery systems depend on knowledge of the flow rate and the temperature. In this paper the sewer system in Bologna (Italy) is taken as case study. Results of a monitoring period have showed the variability of wastewater flow rate and temperature and their correlation. Data analysis allowed to identify the daily trend for the wastewater flow, whose coefficients in relation to the average flow (where average flow = 1) vary between 0.25 and 1.50, and for the wastewater temperature in which the coefficients ranging from 0.90 to 1.05. This study can be useful to map the potential thermal energy of sewage systems and to design of heat recovery system.

1. Introduction

Space heating and cooling and domestic hot water supply represent the biggest share of energy in residential buildings [1]. There are number of uses of hot water in buildings, including showers, tubs, sinks, dishwashers and clothes washers. In virtually all of these cleaning applications, the wastewater retains a significant portion of its initial energy that could be recovered and used every day.

In the world, with finite natural resources and large energy demands, it becomes ever increasingly important to understand the mechanisms that degrade energy and resources and to develop systematic approaches for improving systems and, thus, also reducing the impact on the environment [2].

Buildings, as demonstrated, are responsible for two thirds of total electricity consumption and one third of greenhouse gas emissions [3]. More recently, the data analysis from residential and commercial agglomerations has shown that over half of global emissions of greenhouse gases are generated from the building sector [4]. For example, about 23% of the gas demand of households in the Netherlands is used for heating water [5]. This fact provides a fundamental and substantial reason for reducing such energy consumption, since in doing so the resulting emissions will also decrease. Warm water conservation is thus an important measure to reduce greenhouse gas emissions from households [2–6].

Furthermore, it should be underlined that in recent years the energy performance of buildings has definitely improved, at least as far as new constructions are concerned. However, past studies have focused almost exclusively on the heating and cooling systems and have neglected other aspects such as those linked to water use [7]. Studies made in Swiss [6] showed that 15% of the thermal energy supplied to buildings is lost through the sewer system; this value rises up to 30% in well-insulated buildings with low consumption. This leads to the fact that, today, sewers represent the largest source of heat losses in buildings [6].

Hot water is still discharged into the sewer system making the domestic wastewater a carrier of heat [5]. That heat can be reused, for the production of clean and regenerable thermal energy, through heat exchangers and heat pumps, for the conditioning and heating of buildings [6].

2. System overview

There are several options to recover this heat embedded in water. The heat content of water from households can be recovered within houses (small scale applications), from the sewer (medium

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Nomenclature

Symbols

Cq	hourly flow rate coefficient
Ct	hourly temperature coefficient
COP	coefficient of performance
T	temperature (°C)
V	flow rate (l/s)
A	heat exchange area (m^2)
$\dot{Q}$	thermal power (kW)
cp	specific heat capacity as 4.186 (kJ/kg K)
ρ	density (as 1 kg/l)
ΔT	temperature drop (K)
L	pipes length (m)
N	pipes number
di	pipe diameter
K	heat transfer coefficient (W/m^2 K)
L	required external work (kW)

Indices

inp	input value
out	output value
w	wastewater
F	fluid
B	building

scale applications), or at wastewater treatment plants (large scale applications) [5].

It is important to emphasize that regardless of the type of installation the main elements of the system are the heat exchanger and the heat pump [1]. The heat pump is an energy efficient and environment-friendly apparatus for heating and cooling of built environment [8]. In the past two decades, the wastewater source heat pump has become increasingly popular due to its advantages of energy-saving and environmental protection [2–15].

The heat exchangers are devices that facilitate the exchange of heat between two fluids at different temperature (hot fluid–cold fluid) without exposing them to a direct contact, thus avoiding a mixing of the same. In general, the heat exchangers currently used can be grouped into two types: indirect and direct. The indirect-type (wastewater to circulating water) heat exchangers included plate heat exchanger and shell-and-tube heat exchanger. The direct-type (wastewater to refrigerant) heat exchangers can be further grouped into two categories: flooded and dry-expansion evaporators [9]. The heat exchangers can be also classified on several criteria including: the heat exchange process, the ratio between the exchange surface and the volume, the configurations of the motion of fluids, the geometry and the prevailing mechanism of heat transmission. The design parameters of these systems are: the flow rate and the temperature of wastewater, the temperature difference of the wastewater upstream and downstream from heat exchanger, the geometry of the pipe and of the heat exchanger, the viscosity of the wastewater, the velocity of the fluids in the heat exchanger, the fouling resistance caused by the formation of biofilm, the heat exchange coefficient and the heat transfer surface.

The main problem that happens when the heat exchangers are installed in the sewage pipe is the formation of biofilm on the wall of the heat exchanger [2]. The biofilm leads to a reduction of the efficiency of the heat exchange. In order to overcome this problem many exchangers are designed with an oversize surface of heat exchange to compensate for the reduced coefficient heat transfer.

The other essential element, in a heat recovery system, is the heat pump [9]. It is characterized by a coefficient of performance (COP) which is the number of units of energy delivered to the hot reservoir per unit work input. The value of the COP increases when the temperature difference between the two sources (wastewater and heat transfer fluid) decreases; in Ref. [10] the authors highlight that if the temperature of the wastewater is about 10 °C, the COP ranges from 3.25 to 3.5; if the temperature increases also the value of the COP increases, in particular the value of the COP increases of about 0.3 every +2 °C.

The heat recovery systems like every system that uses the heat pump, have a different behavior in function of the season. In winter, the treated wastewater flows into pipes of the evaporator and the heat of wastewater is absorbed by the refrigerant in the evaporator, and then the heat from the condenser is transmitted to buildings through the air conditioning system. At that time, the wastewater heat is regarded as the "heat source". In summer, the treated wastewater flows into the pipes of the condenser and absorbs the heat from the condenser, and then the heat from the evaporator after the refrigerating cycle is transmitted to buildings through the air conditioning system. At that time, the wastewater heat is regarded as the "cold source" [10].

Independently on the type of technology used, in order to correctly design these equipments, it is essential to have reliable information as regards the wastewater flows and its temperatures, in fact these parameters will obviously affect the performance of the system and the related costs.

Another point to emphasize is that flow into sewers is related to the variability of water demand by users. The flow has a cyclical hourly, daily and weekly pattern, which is different on working days or at weekends [17,18]. Such variations are therefore influenced by the climatic conditions, work activities and the habits of the users. It is also important to understand how temperature changes within the wastewater collectors; usually this aspect is neglected in traditional research on sewer systems.

This study investigates the variability of flow and temperature in sewage systems. Understanding these factors allows to design more accurately not only new installations for the treatment or the conveying of wastewater (in particular hydraulic ones) but also the necessary heat recovery systems.

3. Description of the case study

Usually the modeling of wastewater heat recovery presents several obstacles. First, appropriate input data have to be generated or acquired based on highly variable water usage statistics. Because wastewater heat is almost never considered, there are very few statistics available for wastewater temperature data. In order to implement data related to flow rate and temperature of the wastewater the sewer system of city of Bologna has been analyzed and monitored.

The sewer system of Bologna, a city located in northern Italy, is taken here as case study. The dataset used relate to a measurement conducted by HERA, Manager of the sewer system in Bologna from October 2005 until March 2006. During this monitoring period various area-velocity measuring stations were installed, which provided data concerning the flow, level, speed and temperature of the wastewater.

The characteristics of the conduits in which the sensors were installed are shown in Table 1. It should be noted that all conduits are combined and therefore during the rainfall events the wastewater is mixed with stormwater.

Table 2 shows the network characteristics upstream from the measurement point including the number of inhabitants. This latest information is derived from the 2001 census; it is not intended as population equivalent but as population of residents.