Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 40 (2016) 35 – 40

www.elsevier.com/locate/procedia

13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

Contribution to Exemplary In-House Wastewater Heat Recovery in Berlin, Germany

Samir Alnahhal[a]*, Ernesto Spremberg[a]

[a]Technische Universität Berlin, Institut für Werkzeugmaschinen und Fabrikbetrieb (IWF), Pascalstr. 8-9 10587 Berlin, Germany
* Corresponding author. Tel.: 49-30-314-75835; fax: +49-30-314- 22759. E-mail address: alnahhal@mf.tu-berlin.de

Abstract

Thermal energy recovery from wastewater can be established from centralized wastewater treatment plants and sewage systems. Little attention has been given to In-house wastewater; although it can potentially pave way towards a sustainable heat source. The study was conducted inside student hostels in Berlin, in which water supply, wastewater, and room temperatures variations were observed during winter for one month. It was shown that water supply temperature has insignificant effect on the variations of in-house wastewater temperature as compared to room temperature and water use. The daily average temperature of the in-house wastewater was in a range of 11 °C to 20 °C, with an average of about 15 °C. It was illustrated that by selecting suitable combination of heat exchanger and heat pump, about 40 kWh/h (917 kWh/day) average in-house wastewater thermal heat can be recovered and about 230 €/day saved . This can contribute to reduction of energy needed for hot water provision by about 30% in the targeted hostels.

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing

Keywords: energy recovery; flow; heat exchanger; in-house wastewater; tempreture

1. Introduction

Environmental protection and sustainable management of natural resources stand at the forefront of economic and technological activities worldwide. Current sewage technologies when not focused on resources, nutrient and energy recovery, may not be sustainable[1]. Energy recovered from wastewater is being recognized as a renewable energy resource[2].

Nomenclature

COP	coefficient of performance
Q_F	thermal power (kW)
ΔT_m	temperature drop (K or °C)
c_w	specific heat capacity as 4.186 (kJ/kg K)
ρ_w	density (as 1 kg/l)
V_f	flow rate (l/s)
A_s	heat exchange area (m^2)
L	required external work (kW)
k	heat transfer coefficient (W/m^2 K)

2. In-house wastewater

2.1. Energy carrier

The interrelationship between energy, water and organic content of wastewater can encourage energy recovery operations from many possible sources, including municipal wastewater treatment facilities. The potentials to extract energy from wastewater can be done in a number of ways, including: biomass energy obtained from the biogas produced after anaerobic sludge digestion[3], kinetic energy using micro-hydro systems, chemical energy through sludge incineration, and thermal energy as heat[4] which is related to heated wastewater leaving the houses[5,6]. Therefore, Domestic wastewater is a finite source of thermal energy[7,8,9]and has a true potential of thermal energy recovery from wastewater[4]. The sewer system in Bologna (Italy) investigated the possibility to use sewer water as alternative source of heat[10].

2212-8271 © 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing
doi:10.1016/j.procir.2016.01.046

2.2. Temperature, energy losses and water use

The temperature of tap water can be influenced by soil temperature surrounding the drinking water distribution system, pipe material, pipe diameter and flow velocity[11]. Inside the buildings, water is heated for many purposes and resulting warm wastewater flows into the sewer[12]. This wastewater is characterized by higher temperature than tap water, since 60% of water is heated[10,13].

On account of the ideal source, domestic wastewater temperature ranges from 10°C to 25°C in different seasons of the year[8], resembling a theoretical maximum potential of 56,000 Ton Joule per year (TJ/yr). The actual maximum potential of heat recovery systems in houses is estimated to be 32,000 TJ/yr[9].

On the other hand, estimates by the U.S. Department of Energy (DOE) indicated that the equivalent of 235 billion kWh i.e. 846,000 TJ/yr worth of hot water is discarded annually through wastewater, although large portion of this energy is in fact recoverable[14]. Discharging hot water into sewer system makes domestic wastewater as a carrier of heat[9]. Moreover, looking at heat losses from modern houses, wastewater contributes about 15% - 30% [8], or even 40% of this loss[5,6]. So, a large potential in the amount of heat losses from wastewater leaving buildings[15], need more focus to be recovered and used.

The energy consumption for heating, cooling and domestic hot water supply requires much more energy in residential buildings[16] in countries like Germany[17]. There are a number of uses of hot water in buildings, including showers, tubs, sinks, dishwashers, clothes washers etc. The amount of energy depends on water use inside houses. It was shown that the amount of water use increases in countries with strong economic growth and a high standard of living[8] leading to increase energy demands and to search for sustainable sources, e.g. energy recovery from wastewater.

From another point of view, fossil fuels are usually used for fulfilment of hot water demands[10], which has clear carbon footprint and causes greenhouse gas emission. Although the water sector has only a very small contribution to greenhouse gas emissions compared to other sectors like energy production or mobility. The energy use in water sector needs to be optimize to reduce the carbon footprint of the water sector, and eventually limiting greenhouse gas emissions[5,6,9,18,17]. Optimizing energy use can be through making essential improvements for orientation of future energy demands and quality standards[9]; and innovative technologies that include renewable energy[19].

Energy has a great role in water use. On average, the energy needed for heating water is eight times higher than energy needed for producing, treating and transporting water[9]. Other estimates indicated that such purposes reaches ten times more. Therefore, reducing hot water use and application of heat recovery from wastewater can have a large contribution for further optimization of energy demands [12].

2.3. Energy recovery options

Thermal energy can be recovered from raw wastewater[5,6], or effluent by exploiting temperature differences between wastewater and ambient conditions. This temperature differences can be recovered for use in heating and cooling purposes[2]. The heat available in raw and effluent wastewater is described as low-grade heat, which can be recovered through the application of heat pump technology[15].

Heat pump technology uses a reverse refrigeration cycle to factor low temperatures to useable heating levels[20]. The heat pump technology is simple and proven. Over 500 wastewater heat pumps are in operation worldwide[8]. The first heat pump was built more than 20 years ago. A heat pump system using wastewater as heat source allows for usage of low-cost off-peak electricity with neither noise nor spoil the appearance of the building where it is installed. In addition, it has outstanding energy saving effect since it is operated at high coefficient of performance (COP) without air pollution[21].

Heat exchange technology is another option to recover the heat energy. A heat exchanger is a heat transfer device that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. In most heat exchangers, the fluids are separated by a heat transfer surface without mixing or crossing over[22]. Heat transfer occurs between two fluids of different starting temperatures, such as wastewater and refrigerant. Typically used heat exchangers include pumped heat exchangers, in-tank heat exchangers, and in-pipe or in-trench heat exchangers[20]. On particular, most of the liquid–liquid heat exchangers are shell, tube, and plate type. Both fluids are pumped through the exchanger, so the principal mode of heat transfer is forced convection[22].

The heat exchanger can be used to recover the thermal energy from the wastewater [14]. The heat exchanger can be installed in the sewer system[5], or in the effluent of WWTP[7]. For thermal energy from wastewater, it is estimated that about 50% may be recovered by use of heat exchangers in sewers[5,6].

A combination between heat pump and heat exchanger is other option for the thermal heat recovery[7]. The challenge for coming years is to choose combinations of all possibilities to fulfil the energy demand[6].

3. Scope of work

Generally more heat can be recovered from the wastewater in the sewer than from the wastewater treatment plant (WWTP) effluent. Furthermore, in the sewer, the heat usually is recovered at a location where is close to the consumers[7] However, in practice, the use of wastewater as a source for heating systems is not often considered. The value of higher temperature recovery has not been exploited, and is available only close to the point of use[15]. Therefore, the main scope of this work is to investigate the potentials of wastewater heat recovery inside a house in Berlin, Germany or any other countries of similar climatic conditions.

The amount of thermal energy that can be obtained from