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Optimization of energy utilization from Greywater in hotel buildings

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Abstract

The ever-growing concerns about making buildings more energy efficient and increasing the share of renewable energy used in them, has led to the development of ultra-low carbon buildings or passive houses. However, a huge potential still exists to lower the hot water energy demand, especially by harnessing heat from waste water exiting these buildings. Reusing this heat makes buildings more energy-efficient and this source is considered as a third-generation renewable energy technology, both factors conforming to energy policies throughout the world. Based on several theoretical and experimental studies, the potential to harness non-industrial waste water is quite high. As an estimate about 3.5 kWh of energy, per person per day could be harnessed and used directly, in many applications. A promising example of such an application, are low temperature fourth generation District Heating grids, with decentralized sources of heat. At the moment, heat exchangers and heat pumps are the only viable options to harness non-industrial waste heat. Both are used at different scales and levels of the waste-water treatment hierarchical pyramid.

Keywords: domestic hot water, grey wastewater, rainwater

1. Introduction

There is an increasing interest in the reuse of wastewater in many parts of the world, including both industrial and developing countries. One reason is water shortage, caused by too low amounts of rainfall in combination with high evaporation (e.g., Australia) or too large demands of freshwater from the population (e.g., Japan). On the other side in some countries, the driving force for reuse of wastewater is environmental and economic considerations.

The reuse will lower the total costs for wastewater handling, since there will be a reduced load of water to the treatment plants. Grey wastewater is defined as wastewater without any input from toilets, which means that it corresponds to wastewater produced in bathtubs, showers, hand basins, laundry machines and kitchen sinks, in households, office buildings, schools, etc.

The total grey wastewater fraction has been estimated to account for about 75 vol% of the combined residential sewage (Hansen & Kjellerup, 1994 and references therein). Possibilities of reuse for grey wastewater have come into special focus.

The explanation is that this fraction of wastewater is less polluted than municipal wastewater in the absence of faeces, urine and toilet paper. The characteristics will be of importance when evaluating the possibilities for reuse, including the need for pre-treatment.

Health aspects, mainly micro-organisms, and environmental perspectives like accumulation of xenobiotic organic compounds (XOCs) and metals in soil and groundwater, have to be taken into account.

Use of grey wastewater for urinal and toilet flushing is one of the possibilities since the water that is used for toilet flushing in many countries today is of drinking water quality. It has been estimated that 30% of the total household water consumption could be saved by reusing grey wastewater for flushing toilets (Karpiscak, Foster, & Schmidt, 1990). Reuse of grey wastewater from bathrooms has been successfully used in Germany where it has been shown that it is technically feasible and health requirements can be met. Substantial volumes of water ð15–55 l pd1 Þ can be reused and a dual system is possible (Nolde, 1999). A review of the current water demands in large buildings revealed that not only grey wastewater from bathrooms but also washing machine wastewater or stormwater is needed to provide sufficient recycled water for non-potable uses (Surendran & Wheatley, 1998).

Outdoor applications for grey wastewater could be irrigation of lawns on college campuses, athletic fields, cemeteries, parks and golf courses as well as in the domestic garden (Okun, 1997). Washing of vehicles and windows, fire protection, boiler feedwater and concrete production are examples of other suggested usages.

Civil buildings air conditioning systems and industrial process operation activities are the major sources of energy consumption and greenhouse gas (GHG) direct emissions in over-urbanized areas where heat and electricity are powered by gas and coal sources [1, 2].

For this reason, consistent scientific efforts have been recently carried out aimed at identifying integrated renewable energy production systems capable of supplying energy-intensive users by employing different lowcarbon renewable energy sources whose individual availability is not constant during a typical working day, but, when properly handled through integrated logics, could cover daily needs. In accordance with the so far necessary use of sustainable technologies, and the farsighted craving for maximize energy autonomy, recovering heat content of sewage wastewater (WW) allows to save energy costs and reduce primary energy consume. In fact, besides being composed of water (over 99.9%), WW contains chemical energy (stored in the pollutants) and thermal energy (accumulated in water).

Experimental and economic studies recently carried out on WW heat recovery solutions, can be classified based on the urban water service cycle stage in which heat extraction takes place. In this perspective the most recurring and promising experimental experiences have been implemented into the sewage collection subsystem within domestic grey wastewater discharge system (sullage without fecal contamination upstream of the sewer access) and inside WW draining sewerage system (black waters downstream of the sewer access).

High concentration of grey waters thermal energy observed in largescale public shower facilities, such as in schools, barracks and swimming pools, was harnessed by Liu et al. [3] through heat pump (HP) system able to recover heat from grey waters discharged by 50 shower nozzles (flow rate of 0.067 L/s). Such system was demonstrated to return lower operating costs and GHG emissions then gas, coal, electric, oil and solar thermal (by-itself) boilers.

Graywater

Greywater can be defined as any domestic wastewater produced, excluding sewage. The main difference between greywater and sewage (or blackwater) is the organic loading. Sewage has a much larger organic loading compared to greywater. Some people also categorize kitchen wastewater as blackwater because it has quite a high organic loading relative to other sources of wastewater such as bath water.

People are now waking up to the benefits of greywater re-use, and the term "Wastewater" is in many respects a misnomer. Maybe a more appropriate term for this water would be "Used Water".

The composition of grey wastewater depends on sources and installations from where the water is drawn, e.g. kitchen, bathroom or laundry. The chemical compounds present originate from household chemicals, cooking, washing and the piping. In general grey wastewater contains lower levels of organic matter and nutrients compared to ordinary wastewater, since urine, faeces and toilet paper are not included.

A. Characteristics of Grey Wastewater

Over the last decade, GW has come into the limelight of research not from the perspective of heat reclamation, but to reuse it for domestic applications requiring low-quality water [9]. Hence the availability of usage data of GW is scarce and mostly available from a different viewpoint [6]. The first step in the harnessing of heat is to determine the sources, measure the usage patterns and assess the potential of GW Broadly speaking there are three types of water in the plumbing system of a conventional household. Light GW is the best and most promising to be used in both, heat harnessing and re-usage applications. On the other hand, heavy GW requires grease traps and sludge removal before heat harnessing [2] as these impurities can clog heat exchangers, reducing considerably the efficiency. Blackwater is not suitable for harnessing due to its low temperature and waste contents [5].

In most conventional buildings, the separation of these three classes of water is non-existent.

The characteristics of grey wastewater depend firstly on the quality of the water supply, secondly on the type of distribution net for both drinking water and the grey wastewater (leaching from piping, chemical and biological processes in the biofilm on the piping walls) and thirdly from the activities in the household. The compounds present in the water vary from source to source, where the lifestyles, customs, installations and use of chemical household products will be of importance. The composition will vary significantly in terms of both place and time due to the variations in water consumption in relation to the discharged amounts of substances. Furthermore, there could be chemical and biological degradation of the chemical compounds, within the transportation network and during storage.

The potential ecological benefits of greywater recycling include

1. Reduced freshwater extraction from rivers and aquifers.
2. Less impact from septic tank and treatment plant infrastructure.
3. Reduced energy use and chemical pollution from treatment
4. Groundwater recharge
5. Reclamation of nutrients

Related Work

Postrioti et al. [4] realized a WWHP plant prototype to assess heat recovery performance from civil wastewater, where sewage temperature and discharge fluctuations were simulated by electric water heater system connected to the sewer by an electro-actuated on–off valve. Results showed that during 24 h tests, through partial recovery operation conditions, COP reached an average value of 3.72 constantly higher than COP observed when plant operated without heat recovery from sewage storage system, which was equal to 3.32.

Baek et al. [5] conducted energy system feasibility study where heat recovery is performed over grey WW discharged from a Korean hotel with sauna and exploited as heat source for a compression heat pump applied in domestic hot water (DHW) production. By means of TRNSYS software, yearly mean coefficient of performance (COP) was estimated equal to 4.8, and a need to improve WW temperature and flowing rate control system was highlighted by wide range of COP variation during heating cycles.

Patel et al. [6] stated that to effectively exploit the heat capacity of the soil a heat-exchanger system has to be constructed. Usually an array of buried pipes running along the length of the building, a nearby field or buried vertically into the ground is utilized. A circulating fluid (water or air) is used in summer to extract heat from the hot environment of the building and dump it into the ground and vice versa in winter. A heat pump may also be coupled to the ground heat exchanger to increase its efficiency.

To this purpose Chao et al. [7] conducted an experimental comparative study where two different evaporator devices, a traditional flooded type, and a novel evaporator integrated with defouling function, have been employed to recover heat from grey WW discharged by a commercial sauna center in Shenzhen, China. Heat transfer performance monitoring showed in presence of defouling function heat transfer coefficient 3.1 times higher than a traditional type one’s.

In a second step Chao et al. [8] operated an experimental grey WWHP including a novel dry-expansion evaporator observing that after just 1-month operation period, COP decreased from 3.09 to 2.50 and refrigerant temperature leaving the expansion valve also dropped due to bio-fouling effect. As regards WW sewerage stage, first centralized heat recovery plants inside WW draining sewerage system have been realized during early 1980′s period in Germany, Switzerland and Scandinavian countries [9]. Several studies were conducted in order to quantify the conditioning capacity of WWHP when compared to building peak heat load in winter and summer periods.

Durrenmatt et al. [10] by means of TEMPEST mathematical model, calculated discharge, spatial profiles and temperature dynamics in a sewer conduit, estimating 1.16 kWh thermal energy as the amount of heat capable of being extracted by cooling 1 m3 of sewerage wastewater by 1 °C. Although in untreated urban WW thermal energy amount is significant, HP are not frequently installed at the sewerage stage because of the clogging phenomenon due to sewage filth.

Liu et al. [11] experimented a WWHP provided with auto-avoiding-clogging equipment in order to continuously capture sewage suspended solids. They found that this equipment allowed for thermal resistance resultant due to convective heat transfer and fouling components at the exchanger, equal to 80% of total thermal resistance. COP values for HP unit and whole energy recovery system were 4.3 and 3.6, respectively.

Zhao et al. [12] tested WWHP provided with a filth block device capable of preventing sewage feculence with bigger dimensions to reach the heat exchanger, and to send blocked material back to the original sewage whereas sewage which is free of bigger sized feculence is sent to the wastewater heat exchanger. Experimental data over a 5 months monitoring period showed the overall COP of the system in the heating and cooling modes being equal to 4.3 and 3.5 respectively. Finally, regarding heat recovery at wastewater treatment subsystem level, most of the experimental studies found in literature refer to heat extraction immediately downstream of the treatment plant due to the better quality of treated effluent with respect to raw sewage, that is in order to limit the heat exchangers clogging phenomenon.

Aleksandar et al. [13] described system and shown method for dimensioning of the system for heating domestic hot water (DHW) in hotels using heat from grey waste water as heat source, that is collected from hotel rooms and apartments, and rain water. Water is heating using heat pumps. Also, it was carried out techno economic analysis between mentioned system, system that uses gas boilers as only heat source and system with solar plate collectors supported by gas boiler.

Demands for Domestic Hot Water in Hotel

System sizing and calculation of DHW requirements, energy consumption and sizing of system elements is carried out according to DIN 4800-4804, DIN 4753-1, DIN 4708-13, DIN 1988-1 to DIN 1988-8 that is sublimated in /3/. Also, DHW demands are carried out for hotel/motel facilities, according to Standard 90.1-2004, used in ASHRAE 2007 HVAC applications handbook, chapter 49, for DHW requirements and it showed similar quantity since both handbooks are using data from 40's to 60's of twentieth century, therefore are not applied possibility of reducing needed hot water, regarding using newly designed low flow shower heads and sink aerators.

For hotel category of four stars, located in Novi Sad, Serbia, that is consisted of 144 double-bed rooms with bathroom, nine apartments, restaurant capacity of 76 people, café-restaurant capacity of 60 people, according to references from /3/, it is calculated daily demand of DHW. Total daily demand for DWH is 17,690 litres. In this case, DHW demands are dimensioned according to accumulation method for average daily occupancy of 68 %. For total DHW accumulation needs are selected three water tanks, two tanks of 5,000 l volume and one tank of 3,000 l volume, constructed for DHW propositions, with total accumulation volume of 13,000 l in cell configuration.

Daily energy demands for DHW accumulation heating is 482.66 kWh for cold water temperature of 25 °C and hot water temperature of 60 °C. With 5 % heat losses through pipelines, tanks, e.g. /3/, total daily energy consumption is 506.79 kWh that comes to yearly energy consumption of 184,978.35 kWh. Energy demands calculation is based on simplified energy balance method showed in /3/.

Commercial Water Heating Systems

Energy Consumption The most recent Commercial Buildings Energy Consumption Survey conducted by the Energy Information Administration (EIA) indicates that in 2003, commercial buildings in the United States used over 6.5 quadrillion BTU of energy. Of this total energy expenditure, 501 trillion BTU (7.7%) were used for water heating (EIA, 2008b). Figure 1 shows the energy consumed by various end uses in U.S. commercial buildings.

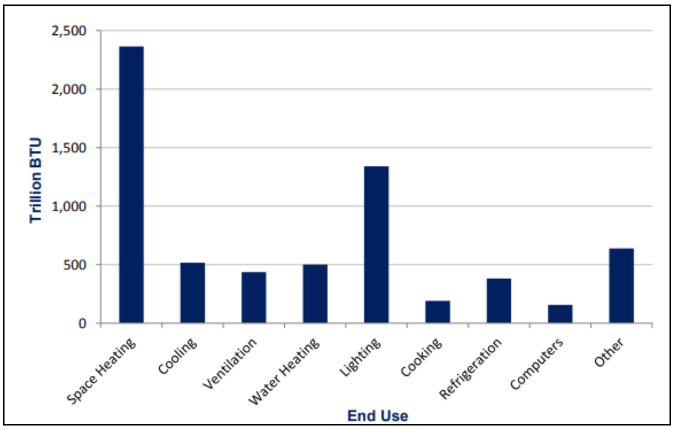

Fig 1: U.S. Commercial Building Fuel End Use (EIA, 2008b)

In lodging buildings, water heating is the largest single end use for energy, making up almost 32% of total energy use, which equates to 160 trillion BTU annually in the U.S. This is 2.5% of the total energy used by all commercial buildings in the United States, including malls. Figure 2 shows the breakdown of energy use in lodging buildings by end use.

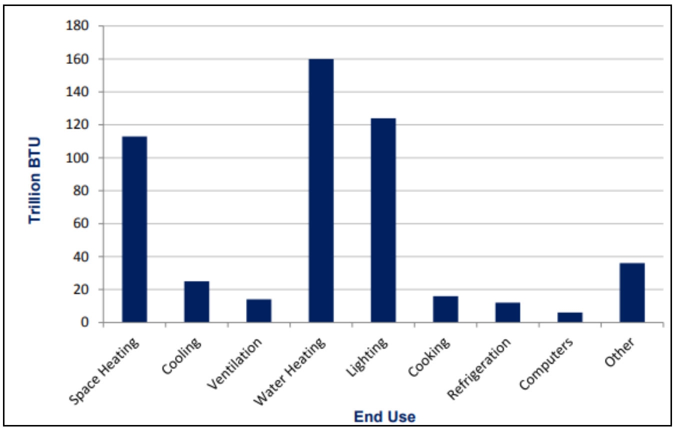

Fig 2: U.S. Commercial Lodging Building Fuel End Use (EIA, 2008b)

At the moment, conventional second generation renewable sources like large scale wind and solar systems are not considered feasible, in dense urban areas, due to the high building densities, sensitive surroundings, limited potentials and their unpredictability [7].

This is a major reason why energy harnessing methods have received tremendous attention, by the researching community over the last decade. All physical processes have an upper limit to their efficiency as per the second law of thermodynamics, therefore there is theoretically an inexhaustible supply of man-made waste energy from conversion processes and fractions of it may be harvested.

So, in a sense energy harnessing mechanisms are considered as a third generation renewable energy technology, since otherwise this unlimited supply of manmade waste energy would be discarded [8]. These sources are generally in the form of thermal, electromagnetic, light and mechanical vibrations [9].

Conclusion

Greywater is an energy source, which can be successfully used for heating and cooling buildings through heat pumps, representing a simple and proven technology. Due to its main characteristics, availability, high amount, small variation of temperature and being warm in winter and cold in summer, WW is a heat source which can be utilized in HP systems. In addition to this, WWSHP technology is a simple and proven technology and WWSHPs present higher efficiency and are more environment-friendly compared to other traditional sources such as gas heaters or oil-fired heaters.

References

1. Heinonen J, Junnila S. Case study on the carbon consumption of two metropolitan cities. Int J Life Cycle Assess 2011; 16:569–79.
2. Lin T, Lin F, Wu P, Hämmerle M, Höfle B, Bechtold S, et al. Multiscale analysis and reduction measures of urban carbon dioxide budget based on building energy consumption. Energy Build 2017; 153:356–67.
3. Liu L, Fu L, Jiang Y. Application of an exhaust heat recovery system for domestic hot water. Energy 2010; 35(3):1476–81.
4. Postrioti L, Baldinelli G, Bianchi F, Buitoni G, Di Maria F, Asdrubali F. An experimental set up for the analysis of energy recovery system from wastewater heat pumps in civil buildings. Appl Therm Eng 2016; 2016(102):961–71.
5. Baek NC, Shin UC, Yoon JH. A study on the design and analysis of a heat pump heating system using wastewater as a heat source. Sol Energy 2005; 78:427–40.
6. Patel AK, Mishra P. Optimization of Ground Source Heat Pump: A Review. International Journal Online of Science, 4(6), 2018, Retrieved from http://ijoscience.com/ojsscience/index.php/ojsscience/article/view/146. DOI: https://doi.org/10.24113/ijo-science.v4i6.146
7. Chao S, Jiang Y, Yao Y, Wang X. An experimental comparison of two heat exchangers used in wastewater source heat pump: a novel dry-expansion shell-andtube evaporator versus a conventional immersed evaporator. Energy 2012; 47:600-8.
8. Chao S, Yiqiang J, Yang Y, Shiming D. Experimental performance evaluation of a novel dry-expansion evaporator with defouling function in a wastewater source heat pump. Appl Energy 2012; 95:202-9.
9. Chen M, Chen Y, Dong S, Lan S, Zhou H, Tan Z, et al. Mixed nitrifying bacteria culture under different temperature dropping strategies: nitrification performance, activity, and community. Chemosphere. 2018; 195:800–9.
10. Durrenmatt D, Wanner O. Mathematical model to predict the effect of heat recovery on the wastewater temperature in sewers. Water Res. 2014; 48:548-58.
11. Liu Z, Liangdong M, Jili Z. Application of a heat pump system using untreated urban sewage as a heat source. Appl Therm Eng. 2014; 62:747-57.
12. Zhao XL, Fu L, Zhang SG, Jiang Y, Lai ZL. Study of the performance of an urban original source heat pump system. Energy Convers Manage. 2010; 51(4):765-70.
13. Aleksandar Anđelković, Danijel Todorović, Mladen Tomić. Heating of domestic hot water in hotels using heat from grey wastewater", International Conference on Smart and Sustainable Technologies (SpliTech), IEEE, 2019.