A Review Regarding the Heat Recovery from Wastewater

O revizuire cu privire la recuperarea căldurii din apele uzate

Amjed Albaiyati [12]

[1] CAMBI Research Center, Technical University of Civil Engineering Bucharest
021414 Bucharest, Romania
E-mail: nume.autor@email.autor

[2] Kut Technical Institute, Middle Technical University
Iraq

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Abstract. *One of the main challenges in the world today is reducing energy consumption and CO2 footprint in existing buildings without major construction work. Many of these buildings represent heritage buildings and the intervention constraints on the original building are much more restrictive for these particular cases. The building sector is one of the world's largest energy consumers, so it is important to seek out and use recovery energies for individual consumers. The main component of energy consumption in buildings is heating, but the demand for the domestic hot water is also very high, especially when daily consumption is high and especially for specific applications (hotels or laundries for example) This is why the implementation of technologies using renewable energy and recovery sources for water heating[1] has become very important and one of these technologies involves the recovery of the thermal energy from wastewater. Usually, heat recovery from wastewater is designed to recover residual energy from the hot drainage water and this recovered energy is used to preheat incoming cold water or to heat pumps.*

Key words: wastewater, energy recovering, heat exchanger

1. Introduction

The European Union (European Commission [1]) decided to reduce its greenhouse gas emissions by 40% and to improve its energy efficiency by 27% until 2030. With a total of 3441 TWh, 26.8% of the EU28 final energy consumption in 2013 originated from the household sector, coming only second to transport (31.6%) (European Commission [2]). Residential domestic hot water (DHW) consumption represented, with 442 TWh, approximately 16% of the EU household heating demand (Enerdata [3]), energy that is currently lost to the environment with its transfer to the sewers. With the improvement of the building envelope, DHW will have an increasingly important role in energy consumption, with a contribution to total heating demand between 20 and 32% in high efficiency single family buildings and between

35 to almost 50% in multifamily buildings (Meggers and Leibundgut[4] , Alnahhal and Spremberg [5], Bertrand et al. [6]).

Much of the heat goes through the drain without recovery, this means that year after year we flush down several kWh of heat straight to the sewer system. By installing a heat exchanger that recovers heat from the wastewater, it is possible to save energy. Greywater is a term used to define water from showers, bath tubs, sinks, dishwashers and washing machines. The focus on recovering energy from greywater has been a priority when it comes to energy savings in buildings.

Globally the domestic sector consumes a significant proportion of the total energy budget. In the UK this consumption is estimated to account for 23% of total consumption [7], in Hong Kong it is reported to be 17%. Within domestic energy consumption a significant proportion of energy use is associated with water heating activities [8] i.e. for washing, water related appliances and cooking. In the UK, 26% of domestic energy consumption is associated with water heating activities [9].

In order to determine the heat recovery potential of grey water streams for residential DHW end-uses heating, mass flow, duration and frequency of use per capita must be characterized to calculate their thermal load. It is also important to define typical temperature levels and to geographically allocate the various end-uses.

In this paper we have tried to complete a literature review for this subject, and we have considered especially theoretical studies to see how the energy can be recovered from wastewater, experimental studies and numerical studies. At the end of the paper we focused on some directions to be followed.

2. State of the art

Experimental studies

Shower water heat recovery in high-rise residential buildings of Hong Kong by using a full-scale experimental setup was used to calculate the deficiency of the effectiveness e of a single-pass counter-flow heat exchanger.

The horizontally installed heat exchanger is a 1 m long cold water PVC pipe (0.1 m in diameter) with a hot water copper pipe (40 mm in diameter) passing through it. The hot water copper pipe which simulates a slope drainage pipe is partially filled with hot water. The results indicated that annual energy savings of 4–15% from shower water heat could be achieved through a 1.5 m long single-pass counter-flow heat exchanger for a drainage pipe of diameter 50 mm[10].

Investigating the efficiency of a vertical inline drain water heat recovery heat exchanger in a system boosted with a heat pump where The facility consists of a 1100 mm vertical copper pipe with an inside diameter of 70 mm, this gives the heat exchanger an inside heat transfer area of 0.20 m2.

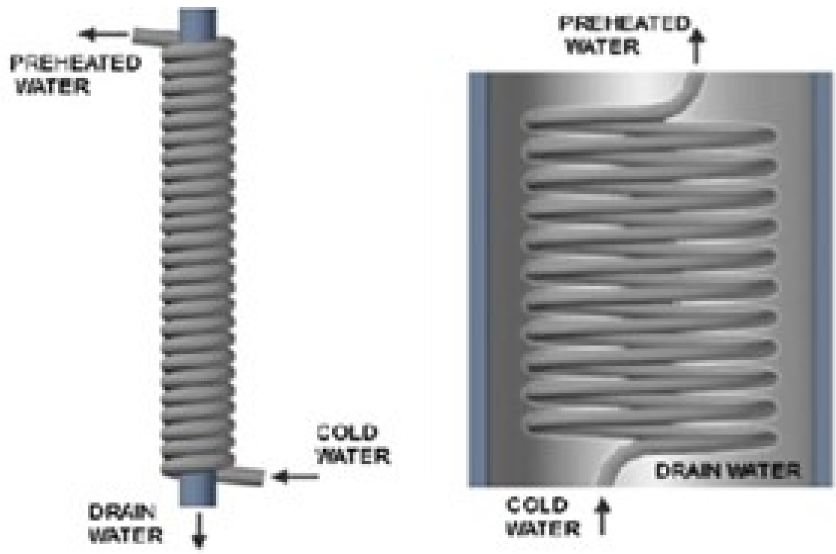

Fig. 1

Around the inner copper pipe a second copper pipe is wound to create the heat exchanger, the outside coil consists of 25 m copper pipe giving the heat exchanger a 0.57 m2heat transfer area of the coil. The results is refer the heat recovery ratio ranges between 32 and 50%, the ratio is dependent on the flow rate of the drain water. The heat recovery ratio decreases when the flow rate increases, even though the heat flux increases. Higher flow rates lead to higher exiting temperature of the drain water, this in turn leads to a larger temperature difference between the wall and the average drain water temperature[11].

Efficient drain water heat recovery in horizontal domestic shower drains. The vertical, grey-water will flow around the entire boundary of the pipe wall as a film flow, while in the horizontal, grey water will flow in the bottom of the pipe. It is clear that film flow is conducive to high efficiency heat exchange occurring across the entire drainage pipe wall. However in the horizontal, heat exchange only occurs along a fraction of the pipe wall, resulting in the lower DWHR device efficiencies found in previous investigations. Therefore modifications to existing designs are required to overcome these efficiency problems in the horizontal, proposed a new design to improve heat transfer efficiency in the horizontal. The proposed design comprised a common 40 mm diameter plastic waste pipe through which waste drainage water would be carried to as normal. The cold water inlet pipe was diverted to run inside the waste pipe a shown maximizing the contact between hot drainage water and incoming cold water. The cold water pipe would consist of copper or any other suitable conductive material to promote heat exchange. In conclusion this study demonstrates that it is theoretically possible to design a DWHR system to operate to a satisfactory level of efficiency in a horizontal orientation. While certain practicalities need to be addressed for horizontal DWHR to be implemented, the economic analysis of this device shows that it could be a viable investment. The results of the investigation show that it is possible to recover energy from horizontal shower drains using a drain water heat recovery device at a satisfactory level of efficiency. The results also demonstrate that such a system may be economically viable depending on a number or external factors. Implementation of this technology on a national level was shown to have the potential to bring about significant reductions in energy usage and CO2 emissions[12].

Fig. 2.

Drain water heat recovery storage-type unit for residential housing. The unit provides reliable measurements of their thermal–hydraulic performance. The experimental unit is thus designed to supply hot and cold water to a DWHR storage device (test section), and to study its performance accumulating and delivering energy.

Besides the DWHR storage device, the experimental unit is made up of two water tanks, two thermal baths, a water pump, a flow meter, a differential pressure sensor, several temperature sensors, valves and pipes. The water tanks are used to pump hot or cold water into the test section. Each water tank temperature is controlled by a thermal bath by means of a coiled pipe. These tanks are linked to the test section through valves and pipes. The water mass flow rate is measured by a Coriolis mass flow meter with an accuracy of ± 0.041% of the actual flow rate within the operating range. The in-tube water inlet and outlet temperatures are measured with K-type thermocouples with an accuracy of ±0.3 ºC. The water pressure drop is obtained from a differential pressure transducer with an accuracy of ±0.04% F.S. The experiments were performed in a climatic chamber in order to control the environmental conditions: the temperature of the chamber was kept constant during the experiments. In addition, all the elements of the experimental facility such as tanks and pipes have been fully insulated to reduce heat losses. A commercial insulation has been used (25 mm insulation thickness) for this purpose. Finally, the stored energy is extracted in the discharging process by cold water pumped through the accumulator coiled pipe. At this point, all the operational steps are completed. The authors conclude from this study the experimental unit provides reliable measurements of the temperatures at different locations (in-tank and in-tube) and the flow rate, to study the storage capacity and the delivering energy process of the DWHR storage device a 50% reduction in stored energy is observed at 24 h, which reveals its limitations for long-term storage applicability. The objective of these devices is the recovery of the waste heat from domestic warm drain water and transferring it to cold water entering the house. From the results, it can be concluded that the objective has been reached with the proposed design[13].

Heat exchanger development Of Waste water heat recovery. Description of experiment of this study prototype heat exchanger with a single "Heatsheet" panel was designed and made. It consists of separated hot and cold water flow systems, a heat exchanger, Single Panel Heat Exchanger; a thermosyphon 'Heat Sheet' was chosen as the key element of the proposed heat exchanger. The performance characteristics were required to be determined. The "Heatsheet" consisted of two plates seam welded together around the edges to form an envelope that has been evacuated and then load with a small amount of heat transfer fluid and hermetically sealed. Both sheets were punched with a dimple pattern for small pools of the working fluid to accumulate. The material of the sheet plates and supply water tube was stainless steel out of concern for the effects of possible fouling on the heat transfer surface by grease and other contaminants in the waste water. All pipes, hot water bath and hot water storage tank were well insulated to reduce heat loss in the system. They were for measuring water inlet and outlet temperature on both hot and cold water sides. Measurements of hot water usage and waste water temperature and flow rates were obtained for a potential application of the proposed exchanger (the dishwasher for the kitchen in the University Halls of Residence). A model of a multi-panel thermosyphon heat exchanger was also developed to predict the energy savings that would be expected if such a heat exchanger was used in this situation. The result indicated that an overall electricity of 7500 kWh could be saved annually from the dishwasher system by employing a four-panel thermosyphon heat exchanger[14].

Decentralized Drain Water Heat Recovery: Interaction between Wastewater and Heating Flows on a Single Residence Scale. System Set-Up The proposed system recovers the drain water and raw sewage in a collection tank, allowing for this tank to serve as a buffer to attenuate potential mismatches between the heat consumption by the heat pump and the flow of drain water. The heat contained in this holding tank is recovered through a heat exchanger, heating the primary fluid of a heat pump, which serves as the low temperature heat source for this heat pump. The heat pump is primarily used for space heating, but in case excess heat is available, it is used to heat up the feed water from the water supply to the desired temperature. The hot water is stored in the domestic hot water storage tank (DHWST), this way the heat pump can be operated continuously over a given time period, improving the performance of the heat pump, and increasing its profitability [15]. The consumed DHW is then pumped from the DHWST to match DHW demand. In case there’s not enough heat available in the holding tank to provide all the space heating and DHW demand, a backup system is provided. When using a drain water heat recovery system, a back-up heating system remains necessary. It is generally used right after the consumption peaks, when the accumulated recovered heat is depleted to meet the peak in demand. The share of heat demand that can be met by the DWHR system varies between 8% and 42%. Due to a mismatch between the availability of waste water heat and the heat demand, recovered heat could be wasted. In order to avoid this hot water reservoir can be used to store the recovered heat. Using a hot water reservoir of 300 mm can reduce the amount of recovered heat that is unused from 25% without a reservoir to 99%, with a reservoir. This shows a mismatch between heat demand and the availability of heat in the wastewater. Using the DWHR system greenhouse gas emissions related to domestic hot water- and space heating can be reduced by 7.6% to 22%. However, this increases heating costs by a factor ranging from 120% to 130%. At current traditional heating prices, the DWHR system for a single residence is not financially competitive with traditional systems, due to its important capital investment. Combining waste water streams from different residences would provide a larger flow, and potentially a high recoverable energy volume. However, heat would be lost between the residence and the collection point, reducing the energy density of the waste water. In turn this could lead to an increased GHG intensity of the recovered heat. An optimal collection point should be found, considering the trade-off between increased energy volume and reduced energy density[16].

COP and Economic Analysis of the Heat Recovery from Waste Water using Heat Pumps. The heat recovery system is composed of the following components: Two 40 meter deep wells as the source of clean water, Two centrifugal pumps for forwarding and pumping the clean water from the well, Plate heat exchanger, Heat pump for low temperatures, Heat pump for high temperatures, Tank for hot clean water, Washing machines, Tank for hot waste water, Two centrifugal pumps for pumping and transporting the waste water, Sewer system for waste water draining, System for automatic control, System of measuring instruments. Concluded from this study the recovery system described in this study is quite efficient both in energetic and economic terms. the system's total coefficient of performance is very high: COP is from 6 to 6.5, the component's partial COPs are the following: 3.19 for the heat plate exchanger, 1.95 for the heat pump1, 1.35 for the heat pump2, the total energy savings expressed in percentages: Minimally (1-1/6) 100% = 83.3% or Maximally (1-1/6,5) 100% = 85%, The energy savings of the components in percentages: Plate heat exchanger 49%, low temperature heat pump 30%, high temperature heat pump 21%, The payback period of the investment is relatively short, about 2 years. In addition to energy and economic advantages this solution is also very favorable in terms of environment protection. The recovery system protects the environment on direct and indirect way. Directly: The waste water does not enter in the sewer while it is still hot, the waste water is cleaned by filtration before getting out of the recovery system[17].

Theoretical studies

Heat recovery from untreated wastewater A case study of heat recovery from sewer line to district heating network. The heat exchanging could be performed either within the sewer or by withdrawing water from the sewer and perform external heat exchanging outside the tunnels. Results showed that during a majority of the year approximately 4 MW of heat could be extracted while staying within conservative limits in regards to a minimum influent temperature as well as a maximum upstream temperature decrease. During wet season however, no or very limited heat could be recovered as the influent temperatures are already in a rather sensitive range in regards to the biological treatment process[18].

Heat exchanger applications in wastewater source heat pumps for buildings. WWHEXs can be classified under two main categories: (i) utilization of WWHEX and (ii) construction of WWHEX. The classification diagram Utilization of WWHEXs; can be used in three different locations to recover heat from WW. Mainly, the WWHEX may be inside the building to recover waste heat from domestic hot water, which is called domestic utilization. WWHEX can also be located inside or outside the sewage channel, which provides a larger excess heat from WW to provide heating/cooling for multiple buildings. Apart from these two locations, WWHEX can be installed downstream of a wastewater treatment plant (WWTP) to efficiently utilize the energy in the treated WW in larger scale. The heat recovery at the sewage treatment plant is technically easier since energy from the treated wastewater can be extracted more efficiently. WWHEXs Construction of HEX can be classified in two categories: (i) material used in construction and (ii) the commercial type of HEXs. These two are very important in selection and installation of WWHEXs to WWSHP system. This study concludes was WWSHP systems are relatively recent, but rapidly growing and developing technology. To achieve a more sustainable world, one of the most important phenomena is energy recovery from otherwise wasted sources.

The key findings of this study and some directions for future research can be summarized as follows: Most commercial applications and academic studies employ special design and shell-and-tube HEXs, Limited number of studies on CFD analysis of WWHEXs is reported in the literature, Rigorous methods for performance improvement of WWHEX should be pursued, Prevention of bio-fouling in WWHEXs is a potentially important area that needs further attention[19].

Heat recovery from municipal wastewater: evaluation and proposals. Methodology in this study is the Conceptual model of Heat Recovery An evaluation of the feasibility of a Sewage Heat Recovery System (SHRS), that is, a system able to recover thermal energy from wastewater (Heat Offer) and to supply it to the potential users (Heat Demand), should take place from the evaluation of a conceptual model, referred to a specific local reality, composed by several elements. A heat recovery system requires three main components: the first one is the heat exchanger, which is responsible for heat transfer from the heat source to transport medium. The second part is the heat pump, which is the tool able to increase the temperature of the recovered heat. The last part is the heat supply system, which is in charge of the transport of the thermal energy to the users, and it has as a main goal the minimization of heat dissipation. To design a specific SHRS model, first of all wastewater characteristics should be considered, then SHRS' components and its position in the sewer (the last issue is determined by nature and location of potential users of the recovered thermal energy) should be defined, together with the potential users, and finally the various implications of the SHRS on the local reality should be discussed. Sewers actually represent the main source of heat loss in buildings[12]. Wastewater as a thermal energy source Municipal wastewater may be considered as an important energy source. In fact, besides the traditional technical solutions devoted to the recovery of the chemical energy contained in sludges by means of anaerobic digestion processes, a relevant amount of thermal energy should be valorized from the sewer system[20].

Numerical studies

The authors also studied numerical analysis to efficient drain water heat recovery in horizontal domestic shower drains. The commercial computational fluid dynamic software package CFX was used to develop a numerical model of the experimental prototype DWHR device. This model was subsequently calibrated against the measured flow and temperature data obtained during the experimental assessments of effectiveness. Following calibration the numerical model was then modified to optimise the energy recovery potential of the device. A 3D model of the prototype device was constructed and meshed using ANSYS Model Builder. A tetrahedral mesh was constructed comprising a 12.7 mm diameter cold water pipe, with a wall thickness (d) of 1.58 mm and a 40 mm diameter outer waste pipe. The model consisted of three domains: a hot fluid domain contained the hot drain-water flowing by gravity in a partially full pipe with air; a cold fluid domain contained the cold water mains flowing under pressure in a copper pipe full of water; and a solid domain representing the 1.58 mm thick copper pipe, the medium through which heat transfer would take place between the two fluids. the differences between the numerical model predictions and measured data were acceptably small and the model was deemed to be calibrated[12].

The authors also studied numerical analysis to Drain water heat recovery storage-type unit for residential housing, A numerical simulation platform has been adapted for the prediction of the DWHR storage system, providing additional and more detailed information. The in-tank water natural convection flow and its local temperature evolution are described by a 3D transient CFD analysis. Extraction process tests were conducted to determine the effect of flow rate and temperature in the heat recovery performance of the DWHR storage device. For the DWHR storage built in this work, the maximum heat recovered is reached at the lowest flow rates (3 l/min) for the two different in-tank temperatures. The DWHR storage had the capacity to recover from 34% to 60% of the energy available in the drain water for the investigated flow rates. In these tests a comparison between the numerical and experimental results has been carried out. Different results of the DWHR storage device are shown, such as the evolution of the non-dimensional temperature over time of the water in-tank and in-tube and the energy recovery ratio, where the numerical results were shown a trend similar to the experimental data for the different tests. A heat losses test was also conducted. There were no significant temperature gradients in the radial direction[13].

Analysis of Grey-water Heat Recovery System in Residential Buildings, Two different simulation programs have been used, Energy Plus and SIMIEN to find what impact the energy reduction would have on the building and to see if the simulations would correspond to the theoretical estimates done in this study. The theoretical estimates based on equations for heat recovery and measured data for energy use in the case building gave a little bit better results than the simulated results for the same case building. Although there is a difference both gave a positive indication that a heat recovery unit would not only reduce the energy consumption but also reduce the annual operating cost of a building[21].

3. Conclusions and Perspectives

One of the main challenges in the world today is reducing energy consumption and CO2 footprint in existing buildings without major construction work. Many of these buildings represent heritage buildings and the intervention constraints on the original building are much more restrictive for these particular cases. The building sector is one of the world's largest energy consumers, so it is important to seek out and use recovery energies for individual consumers. The main component of energy consumption in buildings is heating, but the demand for the domestic hot water is also very high, especially when daily consumption is high and especially for specific applications (hotels or laundries for example) This is why the implementation of technologies using renewable energy and recovery sources for water heating[1] has become very important and one of these technologies involves the recovery of the thermal energy from wastewater. Usually, heat recovery from wastewater is designed to recover residual energy from the hot drainage water and this recovered energy is used to preheat incoming cold water or to heat pumps.

Wastewater heat recovery applications are becoming widespread in energy saving applications. This interesting technology is an efficient and inexpensive way to recover thermal energy for reuse also in facilities systems in buildings, such as the production of sanitary hot water or heating. It is known that a sustainable and low emissions operation in air conditioning and heating processes is achieved by harvesting the otherwise wasted energy in wastewater through specially designed heat exchangers, lying at the core of heat pumps. This combined system is called wastewater source heat pump.

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