Heat from grey wastewater – a sustainable heat pump energy source

Căldura apelor gri de canalizare - o sursă durabilă de energie a pompei de căldură

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Abstract: *Systems for Domestic Hot Water (DHW) preparation generally represents a considerable part (up to 35%) of energy and water consumption in hotels worldwide. As a consequence of that, a vast amount of heat is wasted through the drainage system from rooms and kitchens. Also, in hotel type of buildings, according to their occupancy, demand for DHW can vary. Researchers and practitioners have a very challenging task to select optimal and sustainable solution. This paper describes a DHW heating system operation with a heat pump system which use Grey Waste Water (GWW) and rainwater energy source. The application is developed in combination with experimental site measurements (real system operation) and required standards. The proposed system consists of three energy source parts: the main heat pump system, heat accumulation tanks, and gas boiler as a reserve. In order to evaluate application of the selected heat pump DHW heating system, a comprehensive assessment was carried out with the conventional gas boiler (base case) and solar collectors system. Assessment results for optimized heat pump system operation showed a very good economic indicators (PBP=4.5%, POP=5.1%, IRR=16% and MIRR 13%). The analysis confirmed the main advantages of this heat pump system which are (consists of) lowered energy consumption and reduced total operating costs. Also, this study results can be used for the planning of hotel DHW systems as an example of the best available system selection. In the end, the research presented encouraging practical application as a cost-effective hotel DHW heating system.*

Keywords: *domestic hot water-DHW, grey waste water-GWW, heat pump, rainwater, economic assessment.*

Rezumat: *Sistemele pentru prepararea apei calde menajere reprezintă, în general, o parte considerabilă (până la 35%) din consumul de energie și apă, din hotelurile din întreaga lume. În consecință, o cantitate mare de căldură este irosită prin sistemul de canalizare din camere și bucătării. De asemenea, în clădirile hoteliere, în funcție de ocupația acestora, cererea de apă caldă poate varia. Cercetătorii și practicienii au o sarcină foarte dificilă la selectarea soluției optime și durabile. Acest articol descrie funcționarea sistemului de încălzire a apei cu un sistem de pompe de căldură care utilizează apă uzată gri (GWW) și apa de ploaie ca sursă de energie. Aplicația este* *dezvoltată în combinație cu măsurători experimentale în șantier (funcționare reală a sistemului) și standarde necesare. Sistemul propus constă din trei părți sursă de energie: sistemul principal de pompe de căldură, rezervoarele de acumulare de căldură și cazanul de gaz ca rezervă. Pentru a evalua aplicarea sistemului de încălzire a apei calde menajere selectate, a fost efectuată o evaluare completă cu centrală convențională de gaz (elementul de bază) și sistem de colectoare solare. Rezultatele evaluării pentru funcționarea optimizată a sistemului de pompe de căldură au arătat indicatori economici foarte buni (PBP = 4,5%, POP = 5,1%, IRR = 16% și MIRR 13%). Analiza a confirmat principalele avantaje ale acestui sistem de pompe de căldură, care sunt (constă în) consum redus de energie și costuri totale de funcționare reduse. De asemenea, rezultatele acestui studiu pot fi utilizate pentru planificarea sistemelor de canalizare hotelieră ca exemplu prin alegerea celui mai bun sistem disponibil. În cele din urmă, cercetarea a prezentat o încurajare a aplicării practice ca sistem de încălzire a apei calde menajere în hoteluri.*

Cuvinte cheie: *apă caldă menajeră - DHW, apă uzată gri-GWW, pompă de căldură, apă de ploaie, evaluare economică.*

1. Introduction

If we treat tourism as the biggest single economy branch worldwide, we have to state that more than 210 million employees [1] and thousands of accommodation facilities are an essential part of this still-growing branch. In basics, hotels are actually real estates and which can potentially obtain profit growth by higher investments to make immense capacities and entertainment facilities and by reducing operational costs. If we observe the structure of total operational costs, energy costs will appear as the highest ones with up to 50%. Since those costs have the potential for an increase in price, energy costs come as an obvious first choice in cutting off in order to increase the share of profit. It's estimated that in 2018 hotel revenue worldwide went up to 141,600 mil USD and the economic forecast for 2022 is even higher – up to 187.000 mil USD [2], so it's clear that there is vast possibility for somewhat small measures that can cut costs and increase benefit. Nowadays, the majority of EU countries are searching and applying various technical solutions that grant part restoration of the lost heat and maintain the saved energy as an alternative source for other building needs. This recovered energy can be further used in water preheating, building heating or as a source for air conditioning during summer [3]. The survey presented in [4] shows that DHW represents a substantial part of the energy balance in Norway's hotel sector. According to [5, 6], indicated the share of energy consumption can be in the range of 20-35% of the total energy bill. The maximum energy usage can be up to 50%. Overall, the DWH systems in hotels represent the second-largest consumer after HVAC systems [7]. The study [8], related to the environmental impact of DHW systems in hotels estimates very high, in the range of 2.87–3.2 kg-CO2/ (person · night), specific CO2 emissions.

Some estimations are that it is possible to recover up to 90% of the thermal energy from the GWW [9]. Wastewater contains heat energy mainly from bathing, laundry services, cooking process [9-11]. Flow of GWW is accessible during whole year with its temperature approximately around 30°C. This makes the energy utilization of this low-enthalpy source a suitable option (e.g. a heat pump application) [3]. A GWW can be more applicable as recovered energy because it represents a relatively clean source one [9].

One of the main issues when it comes to the hotel DHW heating system design (or other accommodation facilities), is to foresee the number of occupants because the tourism industry is highly dependent on the season and the occupancy rate may drastically vary on that and many other factors.

Statistical office of the EU, known as Eurostat gives us data that shows the mean occupancy rate of hotels in South part of Europe is around 69%. In Eastern part of Europe this rate has a little bit lower value, around 64% [12]. Regained energy from GWW in the tourism industry can be used for heating and cooling systems in accommodation facilities, agricultural greenhouses and draining dewatered sediment. In scientific circles, studies that are focused on raw GWW energy recovery stated some functional problems such as system corrosion, clog, or bio filth [13, 14].

In order to achieve a highly efficient DHW system, the main task is to select the appropriate renewable or heat recovery source. In the studies [15-17], the authors presented the implementation of a heat pump system with wastewater and solar energy source for a hotel type of building. Those studies mainly analyse the system's efficiency of the system without a techno-economical assessment. In [15], the authors provided data for the economic and environmental impact of integrated solar and wastewater source system. On the other side in this research, the real operated case study with a heat pump system with GWW plus rainwater collection system source associated with a gas boiler is comprehensively analysed (technologically and economically). Optimized system design and operation is proposed. An extensive assessment is carried out in comparison with the solar collectors system and with the conventional gas boiler system as the base case.

2. DHW system selection and description

In general, there are two ways of providing DHW - locally (decentralized) or by centralized systems. Decentralized DHW heating is used for individual consumers, due to their lower water consumption and consequently heat demand, while for a group of consumers, flow-through water heaters may be used. Accumulation heating is used for central systems when consumption is higher with a highly variable number of consumers. Fig. 1 is presented a detailed classification of systems for DHW preparation.

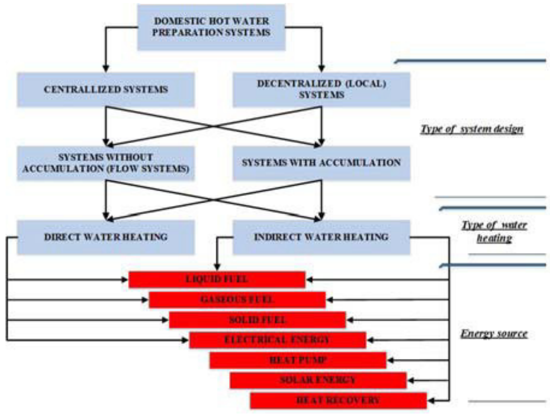

Figure 1: Classification of DHW systems

Depending on the category and year of construction of the hotel, various types of DHW heating systems can be found. In older hotels, the most commonly used systems are electric, oil or gas boilers, which can be implemented as a central or single design. Additionally, where conditions exist, a district heating system can be applied with central design (with accumulation or flow systems).

For the novel or refurbished hotels, DHW production in most cases is obtained by unconventional heating systems usually supported with one conventional source. The most used unconventional system in countries with good solar radiation is the solar collector system with accumulation. In Middle East countries this heat source can be used for the water desalination process, cooling absorption and also for the DHW production. In Europe in countries with similar climatic conditions like Serbia (moderate- continental), this system is mostly used supported with a conventional heat source for building heating or DHW production. For the DHW production in the middle and big size of hotels in Serbian climatic condition, rational techno-economic analysis suggests that solar fraction should be up to 40% of total energy demand.

The second commonly used unconventional system is a heat pump system. In the design process of the DHW system where the main source is the heat pump, one should pay attention to the device limits (maximum water temperature inlet and outlet, changes in capacity under variable operating conditions), compressor and refrigerant type, etc. For each system, the design of the device is considered separately, depending on the price and method of use.

For DHW systems in which the heat pump is the main source of heat, the design practice is most common in terms of capacity sizing. Namely, for the system where the gas boiler is the main and only source, the system is dimensioned for about 2-3 hours of heating. This is a short period for the heat pump system, as a result of the big investment rate of high heat pump capacity. According to that, these pumps are dimensioned to daily operate between 10-12h. With concerning this period it is necessary to provide more significant accumulation buffer volume. The total amount of DHW is usually dimensioned in three tanks, two with 30% and one of with 40% total volume, where operated water temperature in the buffers is achieved one by one. For these systems, one conventional boiler should be added, to ensure that water can heat up to 60°C, since most heat pumps can heat water up to 45-50°C. The boiler is dimensioned for a standard operating time, resulting in a small capacity reserve.

Heat pumps for the energy source usually use air, well water or ground heat. In this case, the system is modified to use waste heat from the sanitary and rainwater collectors. Using wastewater as a heat source for heat pumps requires a separation of grey and black wastewater as well as the filtration of GWW. GWW includes water from showers, washbasins, bars, or water that does not have solids, while black water includes wastewater from toilets and kitchens. Due to complicated purification, black water is not suitable for use in such systems. For this case study, rainwater (depending on the temperature level) is added as an additional heat source.

Coalescent filters are most commonly used for filtration of the GWW reused as an energy source. In addition to coalescent filters, Bernoulli filters, sand filters can be used, although sand filters are more complex to clean and rarely used in such systems. In order to understand which filters are suitable for water purification, it is mandatory to recognize the content of impurities in the wastewater and of course what is actually required for the operation of the system. For this case study, the purpose of wastewater treatment is to protect the plate heat exchanger from soiling, so in this case, mechanical water purification is required (removing elements in water that are not dissolved). Those that are dissolved, like oil, do not pose a problem in this case. A schematic of a coalescent filter is shown in Fig. 2.

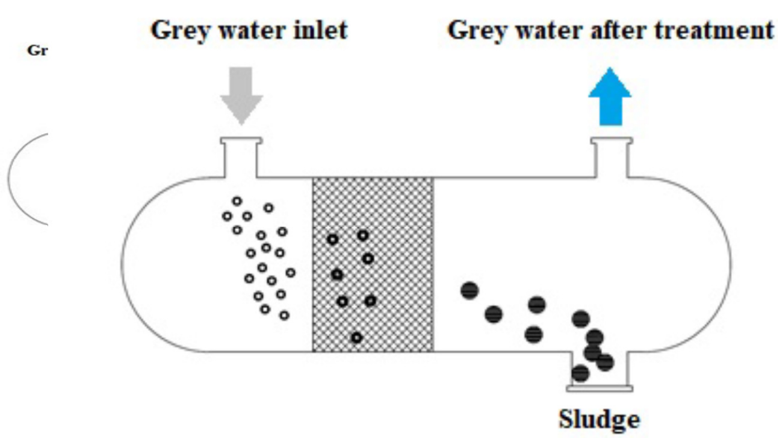

Figure 2: Schematic illustration of a horizontal coalescence filter

Coalescence filters are process vessels filed with the large surface area on which the particles are grouped, which causes them to be separated from the liquid phase by gravity or filtration. The main element of the filter is cartridge, which for water filters are usually made from PVC, in different dimensions of the openings. Filter sizing is based on water characteristics and flow parameters.

3. Selected hotel case study

For this research, a four-star hotel in climatic conditions of Novi Sad is selected and analysed. The building was opened in 2017. The hotel consists of two underground levels which provide space for a garage and technical rooms, and the ground floor has an entrance hall, reception, restaurant with a convenient kitchen for food, area for offices, as well as sanitary blocks. The gallery has a congress hall, a café-restaurant with kitchen, management offices and two sanitary blocks. From the first to the ninth floor are rooms and suites. Totally, the hotel has 144 rooms, 9 apartments, and a restaurant with a café for 136 people. Space for HVAC installations is on the roof. This research investigated totally 167 shower nozzles and bathroom faucet. The DHW is used for guest's personal hygiene and for facility cleaning.

3.1 Description of initial hotel design DHW system

The current hotel system for DHW heating consists of heat pump, gas boiler and other equipment necessary for operation (buffers for GWW collection, DHW accumulation tanks, heat exchangers, pumps, etc.). The problem with this system is the lack of a GWW source to ensure enough energy for heat pump operation. In case when there is a shortage of GWW flow, heat pump system stops and DHW heating is obtained by a gas boiler. In the last 2 years, according to the hotel management, the DHW system had a lot of operational problems where the gas boiler was the dominant energy source. Also, there is a lack of information related to energy data, consumption profiles, GWW capacity, etc.

3.2 System sizing and simulation of DHW energy needs

To ensure adequate DHW system design, this paragraph will provide necessary information related to system sizing and simulation of energy needs. System elements sizing and calculation of DHW requirements are carried out according to ISO 18523-1:2016 [18]. The ASHRAE Standard 90.1-2016 (section for hotel facilities) [19], is used to determine required daily DHW need. These standards showed similar numbers for DHW requirements. Calculated daily hotel demand for DHW is presented in Table 1.

Table 1:
Required daily hotel demand for DHW

Space type	**Number of rooms (apartments)/ number of persons**	**The required daily need for DHW at 50°C [l/individual]**	**Total daily demand [l/day]**
Double-bed room	144	100	14,400
Apartments	9	130	1,170
Café + Restaurant	136	28	2,120
TOTAL			17,690

For the selected hotel, dynamic energy simulation of DHW needs is done by T*SOL software [20]. Software calculation is based on the balance of energy flows and set up for a hotel building type with the usual operation schedule. The results are obtained by a mathematical model calculation with variable time steps from 1 to 6 minutes. In this case, the results of annual energy simulation showed the DHW heating energy supply of 178,824 kWh. Fig. 3 presents the average monthly results collected from dynamic energy simulation.

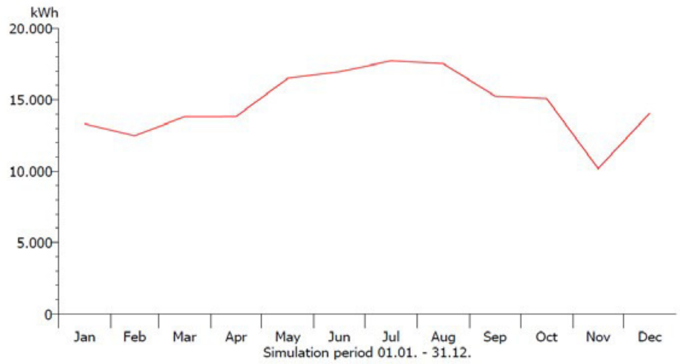

Figure 3: Average monthly values of DHW heating energy requirement

3.3 Onsite measurements

The building has a smart building management system which controls and operates the HVAC system, indoor temperature, and occupancy. Currently, there isn't a separate energy meter for the DHW system, and it's not possible to measure energy consumption. To optimise current design data and equipment capacities, onsite measurements were carried out from 1st May until 1st of October 2017.

During this period, hotel occupancy, GWW temperatures, and quantity of collected rainwater were monitored. On Fig. 4 minimal (33%) and maximal (88%) hotel occupancy can be observed. These values are corresponding to the measured minimal (10.8°C) and maximal (29.4°C) temperatures of GWW. The calculated average values of hotel occupancy are 68% (in agreement with [21]) and corresponded GWW temperature of 25.1°C. The temperature value dependence on occupancy is presented in Fig. 4.

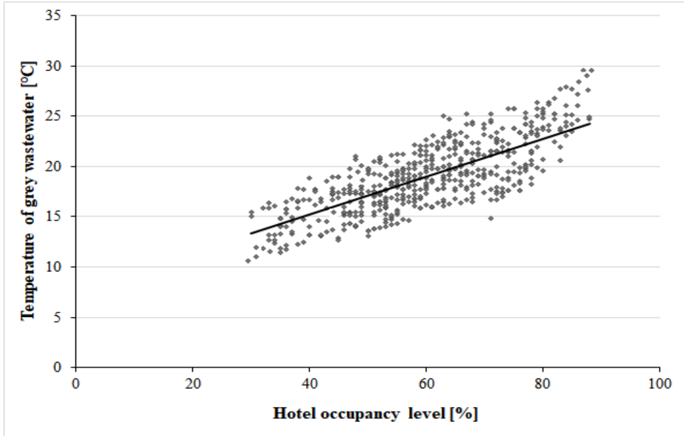

Figure 4: Temperature of GWW vs occupancy level in a hotel in Novi Sad

Additionally, in the same period from nearby meteorological station [22], data of rainwater perspiration were collected (Fig. 5). For the other remaining period of the year, the quantity of rainwater has 20-30% lower values. Average daily volume of collected rainwater from hotel roof area (700 m2) is 1,240 l/day.

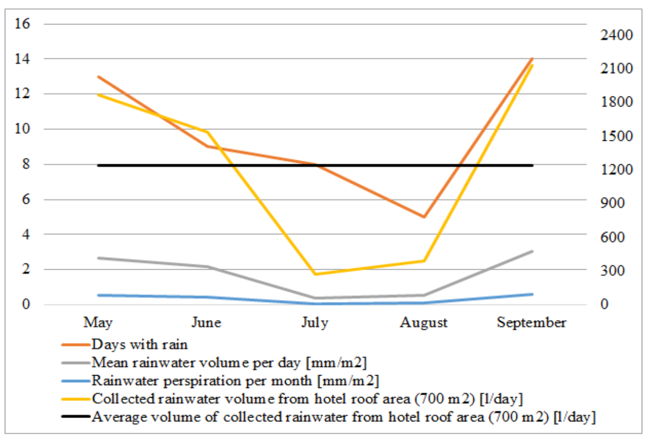

Figure 5: Novi Sad rainwater perspiration data collection [22]

In order to detect the design capacity of DHW system components, summarised initial conditions are provided in Table 2. Information is provided according to measurements and standards requirements. Period for measurement (May to September) is selected based on practice when the DHW is used for the longest time.

Table 2:
Initial hotel design conditions based on measurements and standards requirement

Component	Initial condition/measurement	Remarks
DHW heating temperature	50°C	The gas boiler operates to preheat the water (65°C) to eliminate Legionella
Required daily hotel demand for DHW	17,690 l	Standard requirement (100% hotel occupancy), for 68% hotel occupancy daily demand is 11,968 l
Annual energy for DHW heating	176.6 MWh	Result of dynamic simulation Daily value is 483.8 kWh
Average hotel occupancy	68%	Monitoring result
Average GWW temperature	25.1°C	Measurement result
Mass of GWW	26,693 kg	Calculated on 100% occupancy
GWW tank	15 m^3	Five tanks times 2.5m^3, calculated based on two daily peak consumption.
Mass flow of wastewater		
Minimum temperature of wastewater for heat pump operation	9°C	Control prerequisite
The daily working period for heat pump	16h	Design consideration
The daily working period for gas boiler	2h	Design consideration
The daily average quantity of collected rainwater (rainy day)	1,240 l	Monitoring result
Average rainwater temperature	12°C	Monitoring result, rainwater is used for (as) energy source only in case when the temperature is higher than 9°C. Otherwise, all water will be (is) diverted to the sewer drains.
DHW tank	13 m^3	Design condition for 68% occupancy (5+5+3m^3)
Technical water tank	0.8 m^3	Design consideration

The formula for a mass balance of GWW can be interpreted as:

$$m_{GWW} = m_{DHW} + m_{RW} \quad (1)$$

where are:
m_{GWW} – GWW mass;
m_{DHW} – At 100% hotel occupancy DHW mass of restaurant and room sinks;
m_{RW} – Rainwater mass with Novi Sad mean annual temperature of (average of 12°C).

Accordingly, the GWW system energy balance is equal to:

$$m_{GWW} \cdot c_{wGWW} \cdot t_{wGWW} = m_{DHW} \cdot c_{wDHW} \cdot t_{wDHW} + m_{RW} \cdot c_{wRW} \cdot t_{wRW} \quad (2)$$

c_{wGWW} – GWW specific heat [kJ/kgK];
t_{wGWW} – GWW temperature [°C];
c_{wDHW} - DHW specific heat [kJ/kg];
t_{wDHW} - DHW temperature [°C];
c_{wRW} - Rainwater specific heat [kJ/kg]
t_{wRW} - Rain temperature [°C].

The calculated total mass of GWW for hotel 100% is 26,693kg. For this kind of hotel facility a peak consumption can occur twice per day (first part of the day in the period of 7-9 AM, and a late one in the period of 9 - 11 PM). According to that an entire GWW tanks capacity of 15m^3 is adopted. The GWW accumulation consists of 6 tanks, where each has a capacity of 2.5m^3.

Besides GWW, the system allows the collection of rainwater which can be used also as a source of heat. Minimum temperate of the rainwater is set to 9°C. During the monitoring period [22], a 1,240 l is proved as the daily potential of rainwater accumulation.

Required daily need at 100% hotel occupancy for DWH is 17,690 l. Thus for the occupancy level of 68%, the daily demand is 11,968 l. Therefore, the three water reservoirs with cell configuration are selected for DHW system accumulation (two reservoirs with 0.5m^3 and one with 0.3m^3). The total annual energy consumption obtained from dynamic simulation is 178.8 MWh.

Adopted DHW heating system utilize a GWW collected from rooms and cafe restaurant. Additionally, in system can be added rainwater collection. A system operation precondition is a separation of GWW (hot water from showers and sinks) from black one (toilets). GWW collection varies from hotel occupancy and rainwater perspiration potential. Table 2 shows the calculated quantity of GWW, according to mass and energy balance, and measured data.

4. DHW system selection

4.1 Gas boiler system only

According to design considerations in section 3, the selection of a gas boiler is made. Considering that the gas boiler is the only energy source, the system will be dimensioned to 130% of the required capacity (DHW must be heated for 2 hours). Selection is made for two boilers (261 kW each), which is 65% of the total required capacity, as protection against possible damage to one of the boilers.

4.2 Solar collectors system assisted with gas boiler

For the second case, a solar collector system assisted with a gas boiler is selected. Dynamic simulation is done by T*SOL software [20]. Table 3 and Fig. 6 represent simulation results. This result allows to select an optimal number of solar collectors and the absorber area. The total solar absorber area is 77.7 m^2 (37 plate solar collectors), with inclination and azimuth angle of 30° and 40°, respectively. According to the climatic zone and hotel position with south-west solar collector orientation, this is an optimal system selection. This kind of systems in Serbia requires additional conventional energy source in order to substitute and to help water fast heating. For this purpose is a selected boiler with a nominal capacity of 350 kW.

Table 3:
T*SOL simulation results

Description	Value
Installed solar collector power	65.01 kW
Active irradiation on to collector surface	129,452 kWh
The energy delivered by collectors	57,598 kWh
Solar energy contribution to DHW	54,642 kWh
Energy from auxiliary heating – gas boiler	124,182 kWh
DHW solar fraction	31.2%
System efficiency	40%

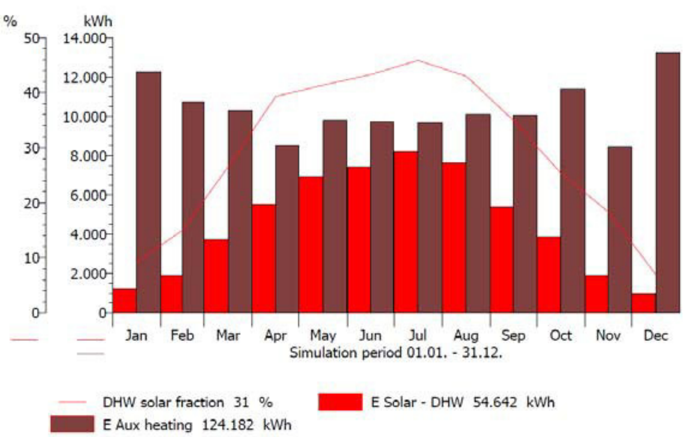

Figure 6: Participation of solar energy in the total DHW heating energy

4.3 Heat pump system with GWW source assisted with gas boiler

The basic requirement for DHW heat pump system design with GWW source is the separation of so-called black water and other GWW from showers, bathtubs, sinks, and bars. Of course, the pipes that conduct the water to the technical room should be preinsulated to preserve energy potential.

In order to choose an appropriate heat pump first step is to calculate available daily water flow. The technical recommendation is that, on the user heat pump side, water temperature change should be in the range from 3 to 5°C. For this case elements of the system at GWW side are selected with a temperature difference of 5°C (Evaporating temperature: te = tGWW - 5 [°C], Condensing temperature: tc = tDHW + 5[°C]). Water diverts to the sewer system by the three way-valve, if the GWW temperature doesn't meet the specification stated before.

In order to have more operating heat pump hours, a three-way regulation valve shall be set up on the return water pipe of the GWW side system. In that case, GWW can be re-used again by returning to the GWW reservoirs (a selected minimum return temperature is 9°C). For safe and stable DHW heating system operation (back up, filter maintenance, accident situation and water fast heating) an additional conventional energy source is necessary. For this purpose, a commercial gas boiler is picked (same as for solar collector system) with the capacity of 345 kW. Daily GWW flow can be calculated as:

$$\dot{V}_{max} = n \cdot \dot{V}_{mo} \tag{3}$$

where are:

$\dot{V}_{max}$ – The maximum water flow [l/day];

n – Re-circulations of GWW flow [-];

$\dot{V}_{mo}$ – GWW flow at maximal hotel occupancy [l/day];

$$n = \frac{t_{max} - t_{min}}{\Delta t_{mean}} \tag{4}$$

t_{max}– GWW temperature for selected hotel occupancy 29.4°C;

t_{min}– GWW minimum temperature of 9°C;

Δt_{mean}– Mean temperature difference of 5°C.

Depending on the occupancy level, the maximum possible recirculation for the maximal registered occupancy is n=3.22, while the average and minimal occupancy are 2.2 and 1 respectively. For further analysis re-circulations of GWW flow, n = 3 is adopted. The maximum daily GWW flow average of 64,400 l/day is calculated regarding starting and minimal required GWW temperature and adopted re-circulations rate. Also, the calculated heat pumps regime on the use side of 17/12°C is adopted.

Since the inflow of GWW is highly variable throughout the year, a heat pump with a power section of 0-50-100% with an operation time of 16 hours per day is adopted. According to that calculated mass flow is 1.12 kg/s. According to flow from the source side, two commercially available heat pumps were selected. Each flow rate from the side of the brine circuit is 0.55 kg/s, the heat capacity of 17.8 kW, with an adopted temperature difference of 55/50°C on the user side. Heat pump performance simulation is done with ProChill SWEGON software [23]. Simulation results, with a variation of GWW temperature at the evaporator side, are presented on Fig. 7. The figure presents values of the heat pump heat load capacity, electrical power, and expected COP. According to that, the calculated average COP of the heat pump is 3.7.

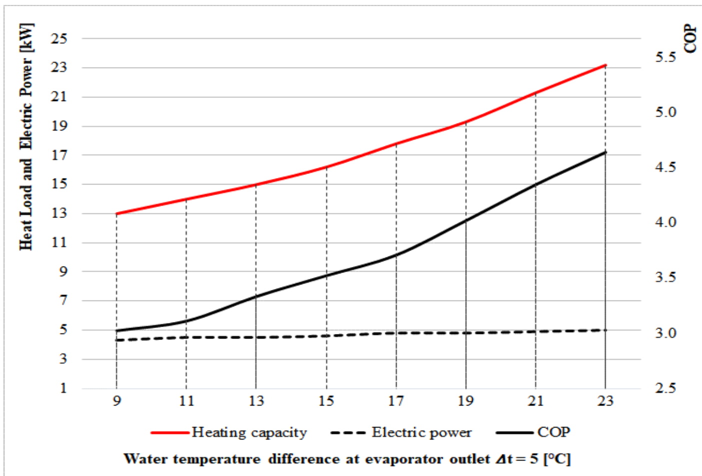

Figure 7: Simulation results of the heat pump performance

4.3.1 DHW heating system control modification and optimization

Fig. 8 presents the new hydraulic scheme of the DHW system with GWW as a source of heat. The new regulation system has two levels of control, which is connected to the hotel reservation system. The first signal comes from a sensor of GWW capacity, while the second signal is obtained by the temperature sensor of the DHW tank. If there is a minimum of 0.3m^3 of GWW in the tank (capacity for one heat pump), heat pump/s will be on depending on the available GWW. The heat pumps heat the technical water tank in the limits from 40°C to 55°C, regarding the GWW capacity and required system response rate (quicker response - lower temperature). After the technical water has been heated according to the mentioned range, a circulating pump of the technical water and DHW tanks will be on. DHW tanks filling priority are determined on the basis of the anticipated hotel occupancy for the next day.

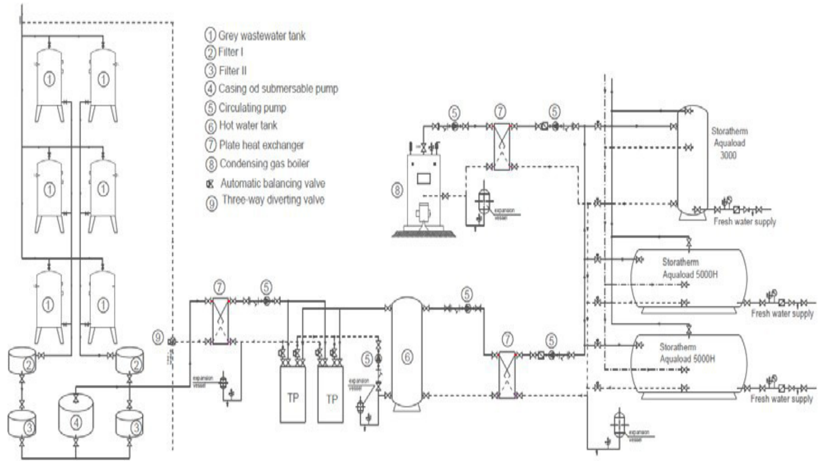

Figure 8: Proposed hydraulic scheme of DHW system with a GWW as a source of heat

The DHW system control is prioritized to operate with the heat pumps part. If there is not enough capacity due to insufficient GWW or slow response, a timed programmed gas boiler for the quick reaction will be on (the time range is from 6h to 23h). An additional exception is when the system is operating in anti- legionella mode (every weeknight between Sunday and Monday, from 1 AM to 3 AM, the total amount of DHW in the tanks is warmed to temperature 65-68°C, minimum for 2h). If the temperature in the DHW tanks falls below 40°C in the day period from 6 to 23h, the gas boilers will be on due to faster water heating. When the DHW temperature reaches 45°C, the gas boiler will switch off to turn off the heat pumps. Regarding interruptions due to coalescence filters cleaning (predicted once in 60 days) or because of potential demands for faster DHW heating, a gas boiler will be more in operation. If collected rainwater is with the temperature above 9°C, the additional water flow will be diverted to the GWW tanks. This can provide a greater potential for DHW system operation due to higher flow. If the temperature of rainwater is below 9°C, water is diverted into the sewage system. According to this optimized DHW system, the calculated percentage of gas consumption from the gas boiler is 6.8%.

Depending on the temperature after the heat exchanger, with a three-way switch valve, the GWW is returned to the tanks (a process of water recirculation). Idea is to reuse the water as long as it has a required temperature potential. If the return flow temperature of the GWW on the heat exchanger is lower than 9°C, the water is diverted to the sewer (controlled by three-way valve T1), which interrupts its further use in the system and disconnect the heat pumps. (Fig. 6).

5. Comparative techno-economic analysis

In today’s practise, the final decision of DHW system selection usually comes from an investor or a company owner. Criteria such as system functionality and reliability are the most common, but in the end, the „decision-maker“, usually become economical assessment. Also, an environmental impact and CO2 footprint are very respectable, but often (in developing countries such as Serbia) they become an added system value or promotional information.

In order to benchmark performed optimization of the heat pump DHW system with GWW source, a comparative techno-economic assessment is done. The analysis includes investment, operation and maintenance costs for three proposed DHW system solutions. For the base case, a gas boiler, as the most usual conventional system for DHW heating, was selected. A comparative analysis is done for the solar collectors' system and optimized heat pump system with the GWW source. Both of analysed systems are assisted with gas boiler. The Payback Period (PBP), discounted payback period (POP), Modified Internal Rate of Rate (MIRR) and Internal Rate of Return (IRR) and are used as economic indicators.

A payback period is a time (in years) it takes to receive cash flows sufficient to cover initial costs of investment with a 0% interest rate. If there is a real interest rate payback period is marked down.

IRR is only on cash flows on the specific project and this is the interest rate that generates the Present Worth PW = 0. The IRR measures the attractiveness of a single project. The main disadvantages of the IRR are:

- in case of two or more jointly privileged investment options IRR can't be compared;
- in case of multiple sign changes of cash flows-e.g. a challenge with 3 negative cash flows, after which come 4 positive cash flows, and then again two negative cash flows-there are 2 sign changes and it may not have an exclusive solution in ***i*** for PW = 0.

Investments that show a negative IRR are very unappealing, and there is a range of negative and positive outcomes that can happen. Sometimes, governments and their agencies also award loans where part of the principal doesn't need to be reimbursed, and those kind of loans are very appealing economically, but they have negative IRR [24].

Changed MIRR that entrust on external rates for investing and financing in order to handle several sign shifts in the series of the cash flow. The Modified Internal Rate of Rate can be calculated by either a single external rate or an external financing rate and an external investment rate. The extraneous qualifier highlights that these rates are extraneous to the project being judged. They come directly from the rates that investor regularly raises its investments [24].

Investment estimation, annual operation costs and results of comparative financial analysis are presented in table 4 and table 5. The result of the first IRR (-13%) iterations of the solar collectors' system revealed at least 26 years of lifespan, which is more than the optimal lifetime of equipment (20 years).

For the optimized heat pump system with GWW source, financial analysis proved very good indicators (PBP=4.5 years, POP=5.1 years, IRR=16%, MIRR=13%). The adopted discount rate for Serbia in 2018 was 4.39 % [24].

Table 4:
Investment estimation and annual operation costs

Selected DHW heating system	Estimation of investment cost [EUR]	Annual operation costs [EUR]	The difference investment costs [EUR]	Difference in annual operation costs [EUR]
Gas boiler system	55,230	7,060	-	-
Solar collectors system assisted with gas boiler	78,500	5,442	23,270	1,618
Optimized heat pump system with GWW source assisted with gas	65,090	4,854	9,860	2,206

Table 5:
Results of comparative financial analysis

System	PBP [years]	POP [years]	IRR [%]	MIRR [%]
Solar collectors system assisted with gas boiler	14.4	26	-13	-100
Optimized heat pump system with GWW source assisted with gas boiler	4.5	5.1	16	13

The previous cost analysis has not included the cost of technical maintenance. For the purpose of the analysis, these costs are projected at 0.5% of the annual investment cost for gas boilers, 1% for the solar system and 2% for heat pumps. The difference between investment, operation costs, and included maintenance costs are shown in Table 6.

Table 6:
Difference between investment and annual operation with maintenance costs

Selected DHW heating system	Estimation of investment cost [EUR]	Annual operation costs [EUR]	Annual operation with maintenance costs [EUR]	The difference in investment costs [EUR]	Difference in annual operation costs [EUR]
Gas boiler system	55,230	7,060	7,336.9		
Solar collectors system assisted with gas boiler	78,500	5,442	6,227.2	23,270	1109.8
Optimized heat pump system with GWW source assisted with gas boiler	65,090	4,854	6,094.5	9,860	1242.5

For the solar plate collectors system, analysis of the PBP has indicated that cumulative cash flows will be equal to investment costs after 21.3 years that is longer than 20 years of projected exploitation period (Table 7). According to PBP investment should not be realized. Calculating period of dynamic payback period would result in even more years and this method of investment's justification could not be applied.

Table 7:

Results of comparative financial analysis (added maintenance costs)

System	PBP [years]	POP [years]	IRR [%]	MIRR [%]
Solar collectors system assisted with gas boiler	21.3	-	-	-
Optimized heat pump system with GWW source assisted with gas boiler	7.9	9.3	5	10

Having in mind that the hotel's occupancy rate depends on the season, the next analysis shows the annual operation costs, including maintenance costs when the occupancy rate is above or below average 60-70%.

For the base scenario of the optimized heat pump system with GWW source, with average hotel occupancy of 68%, simulation results showed total gas participation of 5.1.

The decreasing number of guests results in a reduction of the GWW flow used for DHW heating with heat pumps system.

This will increase the participation of gas heating.

According to that, Table 8 and Fig. 7 show a sensitivity analysis in the case of an increase in gas participation in total consumption.

Table 8:

Adopted trend of an increasing percentage of gas consumption and operation costs

The trend of an increasing percentage of gas consumption [%]	Annual operation with maintenance costs [EUR]
10%	6496.4
15%	6909.1
20%	7321.6
25%	7734.2

Also, in Fig. 9 is presented link with total annual operation cost of gas boiler system only (dotted line).

Analysis of the hotel occupancy data and the gas consumption percentage in the heat pump system with GWW source, regarding only the total operating costs, with the increase of the gas participation from 6.8% to 20%, the heat pump cost-effectiveness will be equal as gas boiler system.

In case when the total costs (investment and total operation costs) are calculated, the cost-effectiveness of investment in heat pumps equals the gas boiler with an increase of the gas participation from 6.8% to 11% (Fig. 10).

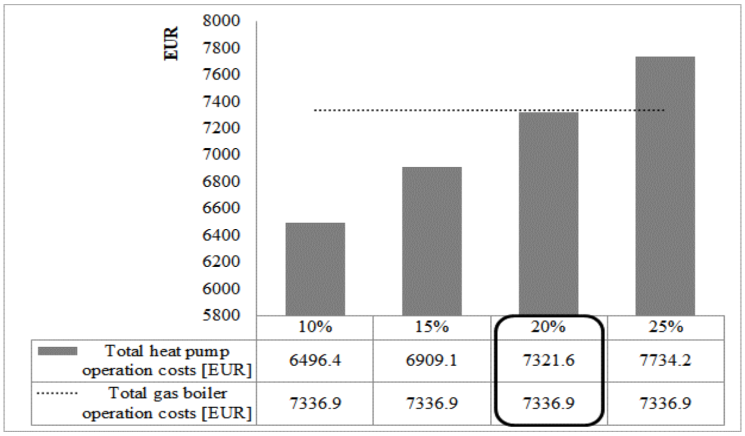

Figure 9: The link of total operating costs and the trend of gas consumption participation

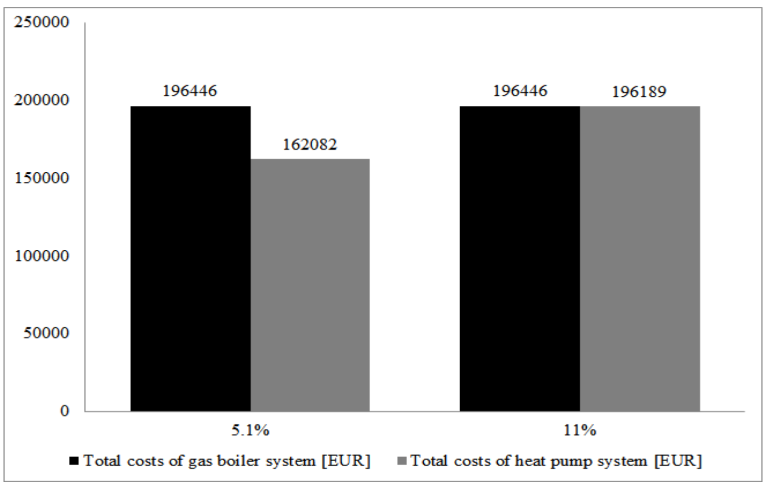

Figure 10: The link of total systems cost and gas consumption participation

6. Conclusions

DHW heating systems are one of the major technical elements of a hotel facility that must be operational all 365 days a year. In addition to the economic side of the system, equally important is the efficiency of the system and the reduction of environmental pollution, which directly affects the health and quality of life of each individual, and as such are very often the subject of analysis and refinement in many branches of engineering.

The conceptual designs for three different DHW heating systems, one system with gas boilers (conventional energy source) and two systems with renewable energy sources in bivalent connection with gas boiler, are presented in the paper. As shown through the calculation, a system that uses a gas boiler (only energy source) has the most expensive energy cost and the least expensive in terms of investment, while a system that uses waste heat from GWW is by far the cheapest operationally, while the investment is slightly higher than the gas boiler system.

Although Serbia is located in a part of Europe with high solar irradiation, solar collectors systems have proven to be an unprofitable choice. The reason for that is because electricity and gas prices are quite low, which is not the case in countries (e.g. Germany and Austria) with significantly higher electricity and gas prices and much lower solar potential. This shows that the profitability of the system depends on the energy market and country energy policy to which the target building belongs.

The system that uses waste heat from the GWW, as a heat pumps energy source, is the most cost-effective since the operation costs are much more favourable than the other two selected systems. The GWW system has great potential as an energy source, but it is very dependable on hotel occupancy and system maintaining. Also, the advantage of this system is that the heat from the GWW is not thrown away, but it is also a disadvantage because the system is quite complex and requires filter maintenance. If the system is not properly maintained, then it does not work properly and efficiently.

Financial analysis proved that the system with heat recovery from GWW is cost-effective and presents an excellent investment, in terms of all economic parameters. Results are very good, even if the worst scenario for the discount rate and maintaining cost is selected. Also, this creates a distinguished image for the hotel and company that operates a technical facility. In the end, the research presented encouraging practical application as a cost-effective hotel DHW heating system.

From the above, in order to have a cost-effective DHW system that functions 365 days a year, it is necessary to consider the real needs of the building for which the system is being dimensioned, the way the facility is used and to project peak consumption. In addition to the design of the system itself, it is necessary to anticipate the control system by which the system operates in the most efficient mode. Unless the system is properly designed and operated, in addition to being expensive, it will not meet customer needs, which is a far greater problem than high costs.

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