PRIPREMA SANITARNE TOPLE POTROŠNE VODE U HOTELIMA KORIŠĆENJEM TOPLOTE IZ SIVIH OTPADNIH VODA¹

HEATING OF DOMESTIC HOT WATER IN HOTELS USING HEAT FROM GREY WASTEWATER

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U ovom radu je opisan sistem i prikazan način dimenzionisanja sistema za pripremu sanitarne tople potrošne vode koji kao izvor energije koristi toplotu iz sivih otpadnih voda koja se prikuplja iz soba i apartmana hotela, kao i toplotu atmosferskih padavina, a sanitarna topla voda se zagreva pomoću toplotnih pumpi. Izvršena je tehnoe ekonomska analiza gde je vršeno upoređivanje investicionih i eksploatacionih troškova za pomenuti sistem i sisteme koji kao izvor koriste samo gasne kotlove i sistem sa pločastim solarnim kolektorima u bivalentnoj vezi sa gasnim kotlom.

Ključne reči: sanitarna topla potrošna voda; sive otpadne vode; atmosferske vode

In this paper it is 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.

Key words: domestic hot water; grey wastewater; rainwater

1 Potential for new investments in hotel industry

Today, tourism is considered to be the largest industry in world, with more than 200 millions people employed worldwide [1], for obvious reasons hotels and accommodation facilities are crucial part of industry. Since hotels are real estates, there are two ways for growth of profit: first one is large investments for larger capacities and entertainment content and second one is to make savings in operational daily and monthly costs. Since costs for energy are considered to go up to 50% of total operational costs and frequent increase of energy price, cut of energy costs comes as obvious choice. Estimated hotels revenue worldwide will go up to 141,588 millions USD in 2018 and will go up to 186,000 millions USD [2] according to statistics web portal statista.com, so there is massive potential for relatively low investments that cuts costs and increases profit.

One of the problems in process of design of systems for hotels and tourism facilities in general is to predict number of occupants, because it is very fluctuant for day to day, from period to period... Of course, there are some periods of year for every region of world when hotels are almost full but those periods are usually short so HVAC systems are most often designed to have lowest costs per unit of delivered energy on average occupancy level. According to Eurostat – statistical office of European union, average occupancy level of hotels in Southern Europe is around 70% and in East Europe is around 65%. Since analysis and design of system will be carried out for hotel in Novi Sad, one of the most developed regions in Serbia, reference occupancy in this case will be 68%.

2 Demands for DHW in hotel. Investment and exploitation costs of base case systems

For hotel category four stars, 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 and shown in table 1 and table 2.

Table 1: DHW demand in rooms and apartments

Space description	Quantity of accommodation units	Daily demand of DHW at 60°C for single accommodation unit in liters [l]	Total daily demand of DHW at 60°C in liters for accommodation units [l]
Double-bed room	144	100	14.400
Apartments	9	130	1.170

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Table 2: DHW demand in restaurant and cafe-restaurant

Space description	Number of people	Daily demand of DHW at 60°C per person in liters [l]	Total daily demand of DHW at 60°C in liters [l]
Restaurant	76	20	1.520
Café restaurant	60	8	600

Total daily demand for DWH is 17,690 liters. For accumulation method of heating DHW, water tanks are dimensioned for average occupancy of 68% to 13,000l with addition for space under heater inside tanks, in cell configuration, two tanks volume of 5,000 l and one volume of 3,000 l. The necessary energy for heating total daily accumulation of DHW is 482.66 kWh for cold water temperature 25°C and hot water temperature of 60°C. With 5% heat losses through pipelines, tanks, e.g., total daily energy consumption is 506.79 kWh that comes to yearly energy consumption of 184,978.35 kWh.

For base cases are chosen two most common systems we can find in hotels in our region, first one that use only boilers as heat source and second one that uses solar plate collectors with bivalent configuration with boilers.

Since hotel that has been used as example for this paper is business type hotel, so its main target clients are business people that travel for business, minimum period for heating DHW is 2 hours. In that manner for base first case as energy source are selected two gas boilers Remeha Gas 310 Eco Pro 285/5, each capacity of 261 kW and yearly efficiency of 88%.

For second base case are selected 37 plate solar collectors, Vaillant VFK 145 V, with total solar absorber area of 77.7 m², with inclination angle of 30° and azimuth angle of 40°. The best orientation of collectors is south-west, regarding hotel position, technical solution of roof and available area for placing of collectors. As support for heating DHW is selected gas boiler Viessmann Vitoplex 100 345, capacity of 345 kW. Simulation for this case is carried out using T-sol 5.5 software. Result of simulation are show in table 3.

In table 4 are shown costs per year and costs during estimated exploitation period for natural gas costs, electricity costs of auxiliary elements like circulation pumps and investments costs for both systems.

Table 3: Simulation results for Solar plate collectors system per year

Description	Value
Installed collector power	65,01 kW
Irradiation on to collector surface (active)	128,74 MWh
Energy delivered by collector loop	45,45 MWh
Energy delivered by auxiliary source	141,7 MWh
DHW solar fraction	23,7 %

Table 4: Investments and operational costs of base case systems

Description	System with boilers	Solar plate collectors system
Investment costs [eur]	55,230,00	78,500.00
Natural gas costs [eur/year]	7,002.62	12,474.88
Electricity costs [eur/year]	58.25	77,95
Total operational costs in exploitation period of 20 years [eur]	141,216.53	108,843.43

3 System with heat recovery from grey wastewater

As proposed case there is system that uses grey wastewater from hotel rooms, apartments, sink from café restaurant and rainwater. Prerequisite for applying this system is to separate grey wastewater – wastewater from bathtubs, shower cabinets, washbasins and black wastewater – wastewater from toilets. Usage of water can vary very much from person-to-person so calculation of quantity for grey wastewater is made using average temperature of DHW in moment of using, mass and energy balance. In table 5 shown average temperatures of hot water in moment of using at faucets. Quantity of grey wastewater is calculated using values of hot water in table 5, mass balance, energy balance and data from experience that around 30% of hot water in hotel rooms and apartments is used on washbasins.

Mass balance:

$$m_{gww} = m_{DHW} + m_{cw} \quad (1)$$

m_{gww} – mass of grey wastewater;

m_{DHW} – mass of DHW for rooms, apartments and café restaurant sinks at 100% occupancy;

m_{cw} – mass of cold water on average yearly temperature of 12°C in Novi Sad;

Energy balance:

$$m_{gww} \cdot c_{p,gww} \cdot t_{gww} = m_{DHW} \cdot c_{p,DHW} \cdot t_{DHW} + m_{cw} \cdot c_{p,cw} \cdot t_{cw} \quad (2)$$

$c_{p,gww}$ – specific heat of grey wastewater [kJ/kg];

t_{gww} – temperature of grey wastewater [°C];

$c_{p,DHW}$ – specific heat of DHW [kJ/kg];

t_{DHW} – temperature of DHW [°C];

$c_{p\text{ cw}}$ - specific heat of cold water [kJ/kg] at temperature 12 °C;
 t_{cw} - temperature of cold water [°C];

Table 5: Temperature of hot water at faucets at moment of using water [4]

Faucet position	Temperature of water
Shower cabinet	38°C
Washbasin	35°C
Hot tube	37°C
Bar	35°C

Total mass of grey wastewater at 100% occupancy of hotel is 28.943,6 kg. For business type of hotel there are, usually, two daily peak consumption, first one in the morning from 7am to 10am and second one in the evening from 6pm to 10pm, so we can say minimum daily consumption period is 2 hours, so grey wastewater are selected to have total capacity of 15.000 l. For space and positioning reason, grey wastewater accumulation is consisted of 6 tanks, each has capacity of 2.500l. For filtration of grey wastewater are selected four coalescing filter. Filters are the most sensible and „the weakest“ element of the system, so it should be carried out with engineer of technology and wastewater treatment.

Beside grey wastewater, there is possibility to collect rainwater and use, also, as heat source, but only in some periods of year, when temperature of rainwater is higher than minimum water temperature possible to use as heat source of 9 °C. According to Republic Hidrometeorological Service of Serbia average daily data for atmospheric precipitation, it is possible to collect 1240 liters of rainwater a day. Unfortunately, there is no data about rainwater temperature. In table 6 are shown average atmospheric precipitations for Novi Sad, for period from May to September 2017.

Table 6: Quantity of rainwater in Novi Sad from May to September 2017 [5]

Month	Total amount of rainwater [mm/m ²]	Number of days with rain	Average rainwater quantity a day [mm/m ²]	Quantity of rainwater for 700 m ² roof area [mm/m ²]
May	82.9	13	2.67	1869
June	65.7	9	2.19	1533
July	12.0	8	0.39	273
August	17.4	5	0.56	392
September	91.5	14	3.05	2135
Average	53.9	9.8	1.77	1240

Average yield of grey wastewater at 68% a day is around 19.700kg and about 1240 liters of rainwater, totally 20.940 liters a day (liter ≈ kg of water).

For period of one week, during Exit festival days in Novi Sad, temperature of grey wastewater (GWW) is recorded from 11th to 17th of July, 2018 in hotel in Novi Sad. Temperature values for mentioned period shown in table 7. As reference temperature for this case is selected value from 14th of July, 2018, because it was possible to observe changes for few hours, during morning peak consumption. Because of relatively low yield of GWW three-way valve should be installed on water return pipe on heat exchanger, on side of GWW so it can be returned to GWW tanks and re-used again, because of relatively high temperature of water. By re-using water, daily exploitation period of unit is much longer and since using heat pumps for water heating is much cheaper than heating it using gas boilers. In this case heat pumps should be selected to source side water flow, because system is dimensioned on available potential, not only on energy demands, so this system must have some additional source like boiler, to help when fast heating of water is needed and also to be back-up source in case of accident situation. For this purposes is selected same boiler that is selected for system with solar plate collectors, Viessmann Vitoplex 100 345, capacity of 345 kW, that has enough power to heat DHW accumulation in two hours.

To select heat pumps. first of all, available daily water flow must be calculated. Since water temperature difference of user side of heat pumps should be 4-7 °C, ideally 5°C, so elements of system, like pumps and pipelines at GWW side of system are selected and to average temperature difference 5°C.

Since average temperature difference is 5°C, minimum inlet temperature of GWW is 9°C because water is changing its physical state from liquid to solid state at 4°C. If GWW temperature is lower than 9°C, water diverts by three-way valve to sewer system by three-way valve. Scheme of mentioned system shown in picture 1.

Calculation of daily GWW water flow regarding reference temperature, minimum temperature on inlet side of heat exchanger and temperature difference between inlet and outlet water flows:

$$\dot{V}_{max} = n \cdot \dot{V}_{25.1} \quad (3)$$

$V_{\max}$ – maximum average water flow regarding reference temperature, minimum temperature on inlet side of heat exchanger and temperature difference between inlet and outlet water flows [l/day];
 n – number of GWW water flow re-circulations [-];
 $V_{25.1}$ – water flow of GWW at temperature of 25.1 °C [l/day];

Table 7: Temperature of grey wastewater in hotel in Novi Sad

Date	Temperature of grey wastewater [°C]	Hotel occupancy [%]
11 th of July 2018	11.5	33
12 th of July 2018	17.8	62
13 th of July 2018	24.3	88
14 th of July 2018	25.1	86
15 th of July 2018	20.8	88
16 th of July 2018	23.0	62
18 th of July 2018	17.73	45

Picture 1: Hydraulic scheme of system for heating domestic hot water using grey wastewater as heat source

$$n = \frac{T_{\text{ref}} - T_{\text{min}}}{\Delta t_{\text{sr}}} \quad (4)$$

T_{ref} – reference temperature of GWW [°C];
 T_{min} – minimum temperature of GWW on heat exchanger inlet [°C];
 Δt_{sr} – mean temperature difference of GWW inlet/outlet at heat exchanger [°C];

Since $n = 3,22$, max water flow is calculated with three re-circulations, so maximum average GWW water flow is 62820 liters a day. For protection of heat pump's evaporator from impurities and to have maximum temperature of fluid on user side of heat pump 23°C – that is maximum temperature that heat pump can work with, there is plate heat exchanger. Regarding maximum temperature of fluid on user of heat pump, mean temperature difference of fluid inlet/outlet, minimum GWW inlet temperature, difference on GWW maximum temperature and heat pump user side fluid maximum temperature, it is calculated average temperature regime on user side of heat pump and it is 17/12 °C. With user side fluid as mixture 85% water and 15% ethylene glycol.

For calculated maximum average water flow, as heating source are selected two heat pumps Blue Box Core 18, with user side temperature regime 60/55°C, each has capacity of 17 kW.

Since user side water temperature regime of heat pump is 60/55°C, temperature regime on DHW side of plate exchanger is 25/58°C, there should be protection against legionella bacteria, so every Sunday to Monday night, total accumulation of DHW should be heated to 68°C ($\Delta t = 10^\circ\text{C}$) for period of two hours every week by gas boiler. Also there are interruptions for filter cleaning once in 30-45 days and possible needs for faster DHW heating, so it is calculated that gas boiler delivers 16.586,6 kWh of energy. Rest of needed energy, 168.192,85 kWh, is delivered from heat pumps with average working time of 13.5 h a day. Investment and exploitation costs are shown in table 8 in chapter 4.

4 Techno-economic analysis

When it comes to final decision which system to install in hotel, naturally it comes to investor, person that is investing company's CEO or company owner to make final decision. There are lot of criteria that will affect decision, first of all, reliability and functionality of system are mandatory and criteria that implies, but then it comes to financial part of criteria that is usually „decision maker“. Of course, CO2 foot print is very important for environment and community in general, but usually it comes as extra value of system and very good data for hotel marketing.

Since hotel is new and all the solutions are considered for installation, techno-economic analysis is carried out for differences in investment costs. Investment costs, exploitation costs, difference in exploitation costs per year and difference of investments costs are shown in table 8 and in table 9 are shown data for PBP – payback period, POP- period of dynamic payback, IRR – internal rate return and MIRR – modified internal rate return, since first result in IRR iterations for system with solar plate collectors is show for 31st year of exploitation (-13.13%), but since estimated life span of equipment is 20 year, result is not considered for this analysis. For analysis is used recommended discount rate for Serbia by most banks of 5%.

Table 8: Investment and exploitation costs difference

System	Investment cost [eur]	Exploitation costs per year [eur]	Difference in investment costs [eur]	Difference in exploitation cost per year [eur]
System with boilers as heat only heat source	55.230,00	7,060.00	-	-
Solar plate collectors system	78,500.00	5,442.17	23,270.00	1,618.65
GWV heat recovery system with heat pumps	65,090.00	4,792.70	9,860.00	2,268.06

Table 9: Results of comparative techno-economic analysis system with gas boiler only as heat source and systems with renewable energy source

System	PBP [years]	POP [years]	IRR [%]	MIRR [%]
Solar plate collectors system	14.38	26.02	-13.13*	-100.00
GWV heat recovery system with heat pumps	4.35	5.03	15.92	15..92

- IRR value is for at least 31 years of life span.
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In charts 1 and 2 are shown cash flows for systems with solar plate collectors and system with GWV as heat source.

Chart 1: Cumulative cash flow for system with solar plate collectors

Chart 2: Cumulative cash flow for system with grey wastewater as heat source

5 Conclusion

As shown in this paper grey wastewater has great potential as energy source, but it must have additional heating source for faster DHW heating and for greater occupancy than average, but still this system is the most sustainable of all presented systems. Usage of fossil fuels in hotels in this way is cutted in minimum for heating of DHW. It is very important because hotels are usually using commercial boilers that, with just basic filtration and cleaning of waste combustion gases, unlike power plants that has already special filters for combustion gases cleaning or will have in near future.

System with solar plate collectors is shown as very unprofitable, even it is calculated for hotel located in Serbia that has very large solar yields. Of course main reason for this is low price for electricity and natural gas. Beside, low prices of electricity and natural gas, there is no any subsidies and regulations in Serbia that could help mass installation of solar plate collectors.

The main reason why solar plate collectors are so unprofitable is the reason why system with heat recovery from GWW are profitable and shown as very good investment, in terms of pay back period, sustainability and also very good for hotel image and for company that manages hotel facility. That good image creates impression of very modern place that attracts people and increases hotel's revenue, profit and makes good position for new investments, what creates space for applying new engineering ideas and technology development.

Financial analysis is carried out using current prices of equipment, installation costs, design costs, gas and electricity costs with recommended discount rate of 5% by many banks in Serbia. If discount rate was calculated, it would be value around 2%, with current interest rates on loans for renewable energy sources and stable inflation rate that we have in Serbia currently. Reason for applying recommended discount rate and not calculated is that Serbian market is small and very fluctuant. For example, if one of the largest international companies decided to go away from country, like Fiat, inflation will rise and it will also affect interest rates on loans and rising interest rates on loans are making large impact to economy. Another reasons for applying larger discount rate is exploitation period of 20 years that is period when lot of changes can happen, especially in small countries like Serbia.

6 References

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