SIMULATION OF COMBINED SYSTEM FOR WATER HEATING

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Abstract: A dynamic simulation was done for DHW production in the summer operating period. The main objective of this paper was to evaluate projects energy benefits of the large-scale solar heating connection to district heating system, for fossil fuels substitution of the hot water production for domestic use during the summer period. Hot water for district heating and domestic use produces in heating plant "Cerak" in Belgrade. The heating plant is placed at the suburb of the Belgrade and supplying one settlement with hot water only during the summer period. There is exists production and distribution system based on fossil fuel energy, mainly of the natural gas. In the first phase of the project it was planned to install about 5000 m^2 of solar collectors.

Key words: Large-Scale Solar Heating, Solar Domestic Water Heating, Energy Benefit

1. INTRODUCTION

Energy situation in the world is changing rapidly. The prices of oil and natural gas have been more than doubled during the last few years. With present tendencies the supply of oil and gas will not be able to satisfy the constantly growing demand due to increase of the world population, industrial activities and consequently energy consumption. Also, environmental problems growing dramatically caused by significant increase of consumption of fossil fuel energy and greenhouse gas emissions. Applying solar energy, as renewable source, appears to be very efficient and effective solution in analysis coping with the environmental problems.

While the price of oil and gas would remain increasing, data show that the costs of solar thermal energy are decreasing. The economic benefit is obtained replacing the substantial amount of import fossil fuel by the solar thermal energy.

Solar energy as an energy resource for heating and domestic hot water consumption has the following advantages: it is free and available; environmentally clean (no combustion occurs, hence no toxic gases emission such as CO, SO, NO and the like); belongs to renewable energy resources, therefore exhaustion of resources cannot occur (not like coal, oil and gas); contributes to sustainable development (sustainable development implies stable society development through generations, i.e. energy resources are used to the extent which allows nature recovery); in combination with classic energy resources it increases plant energy efficiency.

Even assuming stable energy prices, there is significant interest for installing solar thermal systems with payback times between 5 and 15 years, because the average lifetime of solar thermal systems is 20–25 years. The efficient way of solar energy using is in solar domestic water heating system and district heating systems.

Heating plant "Cerak" is an integral part of PUC "Beogradske Elektrane" and it produces and delivers heat energy for heating and domestic hot water to customers in Belgrade municipalities of Cukarica and Rakovica. Basic fuel currently used in the plant is natural gas or fuel oil. Total boiler installed capacity is 244.3MW, the consume capacity for heating and hot water is 230MW, while the estimated installed capacity of 16.3 MW produces hot water. The designed level for summer operation mode (15 June-15 October) is 65/22°C, with the flux of 120 m^3/h for sanitary hot water production. The present summer operation mode is set up at 62/45°C for the capacity of 6MW with flux of 300 m^3/h of hot water. It is expected that in the upcoming period modernization and new operation mode of district heating substations would be set up at 250 m^3/h flux and temperature mode of 60/40°C.

2. SIMULATION

On the basis of location plan overview of the existing plant for water heating in Heating plant “Cerak”, it is determined that the surfaces are suitable for collectors' placing at this moment are distributed at four locations at short distance among each other and therefore relatively easy to connect into one system and integrate them into existing plant.

The simulation has been performed within software package TRNSYS16 [1] specialized for various systems calculation including solar systems.

According to the recommendations for collectors' mounting and maximum avoidance of collectors' shading, the calculation for each individual surface was done for flat-plate collectors manufactured by NAU. The total number of collectors that are possible to mount is 2356, which is round 5018 m^2 of total collector area. Therefore, for the calculation of all collector types, the approximate value of 5000 m^2 is taken.

The scheme integral parts are:

- Collector field,
- Heat accumulator ,
- Existing boiler on natural gas,
- Pumps,
- Operating and regulation systems.

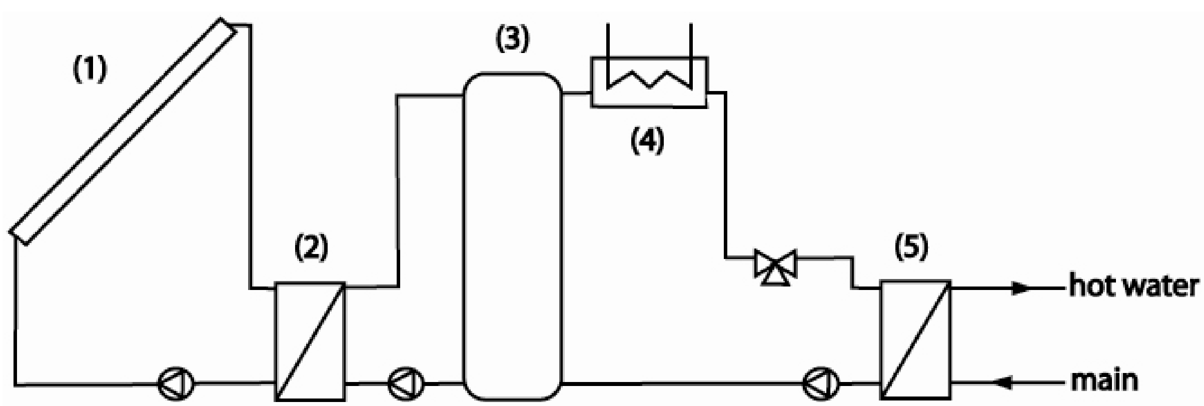


Figure 4. Scheme of considered solar system [6]: (1) Solar Collector Array, (2) Solar Heat Exchanger, (3) Buffer Tank, (4) Auxiliary Boiler, (5) Heat Exchanger

2.1. Collector

Two collector types are used for calculation: evacuated tube collectors (manufacture Apricus type AP-30, Australian-British company manufacturing in China) [2] and flat-plate collector (NAU type FLATLINE BE Ultra plus [3] and manufacture GJ Denmark A/S type GJ 140A, Danish company manufacturing in Vietnam [4]) since they can be purchased in the market, and the data on their features necessary for system simulation have been accessible. All manufactures possess product certificates (Apricus has ISO9001 certificate and SRCC for US and Canada markets, while NAU and GJ have European certificates EN 12975-2) that were the source for necessary simulation data. Simulation has done for collector angle of 20^o.

Collectors are mutually connected in accordance with manufacturer directions; hence the given data are related to the entire collector field.

Table 1. Total and absorber area features for the selected collectors

No.	Manufacturer	Country	Type	Collector area	Absorb. area
				(m^2/pcs.)	(m^2/ pcs.)
1.	Apricus	Australia/ China	Evacuated tube	4.35	2.4
2.	NAU	Germany	Flat-plate	2.14	1.9
3.	GJ	Denmark/ Vietnam	Flat-plate	13.5	12.56

Table 1 presents basic features of total and absorber area for the selected collectors where can be observed that the evacuated tube collectors have significantly smaller absorber area than the total one and in comparison to the flat-plate collectors.

Water is presumed as collector's working fluid; hence the simulation has been performed for the summer operating mode of HP "Cerak", whereby no danger of working fluid freezing exists. The mixture of water and propylene glycol is inserted into the system during the winter operating mode.

2.2. Meteorological data

The data on solar radiation are taken from software package METEONORM [5] obtained from ten years measurements on the Belgrade locations.

2.3. Heat accumulator

This component is used for certain heat accumulation and piques reduction occurred at collector operating. It therefore enables safer boiler operation, since the water input parameters that needs to be additionally heated to the desired temperature have less variations. The accumulator selected has the temperature differentiation by height, and due to the space limitations, the larger volume of the accumulator has not been anticipated where the heat accumulation for longer time period would be obtained.

2.4. Boiler

The boiler in simulation uses natural gas (which corresponds to the actual situation in HP CERAK) and defined consume strength of 6MW. The boiler operation mode is defined by given output temperature, i.e. by consumer requests.

2.5. Pumps

Pumps used in the scheme are standard pumps from the software package and defined according to the flow and loadings required to be satisfied within the system.

2.6. System load

System load represent the consumers request, and in this case three different operating modes of HP "Cerak": current one 62/45^{o}S with a flow of 300 m^3/h of hot water, designed one 65/22^{o}S with a flow of 120 m^3/h and future one 60/40^{o}S with a flow of 250 m^3/h implemented upon anticipated reconstructions and improvements to the whole system of HP CERAK. Installed consumer power in whole three modes is roughly 6MW.

System load obtained by function analyses of HP "Cerak" during 2005 on a hourly basis and according to the measured data in the period of 1 May to 15 October [6]. Those data are presented in the figures 2 and 3. The values measured from 15 April till 1 May is not considered due to the high variations in flow within the period.

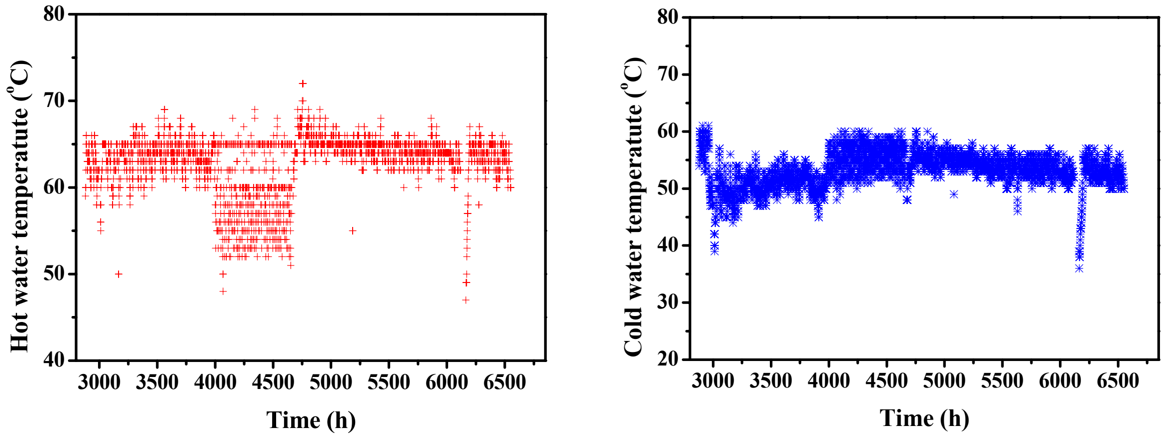


Figure 2. Measured values of domestic hot water flux in the course of summer operating mode of Heating Plant "Cerak" for 2005 (1 May - 15 October): (a) hot water, (b) cold water

It is adopted that the system loading is the constant value in the course of summer operating mode.

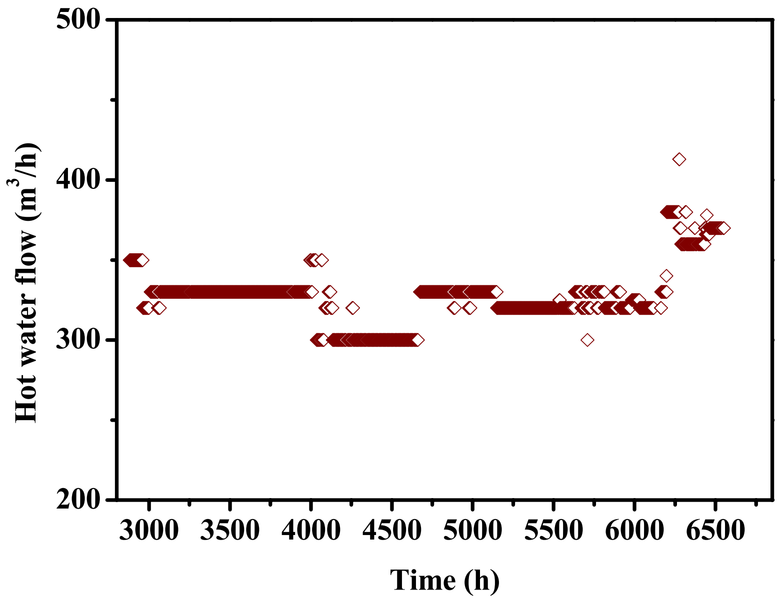


Figure 3. Measured values of domestic hot water flux in the course of summer operating mode of Heating Plant "Cerak" for 2005 (1 May - 15 October)

3. OBTAINED RESULTS

As noted earlier, simulation has been conducted for three types of collectors and three modes of operation for Heating Plant CERAK.

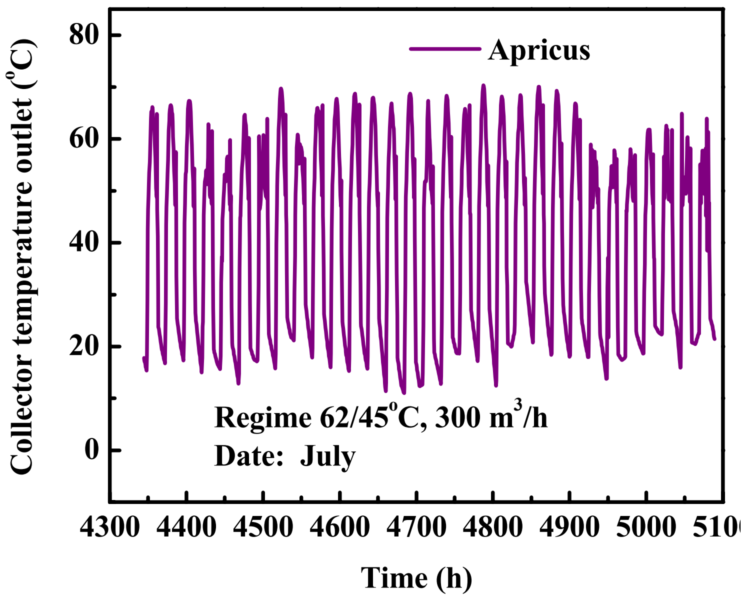


Figure 4. Temperature alteration at collector's field exit for Apricus type of collectors

Figure 4 shows results for July for Apricus type of collectors when the solar radiation was the highest for the current operation mode of HP "Cerak": 62/45^{o}C and 300 m^3/h, for total collector's area of 5000 m^2. It can be observed that temperature variation is between 15^{o}C and 70^{o}C. Collector operation mode has been set up to maximum output temperature of 95^{o}C, to avoid forced interruption of pump operation and possible damage to the collector. During periods when output temperature is lower than 45^{o}C, pump is not functioning, though reduction of temperature occurs due to external heat emission, effected in lower output collector's temperature. Results are similar for all three types of collectors and operation modes.

Figure 5 shows comparison of temperatures at collector's outlet for three types of collectors, for actual operation plant mode during the chosen day. Comparison has been performed for identical electric power conditions at collector's field for three different collectors (identical flow through collector's field). According to the reviewed results it can be concluded that NAU collector, then GJ and finally Apricus, receives the largest heat volume whilst the significant differences exist between volumes for flat plate collectors (NAU and GJ) and vacuum pipes collectors (Apricus). It is expected due to the fact that for the identical total area of collector, absorber area for evacuated tube collector is significantly lower. The difference between NAU and GJ collectors is the result of differences in quality transformation of solar radiation at heat losses quantity.

Figure 6 shows comparison of temperature levels at out point of heat accumulator, where the mutual relation between collectors is identical and temperature level is lower. It is best illustrated on Figure 7 where the exit temperatures at out point of collector's field are shown and heat accumulator for collector type NAU. It can be observed that temperature amplitude, at accumulator out point in comparison to the temperature at out of collector field is lower, which enables more efficient boiler functioning. It can be concluded that, in case of larger heat accumulator volume, the amplitude will be lower. However, high price of these devices causes considerable increase of investment charges, therefore, heat accumulator of larger volume could be profitable only in case of larger solar collectors' surface areas.

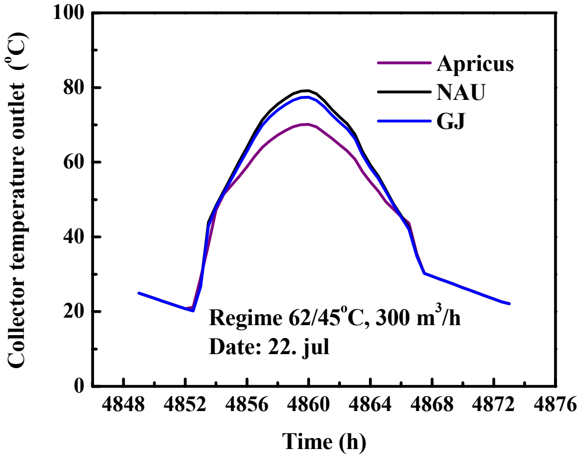


Figure 5. Comparison of temperature at collector field point

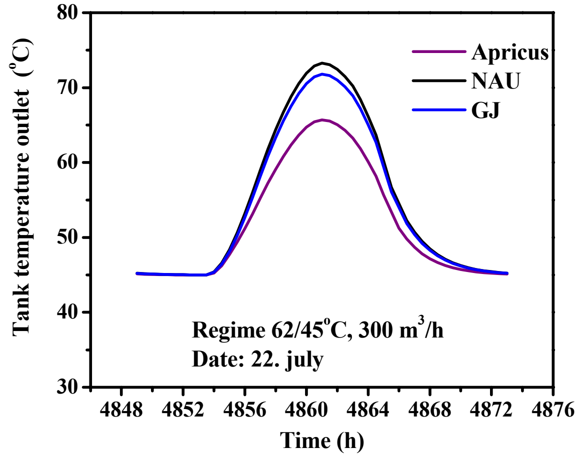


Figure 6. Comparison of temperature levels at heat accumulator's out point

Figure 8 shows comparison of temperature levels at collector's field out point for various operation modes of NAU type of collectors. In order to fairly compare temperatures, convection through collectors filed is identical for all 3 types of operation modes; therefore the exits temperatures are higher than requested ones. This comparison has been shown in order to obtain precise view on operation modes effect on collectors' functioning.

Table 2 contains sum of values of obtained heat by collectors segment in period 15th April-15th October, which corresponds to summer season of HP "Cerak". Displayed values refer to three collectors' types and for all three-simulation operation modes.

Table 2. Heat amount obtained from collector's field for the period 15 April-15 October

Collector	62/45°C, 300m^3/h	65/22°C, 120m^3/h	60/40°C, 250m^3/h
	Q (MJ)	Q (MJ)	Q (MJ)
a) Apricus	8027643.65	9156964.94	8334249.71
b) NAU	9718722.50	12367277.14	10351091.44
v) GJ	9108189.88	11764167.75	9734093.43

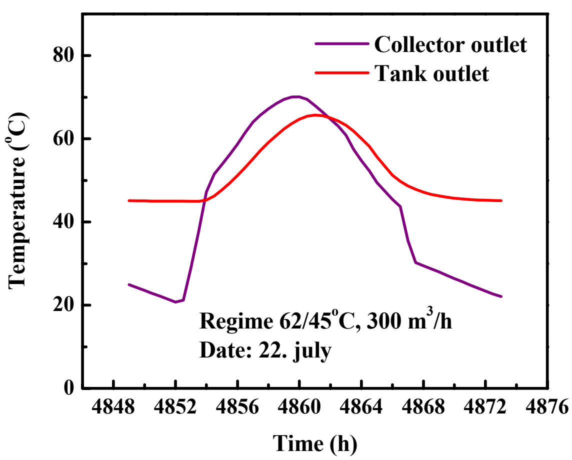


Figure 7. Comparison of temperature levels at collector's field out point and at heat accumulator's out point for NAU type of collectors

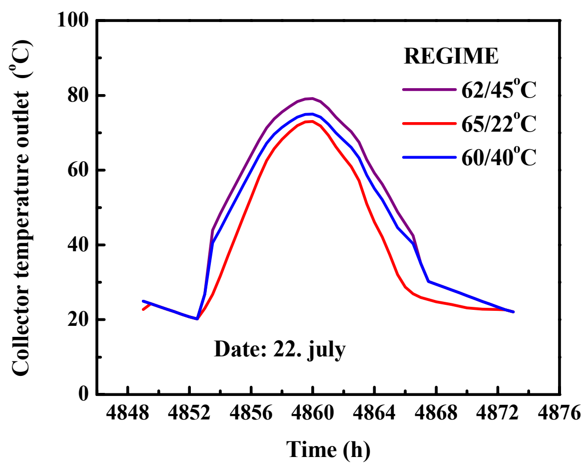


Figure 8. Comparison of temperature levels at collector's field out point for various operation modes of NAU type of collectors

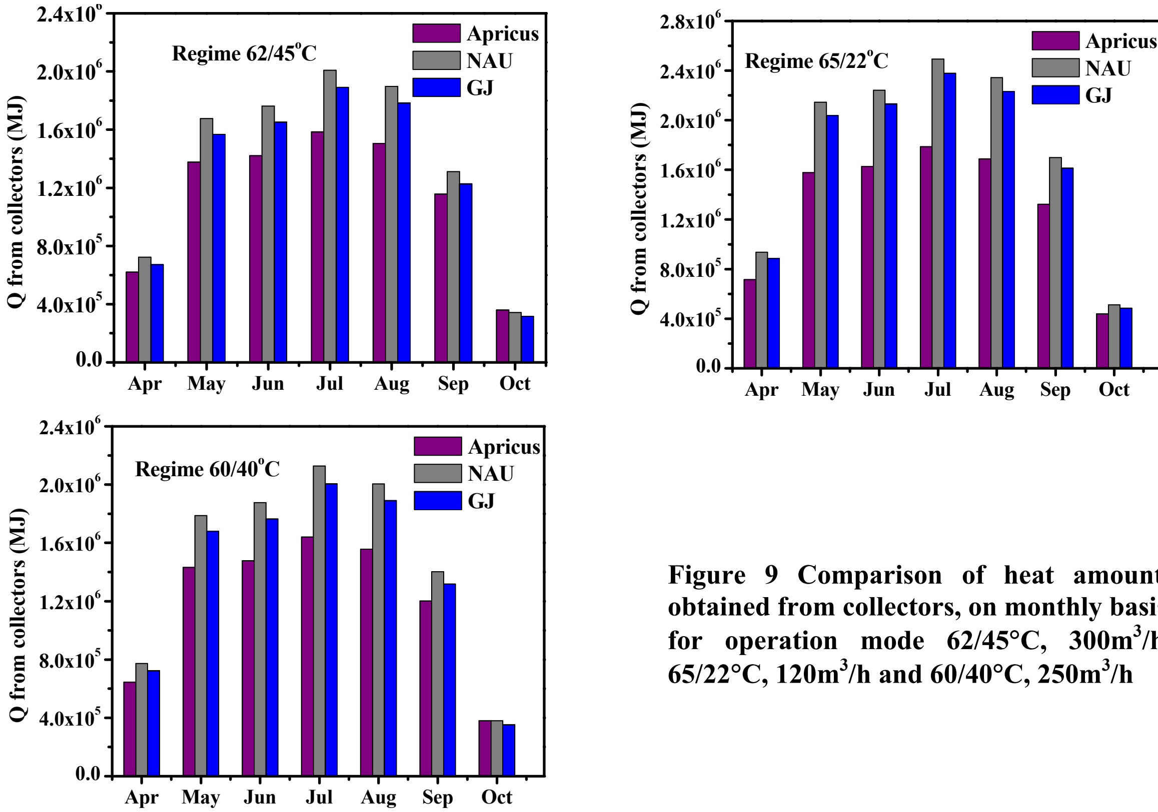
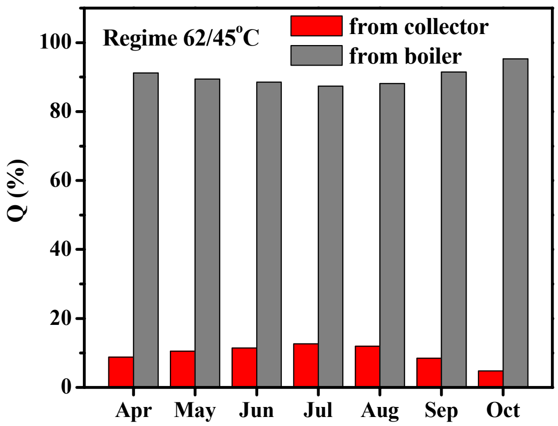
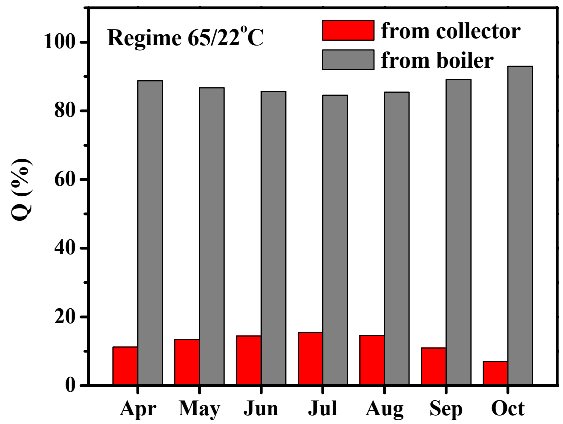


Figure 9 Comparison of heat amounts obtained from collectors, on monthly basis for operation mode 62/45°C, 300m^3/h; 65/22°C, 120m^3/h and 60/40°C, 250m^3/h

On Figure 9 the comparison of heat amounts is given for different types of collectors on monthly basis for all operation modes, with expected outcomes, which correlates to the output temperature results from collector's fields.

On Figure 10 diagrams of percent share of heat quantity obtained from the collector and boiler in comparison to the total heat capacity of combined system for hot water production are presented. The results of all three-operation modes are shown.





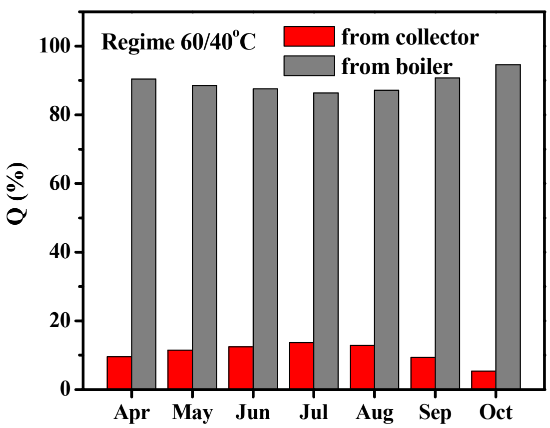


Figure 10. Percent share of heat quantity obtained from the NAU type of collector and boiler in comparison to the total heat capacity of combined system for hot water production for the operation mode 62/45°C, 300m^3/h; 65/22°C, 120m^3/h and 60/40°C, 250m^3/h

The presented diagrams show, as well as data on totally obtained heat quantity from solar collectors that the best results are for the designed operating mode. However, it presents ideal operating mode which cannot be implemented on HP "Cerak", therefore it represents the indicator where the future heating plant modernization should be directed. The comparison of operating modes 62/45°C, 300m^3/h and 60/40°C, 250m^3/h show that under combined production of heat energy by utilization of solar collectors and gas boilers, only on operating mode type, the savings could be up to 7% depending on used type of collector.

Table 8 presents total percentage of possible gas change by usage of collector system in energy units.

Table 8. Percent share from the heat received from collectors' field in the total necessary heat quantity for the specific operating mode for the period of 15 April-15 October

Collector	62/45°C, 300m^3/h	65/22°C, 120m^3/h	60/40°C, 250m^3/h
	%	%	%
a) Apricus	7.58	8.54	8.03
b) NAU	9.18	11.54	9.97
v) GJ	8.60	10.98	9.37

4. CONCLUSION

Simulation is made for combined system for DHW production for collector of 5000 m^2 during summer operating mode of HP “Cerak”. Three possible operating modes of combine system have been analyzed for the specified heat capacity of 6 MW:

- present 62/45 ^{o}S with flow of 300 m^3/h hot water,
- designed 65/22 ^{o}S with flow of 120 m^3/h and
- future 60/40 ^{o}S with flow of 250 m^3/h, that will be achieved after planned reconstruction and modernization of entire system of HP “Cerak”.

Simulation shows that gas savings are proportional to collector area, since significant advantages from solar radiation can be obtained during summer season. In accordance with type of collector and its operating mode, gas savings are ranging from 7.58% to 11.54%.

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