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COMPARATIVE ANALYSIS OF ALTERNATIVE SOLAR COLLECTORS FOR LOW-RISE HOUSING UNITS

Abstract: *Thanks to modern technological advances, a large number of various solar collector types have been developed to date. They vary in their exploitation characteristics, dimensions, mass, efficiency and of course price. Within this paper, for set roof surfaces, various types of solar collectors were used. Calculations of their installed and exploitation characteristics have been performed. Following the calculations an installation possibility analysis was performed to accommodate the fact that the collectors vary in their exploitation characteristics, dimensions, mass, efficiency and of course price. This paper also presents results of solar collector comparisons as well as directions for choosing an optimal solution.*
Keywords: *solar collectors, comparative analysis, domestic use, low-rise housing*

1. INTRODUCTION

The total amount of energy on the earth, except for geothermal, nuclear and fossil fuel energy comes from solar radiation. From the total amount of solar energy which reaches our planet around 30% is reflected from the atmosphere, while the rest is absorbed through it. Direct solar radiation energy can be used through its transformation to heat, electric or chemical energy. Of the aforementioned types of energy the easiest transformation to achieve solar energy to heat energy. Installations which achieve this energy transformation are called solar collectors. Dependent on the construction and method of collecting solar radiation energy, there are flat and focusing solar collectors. Flat solar collectors can reach temperatures of the working fluid of up to 100^0 C, while focusing solar collectors can heat the fluid up to 3000^0 C. Flat solar collectors are more widespread in use.

As a widely used, solar collectors represent a very current and attractive research subject in the field of renewable energy sources worldwide. As a result of research in this field various types of solar collectors have been developed: flat solar collectors with parallel tubes, flat solar panels with serpentine tubes, flat solar collectors with serpentine tubes between two plates, and solar collectors with vacuum tubes.

A very important characteristic in the efficiency of a collector is its position relative to the direction of solar radiation. Tand et al. [1], made a comparative analysis of vacuum solar collectors by measuring their efficiency according to their tilt angle towards the sun. Chen et al. [2], have made a comparative analysis of flat solar collectors with parallel tubes which have the same tilt angle. The difference between the compared flat solar collectors was in the cross-section of the tubes which transported the work fluid. Smyth et al. [3] compared various vacuum solar collectors on which various types of sleeves were installed. Zhang et al. [4] tested vacuum solar collectors with and without a heat shield. Fong et al. [5] made a comparative analysis between building integrated solar collectors and classic roof collectors. Ayompe et al. [6] experimentally compared flat solar collectors with parallel tubes and vacuum collectors for domestic water heating use. The same authors [7] tested flat solar collectors with parallel tubes as a better solution for domestic use. Azad [8] made an analysis of three types of solar collectors built into the same installation with the same exploitation conditions. Ceron et al. [9] conducted a numerical analysis with various versions of flat solar collectors which had parallel tubes above the absorber plate. In Serbia, a study of the amount of solar radiation was made, [10]. This study was done for the area of the Autonomous Province of Vojvodina.

In this paper a comparative analysis of two types of collectors: solar collectors with parallel tubes and vacuum solar collectors. All types of these collectors which are domestically produced, or are available on the market in Serbia have been taken into account. The motivation behind this research is the possibility of creating an optimal choice of solar collectors for domestic use. All types of solar collectors are observed through numerous criteria: dimensions, mass, capacity, efficiency, price, etc. All collector characteristics were taken from their catalogues. The paper concludes with an overview of the most suitable solutions for domestic use for the area of Serbia.

2. SOLAR COLLECTOR FUNCTION

Solar collectors are installations which are used for transforming solar radiation energy into heat energy of the working fluid. In Serbia two types of solar collectors can be purchased: flat solar collectors with parallel tubes and vacuum solar collectors.

2.1 Flat solar collectors with parallel tubes

Flat solar collectors with parallel tubes are the simplest installations for converting solar radiation energy into heat energy of the working fluid. These solar collectors consist of three basic parts: absorber with tubes, insulation housing, and glass. A flat solar collector is shown in Figure 1.

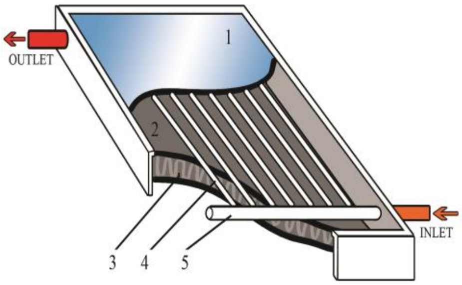

***Figure 1** - Flat solar collector: 1. glass plate; 2. absorber; 3. insulation; 4. tubes for working fluid heating; 5. main tubes.*

The glass plate can be singular, dual, or rarely triple layer. The glass plate has a dual use: to create a greenhouse effect and to thereby heat the thermal fluid, and to protect the absorber with tubes from external weather conditions. The absorber absorbs solar radiation and transfers the heat on the tubes for heating the working fluid. Insulation of the solar collector is there to prevent, as much as possible, dissipation of heat from the solar collector housing, and thereby increase its efficiency. The work fluid flows through the tubes for heating and absorbs heat energy from the absorber plate. The difference in the position of the tubes, whether they are above or below the absorber plate, is negligible. Two main tubes transport the work fluid in and out of the collector. The inlet tube delivers the work fluid at a lower temperature, while the outlet expels the fluid with an adopted heat energy from solar radiation at a higher temperature.

2.2 Solar collectors with vacuum tubes

Solar collectors with vacuum tubes have lower commercial use than flat solar collectors. Figure 2 shows a scheme of the function of a vacuum collector.

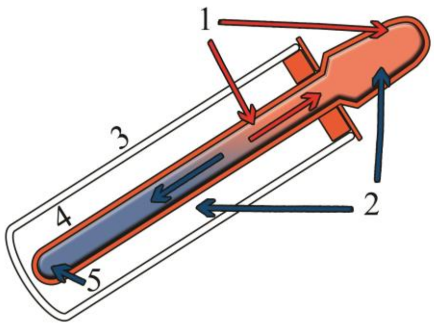

***Figure 2** - Vacuum solar collector: 1. Hot vapor rises to heat tube top; 2. Cooled vapor liquefies and returns to the bottom of the tube and repeat the cycle; 3. Evacuated tube; 4. Copper heat tube; 5. Non-toxic liquid*

Solar vacuum collectors consist of vacuum tubes. Vacuum tubes prevent heat dissipation from the collector. Inside the vacuum tube a copper tube is used as a heat absorber. The working fluid flows through these copper tubes. Vacuum solar collectors have a higher efficiency compared to flat solar collectors, as well as greater gross dimensions.

3. SOLAR COLLECTOR CATALOGUE CHARACTERISTICS

On the territory of Serbia flat solar collectors with parallel tubes and vacuum solar collectors can be purchased. Both types of collectors are generally imported, while very few companies produce them domestically. For the purposes of this research an overview of typical types of collectors which can be purchased in Serbia was created.

3.1 Characteristics of flat solar collectors

Flat solar collectors with parallels pipes are simple to install. This type of collector can be installed on house roofs, they can be integrated with roofs, and they can even be integrated into external walls. These collectors can be used to heat water in water heaters or as help for standard heating systems.

Their basic characteristics are:

- Long work life,
- High efficiency,
- Relatively fast investment return, through the benefits they provide,
- Resistance to weather conditions,
- High impact resistance,
- Simple installation and,
- Good price to performance ratio.

Prices of these solar collectors range from 100 to 150 EUR for 2 m^2 collectors. The price varies by their characteristics. Aside from price, these solar collectors differ by mass and dimensions. Frequently the performances of these collectors, for collectors of the same area vary in the same exploitation conditions. In table 1, nine representative types of flat solar collectors which can be purchased in Serbia, [11-13]. Some of the mentioned collectors are produced in Serbia, while others are imported.

Table 1. *Characteristics of flat plate solar collectors*

	Conseko, [11]			Elsol, [12]			Master solar, [13]		
Collector annotation	**CC-A**	**CC-A/F**	**CC-A/F Premium**	**Tip 1**	**Tip 2**	**Tip 3**	**PFM-S 2,01**	**PFM-W 2,01**	**PFM-S 2,55**
Area [m^2]	2,04	2,8	2,8	1,87	1,98	1,98	2.012	2.012	2.555
Length [mm]	1.900	2.200	2.200	1990	2000	2000	1702	1702	2162
Width [mm]	1.080	1.275	1.275	940	990	990	1182	1182	1182
Height [mm]	95	95	95	79	79	79	62	62	62
Empty collector mass [kg]	39,6	50	50	49	37	39	33	33	42
Working volume [l]	1,18	1,63	1,63	2,85	1,25	1,25	1,4	1,4	1,7
Absorption coefficient [%]	92	92	95	95	95	95	95	95	95
Working pressure [bar]	10	10	10	10	10	10	10	10	10

All collectors in table 1 have similar flow characteristics, which vary from 40-60 l/h, and work fluid pressure in collector tubes, which are around 10 bar.

3.2 Vacuum solar collector characteristics

Vacuum solar collectors are more complicated for installation than flat solar collectors. Vacuum solar collectors can be installed on house roofs or on previously prepared carrying structures. Vacuum collectors can be used for the same purposes and flat solar collectors. Basic characteristics of this type of collector are:

- Long work life
- Greater efficiency than flat solar collectors,
- Resistance to weather conditions,
- Good working efficiency in poor weather

conditions,

- Good price to performance ratio.

The price of vacuum solar collector is not calculated by surface area, as is the case with flat solar collectors, but by the number of vacuum tubes in the collector. For covering 2 m^2 with vacuum collectors, an investment of approximately 450 to 500 EUR must be made. The biggest variation with these collectors is in the dimensions and order of their tubes (how many tubes are in the collector). Generally vacuum collectors are made with 10, 15, 20, 25 or 30 tubes per solar unit. It is possible to create a collector which has an area suitable for the installation needs. In table 2 three representative types of vacuum solar collectors which can be found on the Serbian market, [14-16]. The BC-12ST collectors are domestically made, while others are imported.

***Table 2**. Characteristics of vacuum solar collectors*

	UNIS, [14]	Teflon inzenjering, [15]	Etaz, [16]
Collector annotation	**SP-S70/10**	**BC-12ST**	**CVSKC-10**
Area [m^2]	1,88	2,02	1,84
Length [mm]	1760	2040	1647
Width [mm]	1069	1110	1120
Height [mm]	155	180	107
Number of tubes [-]	10	12	10
Working pressure [bar]	8	8	10
Empty collector mass [kg]	35.2	46	31
Absorption efficiency coefficient [%]	81,9	82	81
Working flow [l/hour]	90	110	85

All vacuum collectors from table 2 have similar efficiencies. The greatest difference between them are their ability to operate under poor weather conditions.

4. COMPARATIVE ANALYSIS

For this comparative analysis two types of solar collectors, and three vacuum collectors were selected. These collectors were compared by the following criteria:

- dimensions,
- area,
- mass,
- work flow
- working fluid pressure in the collector.

4.1 Comparison of collectors by dimensions

By the dimension criteria flat solar collectors have a greater width and length than vacuum collectors, while vacuum collectors are almost twice as thick. Figure 3 shows a comparative diagram of average dimensions of the same classes of vacuum and flat solar collectors.

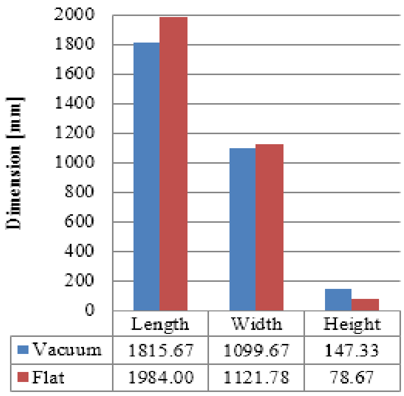

***Figure 3** - Comparison of dimensions*

Flat solar collectors are on average 9% longer and 2% wider than vacuum collectors. However vacuum collectors are almost 100% thicker.

4.2 Comparison of collectors by area

From the comparison of collectors by surface area in can be seen that flat solar collectors have a slightly larger surface area. This can also be concluded from the previous comparison of dimensions. Figure 4 shows a comparative diagram of average areas of flat and vacuum solar collectors.

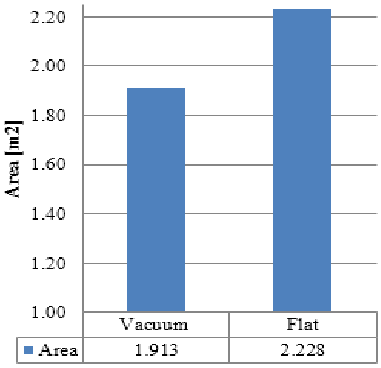

***Figure 4** - Comparison of area*

From Figure 4 it can be concluded that flat solar collectors have a 15% larger average area than vacuum collectors.

4.3 Comparison of collectors by mass

In terms of mass, flat solar collectors are again in a slight advantage over vacuum collectors. Figure 5 shows a comparison diagram of average masses of both collector types.

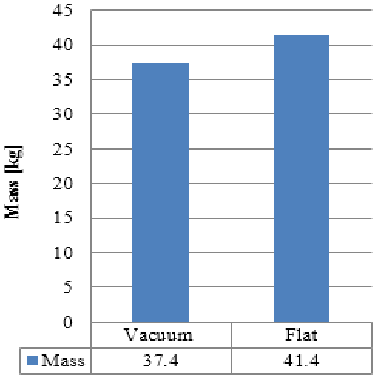

***Figure 5** - Comparison of mass*

From Figure 5 it can be concluded that flat solar collectors have on average a 10% greater mass than vacuum solar collectors.

4.4 Comparison of collectors by work pressure and flow

According to flow criteria, vacuum solar collectors have a far greater flow than flat solar collectors, however their pressure is somewhat less than that of flat solar collectors. Figure 6 shows a comparison diagram of flow and pressure in the system for flat and vacuum collectors.

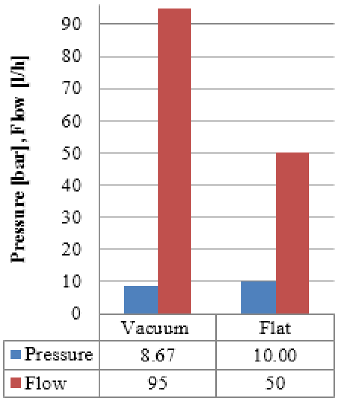

***Figure 6** - Comparison of pressure and flow*

Compared to flat solar collectors vacuum collectors have 48% heater flow in l/h. Flat solar collectors have in average 13% greater pressure in the system than vacuum solar collectors.

5. CONCLUSION

In this paper the method of functioning of two most widely used types of solar collectors was presented. A comparative analysis has been conducted based on their dimensions, mass, method of installation and price. Flat solar collectors, compared to vacuum collectors, are much easier to install. Flat solar collectors can be installed on roofs, integrated into roof structures, or even installed on external walls, while vacuum solar collectors can be installed either on roofs or on previously fabricated mounting structures. The advantages of vacuum solar collectors over flat collectors is that they can be set on an area depending on the number of tubes. This would mean that the entire roof of a house can be covered in vacuum collectors with tubes, while flat solar collectors would leave part of the roof unused. Another major advantage of vacuum collectors is a much greater ability to work in poor weather conditions. However the greatest drawback of vacuum solar collectors is a longer payoff time compared to flat solar collectors. Vacuum solar collectors are 60-75% greater than for flat collectors.

This paper gives rudiments for choice of solar collector according to installation type and exploitation payout. Technical specifications have been given for all compared collectors, and their characteristics have been compared. Further research in this field would be conducting experiments on these collectors and comparing their results. This research has a goal to determine the type of collector most suitable for implementation in the climate area of Serbia.

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