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COMPARISON OF EFFICIENCY VACUUM AND FLAT SOLAR COLLECTORS

The study characterized the construction and principle of operation of flat plate collectors and vacuum collectors. Describes the impact of design and operating conditions on the efficiency of solar collectors. Approximated the impact of various factors such as the temperature difference of the absorber and the surroundings and reflection solar radiation on the efficiency of the collectors. Presented a method for calculating the instantaneous efficiency by taking into account the optical efficiency, heat loss coefficient of linear, temperature difference between the absorber and the surroundings and solar radiation intensity. It described the issue of optical efficiency.

In order to compare the efficiency of flat collectors and vacuum collectors were carried out simulation studies for two installations and shows the results. The first of these is the solar system equipped with flat plate collectors and the other in the vacuum tube collectors with single glazing. Simulation studies conducted in computer application Kolektorek 2.0.

Based on the analysis of the construction of collectors, used insulation and conducted simulation studies, it was found that the more effective the insulation, the higher the efficiency of the collector. The greater the temperature difference, and ambient absorber, the lower is its efficiency and increased heat losses. The efficiency of the solar collector is variable over time and depends on various factors.

Key words: flat plate collectors, vacuum solar collectors, efficiency, absorber, Kolektorek 2.0

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СРАВНЕНИЕ ЭФФЕКТИВНОСТИ ВАКУУМНЫХ И ПЛОСКИХ СОЛНЕЧНЫХ КОЛЛЕКТОРОВ

Исследование охарактеризовал строительство и принцип работы плоских коллекторов пластины и вакуумных коллекторов. Описывает влияние конструктивных и эксплуатационных условий на эффективность солнечных коллекторов. Аппроксимировать влияние различных факторов, таких как разность температур абсорбера и окружающей средой и отражения солнечного излучения на эффективность коллекторов. Представлен метод расчета мгновенной эффективности с учетом оптической эффективности, коэффициент потери тепла линейных, разность температур между абсорбером и окружающей средой и интенсивности солнечной радиации. Он описал вопрос оптической эффективности.

Для того чтобы сравнить эффективность плоские коллекторы и вакуумные коллекторы были проведены исследования моделирования для двух установок и показывает результаты. Первым из них является солнечная система оснащена плоскими коллекторами, а другой в вакуумных трубчатых коллекторов с одинарным остеклением. Исследования моделирования проведены в компьютерное приложение Kolektorek 2.0.

На основе анализа конструкции коллекторов, используемых изоляции и проведенных исследований по моделированию, было установлено, что более эффективным изоляции, тем выше эффективность работы коллектора. Чем больше разница температур, и окружающего воздуха абсорбер, тем ниже его эффективность и повышенные потери тепла. Эффективность солнечного коллектора изменяется с течением времени и зависит от различных факторов.

Ключевые слова: плоские коллекторы пластины, вакуумные солнечные коллекторы, эффективность, абсорбера, Kolektorek 2,0

1. Introduction

Solar collectors are devices receiving heat from solar radiation and conveying them to the working fluid which then heats water in the tank. Due to the construction, solar collectors can be divided into flat and vacuum. Flat plate collectors and vacuum differ in terms of efficiency. The efficiency of solar collectors indicates what part of the solar radiation, falling on a given surface of active absorber, is changed to thermal power. The efficiency of the collectors is dependent on: the absorber, the heat insulation and the transparent cover, which differ flat plate collectors and vacuum. An important element of each collector is the absorber. Flat plate collectors are equipped with absorber made of flat aluminum or copper sheet coated with the coating selective or non-selective. Types of coatings are shown in Table 1. Absorber coating should have a maximum absorption coefficient α and the minimum emission factor ε [1, 2].

Table 1.

Coatings of absorber [6]

absorber coating	absorption coefficient (α)	emission factor (ε)
paint gray and black	0,87	0,87
lacquer „Solar "	0,90	0,25
black chrome	0,98	0,14
Aluminium covered by copper oxide	0,85	0,11
black copper	0,93	0,11
Tinox	0,95	0,05
Sunselect	0,95	0,05

Vacuum tube collectors have a different shape of the absorber than flat plate collectors. Depending on the type of vacuum collector, the absorber may have different shapes. The absorber is disposed around the periphery of the inner tube in the case of collector with double pipes or in the form of a flat plate located inside the single pipe of heat pipe collectors. Another factor affecting the efficiency is insulation. In the flat collectors, the mineral wool or polyurethane is used as insulation. Insulation in the vacuum collectors is vacuum, which is provided between concentric tubes or in the case of single pipe, the vacuum insulation is in entire volume of pipe. The vacuum insulation is much better insulator than wool. On the efficiency also affects the glass cover, which should have a maximum transmittance of solar radiation [3, 4].

2. Efficiency of solar collectors

The efficiency of the solar collector changes with time and is dependent on many factors. One of them is the difference in temperature of the absorber and the environment.

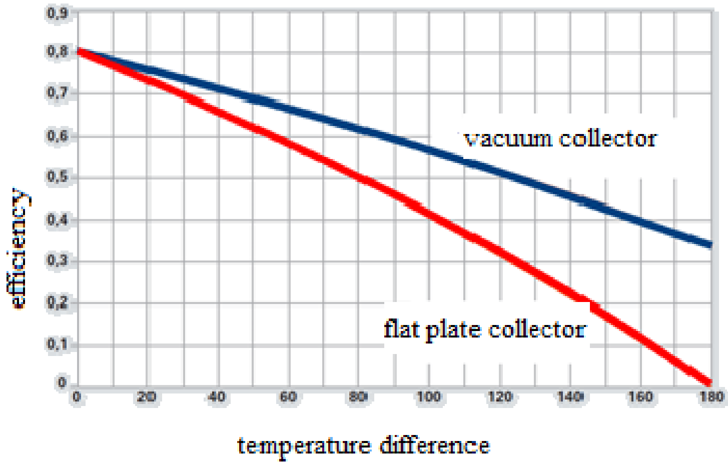

Fig. 1 – The dependence of the efficiency of a flat plate collector and single wall vacuum collector from the temperature difference of the absorber and the environment [8]

Figure 1 shows the dependence the efficiency of solar collectors on the temperature difference. The efficiency of the solar collector depend on many factors. One of the factors is the temperature of the collector, the higher the temperature, the greater the heat loss to the environment and reduced efficiency. The collector heats up and loses heat to the surroundings by convection, heat transfer and heat conduction processes. Heat losses are closely related to the temperature difference between absorber and environment. In addition to heat loss can be distinguished the optical losses, which reduce the efficiency of the collector. The optical losses are associated with the absorption and a reflectivity of solar radiation through the transparent cover of the solar collector. The graph also shows that the more effective the insulation, the higher is the efficiency. Vacuum is a better insulator than mineral wool, so a single wall vacuum collector achieves higher efficiency at the same temperature difference dT in comparision to the flat plate collector. Despite that vacuum is a very good insulator, efficiency in double glazing vacuum collectors may be lower than in the case of flat plate collectors. This is due to the double barrier of glass, which solar radiation has to overcome.

The efficiency of the solar collector is a quotient of the of heat energy obtained by the heating fluid by irradiation of the surface of the collector at a given time. The formula for the calculation of the efficiency of the solar collector is expressed as follows:

$$\eta = \frac{Q_u}{M_e \bullet S} \bullet 100\%$$

where η – efficiency of solar collector [%],

Q_u - stream of useful energy [W],

M_e - solar radiation power [W/m^2],

S – active absorption surface of solar collector [m^2].

After transformation, the following dependence is obtained:

$$\eta = \frac{m \bullet c_p \bullet (T_{wy} - T_{we})}{M_e \bullet S} \bullet 100\%$$

where η – efficiency of solar collector [%],

m – a mass flow of refrigerant in the collector [kg/s],

c_p - specific heat of solar fluid [J/kg• °C],

T_{wy} - temperature of heating medium at the outlet of the collector [°C]

T_{we} - temperature of heating medium at the outlet of the heat exchanger [°C]

M_e - solar radiation power [W/m^2],

S – active absorption surface of solar collector [m^2].

The highest value of efficiency, which can be achieved by solar collector, is optical efficiency. The optical efficiency is determined in the absence of heat loss to the surroundings and indicates which part of the solar radiation reaches to the absorber and can be used to produce heat. Optical efficiency depends on design features and materials used for the construction of the collector.

Is applied the concept of the daily average efficiency and average efficiency over the entire operating cycle, which is an average value of the instantaneous efficiency at a given time. Instantaneous efficiency η (figure 2) is calculated with the following formula:

$$\eta = \eta_0 - \frac{a_1 \bullet \Delta T}{E_g} - \frac{a_2 \bullet \Delta T^2}{E_g}$$

where η_0 – optical efficiency,

a_1, a_2 – coefficients of heat loss,

ΔT – the temperature difference between the absorber and the environment,

E_g – solar irradiance.

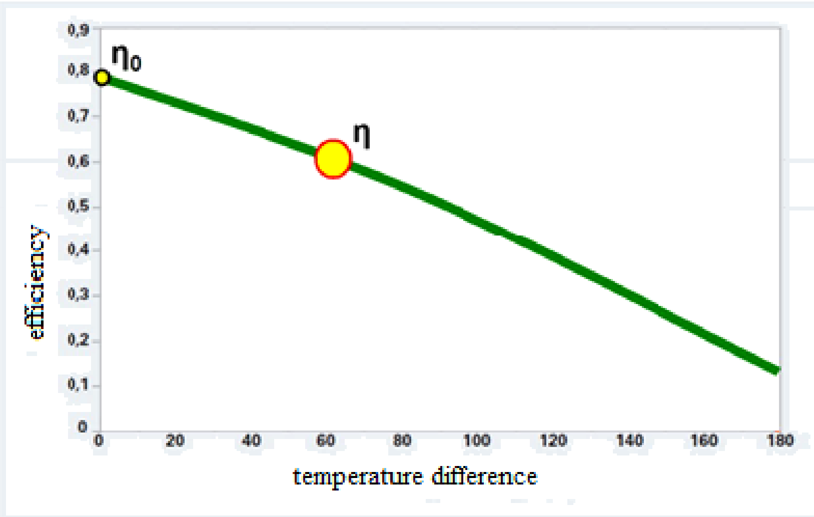

Fig. 2 – The instantaneous efficiency of the solar collector [8]

With the increase in the coefficient of heat loss a1 the slope of the efficiency curve is increasing. Then, when the temperature of the absorber is higher than the ambient temperature, the collector will obtain lower efficiency. The higher the coefficient of heat loss a2, the efficiency curve is more convex. The collector has high efficiency when operating at lower temperatures the absorber.

Vacuum tube collectors with a single pipe are characterized by high optical efficiency, allowing achieve high efficiency in a wider range of work than flat plate collectors. Collectors with double-walled pipes have a lower optical efficiency and despite the vacuum as an insulator, only in a limited range of work achieves higher efficiency than flat-plate collector [7].

3. Comparison of the efficiency of flat and vacuum collectors on the example

3.1. Methodology

Collectors efficiency were compared based on the results of simulation studies. Simulation studies were carried out in a computer application Kolektorek 2.0. Algorithm of the program is composed of five areas, which are marked in figure 3:

- Selection of devices and locations (marked in red),
- Selection of the type of installation (marked in green),
- Project assumptions (marked in gray),
- Information about selected devices and locations (marked in yellow),
- The most important results (marked in blue).

The program after entering the design assumptions, choosing the devices and locations generates a report, which contains information about monthly and yearly energy yield from m2 of solar collector, period of investment payback, the average annual savings, annual pollution reduction, installation costs and monthly average efficiencies of collectors and entire installation. Were conducted two simulations. The first relates to the installation of solar flat plate collectors and the second relates to installation of solar heat pipe vacuum collectors. From both reports get graphs of the efficiency in each month to compare the efficiency of the collectors.

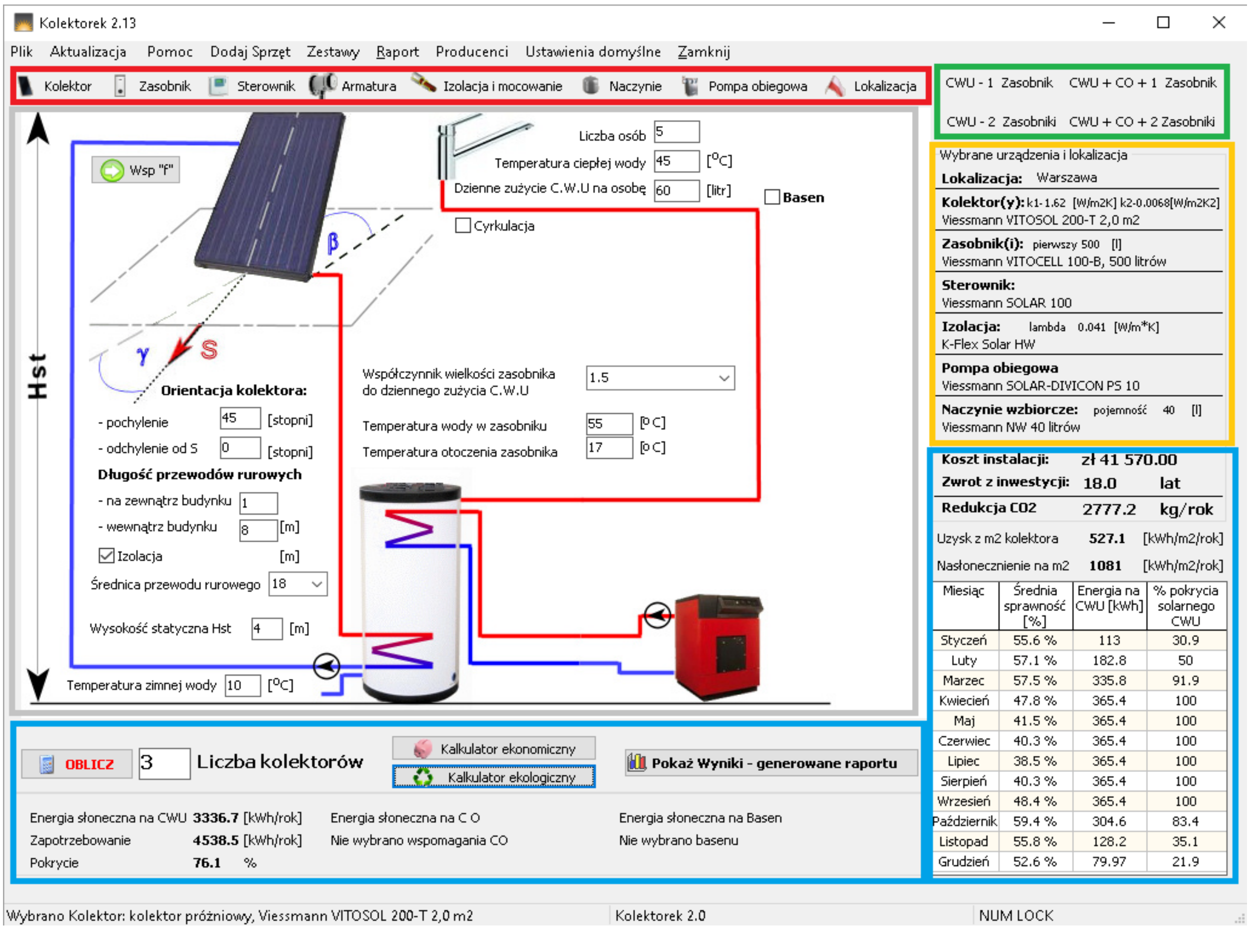

Fig. 3 – The program window Kolektorek 2.0 [own study - Kolektorek 2.0]

3.2. Results of simulation studies

The simulation tests compared three solar collectors flat and three solar collectors Vacuum heat pipe. Effective surface of flat solar collectors was 6.99 m^2 whereas solar collectors type of heat pipe 6.33 m^2. The data on the selected solar collectors is shown in table 2 and 3.

Table 2.

The data collector Viessmann VITOSOL 200-F [own study program Kolektorek 2.0]

manufacturer or distributor	Viessmann Sp. z o.o.
type	Flat plate collectors
manufacturer - model	Viessmann VITOSOL 200-F 2,3m2
coefficients linear	2.565 [W/m2*K1]
coefficients quadratic	0.02 [W/m2*K2]
optical efficiency	84.4 [%]
the intensity of unit	92 [litr/h]
unit pressure	200 [mbar]
capacity absorber	1.83 [litr]
effective surface	2.33 [m2]
net price	2 975.00 zł

Table 3.

The data collector Viessmann VITOSOL 200-T [own study program Kolektorek 2.0]

manufacturer or distributor	Viessmann Sp. z o.o.
type	Vacuum solar collectors
manufacturer - model	Viessmann VITOSOL 200-T 2,0 m2
coefficients linear	1.62 [W/m2*K1]
coefficients quadratic	0.0068 [W/m2*K2]
optical efficiency	82 [%]
the intensity of unit	180 [litr/h]
unit pressure	5 [mbar]
capacity absorber	4.2 [litr]
effective surface	2.11 [m2]
net price	6 923.00 zł

Figure 4 and 5 present graphs of the efficiency of solar collectors obtained from simulations. Calculations show that the annual average efficiency of flat solar collectors is 44.5%. It is anticipated that the highest efficiency they achieve in October and it will amount to 48.7%. In the case of vacuum collectorsannual average efficiency is 58.8%. Calculations suggest that the highest efficiency is 61.4% and occurs in October.

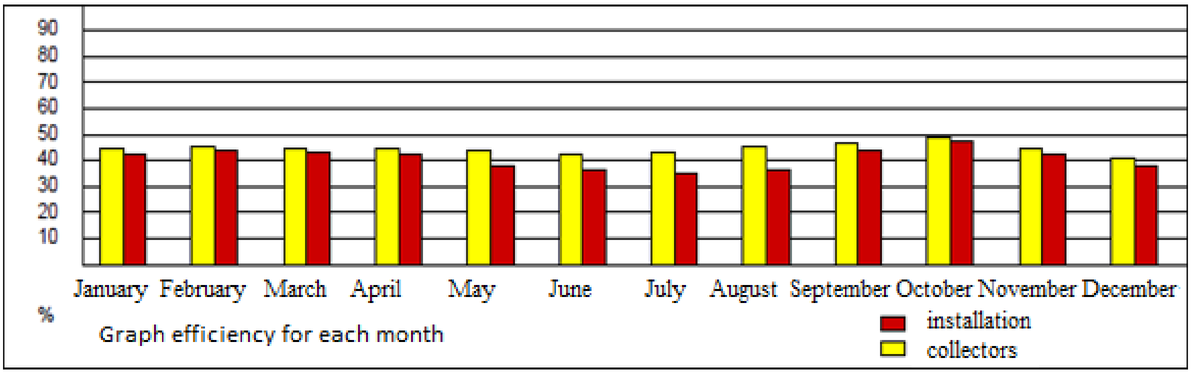

Fig. 4 – Graph efficiency for each month for the flat-plate collectors installation [own research - Kolektorek 2.0]

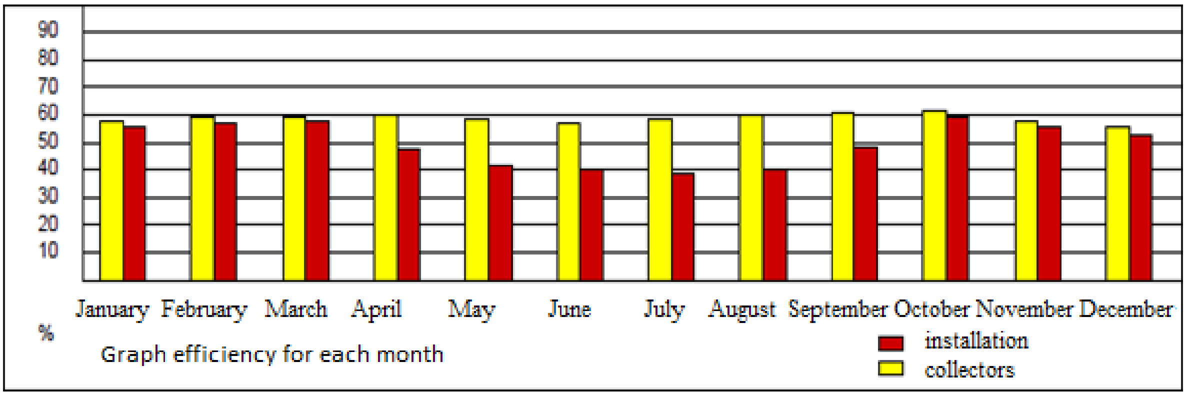

Fig. 5 – Graph efficiency for each month for the vacuum tube collectors installation [own research - Kolektorek 2.0]

In table 4 were collected the results of simulation studies. The annual average efficiency and maximum monthly average efficiency are much higher for vacuum collectors. Calculations show that the minimal average monthly efficiency for both types of collectors is at a similar level. Although the optical efficiency of vacuum tube collectors is lower, they have higher efficiency than flat plate collectors.

Table 4.

Comparison of the efficiency of solar collectors on the basis of the results of simulation studies

Comparison of the efficiency of the collector		
	Flat plate collectors	Vacuum solar collectors (heat pipe)
Average annual efficiency	44,5%	58,8%
Maximum monthly average efficiency	48,7%	61,4%
Minimum monthly average efficiency	40,8%	40,3%
Optical efficiency	84,4%	82,0%

Summary and conclusions

On the basis of analysis conducted in the work, literature studies and own research, can be found that vacuum tube collectors with a single tube are reaching higher efficiency than flat plate collectors. The efficiency of the collector is variable over time and depends on various factors. The more the temperature of collectors increases, the greater are the heat loss and the lower is the efficiency. On the basis of the characteristics of efficiency can be read the typical workspaces of collector. Simulation studies have enabled to analyze the efficiency of collectors throughout the year.

References

1. Gałusza M., Paruch J., Guła A., 2008. Odnawialne i niekonwencjonalne źródła energii : poradnik. Wydawnictwo TARBONUS. Kraków-Tarnobrzeg.
2. Lewandowski W. M., 2006. Proekologiczne odnawialne źródła energii. Wydawnictwo Naukowo-Techniczne. Warszawa.
3. Nowicki M., 2012. Nadchodzi era słońca. Wydawnictwo Naukowe PWN. Warszawa.
4. Smolec W., 2000. Fototermiczna konwersja energii słonecznej. Wydawnictwo Naukowe PWN. Warszawa.
5. Tytko R., 2013. Urządzenia i systemy energetyki odnawialnej. Wydawnictwo i Drukarnia Towarzystwa Słowaków w Polsce. Kraków.
6. Wolańczyk F., 2011. Jak wykorzystać darowaną energię. Wydawnictwo i Handel Książkami "KaBe". Krosno.
7. Wiśniewski G., Gołębiewski S., Gryciuk M., 2001. Kolektory słoneczne poradnik wykorzystania energii słonecznej. Centralny Ośrodek Informacji Budownictwa. Warszawa.
8. http://www.oze.utp.edu.pl/zseminarium/3.3%20Instalacje%20solarne%20-%20Projektowanie.pdf [dostęp 12.03.2016r.]

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