EFFICIENCY ANALYSIS OF SOLAR FACILITIES FOR BUILDING HEATING AND HOUSEHOLD WATER HEATING UNDER CONDITIONS IN THE CZECH REPUBLIC

ANALÝZA EFEKTIVITY SOLÁRNYCH ZARIADENÍ PRE OHREV ÚŽITKOVEJ VODY A VYKUROVANIE BUDOV V PODMIENKACH ČESKEJ REPUBLIKY

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Abstract

The paper studies the efficiency of solar facilities applied for the heating of buildings and household water heating in the Czech Republic. The Czech Republic is situated in the temperate zone characterized by changeable weather. It is respected in the assessment of a solar facility installation. The efficiency of solar facilities is evaluated according to energy and economic balances. It is analyzed for solar facilities heating both household water and buildings. The main problems relating to the implementation of solar facilities and their operation in the temperate zone with hot summer and freezing winter are discussed.

Abstrakt

Štúdia v tomto článku sa zaoberá efektivitou solárnych zariadení pre ohrev úžitkovej vody a vykurovanie budov v Českej republike. Česká republika je situovaná v miernom podnebnom pásme, to by malo byť brané do úvahy pri inštalácii solárnych zariadení. Efektivita solárnych zariadení je hodnotená podľa energetických a ekonomických bilancií. Analyzované sú solárne zariadenia pre ohrev úžitkovej vody a vykurovanie budov. Hlavný problém súvisí s implementáciou solárnych zariadení a ich prevádzka v miernom podnebnom pásme so striedajúcimi sa horúcimi letami a chladnými zimami.

Key words: Solar facilities, Czech Republic, energy exploitation, economic balance.

1 INTRODUCTION

Due to the increase in conventional energy prices and environmental effects, such as air pollution, ozone layer depletion and greenhouse effects, the use of solar energy has increased, following the energy crisis in the 1970s. Solar energy is being seriously considered for satisfying a part of the energy demand in countries of European Union [1]. Alternative energy resources such as solar energy have made public and private sectors interested in investing in energy generation from this source extensively. The common drawbacks to solar energy options are their unforeseeable nature. However, there are daily and seasonal complementary relationships between fossil fuel energy and solar energy [2]. There are many solar facilities exploiting solar energy and thus it is complicated to decide for the most suitable one without sufficient knowledge and ability to gain insight into the data provided by solar facility producers, which are often distorted or just theoretical, practically unverified ones. Confusing results and a promised energy profit recalculated to economic profit fundamentally affect the decision to implement a solar facility. Therefore, it is essential to take into account several basic principles such as the purpose of solar facility utilization, the climate of the place, the initial investment costs, payback period and the age of the building, and whether it is a passive house or not. Accurate information on the intensity of solar radiation in a given location is essential for the development of solar energy-based projects. This information is used in the design of a project, in the cost analysis, and in the calculations of the efficiency of the project. In particular, the clearness index of the area, in addition to other meteorological information such as humidity and temperature for a specific period, is extremely important to assess the feasibility of a solar-driven project [3]. As there are many aspects in these issues it is necessary to focus on specific building properties. Tabulator values represented by sellers of solar facilities are a general problem. However, an installation of a solar facility demands to elaborate a design of specific building properties respecting the specific area and all aspects which affect its advantages.

2 CLIMATE AND TECHNICAL CONDITIONS IN THE CZECH REPUBLIC

At the beginning, before the implementation of a solar facility, it is necessary to consider climatic conditions typical for the area. The most important indicator characterizing the efficiency of solar facility operation is the annual sum of global solar radiation. The average for the Czech Republic is about 1 080 kWh/m^2 [4]. However, in case of the Czech Republic it is important to take under consideration the locality of a solar facility installation because the climate here differs significantly from place to place. Fig. 1 serves as an example.

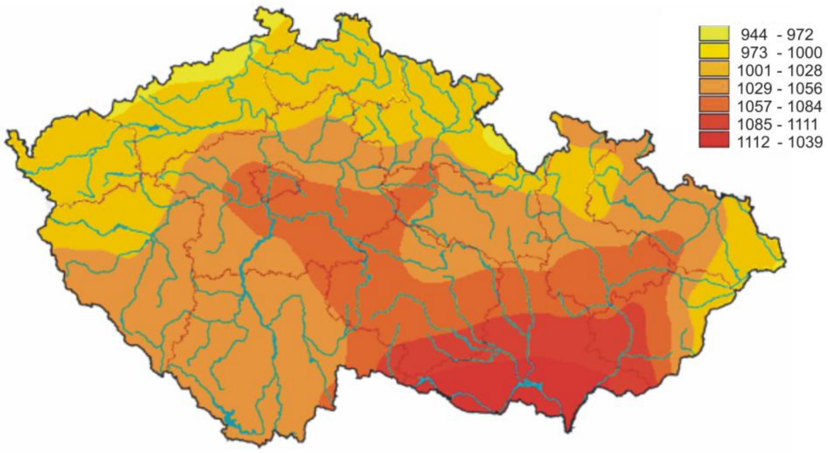


Fig. 1 Average annual sum of global radiation [kWh/m^2] [5].

Fig. 1shows that the least sun radiation per year is in the north-west of the Czech Republic; its biggest amount is in the south of Moravia. As with the sun radiation amount, the average sun radiation period in the Czech Republic varies up to 500 hours per year. Moreover, it is necessary to be aware of the number of cloudless days that vary up to 40 days per year [5]. This essential information is not often respected and sellers of solar equipment present the average values which distort the real energy profit of the facility. The efficiency of a solar facility, or a solar collector, depends especially on the difference between the temperatures of its absorber (fluid heat carrier) and the surrounding air [6]. The higher the temperature we require for household water heating, the worse efficiency of the facility is. For that reason, the temperature of the outside air is important. The average outside temperature in the area of the Czech Republic in last ten years is worked out in Tab. 1.

Tab. 1 The average temperature in the Czech Republic in the period of 2001 – 2010.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
January	-1.3	-1.1	-2.2	-3.7	0.0	-6.0	3.6	1.7	-3.7	-4.7	-1.7
February	0.5	3.7	-4.1	0.8	-3.3	-2.7	3.2	2.6	-0.6	-1.4	-0.1
March	3.8	4.5	3.7	2.8	1.2	0.4	5.5	3.4	3.6	3.1	3.2
April	7.2	7.9	7.6	9.1	9.3	8.6	10.6	8.3	12.3	8.5	8.9
May	14.6	15.8	15.4	11.7	13.3	13.1	14.8	13.9	13.6	11.9	13.8
June	14.5	17.7	19.7	15.7	16.4	17.3	18.5	17.8	15.3	17.0	17.0
July	18.3	19.0	18.7	17.5	18.3	21.7	18.7	18.4	18.5	20.4	19.0
August	18.6	18.9	20.5	18.5	16.2	15.5	18.1	17.9	18.8	17.5	18.1
September	11.6	12.2	13.6	13.2	14.4	15.8	11.7	12.4	15.1	-	13.3
October	11.6	7.2	5.3	9.6	9.3	10.4	7.5	8.6	7.6	-	8.6
November	1.8	5.1	5.0	3.6	2.3	5.9	1.8	4.9	5.8	-	4.0
December	-3.4	-2.8	-0.4	-0.4	-1.0	2.5	-0.6	1.1	-0.7	-	-0.6
Average	8.2	9	8.6	8.2	8.0	8.5	9.4	9.2	8.8	9.0	8.0

The average annual temperature in last decades oscillates between 8 °C to 9 °C. The highlighted months are the months of heating season when the heat produced by a solar facility is the most useful one. There is a variance between the ration of produced energy by a solar facility and the energy useful for the heating of each carrier in a solar facility. The relation between the energy demand for heat production and the solar facility power is depicted in Fig. 2.

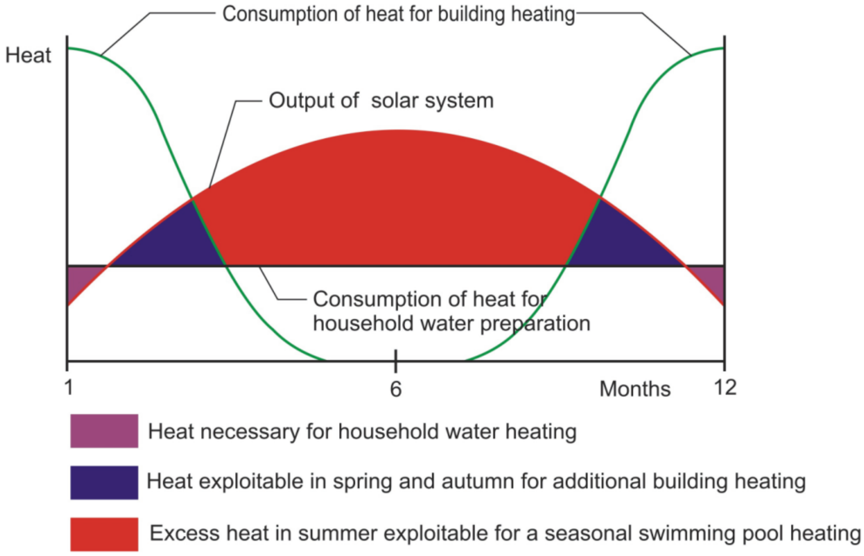


Fig. 2 Potential of energy for solar facilities [6].

The demand of heat for the building heating and household water heating during a year is clear from Fig. 2. An enormous disproportion in energy is apparent. In summer, a solar facility reaches the excess energy and in winter it misses a significant ration of heat to supply its own order. In the Czech Republic, 75 % of annual solar radiation is outside the heating season, just 25 % of solar energy is in the months of the heating season [5]. It is a main disadvantage of solar facilities, which has to be taken into consideration during the decision making for the solar facility purpose.

3 DISCUSSION OF SOLAR FACILITIY EXPLOITATION

Heating a building requires much more energy and larger panels than heating a building's water system. There are several possibilities of solar facility exploitation. It is necessary to be aware of the solar facility purpose, the climate in the area, possible initial investment and economic demand of the facility during its whole lifecycle [7].

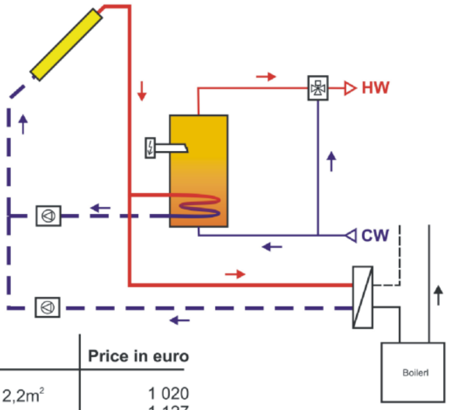
Solar heating of buildings and household water

At the first sight, the solar heating of buildings and household water sounds as a good environmental solution. The sellers of solar facilities often present their great advantage in the ability to heat or just preheat household water during months such as April, May, September, eventually, October when the sun radiation is not so sufficient. It is not an adequate solution for the majority of buildings and the energy profit is negligible. The prerequisite for building solar heating such as a good term isolation and the availability of low term heating in the floor, walls or ceilings is often marginalized. However, the possibilities of solar systems usage for heating are considerably limited in the Czech Republic. In Fig. 3, economic balances are recalculated for a little detached house. It is a heating system with an immediate exploitation of solar energy. The energy profit of the system is low so in a long period it seems really uneconomical. It is clear, there are a lot of technical possibilities for solar heating but the purchase costs are often so high that it is not possible to ensure their payoff in a reasonable period.

Economic balance of heat for building heating

Price of collectors in euro	**1 020**
Number of collectors	**4**
Investments in euro without VAT	**6 156 ***
Energy profit of collector GJ/year	**3,57**
Energy profit of system GJ/year	**14,28**
Price of Gas in euro/GJ **[8]**	**15,2**
Annual profit of system in euro	**217**
Payoff in years	**28,4**
Lifetime of collector 25 to 30 years	

*VAT, installation, maintanance, energy consumption are not included in the price.



Components	**Type**	**Price in euro**
Collector	Collector/vacuum tube collector KTU 9R 2,2m^2	1 020
Acummulative reservoir	Acummulative reservoir NADO 1000 v3	1 127
Tube	20 m	205
Pump	Circulatory pump GRUNDFOS Alpha	152
Tree-way valve	SF20-E3/4"	64
Ventilation valve	FlwoSep V	61
Expansive tank	Reflex S 25	158
Equipment for fixation	S-UPS3	167
Anti-freezing fluid	KOLPS-10	64
Heat sensor	FRP6	18
Regulator	SR 1.0	60

Fig. 3 Scheme of a heating system with the immediate exploitation of solar energy.

Solar energy serves in the Czech Republic effectively just during summer and alternatively on hot days of transition time. It is important to emphasize, the energy used just for household water heating is advantageous. Solar energy in the Czech Republic is not recommended for the heating of buildings. The main reason is the temperature needed for the household water heating. It is enough to be about 40°C warm, in contrast with the temperature of water used for the heating of buildings where the temperature on the reverse heater has to be 40 – 60 °C, moreover on conditions of low term heating [9]. Because of climate variations, it is almost impossible to reach a sufficient operating temperature. The rotation of seasons during the year is the main disadvantage of solar systems. The insufficient solar radiation and low temperatures in winter make the solar system for water heating nearly impossible to reach required efficiency because it demands much higher operating temperature. On the contrary, in summer with enough sun energy there is a problem with the excess energy which is difficult to process valuably. The frequent solution is the heating of water for home swimming pools. In summer, solar systems composed of flat plate solar collectors are more advantageous than vacuum ones which are less sufficient in warm months. The tubular collectors have an absorber isolated by vacuum, which enables the facilities to operate in chilly months. In Fig. 4, enormous heat losses mainly of flat plate collectors are presented. However, in summer its losses are unsubstantial. On the contrary, medium tubes of vacuum tubular collectors are overheated in summer, which causes damages on the facility.

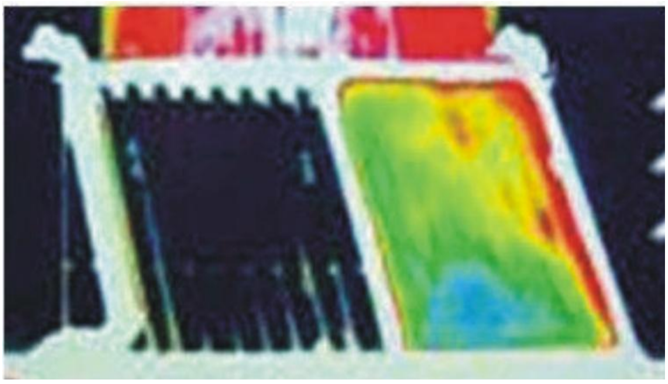
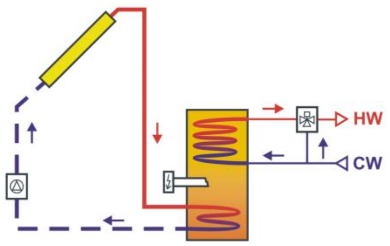


Fig. 4 Thermo shot of a flat plate collector and tubular collector (on the left) [10].

Generally, it is necessary to use a huge area of collectors of high efficiency to cover partially the demands for the heating of buildings and household water heating in winter. The main disadvantage of a highly efficient vacuum collector is high costs for its purchase. The payoff of its purchase costs on the conditions in the Czech Republic is possible just in a long period which is almost as long as its lifetime. The purchase costs have to be taken into consideration for the overall evaluation of the solar facility. The simple flat plate collector whose efficiency slumps with the difference of temperatures is almost incapable to heat the household water in winter.

All in all, the flat plate collector is able to cover 52% – 60% of its purchase costs for household water heating in months of summer and transition time, which is supposed to be a satisfactory solution [10]. In Fig. 5, a simple economic balance corresponding a small detached house is depicted. It deals with the heating of household water by the flow through a storage reservoir with an electric afterheating. In this case, the temperature of water does not reach required values, the electric afterheating of water in the reservoir starts operating.



Economic balance of heat for household water preparation

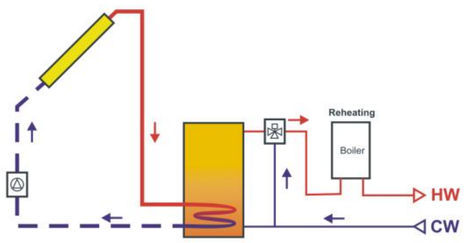
Price of collectors in euro	**1 021**
Number of collectors	**4**
Investments in euro without VAT	**2 592 ***
Energy profit of collector GJ/year	**4,31**
Energy profit of system GJ/year	**17,24**
Price of Gas in euro/GJ **[8]**	**15,2**
Annual profit of system in euro	**261**
Payoff in years	**9,9**
Lifetime of collector 25 to 30 years	

* VAT, installation, maintanance, energy consumption are not included in the price.

Components	Type	Price in euro
Collector	Vacuum tube collector KTU 9R 2,2m^2	1 020
Solar reservoir	Acummulative reservoir NADO 1000 v3	1 127
Tube	20 m	205
Pump	Circulatory pump GRUNDFOS Alpha	152
Three-way valve	SF20-E3/4"	64
Ventilation valve	FlwoSep V	61
Expansive tank	Reflex S 25	158
Equipment for fixation	S-UPS3	167
Anti-freezing fluid	KOLPS-10	64
Heat sensor	FRP6	18
		60

Fig. 5 Scheme for the heating of household water by the flow through a storage reservoir with an electric afterheating.

Further possibility of household water heating is shown in Fig. 6. The heat transfer fluid flows through a storage reservoir, and in case of insufficient temperature a gas boiler initiates the afterheating. The example presents the earlier return on the facility purchase, which is not caused by the difference in the chart for household water heating but by the number of collectors. In Fig. 6, more warm household water is demanded than in Fig. 5 so it is necessary to enhance the area of collectors. It is confirmed the larger area of collectors, the biggest energy profit and earlier payoff of the facility [10].



Economic balance of heat for household water preparation

Price of collectors in euro	**303**
Number of collectors	**10**
Investments in euro without VAT	**4 526 ***
Energy profit of collector GJ/year	**4,31**
Energy profit of system GJ/year	**43,1**
Price of Gas in euro/GJ **[8]**	**15,2**
Annual profit of system in euro	**654**
Payoff in years	**8,0**
Lifetime of collector 25 to 30 years	

*VAT, installation, maintanance, energy consumption are not included in the price.

Components	Type	Price in euro
Collector	Vacuum tube collector KTU 9R 2,2m^2	303
Solar reservoir	VTS 500/2 bivalent	1 021
Tube	50 m	512
Pump	Circulatory pump GRUNDFOS Alpha	152
Three-way valve	SF20-E3/4"	64
Ventilation valve	FlwoSep V	61
Expansive tank	Reflex S 25	158
Equipment for fixation	S-UPS3	167
Anti-freezing fluid	KOLPS-10	64
Heat sensor	FRP6	18

Fig. 6 Scheme for household water heating with a gas boiler afterheating.

4 ENERGY BALANCE OF COLLECTORS

An essential issue for the effective operation of a solar facility is the amount of solar radiation which is adsorbed and further converted into heat energy [11]. In the respect of variance of the materials and quality of solar facilities construction, the efficiency of facilities differs considerably. Tab. 2 compares the energy balances of vacuum and flat plate collectors. As mentioned above, tubular collectors are not so efficient, however, in cold months they are able to reach a bigger energy profit in comparison with flat plate collectors because of the vacuum isolation of the absorber and a low heat loss. The calculation of a theoretical heat profit for solar collectors is showed below (1) .

$$Q_u = G \, . \, A_k \, . \, \tau \, . \, \alpha - U_p \, . \, A_k \, . \, (t_{abs} - t_e) - U_z \, . \, A_k - (t_{abs} - t_e) - U_b \, . \, A_b \, . \, (t_{abs} - t_e) \quad (1)$$ [12].

where:

Q_u - max theoretical heat profit for solar collector [GJ/year],

η - collector efficiency,

η_0 - collector optical efficiency,

t_{abs} - average temperature of absorber [°C, K],

t_e - outdoor temperature [°C, K],

G - global sun radiation [W/m^2], (counted with average sun radiation),

A_k - collector surface [m^2],

A_b - absorber surface [m^2],

τ - permeability of collector glazing for sun radiation,

α - absorptation capacity of absorber for sun radiation,

U_p - heat passage coefficient through the front of the collector [W/m^2.K],

U_z - heat passage coefficient through the back of the collector [W/m^2.K],

U_b - heat passage coefficient through the lateral sides of the collector [W/m^2.K].

Tab. 2 Calculation of theoretical heat profit for solar collectors. (Data from technical lists of cllectors).

Parameters	Vacuum Tubulous Collector	Flat Plate Collector
η	0,68	0,83
η_0	0,708	0,86
t_{abs} [°C]	28,75	28,75
t_e [°C]	8,2	8,2
G [W/m^2]	846	846
A_k [m^2]	2,15	2,12
A_b [m^2]	0,9363	2
α	0,92	0,95
τ	0,92	0,89
U_p [W/m^2.K]	1,57	1,55
U_z [W/m^2.K]	0,007	0,0068
U_b [W/m^2.K]	0,007	0,0068
$\mathbf{Q_u}$ [GJ/year] (1)	**3,57**	**4,31**

It is possible to acquire 300 - 800 kWh/m^2 of heat per year. However, the profit differs from month to month and there is no useful exploitation for the excess energy during summer. We consider 380 - 420 kWh/m^2 (kilowatt-hours per square meter of collector surface) per year as an actual estimation of gross energy production in solar facilities in the Czech Republic [13]. The range is considered to be a usual value. However, in Tab. 2, it was counted with real values of middle irradiation in summer because it is not possible to acquire the mentioned energy profit in winter. The acquired profit in summer is very uncertain, often unexploited. It is hardly assessed to say whether the heat is exploited effectively or not.

5 COMPARSION OF ECONOMIC BALANCES

The basic indicators for a solar facility installation are investments, a payoff period and further savings, a profit of the solar facility [14]. Tab. 3 shows the comparison of costs on building heating with costs on household water heating in a detached house. It refers to costs on heating by gas and by solar energy, on the other side, to savings within flat plate and tubular collector installation.

Tab. 3 Comparison of costs on building heating and household wather heating in a detached house.

Energy exploitation	**Facility**	**Consumption**	**Price**	**Costs**	**-**
Heating of buildings and household water	Gas boiler	106 GJ/year	15,2 eur	1 609 eur/year	-
Energy exploitation	**Facility**	**Energy Profit**	**Saving**	**Input Costs**	**Payoff**
Heating of household water	Flat Plate Collector	17,24 GJ/year	261 eur/year	2 592 eur	9,9 years
Energy exploitation	**Facility**	**Energy Profit**	**Saving**	**Input Costs**	**Payoff**
Heating of buildings and household water	Vacuum collector	14,28 GJ/year	217 eur/year	6 156 eur	28,4 years

As is obvious from the table, just the heating of household water is a profitable usage of solar systems. In regard of initial investments and payback period of facility (vacuum collectors), the facility for heating both building and household water is not suitable in a view of its payoff and lifetime [15]. The gas heating does not present savings, by contrast, the prices of gas have been increased. It is obvious, both savings and costs on the facility will rise up. Fig. 7 illustrates the facility with its costs and payoff.

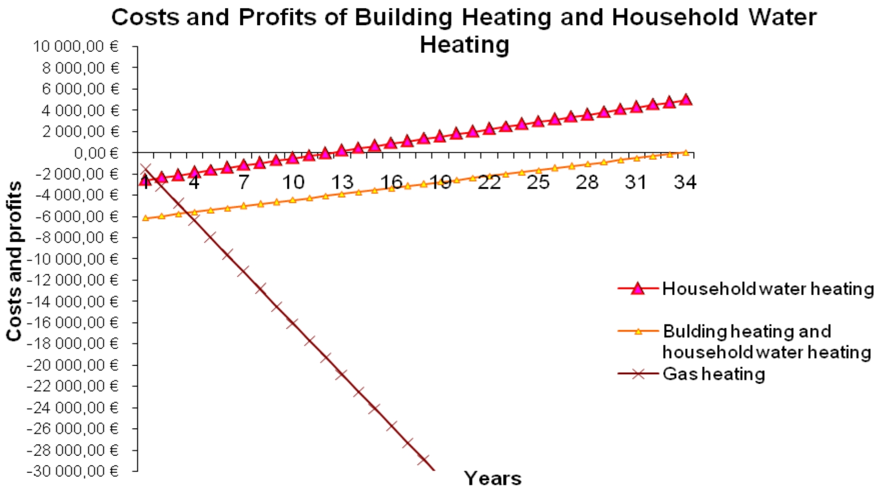


Fig. 7 Costs and profits on building heating and household water heating.

6 CONCLUSIONS

The results in the discussion present the efficiency of a solar facility. The solar facility is not effective for building heating on conditions in the Czech Republic. Its payoff period exceeds twenty eight years, as seen in Fig. 3. With regard to its lifetime, it is not advisable from the economic point of view. The solar facility for water heating is recommended especially in the circuit with a gas boiler. The facility for water heating works more efficiently with a gas boiler in Fig. 6 than an electric heater in Fig. 5. The payoff period is significantly shorter in comparison with the facility for building heating. The facility for water heating is fully paid off in 8 years on conditions in the Czech Republic. The most suitable variant of the usage of effective solar systems is their integration into projects of low-energy houses. Older buildings are characterized by energy losses, low energy exploitation. It is necessary to assess the payoff of the investments in an adequate period. It is usual, the facility does not cover the initial investments during its lifetime. For that reason, a well considered project prepared by a specialist directly applied on a defined building is a necessity.

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RESUMÉ

Článok je venovaný hodnoteniu solárnych zariadení a to predovšetkým na ohrev úžitkovej vody a vykurovanie budov, ktoré sú z novodobého hľadiska veľmi atraktívne. V klimatických podmienkach Českej republiky je však potrebné dôkladne prehodnotiť, aké zariadenie je vhodné inštalovať. Z hľadiska rentability sa nie všetky inštalované sústavy javia ako efektívne a spoľahlivé. Dôvodom je vysoká energetická náročnosť na pokrytie tepelných potrieb na vykurovanie budov v zimných či prechodných obdobiach a neexistujúce nízko vykurovacie systémy, ktoré sú základnou podmienkou pri inštalácii solárnych zariadení. Jedná sa predovšetkým o solárne sústavy na vykurovanie budov. Návratnosť týchto typov zariadení sa pohybuje na hranici ich životnosti a preto ich v podmienkach Českej republiky nemožno odporučiť. Naopak solárne sústavy na ohrev úžitkovej vody sú schopné pokryť až 52 -60% potrieb tepla v letných a prechodných mesiacoch v podmienkach Českej republiky a ich návratnosť sa pohybuje okolo desiatich rokov. Tieto zariadenia sú schopné pokryť svoje náklady a počas nasledujúcich 15-tich rokov vykazovať zisk. Z komplexného hľadiska je nutné vychádzať z množstva faktorov ovplyvňujúcich schopnosť týchto zariadení pracovať efektívne a preto treba ku každej inštalácii solárnych zariadení pristupovať individuálne.