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Analysis of solar thermal systems and future development possibilities in Lithuania

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Solar thermal systems with a total solar panel area varying from 2 to 204 m^2 have been installed in Lithuania for over 20 years. The reviewed solar thermal domestic hot water systems in Lithuania produce up to 528 kWh per year per one square meter of solar collector absorber area. However, the performance of these systems varies depending on the type of energy users, equipment and design of the systems, as well as their maintenance. The aim of this paper was to analyse solar thermal systems from the perspective of energy production and economic benefit as well as to outline the differences of their actual performance compared to the numerical simulation results. A number of different solar thermal systems in Lithuania were selected for the analysis varying both in equipment used (flat type solar collectors, evacuated tube collectors) and type of energy user (domestic hot water heating, swimming pool, district heating). The simulation software Polysun 8.1 was used for evaluation of solar thermal system performance, as well as financial analysis of alternatives of these systems. The results of the analysis showed that in the analysed cases the gap between measured and modelled data of heat energy produced by solar thermal systems was up to approximately 11%. The calculation of internal rate of return showed that a grant is required in most cases for solar thermal projects to be fully profitable.

Key words: solar collectors, solar thermal systems, domestic hot water, energy prices, simulation and monitoring, payback time

INTRODUCTION

Renewable energy consumption continued to grow in recent years alongside with the increasing global energy consumption, particularly in developing countries, and a dramatic decline in oil prices during the second half of 2014. Renewable energy provided an estimated 19.1% of global final energy consumption in 2013, and growth in capacity and generation continued to expand in 2014.

The deployment of solar thermal technologies continued to slow, mostly due to declining markets in Europe and China. The cumulative capacity of water collectors reached an estimated 406 GWth by the end of 2014 (with air collectors adding another 2 GWth), providing approximately 341 TWh of heat annually. China accounted for approx. 80% of the world market for solar water collectors, followed by Turkey, Brazil, India and Germany. The trend continued towards larger domestic hot water (DHW) systems in hotels, schools and other large complexes. The interest in the use of advanced collectors for district heating systems, such as solar cooling and industrial applications was growing as well, although advanced systems represent only a small fraction of the global market [1].

In 2014, the European market underwent a reduction in the newly installed capacity. In 2014, the market amounted to 2 GWth (approximately 2.9 million m²). This represents a decrease of 7.1% in comparison with the previous year. The total installed capacity registered a net increase of 1.6 GWth, now reaching 31.8 GWth (45.4 million m²). This represents an increase of 5.3% compared with the total installed capacity at the end of 2013. Only about 10400 m² (7280 kWth) of glazed solar collectors were installed by the end of 2014 in Lithuania, and the applications were mostly limited to single-family buildings [2].

The major part of thermal energy used in public and multi-family buildings in Lithuania is supplied via the district heating network. 72.4% from all district heating produced energy was used for household purposes in 2012 [3], and the price in different Lithuanian cities varied in the range from 0.047 to 0.091 Eur/kWh. In the last year, district heating energy price dropped by 9.3% [4]. Quite frequently, natural gas, biofuel or electricity is used for building heating systems.

Despite the growth of energy prices during the past decade, switching from natural gas to biofuel reduced the district heating energy price significantly within last two years. However, due to a dramatic decline in oil prices during the second half of 2014, conventional fuel prices decreased as well [5]. Energy prices for electricity, natural gas and district heating are presented in Fig. 1.

The aim of this study was to review the existing solar thermal (ST) systems and their potential in Lithuania in relation to traditional energy prices and government policies.

REVIEW OF SOLAR THERMAL MARKET IN LITHUANIA

The average global solar irradiation in Lithuania is similar to the irradiation levels in such countries as Germany, Austria, Denmark, Poland, Latvia and Estonia with the annual potential of solar energy yield of approx. 1000 kWh/m². The daily potential in the country varies from 0.55 kWh in January to 5.8 kWh from one square meter in June; therefore, almost the whole irradiated solar energy can be collected during the warm period of the year (from April till the end of October). Due to this fact, solar hot water (SHW) systems are most efficient in DHW applications in Lithuania [6]. Nevertheless, technical-economic potential of solar heat energy production in the country reaches up to 1.5 TWh/year (129 ktoe).

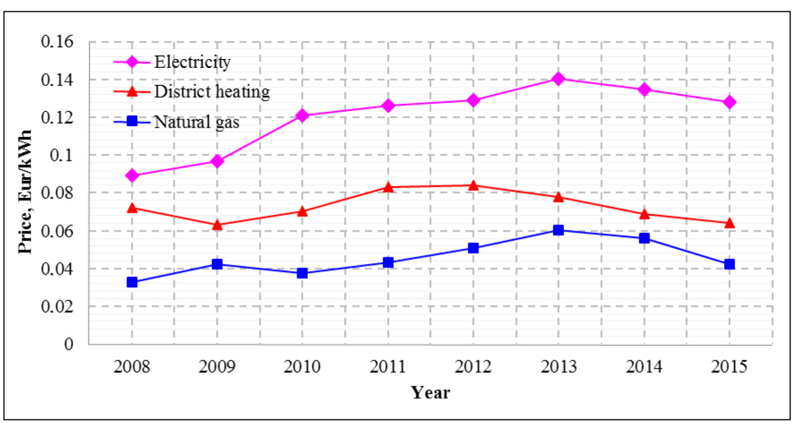

Fig. 1. Dynamics of energy prices in Lithuania from 2008 to 2015

The values of expected solar energy yield are increasing during the last decade as solar irradiation increased by 7% during the years of 2005 to 2014 compared to the long-term statistical data [7].

Several studies showed that despite the fact that evacuated tube and flat plate collectors are considered suitable for solar heating in Central European Climates, the evacuated tube collectors do not reach the additional expected energy yield [8]. Flat plate collectors and evacuated tube collectors produce the same amount of energy from effective area during summer season in Lithuania, but it is much less expensive to use flat collectors in most cases [9–11]. In recent years, the price of evacuated tube collectors is slowly decreasing, and the usage of this technology is increasing, but there is still a lack of real efficiency and life span data at the moment. According to the European standard [12] the life span of solar collectors is from 15 to 25 years, but the life of the vacuum varies from collector to collector, somewhere from 5 to 15 years [13].

Some studies in Lithuania and in other countries of similar climate showed that small- and medium-scale solar DHW systems with flat plate or evacuated tube collectors can produce from 335 to 523 kWh/m^2 of thermal energy per year, and the payback time of these systems is over eight years without subsidies. The potential of ST systems is quite high; however, the support from government and EU funds is still necessary in most cases to achieve reasonable payback [7, 14–19]. In Lithuania, some limited subsidy systems and funds for renewable energy installations exist since 2005. Depending on a project, it is possible to apply for a subsidy covering from 30 to 100% of initial costs.

Some studies showed that relation between installation costs and area of the flat plate solar collectors (including heat storage tanks and auxiliary equipment) can vary in the range from 600 to 150 Eur/m^2 in SHW from 10 m^2 to 10000 m^2. The installation costs, annual maintenance and repair costs vary in a wide range depending on the type of solar collectors and other components, but in general, larger SHW installations are relatively cheaper to maintain than small-scale SWH systems [20, 21]. Additional costs for design of the systems in Lithuania add up to 8% from the installation costs. In some cases, installing SHW systems in existing buildings can cost up to 20% more than in new buildings [7].

The number of medium-scale SHW systems in Lithuania are still relatively low at the time and represent the potential direction for development of these systems. There are a number of medium-scale SHW systems installed in the country varying from 60 to 204 m^2 of the total solar panel area. Most of these systems were installed within the past few years in public buildings, hospitals and industrial facilities. The oldest still operating SHW system of 77 m^2 was installed in 2002 in a children sanatorium "Žibutė" (Kačerginė). However, it took ten years for the first SWH system to be installed in a multi-family building, as the first such system was launched only in 2012 [7, 19, 22, 23].

Some studies in Lithuania showed that public and multi-family buildings represent one of the major potential for SWH installation, as it is one of the best renewable energy alternatives for these buildings [7, 14, 19, 24]. More uniform DHW usage during the day is common for public or multi-family buildings, compared to the single-family houses. It is related to variability of occupants and their hot water consumption habits, and this aspect brings out a higher solar energy share without adding additional volume to the accumulation tank. Moreover, DHW consumption throughout the day presents a possibility to keep lower temperatures in the collectors even during periods of high solar radiation. Public or multi-family buildings provide a possibility to connect several users to the same combined SHW system; therefore, the heat losses due to transformation and transportation of hot water will be incurred to a lesser extent during the system operation [25].

METHODS OF ANALYSIS OF SOME SOLAR THERMAL SYSTEMS IN LITHUANIA

Ten different ST systems in different Lithuanian cities were evaluated in this study. Most of these systems were designed for DHW applications. Flat plate and evacuated tube collectors and other equipment produced by different manufacturers were used. All of these systems are in operation for up to 5 years. Only some of the systems are equipped with heat meters or monitoring systems and only a few have been supported by schemes of subsidy, which led to reduced investments. Technical and economic characteristics of the analysed systems are presented in Table 1.

The measured performance of the existing ST systems was compared to the theoretical values obtained by means of the simulation software Polysun 8.1 (Velasolaris, 2015). This simulation tool allows dynamic calculation of the annual solar energy yield and designing ST systems to achieve economic efficiency. All technical parameters of the existing systems such as inclination angle, orientation, energy demands and characteristics of the installed equipment were used as boundary conditions for the simulations.

Financial analysis was performed for ten different ST systems. In this study, an assumption was made that the entire cost of the ST systems is covered during the installation and the systems were installed without any subsidies. The life span of the ST systems is considered to be 20 years. Parameters used for financial assessment of the ST systems are presented in Table 2.

Table 2. **Parameters used for the simulations of ST systems**

Life span of ST systems, years	20
Specific district heating energy price (average), Eur/kWh	0.041
Specific energy from natural gas price (average), Eur/kWh	0.076
Specific electricity costs (standard), Eur/kWh	0.129
Index for energy prices, % per year	3.0
Interest capital, %	2.5
Running costs, %	1.5

RESULTS OF THE ANALYSIS

Analysis showed that relation between installation costs and area of the flat plate and evacuated tube solar collectors (including heat storage tanks and auxiliary equipment) varies in the range of 320–1079 Eur/m^2 in ST systems from 25 to 166 m^2 gross area. The average price of flat plate solar collector systems is 527 Eur/m^2, but the investment for evacuated tube solar collector systems per 1 m^2 gross area in a wide range is 320–1079 Eur/m^2, with the average price of 657 Eur/m^2. Compared to the analysis made ten years ago [18], the prices of ST systems have not significantly changed.

Table 1. **Technical and economic characteristics of the analysed ST systems**

	Description of ST systems	Total gross / absorber area, m^2	Investment per 1 m^2 gross area, Eur	Annual energy production per 1 m^2 gross area, kWh
Flat plate solar collectors	SHW, main energy source – natural gas	25 / 23	519	512 (2015)
	SHW, main energy source – district heating	40 / 37	516	382 (2015)
	SHW, main energy source – district heating	72 / 67	418	n/a
	SHW, main energy source – electricity*	114 / 106	479	488 (2013)
	Indoor swimming pool heating and SHW. Main energy source – natural gas**	166 / 155	701	411 (2013)
Evacuated tube solar collectors	SHW, main energy source – electricity	27 / 15	571	528 (2014)
	SHW, main energy source – district heating	36 / 33	692	414 (2015)
	Preheating the return water in the district heating network***	82 / 72	1079	343 (2013)
	SHW, main energy source – district heating*	90 / 63	621	n/a
	SHW, main energy source – district heating	145 / 77	320	n/a

* Investment per 1 m^2 gross area is estimated.

** System was not in operation for three weeks during August 2013.

*** System was upgraded a few times due to improper operation, and the total investment is estimated.

The results of the analysis showed that ST systems with solar flat plate and evacuated tube collectors can produce from 343 to 528 kWh/m^2, and almost the whole (approximately 80%) irradiated solar energy can be collected during the warm period of the year (from March till October).

Simulations showed that the analysed ST systems in Lithuania can reduce greenhouse gas emissions from 49 to 232 kg $CO_2/m^2_{absorber}$ per year. However, CO_2 reduction per absorber area can vary in a wide range depending on the type of the system and alternative source of energy production.

The price composition of the analysed ST systems is presented in Fig. 2. The price of solar collectors and mounting systems comprises more than half of the total system price in cases when evacuated tube collectors are used.

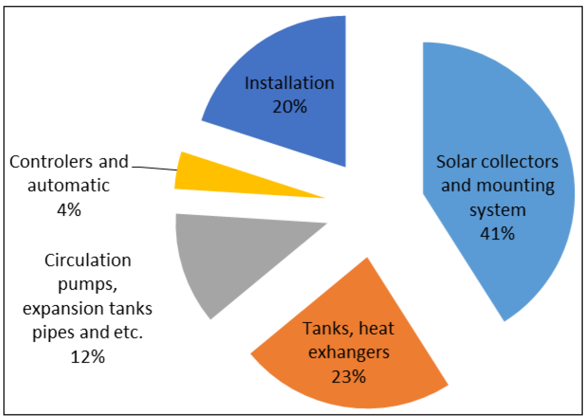

Fig. 2. Price composition of equipment in the analysed ST systems

The financial analysis showed that heat energy generated by the analysed ST systems is not competitive in most cases in comparison with district heating (payback period from 11 to 40 years) and natural gas applications (payback period from 24 to 27 years). But projects were fully profitable (payback period from 6 to 10 years) in cases when electrical energy was used as an alternative to energy produced by SHW systems. The average solar energy cost (life span 20 years) in the analysed cases was 0.073 Eur/kWh.

DISCUSSION AND CONCLUSIONS

The results of the analysis presented in this study showed that ST systems with solar flat plate and evacuated tube collectors can produce from 343 to 528 kWh/m^2 of heat energy and reduce greenhouse gas emissions from 49 to 232 kg $CO_2/m^2_{absorber}$ per year. The district heating system from a return pipe into a return pipe proved to be less effective compared to local SHW applications.

The results of the analysis showed that in the analysed cases the gap between measured and modelled data of heat energy produced by ST systems was approx. 11%. From the economic perspective, the system with flat type solar collectors used for DHW production is profitable if compared with the electrical energy as an alternative.

The most expensive equipment in ST systems are solar thermal collectors. In the analysed cases, from 28% (flat plate collectors) to 51% (evacuated tube collectors) of initial investment is required to cover the costs of solar collectors themselves.

The market growth of ST systems in most countries depends on the policy of the governments. In Lithuania, the payback period of ST systems in most cases is too long to ensure the stable growth of ST applications without the governmental grants.

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SAULĖS KOLEKTORIŲ SISTEMŲ ANALIZĖ IR ATEITIES PLĖTROS GALIMYBĖS LIETUVOJE

Santrauka

Saulės kolektorių sistemos nuo 2 iki 204 m^2 Lietuvoje instaliuojamos jau daugiau kaip 20 metų. Apžvalga parodė, kad saulės kolektorių sistemos, ruošdamos karštą vandenį, per metus gali pagaminti iki 528 kWh energijos iš 1 m^2 saulės kolektoriaus efektyvaus ploto. Be abejo, šių sistemų efektyvumas labai priklauso nuo sistemos tipo, projektuojant priimtų sprendimų, tinkamos sistemos eksploatacijos. Šio straipsnio tikslas – išanalizuoti skirtingas saulės kolektorių sistemas, jų pagaminamus energijos kiekius, galimą ekonominį efektą, taip pat palyginti matavimų metu gautus rezultatus su modeliavimų rezultatais. Keletas skirtingų saulės kolektorių sistemų, skirtų karštam vandeniui ruošti, baseinams šildyti bei integruotų į centralizuotus šilumos tinklus, buvo pasirinktos analizei. Modeliavimo programa „Polysun 8.1“ buvo naudojama nustatyti saulės kolektorių sistemų efektyvumą, įvertinti tokių sistemų ekonominę naudą. Analizės rezultatai parodė, kad skirtumai tarp modeliavimo metu gautų ir faktinių saulės kolektorių sistemų pagamintų energijos kiekių skyrėsi iki 11 %. Skaičiavimai atskleidė, kad dažniausiai saulės kolektorių sistemoms reikalingos dotacijos, kad jos būtų konkurencingos su tradiciniais energijos šaltiniais.

Raktažodžiai: saulės kolektoriai, saulės kolektorių sistemos, karštas vanduo, energijos kainos, modeliavimas ir analizė, atsipirkimo laikas