An analysis of the feasibility of renewable energy sources to supply thermal loads

Valentin Totev
Faculty of Electrical Engineering
Technical University of Sofia
Sofia, Bulgaria
valentintotev@tu-sofia.bg

Vultchan Gueorgiev
Faculty of Electrical Engineering
Technical University of Sofia
Sofia, Bulgaria
vulchy@tu-sofia.bg

Hristo Vasilev
Faculty of Electrical Engineering
Technical University of Sofia
Sofia, Bulgaria
h4510@abv.bg

***Abstract*—An analysis of the feasibility of renewable energy sources (RES) to supply thermal loads is performed in this paper. Additionally, the possibility to return hot water in district heating (DH) system is explored. The object of the analysis is a large swimming pool and considered RES are solar collectors (SCs), photovoltaics (PVs) and photovoltaic thermal (PVTs). Based on a techno-economic assessment the following conclusions can be drawn – PVs have the lowest payback period, SCs exhibit the best efficiency to capital cost ratio. However, with current state of PVs, their low price can easily push oneself towards investing in increasing the overall PV capacity and also in battery storage systems. PVTs are an emerging technology that has yet to prove itself. Unfortunately, it is inexpedient to return hot water in the DH system, as this is bound to increase water losses drastically.**

Keywords—district heating, energy efficiency, photovoltaics, renewable energy.

I. Introduction

The modern day energy supply is without a doubt characterized with utilization of renewable energy sources (RES). Apart from the point of view of distributed generation of electric energy, *RES* can be employed to produce thermal energy locally as well. The focus is directed towards the solar RES. There are three primary categories of solar *RES* that can supply the heat demand of thermal loads, which are, namely, solar collectors (SCs), photovoltaics (PVs) and the photovoltaic thermal (PVTs) panels [1]. Even though *SCs* can be treated as the general and oldest technology out of the three to solve heat demand problems, some facts must be noted. *SCs* have been popular in early 2010s as in that time their cost was significantly lower than *PVs*. Nonetheless, in terms of Bulgaria even *SCs* were seen as luxury in small villages and resorts as heat and hot water demands are generally solved either by supply from district heating (DH) networks (in the case of big cities) or otherwise by use of electric boilers (in smaller cities and villages). However, with *PVs*' price reduction throughout the years and introduction of governmental subsidies there has been an eminent rise in *PV* utilization to supply self-consumption or to even sell produced energy not only in industry, but in domestic environment also. This has pushed back even more on *SCs*. Of course, *PVs* cannot directly influence thermal loads as they produce only electrical energy. However, they can be utilized indirectly – to reduce expenses of energy or to feed boilers or heat pumps with electricity.

With that being said, *PVTs* can be regarded as an alternative hybrid technology that can be used to supply both electrical and thermal energies. Furthermore, produced electrical energy from *PVs* and *PVTs* can also be accumulated in storage devices.

As a technology *PVTs* are relatively younger than *SCs* and *PVs* which is the cause that they have not been studied as much as its contemporaries and literature is significantly scarcer. Hence, the literature review part of this paper is focused towards *PVTs*. Nonetheless, *PVTs* are interesting and topical subject to researchers in recent years.

Many of these papers have studied the possibilities to incorporate *PVTs* in *DH* systems. In [2] a review on the current status of *PVTs* in *DH* has been performed while also putting some light upon their opportunities and prospects. The review is based on academic papers, governmental reports, environmental agencies, etc.

It has been summarized [2] that albeit the fact that air cooled *PVTs* were 37 % of global shares of *PVTs* at the end of 2020, a trend towards more efficient water based *PVTs* has been observed. However, there are a lot of commercially available systems with ethylene glycol which are barely mentioned as less preferable than air based ones to installers.

It is also noted [2] that the *PVT* market is quite dynamic (as it is generally the case of *PVs*). Furthermore, it is observed that there is a lack of research on control strategies of *PVT* systems with thermal storage and systems with heat pumps. Further knowledge and optimization of which can be used to enhance *PVT* technology and progress it towards fourth generation *DH* systems. With regards to *DH* systems (and district cooling as well), similar conclusions have also been drawn by Werner in his study [3]. It is expressed that utilization of *DH* in buildings is widely variable with some countries having almost no *DH* systems while others have implemented them over fifty percent. Furthermore, it is also observed that on a fundamental basis there is moderate commitment as still there are uses of fossil fueled boilers with examples given to Russia and China. In Europe there is still high utilization of natural gas as high as 41 %. Albeit that, the overall conclusion towards future prospects is positive that *DH* systems are viable with efforts focused towards fourth generation district heating and cooling.

Pakere et al. in [4] have performed a case study on boiler house of a *DH* system in Latvia that has been using natural gas in its heat production but plans to change its energy source to solar via *PVTs* in order to reduce energy expenses. In the case study the researchers have explored eight scenarios tasked to find the specifically optimal one. While each scenario considers *PVTs* to supply thermal demand, there are differences with regards to installed area and nominal power, respectively produced electric energy and heat. To assess heat

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economically a fixed *DH* tariff is introduced. However, with respect to electricity there are some variations during hours of excess production. They have considered three solutions, namely feeding electric energy into the grid whenever hourly electricity market price is higher than the considered fixed *DH* tariff; the second option is to convert electric energy to heat when *DH* tariff is higher than electricity price via an electric boiler, and the third option is to store it in Li-ion batteries. An indicator, named *solar fraction*, is introduced that is used to total consumption (electric and heat) that can be covered by *PVTs*. Based on the results they have obtained, the scenarios with the largest installed area and largest power (with and without batteries) present the highest values of this indicator. The scenario with largest area and power and without batteries also present highest net present value in the techno-economic assessment. A conclusion is drawn that it is economically feasible to convert the electric energy into heat whenever electricity price is lower than *DH* tariff in the case without batteries.

In a later study [1] Pakere and Blumberga have presented a methodology to compare the three solar technologies, namely *SCs*, *PVs* and *PVTs*, for a *DH* system in Latvia. They have explored four scenarios for each of the renewable technologies. Analogously to previous study, they consider electric energy to be returned to the grid during high price hours, however, during low price hours, instead of an electric boiler, a heat pump is considered in this study. Additionally, apart from using previous *solar fraction* indicator, production analysis has been enhanced by introduction of another indicator, named *self-consumption index*, which exhibits the part of produced solar energy that is used on-site. They have also employed multi-criteria methods to evaluate the optimal scenario. Based on this the obtained results are highly variable in different scenarios – with regards to lowest payback period *PV* system is optimal; with regards to lowest levelized cost of energy a *SC* scenario is optimal; with regards to net present value, again *PV* is optimal; with regards to lowest cost of avoided emissions – *SC* scenario. Furthermore, if temperature of supply and returning temperature of *DH* system is reduced, then highest net present value is obtained by *PVT* and *SC* scenarios. Based on the multi-criteria methods the optimal solution is *SC* for reference scenario, while for larger systems – *SC* and *PV* scenarios. If then the temperature is considered to be reduced again, then *PV* scenario is optimal.

In the study of Ngunzi, Njoka and Kinyua [5] the application of *PVTs* is explored in the tropical climate conditions of Kenya with focus concentrated on local manufacturers which are classified as small, medium and large. It is described that *PVs* operate with lower efficiencies due to high temperatures. This is why it is sought to increase energy efficiency by *PVTs*. Based on their results it is concluded that implementing *PVTs*, instead of *PVs*, has led to improvement in electrical, thermal and overall efficiencies by 16 %, 20 % and 36 %, respectively. Primary targets of this improvement are agro-processing manufacturers in the small category, of which predominant are tea and coffee ones.

Saidi, Brahim and Jemni [6] have performed a dynamic simulation of an indirect *PVT* system with storage tank under Tunisian climatic conditions and have achieved numerical validation. Based on their results electrical and thermal efficiencies have been improved by nearly 8 % and 25 %, respectively.

Roshanzadeh, Premer and Mohan [7] have explored the increase of thermal efficiency of domestic hot water system via *PVTs*. In their study three types of *PVT* collectors have been considered – evacuated *PVT* (in a vacuum glass tube), glazed *PVT* (in an atmospheric pressure glass tube) and unglazed *PVT*. As in previous references, Roshanzadeh et al. have also explored the possibility to utilize produced electric energy and transform it into heat by heat pumps or otherwise feed electricity back to the grid. Three sets of heat pumps have been considered with coefficient of performance (COP) equal to 3, 4 and 5, respectively. Further, they differentiate their scenarios by mass flow rates and solar irradiances. Based on the achieved results it is concluded that evacuated *PVT* has presented highest thermal efficiency and flexibility. A point of interest is brought that encapsulating the *PVTs* have not decreased electrical efficiency. The unglazed *PVT* have performed the poorest at higher outlet water temperatures or at low solar irradiance. The scenario with evacuated *PVT* and heat pump with *COP* equal to 5 had the minimum dependency on the grid, for which it is estimated that it can reduce required external power up to 620 W/m^2.

The study of Terashima, Sato and Ikaga [8] presents a novel practical environmentally friendly PVT system based on thin-film Copper – Indium – Selenium modules aimed to be applied in building-integrated photovoltaic thermal systems for hot water supply in Japan. Two temperatures of hot water are considered, namely 40 °C and 60 °C. Achieved results exhibit that at 40 °C the developed panel converts 73.5 % of solar energy with heat collection efficiency of 60.5 %, while at 60 °C converts roughly 46 % of solar energy with heat collection efficiency of nearly 34 %.

Garcia, Zubi, Pasaoglu and Dufo-Lopez [9] have studied *PVT* system supported by heat pump in Central Europe in three scenarios – a multi-family building, in which there is no excess heat; hybrid scenario, in which the building's direct heat consumption has priority and excess heat is exported in *DH* system; thirdly, *DH* scenario, in which produced heat is entirely fed into the *DH* system.

Beside domestic heating and hot water supply, and industrial processes, some of the largest thermal loads are hospitals, SPA hotels and swimming pools. A very small portion of Bulgarian rooftops are utilized by renewable technologies. Thus, there is a prospect to increase energy efficiency and to reduce cost expenses by the incorporation of mentioned technologies more widely. As such a large swimming pool that is a heavily impactful and demanding thermal load is an example of an object whose heat demand can be potentially optimized by *RES*. Thus, a case study on such a pool is considered in this paper. The prospects of utilizing *SCs*, *PVs* and *PVTs* as heat producing sources in Bulgaria's conditions are explored. Furthermore, a techno-economic analysis is conducted and feasibility is evaluated.

II. Case Study of a Swimming Pool

A large swimming pool is considered in this case study. The pool is a significant heat consumer with an annual heat consumption E_h in the realm of 2.3 GWh.

Based on the annual heat consumption profile (Fig. 1) and its respective energy expenses, a techno-economic analysis is conducted on the prospects of utilizing *SCs*, *PVs* and *PVTs* as energy sources. Furthermore, the possibility of returning hot water in *DH* system are taken into considerations.

Naturally, the techno-economic assessment is based on the net present value (NPV), described by (1).

$$NPV = -C + B\left(\frac{1}{(1+r)^t}\right) \quad (1)$$

where C is total capital cost, B is annual revenues, r is interest rate and t is number of years.

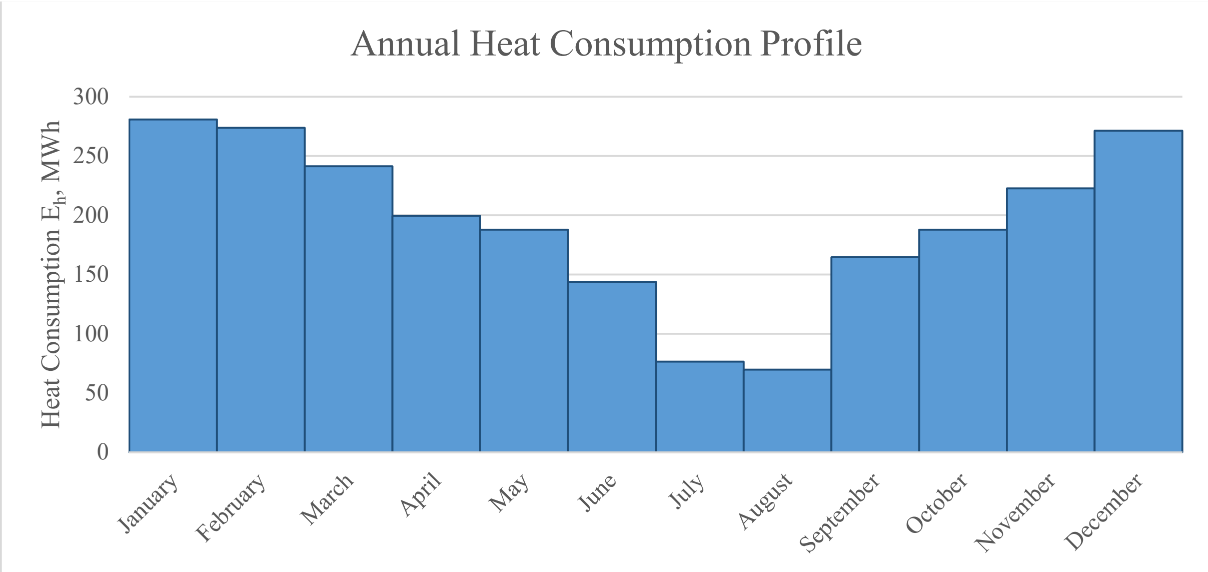

Fig. 1. Annual heat consumption profile of the considered swimming pool.

TABLE I. ASSUMED VALUES OF QUANTITIES.

№	Assumptions made in the study		
	Quantities	***Value***	***Units***
1.	Maximum solar irradiation	1000	W/m^2
2.	Roof area	6630	m^2
3.	PV panel power	550	Wp
4.	PVs' average annual electrical energy yield	1350	kWh / (kWp * year)
5.	PVs' efficiency (electrical)	21	%
6.	SC module power (200 L flat plate)	1000	W
7.	SC's average annual thermal energy yield	500	kWh / (m^2 * year)
8.	SC's efficiency (thermal)	65	%
9.	PVT module power (electrical / thermal)	340 / 920	Wp / W
10.	PVTs' average annual combined (electrical + thermal) energy yield	650 (300 + 350)	kWh / (m^2 * year)
11.	PVTs' efficiency (electrical / thermal)	18 / 60	%
12.	Total electricity price for household consumers (day / night), without VAT	239.88 / 141.22	BGN/MWh
13.	Total single-component price of thermal energy, without VAT	137.93	BGN/MWh
14.	Specific cost	1 (0.511)	BGN/Wp (€/Wp)
15.	Rate of return	0.2 (0.1)	BGN/kWh (€/kWh)
16.	Interest rate	10	%

The following assumptions are made (TABLE I.). The roof allows only for mounting, oriented in East-West direction. *PVs* are taken as a baseline as they are the most widespread of the considered *RES*.

Then, based on the allowable area and taking service corridors in consideration, occupied area is 2210 m^2.

III. Results

Having the necessary nominal powers of each respective *RES*, the techno-economic analysis can be performed.

In the considered study, the annual revenues are not in the shape of pure income, but as saved expenses.

A. Techno-economic assessment on PVs.

PV plant on this occupied area is with 810 kWp nominal power.

PVs' monthly energy generation is visualized on Fig. 2, by PVGIS. Average annual generation is 1.06 GWh. This attributes to 46 % of E_h.

PV panels' cost is 221 000 BGN (112 931 €) with VAT. Inverters, conductors and protection devices are considered as additional 100 000 BGN (51 100 €) with VAT. Total capital cost C is 321 000 BGN (164 031 €) with VAT. Substituting in (1) gives a payback period that occurs on second year.

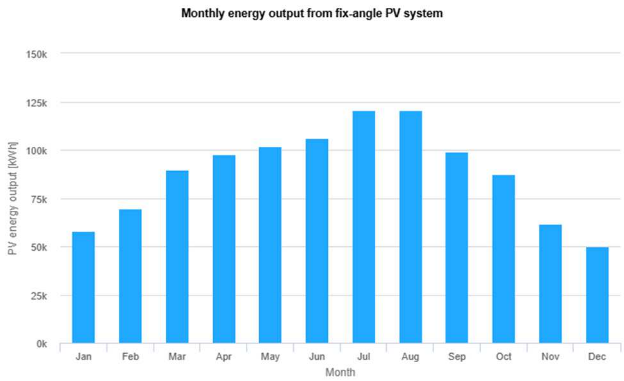

Fig. 2. Monthly generation of considered PVs.

B. Techno-economic assessment on SCs

Based on *SCs* average annual thermal energy yield, the average annual generation is 552.5 MWh/year or 24 % of E_h. *SCs*' cost is 328 000 BGN (167 608 €) with VAT. Pipes, fittings, etc. are considered as additional 64 000 BGN (32 704 €) with VAT. Total capital cost C is 392 000 BGN (200 312 €) with VAT. Substituting in (1) gives a payback period that occurs on fifth year.

C. Techno-economic assessment on PVTs

Based on *PVTs* average annual thermal energy yield, the average annual generation is 897.8 MWh/year or 39 % of E_h. *PVTs*' cost is 564 000 BGN (288 608 €) with VAT. Pipes, fittings, etc. are considered as additional 148 000 BGN (75 628 €) with VAT. Total capital cost C is 712 000 BGN (363 832 €) with VAT. Substituting in (1) gives a payback period that occurs on sixth year.

D. Discussion

The main objective that has been set in the analysis is to evaluate the capabilities of each *RES* technology to supply the heat load and its respective feasibility. The results vary based on explored criteria as payback period, capital cost and efficiency. These criteria are the main driving force in such investments.

Based on payback period *PVs* are most feasible. However, based on efficiency to capital costs ratio – *SCs* become most feasible. Furthermore, whenever talking about incorporating expensive heat pumps and battery storage into the systems, further feasibility evaluation is needed. A summary of obtained results is presented in TABLE II.

TABLE II. SUMMARIZED RESULTS OF TECHNO-ECONOMIC ANALYSIS.

RES	**Criteria**			
	Heat supply	***Payback period***	***Capital cost***	***Efficiency***
SCs	24 % of E_h	Medium	Medium	65 %
PVs	46 % of E_h	Shortest	Lowest*	21 %
PVTs	39 % of E_h	Longest	Largest*	18 / 60 %

*electric energy is supplying local boilers.

IV. CONCLUSIONS

A study on the prospects to increase energy efficiency of heat supply of a large swimming pool by utilization of different *RES*, namely *SCs*, *PVs* and *PVTs* has been performed. Furthermore, a techno-economic analysis has been conducted and the possibility of returning hot water in *DH* system has been explored.

Based on obtained results, each of the *RES*, considered in this paper, can be used to supply the heat demand decently. However, depending on criteria the feasibility is variable.

Unfortunately, with regards to *DH* system, it is inexpedient to return hot water in it, as this is bound to increase water losses drastically (in most cases more than double).

As further expansion on this work, a case with addition of a heat pump and battery storage can be studied. With current state of PVs, their low price can easily push oneself towards investing in increasing the overall PV capacity and also in battery storage systems.

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