COMPLEX, ENERGY, ECONOMIC AND ENVIRONMENTAL ANALYSIS OF DIFFERENT SOLUTIONS FOR INTEGRATING SOLAR THERMAL PANELS (PT) IN TO DISTRICT HEATING SUBSTATION (DHS)

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In the current energy policy, a special priority is the efficiency of the public heat supply service. The evaluation of the quality of the centralized heat supply system in Bucharest highlights major deficiencies, respectively substantial heat losses. The solution analyzed in this paper for the efficiency of the centralized thermal energy supply is represented by the integration of renewable energy sources in the existing system. So, a complex analysis (energy, economic and environmental) was conducted to find out the optimal variant for integration of the three constructive solution of solar thermal panel in the district heating substation (DHS).

Keywords: district heating, renewable energy, solar thermal panels, energy efficiency, energy, economic, environmental analysis

1. Introduction

The centralized district heating system represents a viable solution that should be permanently improved so to ensure a high-quality service for heat supply respecting norms for continuous, qualitative and flexible heat supply [1-3].

To achieve this objective the priority today is to increase the efficiency of district heating systems through integration of renewable energy sources.

The utilization of renewable energy sources can lead to decreasing pollutant emissions at local level. Studies [4] and [5] regarding district heating systems have shown that centralized heat supply systems can reduce costs with CO_2, between 42% and 56%.

The paper presents a complex study for choosing the optimal solution from the technical/energy, economic and environmental points of view.

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Integrating the optimal solution using renewable energy source into a heat substation can lead increasing the efficiency of the entire district heating system.

For this study there have been selected a number of heat substation from Bucharest district heating system having common characteristics: location of heat substation at the of the network branch, deficiencies for high quality heat supply. Thermal and hydraulic operating regimes of these heat substation do not allow high quality heat supply for heating and especially for hot water preparation during the summertime.

The major objective of this paper is to evaluate the feasibility of implementation of solar thermal panels into heat substation and identifying the optimal solution for a heat substation from the Bucharest district heating system.

There has been performed a complex analysis (technical, energy, economic and environmental) for integration of solar thermal panels into a heat substation using 3 solutions.

The complex analysis is an essential part for a project implementation. It is an important part of the feasibility study, and the final decision is always taken based on economic criteria for selecting the optimal solution.

The complex analysis is structured into three main phases, as it can been in Fig. 1:

• Energy analysis including determination of fuel savings (natural gas) due to integration of solar thermal panels.

• Environmental impact analysis including determination of reduction of CO_2 emissions.

• Economic analysis including determination of different criteria, NPV, IRR, GPP.

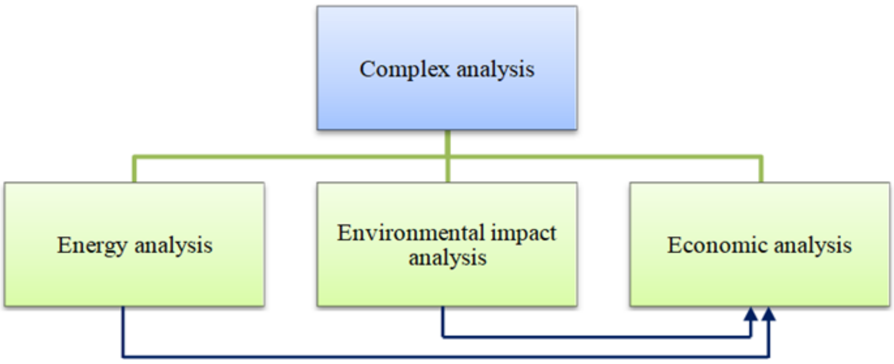

Fig. 1. The structure of the complex analysis.

The results are even more concluding if the complex analysis model quantifies the positive environmental of the proposed solutions. The economic quantification of the positive environmental effects needs however legal framework that can allow such a quantification [6].

2. Synthesis of the necessary heat demand

The complex analysis has been performed for a heat substation located at the end of a district heating network branch. Table 1 shows the installed capacities for heating and domestic warm water preparation [7].

Table 1

Installed thermal capacities in the analyzed DHS

DHS name	Nominal tap hot water heat flow rate - Q_{w_n}, MW	Installed capacities - $Q_{h\_installed}$, MW	Real nominal heat flow rate demand for heating - Q_{h_n}, MW
21 C5/2	1.94	10.1	5.05

Table 2 shows the climate data needed for simulations and for the complex analysis.

Table 2

Climate data for Bucharest [8]

Parameter name	Symbol	Unit	Value
Outdoor design temperature	T_{out}	°C	-15
The outdoor temperature that delimits the heating period	T_{heat}	°C	10
Heating degree-days[a]	HDD	°C·d/y	2940
Duration of the heating period[a]	τ_{heat}	d/y	171
Indoor design temperature	T_{in}	°C	20
Average temperature during the heating period[a]	T_{av}	°C	2.81

a. for t_e^x = 10 °C

The design of the solar thermal panels system has been performed for covering the domestic warm water demand for 5 months of the year (when there is no heating demand, mainly summertime). For this specific heat substation heating for domestic warm water preparation has a weight of about 50-60% from the total annual supply [9]:

- annual heat supply for domestic warm water preparation for the analyzed heat substation 12414 MWh.

- annual heat supply for heating for the analyzed heat substation 10145 MWh.

- total annual heat supply for the analyzed heat substation 22559 MWh.

The hypotheses for determination of heat quantities were:

- There were defined 3 characteristic days from the point of view of domestic warm water consumption, respectively high, average and low consumption days.
- The daily heat supply is dependent on the day of the week.

- Total heat demand/supply has been estimated using heat load curves for domestic warm water preparation.

The data from the heat demand/supply curves show that there is minimum demand during the night, a low during the lunch time and two peaks during the evening time. For one day the difference between the maximum and the minimum values of heat demand is about 70%. The maximum and minimum heat demands for one day cover approximately 6 hours each.

3. Presentation and description of the proposed solutions

The studied technological solutions, regarding the three solar thermal panels are presented in table 3.

Table 3

Solar thermal panel types

Solar thermal panel unpressurized	Number tubes	Length tube	Outer tube diameter	Surface total	Stainless steel collector
(types)	(-)	(m)	(m)	(m^2)	(l)
INSTECH Solar thermal panel unpressurized, Hot water, 10 Tubes 58/1800, floating system 5 L	10	1.8	0.058	3.28	100
GOBE Solar thermal panel, 10 Vacuum Tubes for hot water with unpressurized tank 100 L	10	1.7	0.055	2.94	100
HEIZTECH Solar thermal panel, 10 Vacuum Tubes for hot water with unpressurized tank 100 L	10	1.7	0.033	1.76	100

The solar thermal panel has an area of 1,5m^2. The collector is made of copper. The interior tubes are from stainless steel and under vacuum using the thermosyphon principle for collecting solar energy.

For all three analyzed solutions there have been considered the following:

- The inlet temperature is 15^{o}C.
- Heat losses are neglectable.
- There has not been considered shadowing effects, considering that panels are correctly placed and correctly maintained and periodically cleaned.
- There has been considered that solar thermal panels are South oriented inclined by 35^o.
- The mass flow is constant.

Sizing was done in two main steps, using TRNSYS software [9]. Tables 3 and 4 show the main results of simulations.

Table 4

Monthly total energy produced by a single solar thermal panel

Month	INSTECH	GOBE	HEIZTECH
	Energy - E_{th} (kWh)	Energy - E_{th} (kWh)	Energy - E_{th} (kWh)
May	121,631	127,160	131,306
June	161,758	169,111	174,625
July	180,756	188,972	195,134
August	162,638	170,031	175,576
September	91,969	96,149	99,284
Total	718,753	751,423	775,926

Table 5

Installed thermal capacities in the DHS and the number of PT resulting from dimensioning

DHS name	INSTECH	GOBE	HEIZTECH
21 C5/2			
Number of panels	6163	5895	5709
Total area (m^2)	10168.95	9726.75	9419.85
Energy - E_th (MWh)	4429.672	4429.639	4429.762

4. Complex analysis

Defining the complex analysis boundaries: operation scenario, and hypotheses

The solar thermal panels system includes solar panels and heat storage tank for all analyzed solutions.

Energy analysis. Performance criterion – fuel savings

The implementation of solar thermal panels system leads to increasing of energy efficiency of the analyzed heat substation and of the entire district heating system. The energy efficiency can be quantified through fuel savings due to replacement of natural gas by solar energy for domestic warm water preparation.

The fuel savings are determined by estimating the natural gas consumption before the implementation of the proposed solutions.

According to statistical analysis [10], the heat losses in the district heating system are totaling 68.45% from the heat supplied into the district heating system by heat generation facility. The heat losses are due to working fluid losses ad heat losses to the environment. The heat losses to the environment represent 76.33% from the total. During summertime the situation is even worse, since losses can reach even 90%. The study also indicates that only 31% of generated heat is billed to customers.

Ton of oil equivalent (TOE) is an internationally agreed unit of measurement as an energy equivalent. TOE measures the energy produced by burning one ton of oil. Not all oil has the same chemical composition, so an average is proposed by the International Energy Agency.

The recommended value by the International Energy Agency (IEA) for one ton of oil equivalent (TOE) is 11.63 MWh [11] and [12]. As a result we have 1 TOE = 11.63 MWh = 1.4285714285714 tons of coal. We obtained the following results for DHS 21 C5/2, according to the equation 1: Thermal Energy demand 4430 [MWh] – 380 (TOE) and Primary energy saving 984 [TOE].

$$ET_{PT,[TOE]} = ET_{PT,[MWh]}/11.63 \quad \text{[TOE]} \tag{1}$$

The primary energy saving would be 77% compared to the production of thermal energy required from current sources operating on natural gas, according to the equation 2.

$$EETP_{DHS\ 21\ C5/2} = \frac{ETP_{source} - ET_{PT}}{ETP_{source}} \cdot 100 \tag{2}$$

where: ETPsource can be determined for the hypothesis that thermal energy (ET_{PT}) is generated by burning natural gas, in installations with an estimated conversion efficiency (η_{source}) of 90% and with a transmission and distribution efficiency ($\eta_{T\&D}$) of 31 %, according to the equation 3:

$$ETP_{source} = \frac{ET_{PT}}{\eta_{source} \cdot \eta_{T \cdot D}} \cdot 100 \quad \text{[MWh]} \tag{3}$$

The environmental impact analysis. Environmental impact criterion – reduction of CO_2 emissions

The determination of the reduction of CO_2 emissions has been done taking into consideration that natural gas is totally replaced by solar energy for supplying heat for domestic warm water preparation for the analyzed heat substation for the analyzed period. Table 6 shows the Global Warming Potential for different Green House Gases.

Table 6

GWP (global warming potential) greenhouse effect gases

Substance	GWP (20 years)	GWP (100 years)	GWP (500 years)
CO_2	1	1	1
CH_4	35	11	4
N_2O	260	270	170

Determining the GWP index for a system is done by summing the elementary greenhouse potentials of each gas that is part of the gaseous effluent of the system, multiplied by the amount corresponding to each component, according to the equation 4.

$$GWP = \sum_i m_i \cdot GWP_i \text{ [years]} \tag{4}$$

where: GWP_i - the greenhouse effect potential of element i in the gaseous effluent (kg CO_2 equivalent)

m_i: quantity of element i in (kg/functional unit).

The reduction in CO_2 emissions is directly proportional to the fuel saving achieved by implementing new solutions, as well as the type of fuel saved.

According to [11] I considered that for 1 MWh of thermal energy produced on natural gas in an installation with an average efficiency of 90%, a quantity of 185 kg CO_2 is obtained, we can see in table 7.

Table 7

Reducing emissions of CO_2

DHS name	Energy requirements	Emissions CO_2	
	MWh	KgCO_2	tCO_2
21 C5/22	4430	819550	819.55

Economic analysis. Economic criteria – NPV, IRR, GPP

The economic analysis using different criteria allows identification of the optimal solution that corresponds to minimal financial effort and maximum revenues with the lowest risk. The investment costs, maintenance costs of all components have been estimated based on literature [13, 14], and also analyzing the market at the time of paper elaboration. For a correct comparison of all analyzed solutions there has been considered the following:

- The thermal solar panels cover all heat demand for domestic warm water preparation for the studied period.
- All three analyzed solution have the same life span (25 years).
- The economic analysis is performed in Euro.
- The discount rate was in the interval of 6%.
- The investment costs are presented in Table 9.
- It has been considered that project is implemented in one year.
- The maintenance and operation costs are considered to be constant throughout the entire period of analysis.
- The prices of natural gas and electricity are considered to be constant throughout the entire period of analysis.

Tables 8 and 9 show the input data for the economic analysis [15]. All monetary values are in constant currency, euro, at an exchange rate of 5 lei for 1 euro.

Table 8

Economic input data on the types of solar thermal panels used

Producer- solar thermal panels	INSTECH	GOBE	HEIZTECH
Cost/unit (euro)	220	238	252
Cost/m^2 (euro)	137	149	158

Maintenance Cost /panel/year (euro)	2.20	2.38	2.52
Lifetime [years]	25	25	25

Table 9

Economic input data for DHS name 21 C5/2 - solar thermal panel INSTECH

No.crt.	DHS name 21 C5/2 - solar thermal panel INSTECH	
1	discount rate, a [%]	6
2	lifetime period [years]	25
3	thermal energy price [€/MWhe], [16]	61
4	price of electricity purchased from the market, without taxes [€/MWhe], [17]	91
5	medium price for a tone of CO_2, without taxes [€/t], [18]	53
6	total number of solar thermal panel [buc]	6.163
7	price solar thermal panel, [Euro/unit]	219
8	total price solar thermal panel, [Euro]	1354627
9	self-consumption of electricity for solar thermal panel [MWh]	44
10	TES maintenance costs, [Euro/year]	3783
11	solar thermal panel maintenance costs, [Euro/year]	19659
12	TES investment, [Euro]	75660
13	total investment [Euro]	1430287
14	CO_2 avoided by the system, [t/year]	819

GPP – Gross Payback Period, is the total investment (Inv, Euros) related to the annual cashflow (the difference between total income (IN, Euros) and total expenditure (Ex, Euros)). The solution is economically efficient if GPP≤ n, where n is the service life of the equipment, according to the equation 5.

$$GPP = \frac{Inv}{IN - Ex} \text{ [years]} \tag{5}$$

NPV – Net Present Value, represents the algebraic sum of annual net present value over the lifetime (n- number of years), where (a) is the discount rate, according to the equation 6. One solution is cost-effective if NPV ≥ 0, and in the case of comparing several solutions, the optimal solution corresponds to the condition NPV = max.

The analytical form of the indicator depends essentially on the reference moment considered for the update, a reference moment, is the moment of starting the investment project.

$$NPV = \sum_{k=1}^{n} \frac{(IN-E_x)_k - Inv_k}{(1+a)^k}, \quad \text{[Euros]} \tag{6}$$

IRR – Internal Rate of Return, can be defined as the discount rate which, when applied to the cash flows of a project, will generate a net present value (NPV) equal to 0 (IRR= a_0). A solution is cost-effective if IRR ≥ a, according to the equation 7.

$$NPV = \sum_{k=1}^{n} \frac{(IN - E_x)_k - Inv_k}{(1+a)^k} = 0 \tag{7}$$

5. Results and discussion

Figs. 2-4 show the results of the economic analysis for 3 analyzed solutions.

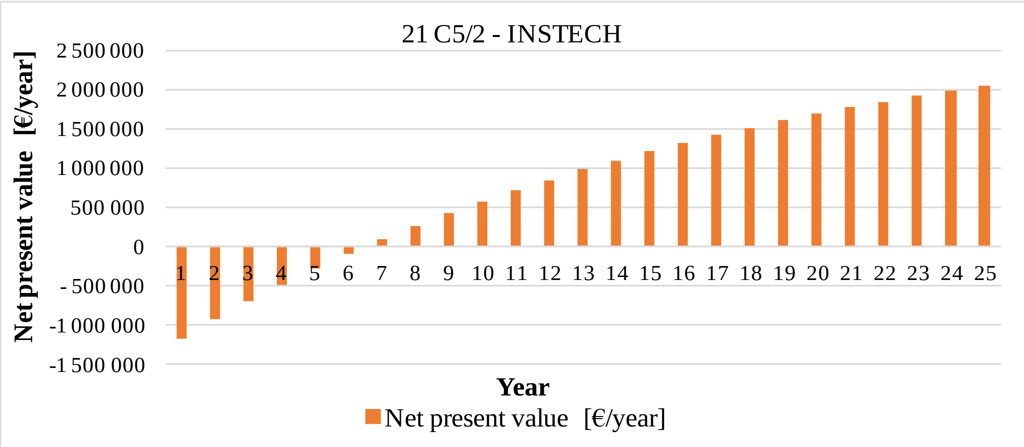

Fig. 2. DHS name 21 C5/2 – INSTECH solar thermal panel

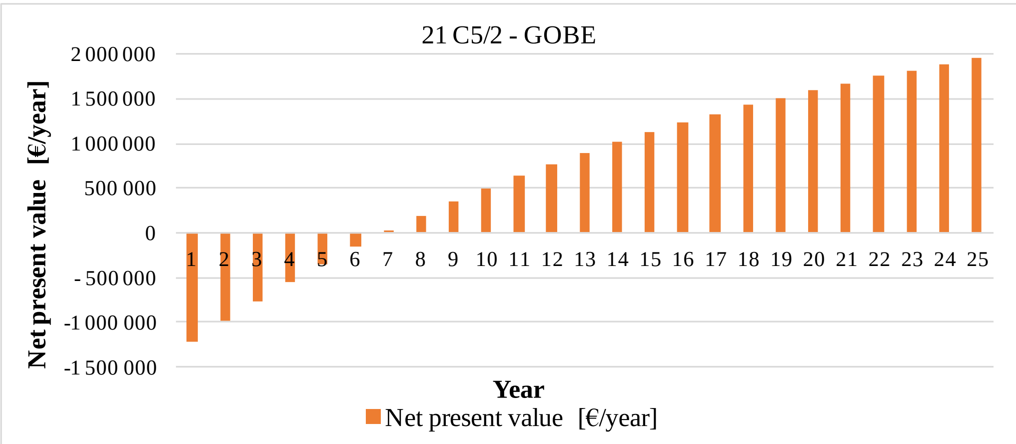

Fig. 3. DHS name 21 C5/2 – GOBE solar thermal panel

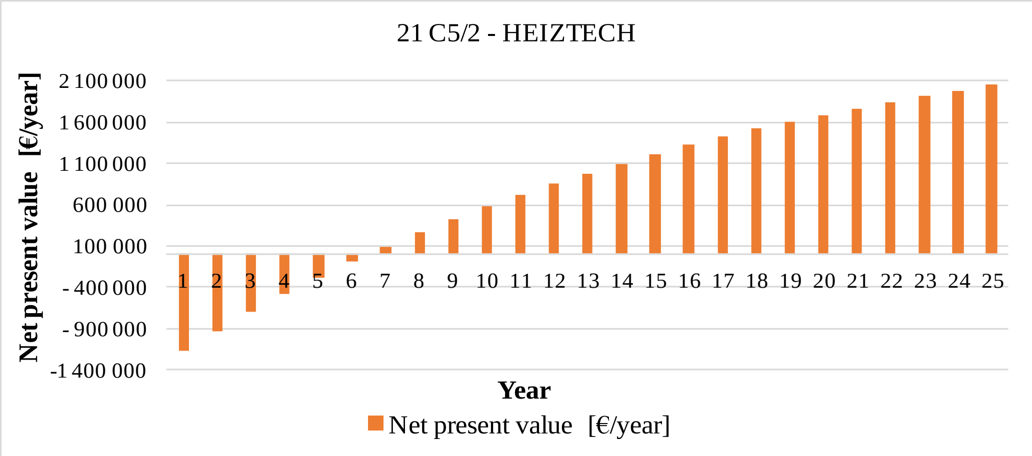

Fig. 4. DHS name 21 C5/2 – HEIZTECH solar thermal panel

The optimal solution from the economic point of view is the one equipped withtype 1 thermal solar panel – INSTECH leading to a NPV after 25 years of 2049635 Euro. The internal rate of return for this solution is 18.77%. The profitability index is greater than 1. The economic feasibility of the optimal solution stands even when the investment is done using 100% own funds. Table 10 shows the main economic criteria for all 3 studied solutions.

Table 10

Economic indicators for DHS name 21 C5/2

Economic indicator for 3 solar thermal panels	INSTECH	GOBE	HEIZTECH
-Net Present Value (NPV) [€]	2 049 635	1 951 312	2 007 271
-Gross Payback Period (GPP), [years]	5.25	5.51	5.50
-Profitability index (PI) [€/€]	2.43	2.32	2.33
-Internal Rate of Return (IRR) [%]	18.77%	17.85%	17.89%

6. Conclusions

Table 11 shows the technical, energy, economic and environmental data for the optimal solution after the complex analysis, which is thermal solar panel type 1 – INSTECH.

Table 11

Technical, energy, economic and environmental data for the optimal solution

DHS name 21 C5/2	INSTECH
- Number of panels	6163
- Price solar thermal panel, [Euro/unit]	219
- Thermal Energy demand [TOE]	380
- Primary energy saving [TOE]	984

CO_2 avoided by the system, [t/year]	819
Economic indicator	
- Net Present Value (NPV) [€]	2 049 635
-Gross Payback Period (GPP), [years]	5.25
-Profitability index (PI) [€/€]	2.43
-Internal Rate of Return (IRR) [%]	18.77%

The economic analysis also shows that the investment can be done, and it is financially feasible, with 100% own funds. The optimal solution from the 3 analyzed cases is type 1 thermal solar panel ***INSTECH***, with a NPV of 2049635 Euro, GPP is 5.25 years; profitability index is 2.43 [€/€] and internal rate of return is 18.77%.

In conclusion the utilization of thermal solar panels for heat generation on-site at heat substation within a district heating system can be an economically viable and feasible solution, leading also to reduction of the environmental impact.

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