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THEORETICAL ANALYSIS OF WATER COOLED PHOTOVOLTAIC THERMAL PANELS

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Abstract: The sustainability and the efficient capitalization of the solar energy are studied for a system that incorporates two different subsystems: photovoltaic panels (electricity production) and their cooling (heat production). This complex system ensures the production of electricity and thermal energy in order to satisfy the need for electricity and heating of the buildings. The two types of energy are quantitatively dependent on each other and, therefore, they must be managed in such a way that the production of either of them does not fall into the detriment of the other. In other words, the maximum efficiency is reached at the intersection of the two curves of electricity and heat production and the instrument that manages the two types of energy is the photovoltaic thermal panel. The photovoltaic thermal panels, especially if they are integrated into the buildings, are able to bring an important contribution to the concept of nearly Zero Energy Building (nZEB). The amount of heat resulting from the cooling of the panels can be utilized for preheating domestic hot water, space heating or other usage in the buildings. The article presents the theoretical and analytical model that can be used to analyse the cooling of photovoltaic panels by means of a water-based system. This theoretical model was implemented in a module dedicated to the cooling of photovoltaic thermal panels, in the Cool-PV computer application developed by researchers at the Faculty of Civil Engineering and Building Services in Iasi, Romania. In conclusion, the constructive variant that presents maximum efficiency, in according with input and output data (heat gained from PV/T panel) is represented by 22mm Cu diameter cooling PV/T system, on 250mm M40 concrete think. As a result of the theoretical analysis, will be materialize in a experimental set-up, using a monitoring system of the panel temperature and control solution in order to optimize the energy consumption is presented. The analysis is also aiming at determining the optimal time for using the cooling system and the calculation of the amount of heat resulted.
Key words: *photovoltaic thermal panels, nZEB, optimal time.*

1. INTRODUCTION

The photovoltaic thermal panels (PV/T) have become one of the most popular renewable energy sources [1]. They work by converting solar radiation into electrical energy and do so very efficiently, the conversion efficiency reaching up to 28% [1]. PV panels also reduce carbon emissions due to their high efficiency, which makes them an excellent option for environmentally friendly power projects [2].
Sustainably produced electricity is a developing industry that has a tremendous impact nowadays. As the global population continues to increase and climate change becomes a more pressing issue, more and more people are looking towards renewable energy sources such as solar power and electric cars to help meet their own energy needs and cut down on carbon emissions [2, 3].
The PV/T system is not only cost-effective but also environmentally friendly, and they represent another step in developing the nZEB (nearly Zero Energy Buildings). Various measures may be taken to ensure the installation is both efficient and environmentally friendly [4]. The paper presents some theoretical and practical information regarding the photovoltaic thermal panel (PV/T), the cooling systems with water, the total energy and efficiency that may help ensure the project complies with safety regulations as well as the code standards in the future.
The photovoltaic thermal panel (PV/T) is particularly effective in areas with hot climates where electricity may be generated at low temperatures. For example, in the US only approximately one third of the electricity generated in Texas is consumed due to the high temperature of the state [5]. Countries or regions with hot climates that have less developed solar energy industries are often ideal locations for such systems due to the low cost of installation and maintenance [2, 6].

The cell temperature of a photovoltaic panel is higher than the ambient temperature by at least (2-3)°C [7]. If we consider a system of photovoltaic panels mounted on the roof or terrace of a building which is made of materials with a high heat absorption coefficient (sheet metal, metal canopy, tile), in the summer the temperature of the photovoltaic cells can reach 65-70°C (in the middle of the day, when the sun is high in the sky, without clouds and without wind the roof temperature can reach even 80°C) [8, 9].
For each degree Celsius of the photovoltaic cell above the value of 25°C, the electricity production decreases by 0.5%. This means that for a photovoltaic cell temperature of 65°C, the decrease in energy production can be up to 20% [10].
The amount of heat gained by the system is calculated by taking the total amount of heat generated by the photovoltaic panels and subtracting the amount of thermal energy dissipated by the system components so that a constant temperature is maintained [11].
The calculation regarding the thermal energy recovered by the cooling system was made based on two concrete situations, namely for a photovoltaic system mounted on the terrace of a building, with sun exposure, in two constructive variants:

- M40 concrete 300 [mm] THICK SLAB;
- M40 concrete 250 [mm] THICK SLAB.

Depending on the material from which the terrace is built, its heating is different, the thermal inertia is different and the heating of the environment, which influences the heating of the PV/T, is done differently, directly proportional to the nature of the material and the thermal inertia [12].
The photovoltaic thermal cooling systems can be installed on rooftops or on the ground, making them accessible to a wider range of people.
The safety and risk of photovoltaic thermal cooling system can be highly debated topics in the industry. Some experts assert that the risk is minimal and even negligible [13]. They suggest that this type of system is safe and can actually provide better safety than conventional air-cooled (or air-to-water) systems. According to a study, the risk of an air-cooled system is 1 in 10,000. However, with PV/T cooling system, the risk is reduced to 1 in 1 million. This means that thermal energy can be a safer replacement for water-cooling [11, 14].
A PV/T system provides a greater amount of cooling in a given amount of time as compared to a water-cooled system [11, 14]. In case of emergency or power outage, it can rely on the cooling system to keep homes or buildings at a safe temperature.
Water-cooled photovoltaic thermal panels embedded in buildings have several disadvantages, such as freezing during the winter, the necessity of electric pumps and higher weight than standard panels [15].
Taking into account the aspects listed above results the need to carry out very serious and punctual theoretical and experimental research in order to determine the efficiency of such a hybrid system, the ratio of costs with operation / level of efficiency and the return of investment of the system [16].

2. CALCULATION OF THE HEAT GAIN

A The amount of heat taken over by a PV/T system is directly proportional to the ambient temperature, temperature that depends on the construction type of the roof / terrace, the material from which it is made, the thickness of the roof.
The scenario on which the theoretical calculation of the amount of heat taken over by a PV/T system is based is as follows: it is considered a PV/T system in 3 constructive variants (the cooling of photovoltaic panels is done with a pipe system of 15 mm diameter, 18 mm diameter and 22 mm diameter) arranged on an M40 concrete terrace, in 2 constructive versions: thickness of 300 mm or 250 mm.
In figure 1 and 2 is presented the influence of solar radiation intensity on the 2 constructive types of the terrace (M40 concrete 300mm thick and M40 concrete 250 mm thick) and the temperature evolution over time, between 0-24 hours. The amount of heat generated by the terrace is one of the main factors influencing the heating mode of photovoltaic panels, their cooling analysis and how efficiency is affected.
Heat loss is measured at the system temperature and is the amount of air displaced by the system components minus the amount of heat gained by the system [3, 17]. This is called heat loss.
The amount of air displaced by the system components is measured at the system temperature and is the amount of air displaced per hour.
Fig. 3 nu este în text!!!

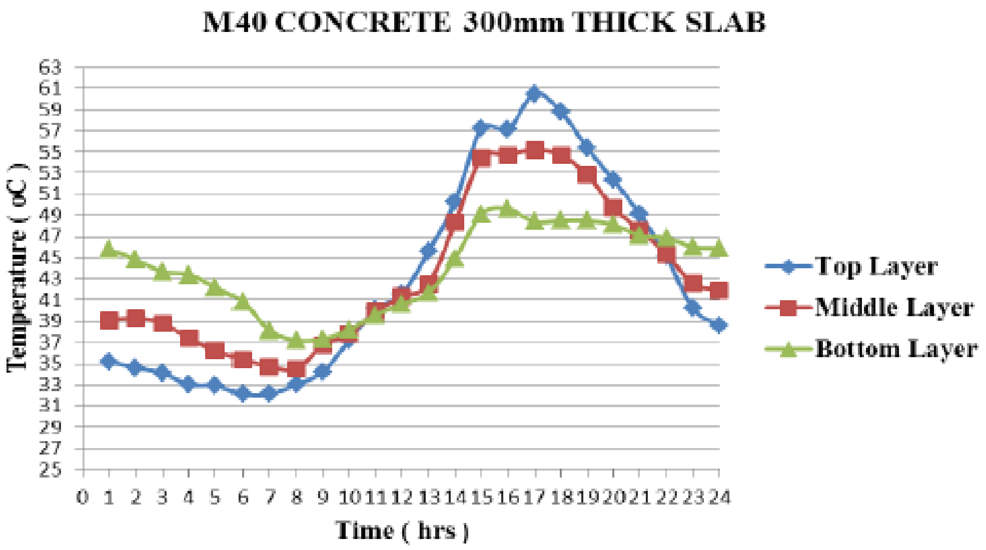

Fig. 1. The influence of the intensity of solar radiation over M40 concrete 300mm thick slab, [2]

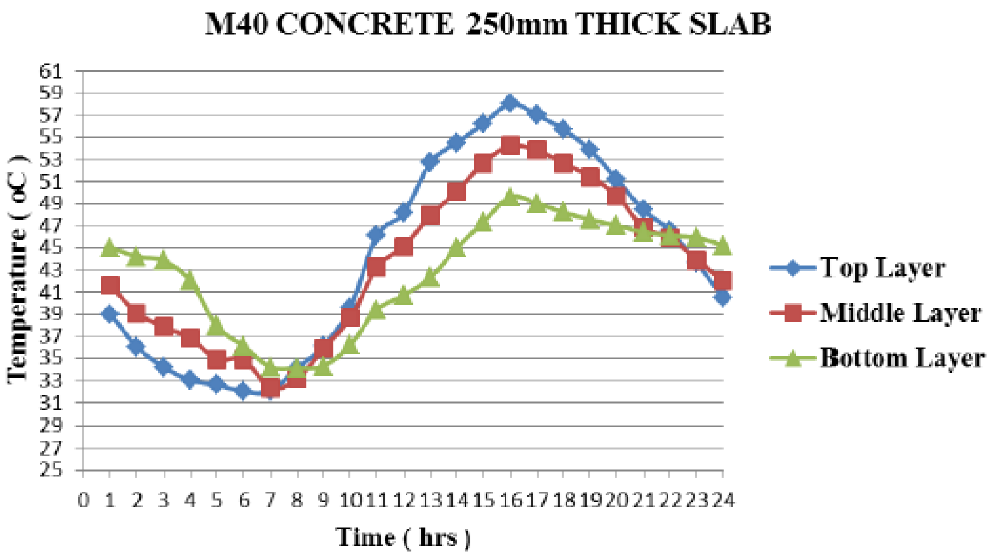

Fig. 2. The influence of the intensity of solar radiation over M40 concrete 250mm thick slab, [2]

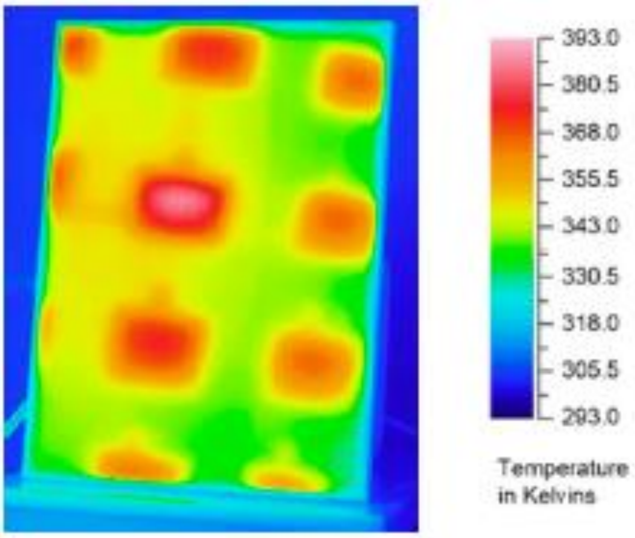

Fig.3. The influence of the intensity of solar radiation over the temperature of the PV panel, [3]

3. THE THEORETICAL ANALYSIS

The energy balance, the amount of energy entering the system (E_{in}) and the evacuated energy from the system (E_{out}), is based on the first principle of thermodynamics and can be expressed by the relation (1):

$$\Delta E = E_{in} - E_{out} \tag{1}$$

The electrical efficiency (η_e) of a photovoltaic panel can be expressed by the relation (2):

$$\eta_e = \frac{P}{A \cdot G} \tag{2}$$

where: P = photovoltaic panel power [W]; A = surface of PV panel [m^2]; G = intensity of solar radiation [W/m^2].
The total efficiency ($\eta_{overall}$) of a thermal photovoltaic panel can be expressed by relation (3):

$$\eta_{overall} = \eta_{th} + \eta_e \tag{3}$$

where: η_{th} = thermal efficiency of PV/T [%]; η_e = electrical efficiency of PV/T [%].
The amount of heat absorbed by the water in the cooling system depends on the contact surface between the water and PV/T, the amount of water at a certain time in direct contact with PV and the temperature difference between the two averages.
From the point of view of the thermal calculation, for a tubular wall the amount of heat collected (Q_u) can be expressed with the generalized equation (4) of heat transfer, as follows:

$$Q_u = k_S \cdot S \cdot \ln(T_{out} - T_{in}) \tag{4}$$

where: k_S = overall heat exchange coefficient [W/m^{2}K], relation (5);

$$k_S = \frac{1}{\frac{1}{\pi d_i \alpha_1} + \frac{R_{sd1}}{\pi d_i} + \frac{1}{2\pi\lambda_p}\ln\frac{d_e}{d_i} + \frac{R_{sd2}}{\pi d_e} + \frac{1}{\pi d_e \alpha_2}} \tag{5}$$

S = contact surface [m^2]; T_{in}= input temperature of the thermal agent [°C]; T_{out}= output temperature of the thermal agent [°C]; d_i = interior diameter = 15, 18, 22 [mm]; d_e = exterior diameter = 16, 19, 23 [mm]; δ_p = thermal thickness of the wall thermal thickness of the wall = 1 [mm]; λ_p = thermal conductivity of the copper pipe wall = 394 [W/mK]; α_1=convection coefficient for primary fluid (air) = 10 [W/m^2·K]; α_2 = convection coefficient for the secondary fluid (water) = 280[W/m^2·K]; $R_{s\,d1}$, $R_{s\,d2}$ = the surface thermal resistances of deposits of the primary fluid (air) side and of secondary one (water) [W/m^2·K].
The theoretical calculation of heat gains and loss in a PV system is based on the fact that the temperature of a PV module will change depending on the amount of solar radiation that it receives. When there is not enough solar radiation to power the PV panel, heat is lost. But if there is enough solar radiation, the temperature of the panel will increase, which is why it is referred to as a 'heat source'. The amount of energy that is transferred from the sun to the PV panel is referred to as the heat gain. The amount of energy that is transferred from the PV panel to the building is referred to as the heat loss. The amount of heat gained and lost in a PV system can be calculated based on the information provided in the module datasheet. The module efficiency will be provided [18].
Heat gain and loss are critical considerations when designing a photovoltaic thermal panel system. Heat gain and loss can be estimated using various calculations, which can be difficult to understand and implement. This paper provides a theoretical case study of heat gain and loss calculations, including the factors that impact them, the equations used to calculate them, and examples of how to apply them in a photovoltaic thermal panel system.
A theoretical analysis was performed for two values of water temperature at the entrance to PV (10°C and 15°C respectively) between 05.00 AM and 07.00 PM. The numerical analysis was carried out for a single photovoltaic panel with three copper pipes attached on the backside, with a length of 2 m (a total length of 6 m). Three different diameters were utilized, leading to three values of the amount of water used in the PV/T cooling, according to the Table 1.
For each construction case, the amount of heat extracted by the cooling system for the same PV/T system located on an M40 CONCRETE terrace, 300 mm thick and 250 mm thick, was calculated. The amount of heat ceded to the PV/T system by the environment depends on the construction model and material from which the terrace is made, the inertia of the heating / cooling cycle being directly proportional to the thickness of the terrace. Also, the amount of water is given by the volume of the cooling system.

Table 1. Technical data for one PV/T cooling panel system, [5, 6]

Nr. crt.	Ø pipe [mm]	Length pipe [m]	Water volume	
			[m^3]	[l]
1	15	22	0.00389	3.89
2	18	22	0.00559	5.59
3	22	22	0.00836	8.36

Case 1.1. (M40 concrete 400 mm): Ø pipe = **15** [mm]; Length pipe = 22 [m]; Volume of water = 3.89 [l]; $k_{S\ Cu}$ = 394 [W/m^{2}K];

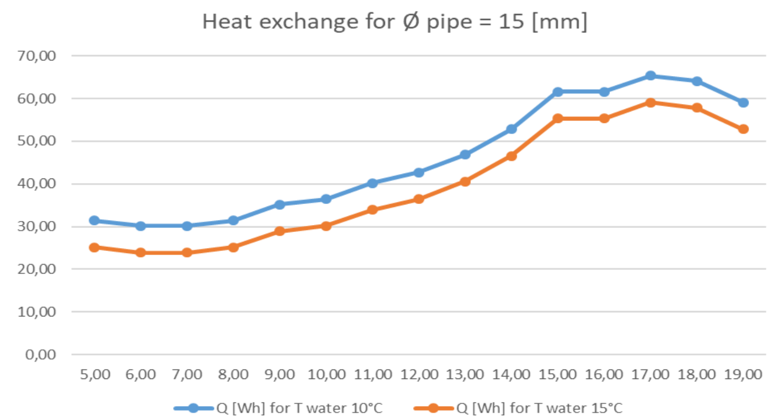

Fig. 4. Hourly heat extraction of the Ø 15 [mm] Cu pipe cooling system from the PVT

Table 2. Input data for the Ø 15 [mm] pipe cooling system

Hour [h]	Temperature of M40 concrete [°C]	Temperature of PV panel [°C]	Q [Wh] for T water 10°C	Q [Wh] for T water 15°C
5.00	33	35	31.43	25.14
6.00	32	34	30.17	23.88
7.00	32	34	30.17	23.88
8.00	33	35	31.43	25.14
9.00	36	38	35.20	28.91
10.00	37	39	36.45	30.17
11.00	40	42	40.22	33.94
12.00	42	44	42.74	36.45
13.00	45.3	47.3	46.89	40.60
14.00	50	52	52.79	46.51
15.00	57	59	61.59	55.31
16.00	57	59	61.59	55.31
17.00	60	62	65.36	59.08
18.00	59	61	64.11	57.82
19.00	55	57	59.08	52.79
TOTAL [Wh]	-	-	689.21	594.93

According to the input data presented in table no. 2, for a cooling system with a pipe diameter of 15 mm, the amount of heat extracted from a PV/T is between 595Wh and 690Wh, in according with the input water's temperature in the cooling system.

Case 1.2. (M40 concrete 400 mm): Ø pipe = 18 [mm]; Length pipe = 22 [m]; Volume of water = 5.60 [l]; $k_{S\ Cu}$ = 394 [W/m^{2}K];

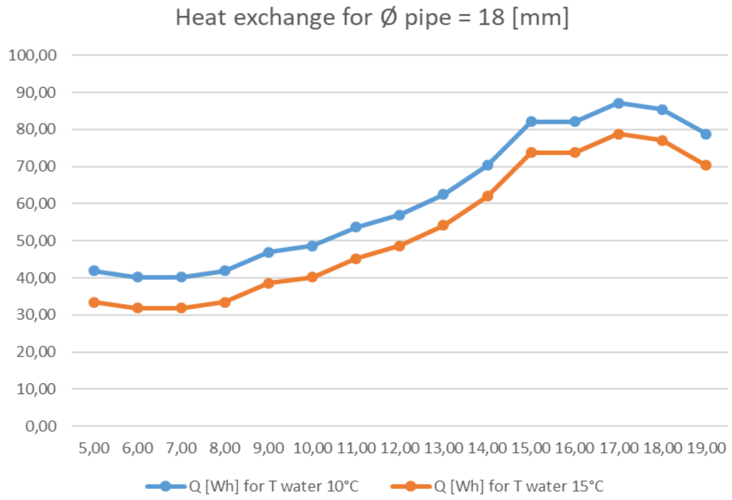

Fig. 5. Hourly heat extraction of the Ø 18 [mm] Cu pipe cooling system from the PVT

Table 3. Input data for the Ø 18 [mm] pipe cooling system

Hour [h]	Temperature of M40 concrete [°C]	Temperature of PV panel [°C]	Q [Wh] for T water 10°C	Q [Wh] for T water 15°C
5.00	33	35	41.90	33.52
6.00	32	34	40.22	31.84
7.00	32	34	40.22	31.84
8.00	33	35	41.90	33.52
9.00	36	38	46.93	38.55
10.00	37	39	48.60	40.22
11.00	40	42	53.63	45.25
12.00	42	44	56.98	48.60
13.00	45.3	47.3	62.51	54.13
14.00	50	52	70.39	62.01
15.00	57	59	82.12	73.74
16.00	57	59	82.12	73.74
17.00	60	62	87.15	78.77
18.00	59	61	85.48	77.10
19.00	55	57	78.77	70.39
TOTAL[W]	-	-	918.95	793.25

The input data presented in table no. 3, for a cooling system with a pipe diameter of 18 mm, pipe at an amount of heat extracted from the same PV/T between 793Wh and 920Wh, in according with the input water's temperature in the cooling system.

Case 1.3. (M40 concrete 400 mm): Ø pipe = 22 [mm]; Length pipe = 22 [m];
Volume of water = 8.36, [l]; $k_{S\ Cu}$ = 394 [W/m^{2}K];

In table no. 4, for a cooling system with a pipe diameter of 22 mm, data are presented on the amount of heat extracted from a PV/T.

Analyzing the data presented in case no 1.1., no. 1.2. and 1.3., the highest amount of heat extracted from PV/T is obtained for the constructive cooling system with a pipe diameter of 22mm for the input water's temperature of 10°C; in conclusion the last constructive system is the most efficient.

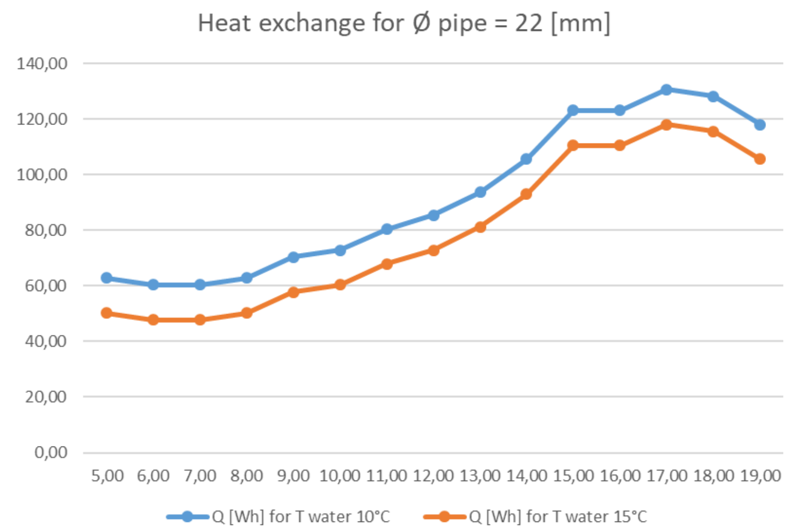

Fig.6. Hourly heat extraction of the Ø 22 [mm] Cu pipe cooling system from PVT

Table 4. Input data for the Ø 22 [mm] pipe cooling system

Hour [h]	Temperature of M40 concrete [°C]	Temperature of PV panel [°C]	Q [Wh] for T water 10°C	Q [Wh] for T water 15°C
5.00	33	35	62.85	50.28
6.00	32	34	60.34	47.77
7.00	32	34	60.34	47.77
8.00	33	35	62.85	50.28
9.00	36	38	70.39	57.82
10.00	37	39	72.91	60.34
11.00	40	42	80.45	67.88
12.00	42	44	85.48	72.91
13.00	45.3	47.3	93.77	81.20
14.00	50	52	105.59	93.02
15.00	57	59	123.19	110.62
16.00	57	59	123.19	110.62
17.00	60	62	130.73	118.16
18.00	59	61	128.21	115.64
19.00	55	57	118.16	105.59
TOTAL [Wh]			1378.42	1189.87

Case 2.1. (M40 concrete 250 mm): Ø pipe = 15 [mm]; Length pipe = 22 [m]; Masse water = 3.89 [l]; $k_{S\ Cu}$ = 394 [W/m^{2}K];
According to the input data presented in Table no. 5, for a cooling system with a pipe diameter of 15 mm, for an M40 concrete terrace with a thickness of 250 mm, the amount of heat extracted from a PV/T is between 621Wh and 715Wh, in according with the input water's temperature in the cooling system.
Case 2.2. (M40 concrete 250 mm): Ø pipe = 18 [mm]; Length pipe = 22 [m]; Masse water = 5.60 [l]; $k_{S\ Cu}$ = 394 [W/m^{2}K];
The input data presented in table no. 6, for a cooling system with a pipe diameter of 18 mm, pipe at an amount of heat extracted from the same PV/T between 828Wh and 954Wh.
Case 2.3. (M40 concrete 250 mm): Ø pipe = 22 [mm]; Length pipe = 22 [m]; Masse water = 8.36 [l]; $k_{S\ Cu}$ = 394 [W/m^{2}K];

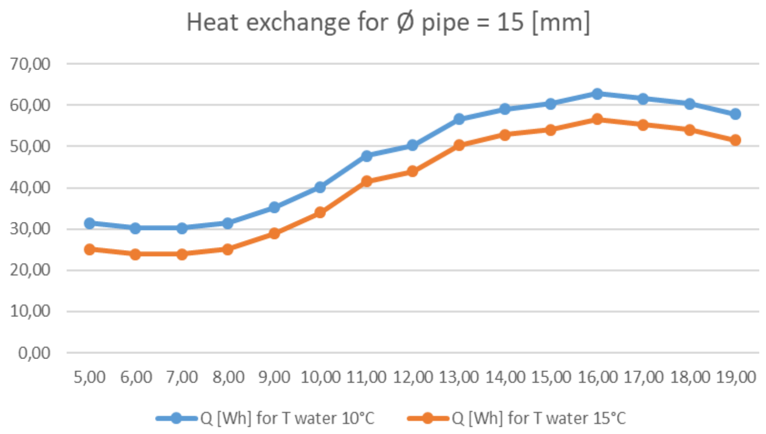

Fig.7. Hourly heat extraction of the Ø 15 [mm] Cu pipe cooling system from the PVT

Table 5. Input data for the Ø 15 [mm] pipe cooling system

Hour [h]	Temperature of M40 concrete [°C]	Temperature of PV panel [°C]	Q [Wh] for T water 10°C	Q [Wh] for T water 15°C
5.00	33	35	31.43	25.14
6.00	32	34	30.17	23.88
7.00	32	34	30.17	23.88
8.00	33	35	31.43	25.14
9.00	36	38	35.20	28.91
10.00	40	42	40.22	33.94
11.00	46	48	47.77	41.48
12.00	48	50	50.28	44.00
13.00	53	55	56.57	50.28
14.00	55	57	59.08	52.79
15.00	56	58	60.34	54.05
16.00	58	60	62.85	56.57
17.00	57	59	61.59	55.31
18.00	56	58	60.34	54.05
19.00	54	56	57.82	51.54
TOTAL [Wh]			715.23	620.95

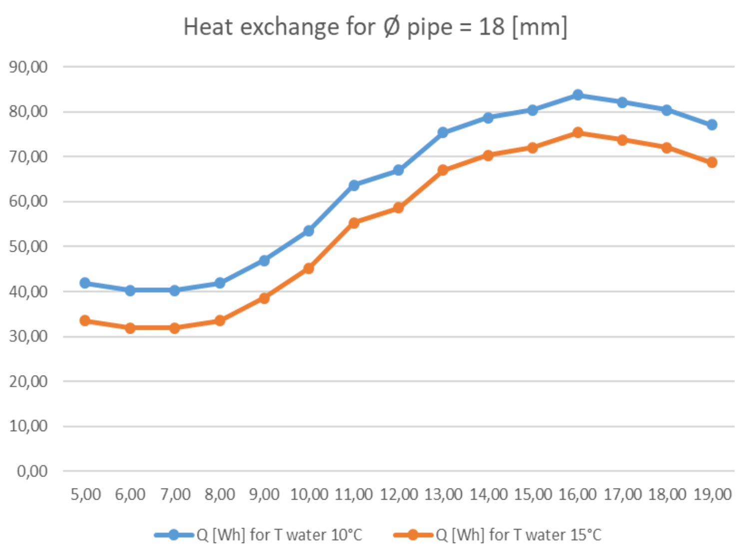

Fig 8. Hourly heat extraction of the Ø 18 [mm] Cu pipe cooling system from the PVT

Table 6. Input data for the Ø 18 [mm] pipe cooling system

Hour [h]	Temperature of M40 concrete [°C]	Temperature of PV panel [°C]	Q [Wh] for T water 10°C	Q [Wh] for T water 15°C
5.00	33	35	41.90	33.52
6.00	32	34	40.22	31.84
7.00	32	34	40.22	31.84
8.00	33	35	41.90	33.52
9.00	36	38	46.93	38.55
10.00	40	42	53.63	45.25
11.00	46	48	63.69	55.31
12.00	48	50	67.04	58.66
13.00	53	55	75.42	67.04
14.00	55	57	78.77	70.39
15.00	56	58	80.45	72.07
16.00	58	60	83.80	75.42
17.00	57	59	82.12	73.74
18.00	56	58	80.45	72.07
19.00	54	56	77.10	68.72
TOTAL [Wh]			953.64	827.94

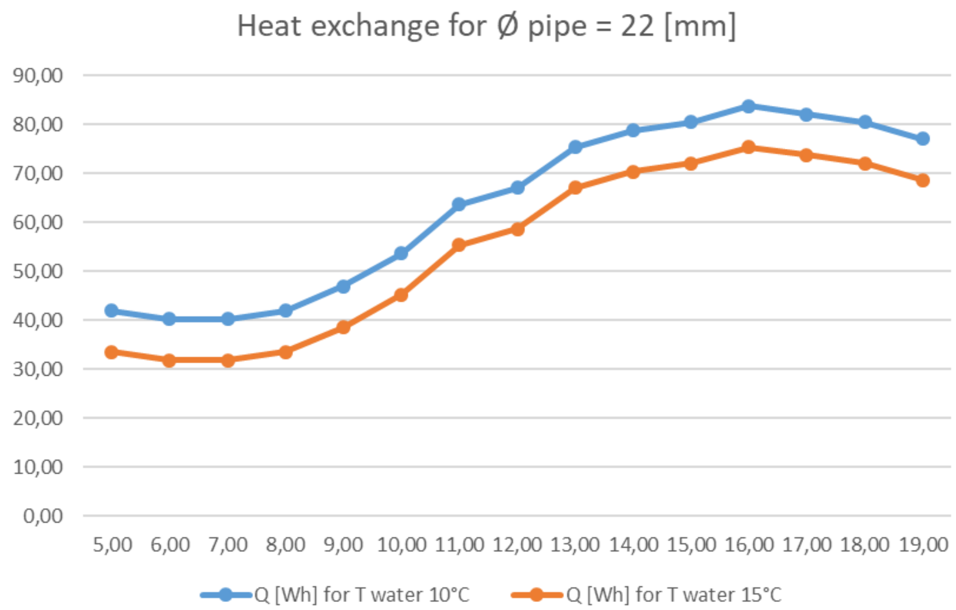

Fig.9. Hourly heat extraction of the Ø 22 [mm] Cu pipe cooling system from the PVT

Table 7. Input data for the Ø 22 [mm] pipe cooling system

Hour [h]	Temperature of M40 concrete [°C]	Temperature of PV panel [°C]	Q [Wh] for T water 10°C	Q [Wh] for T water 15°C
5.00	33	35	62.85	50.28
6.00	32	34	60.34	47.77
7.00	32	34	60.34	47.77
8.00	33	35	62.85	50.28
9.00	36	38	70.39	57.82
10.00	40	42	80.45	67.88
11.00	46	48	95.53	82.96
12.00	48	50	100.56	87.99
13.00	53	55	113.13	100.56
14.00	55	57	118.16	105.59

15.00	56	58	120.67	108.10
16.00	58	60	125.70	113.13
17.00	57	59	123.19	110.62
18.00	56	58	120.67	108.10
19.00	54	56	115.64	103.07
TOTAL [Wh]			1430.46	1241.91

In table no. 7, for a cooling system with a pipe diameter of 22 mm, data on the amount of heat extracted from one PV/T shall be provided; the values are also in according with the input water's temperature in the cooling system. Analyzing the data presented in case no 2.1., no. 2.2. and 2.3., the highest amount of heat extracted from a PV/T is obtained for the cooling system with a pipe diameter of 22mm at an input water temperature of 10°C.
Analyzing the data presented in all cases (from 1.1 to 2.3.), it can be concluded that the maximum value of the quantity of heat extracted from a PV/T is obtained for the construction system with a pipe diameter of 22 mm; the large volume of the pipe system also produces a large amount of water needed for cooling system.
A second factor that determines the amount of heat is the thickness of the M40 concrete from which the terrace is made. Comparing the two constructive types of a terrace (M40 concrete 300mm thickness and 250mm thickness), the result is that for a terrace of 250 mm thickness the heating / cooling cycle frequency is higher, the inertia is lower and this results in a greater heating of the environment.
Also, the temperature of the input water in the cooling system plays a very important role, in the sense that a greater difference between the coolant temperature and the ambient temperature determines a higher heat exchange, therefore a higher amount of heat extracted from PV/T.
In figure no. 10 the results of a comparative analysis of the amount of heat extracted from a PV/T by a cooling system in different construction variants are presented.
For the cooling system, 3 constructive variants were taken into account (pipe diameter of 15mm, 18mm and 22mm); for the terrace, the 2 constructive variants were taken into account, in terms of M40 concrete thickness, of 300mm and 250mm.
From the point of view of system efficiency, constructive variants of the cooling system with a pipe diameter greater than 22 mm are not justified because the amount of water required for cooling is large, which requires a complex pumping system with high energy consumption.
Also, an oversized pipe system would put additional pressure on the resistance structure of the building.

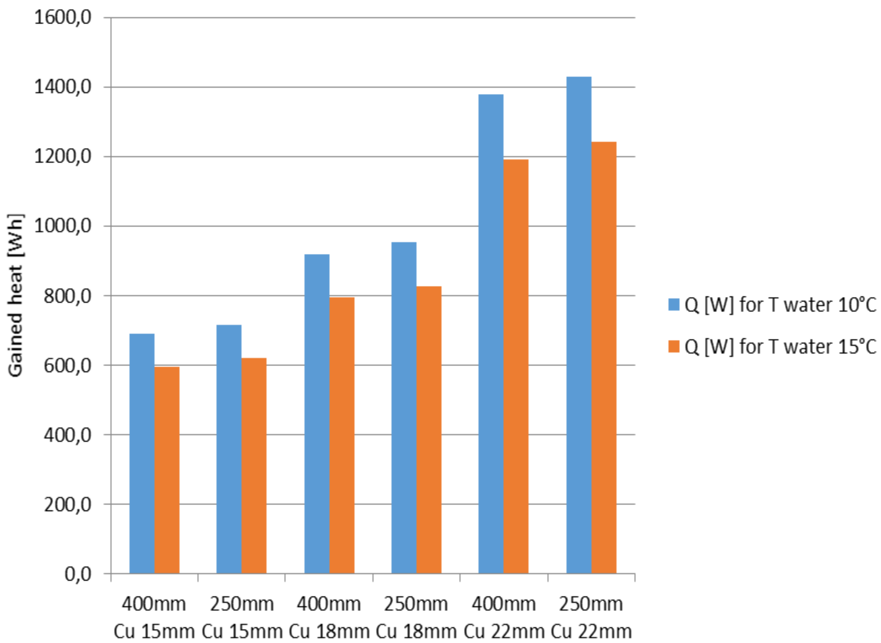

Fig. 10. Heat gained from a PV/T panel during a summer day

According to the calculations, a module of 24 photovoltaic panels on a M40 concrete 250 mm roof, with a Ø 22 mm pipe will produce 34,3 kW (24 PV/T * 1430W) daily, that is 1020 kW in a full summer month. A small pump has the consumption of (50-60) W x12 hours = (600–720) Wh, resulting in a positive efficiency of the photovoltaic thermal system, cooled by water.

The output data (amount of heat extracted by the cooling system and volume of water) calculated for one PV/T (fig. 10) and 24 PV/T (fig. 11) system are presented in table 8.

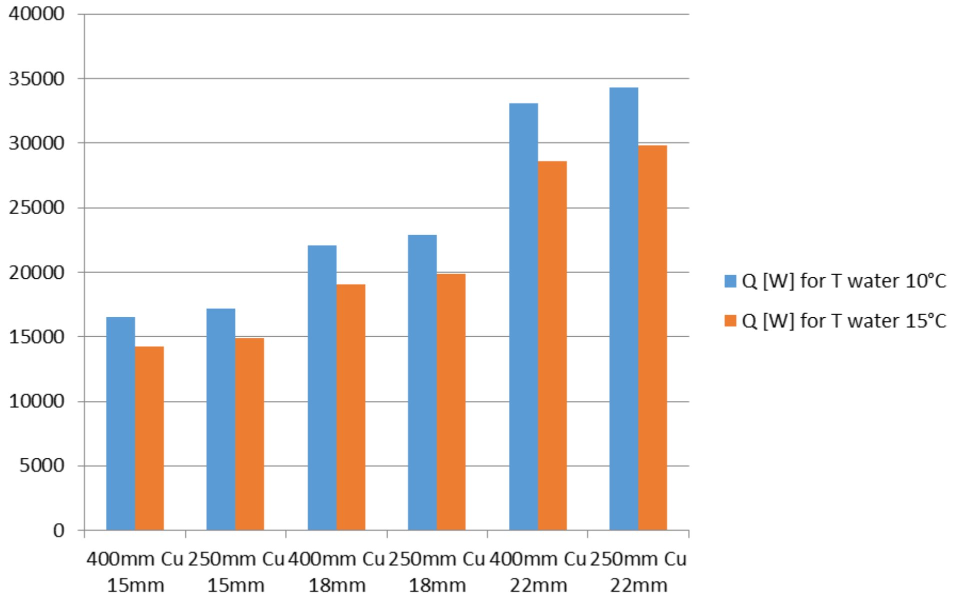

Fig. 11. Heat gained from the 24 PV/T on a shiny summer day

Table 8. Output data for the PV/T cooling system (1 PV/T panel and 24 PV/T panels)

-	M40/400mm Cu 15mm	M40/250mm Cu 15mm	M40/400mm Cu 18mm	M40/250mm Cu 18mm	M40/400mm Cu 22mm	M40/250mm Cu 22mm
1 PV/T panel						
Q [Wh] for T water 10°C	689.2	715.2	919.0	953.6	1378.4	1430.5
Q [Wh] for T water 15°C	594.9	621.0	793.3	827.9	1189.9	1241.9
Water mass [l]	3.89		5.60		8.36	
24 PV/T system						
Q [Wh] for T water 15°C	16541	17166	22055	22887	33082	34331
Q [Wh] for T water 15°C	14279	14903	19038	19871	28557	29806
Water mass [l]	93.36		134.40		200.64	

The amount of electricity and heat produced by the photovoltaic thermal panels is directly proportional to the technical solution adopted for the cooling system, the amount of recirculated water and the velocity of the water [17, 18]. These input values lead to the calculation of the pumping system, whose electricity requirement should not exceed the energy recovered by cooling the PV/T. Additionally, too much water leads to an increase in the PV/T weight, respectively the increase of the pressure on the panels.

This is one of the reasons why the diameter of the Cu pipes should not exceed a maximum of 22mm diameter, and the panels divided into a maximum of three cooling zones.

In order for the entire system to be efficient and the electricity and heat production to be maximum, the water cooling should be done using a pump, with the inlet of cold water at the top of the PV/T, and the outlet the bottom.

The efficiency of the cooling system achieved by correctly dimensioning the water volume, the flow rate, the length and the section of the pipes, and the size of the pump is an important factor in the development of the cooling system. Therefore, the ratio between the amount of the heat extracted and transferred to the heat exchanger and the energy consumed must be positive [19].

Figure 12 shows a constructive model, at the project stage, of a PV/T system, consisting of 24 water-cooled photovoltaic panels. The entire amount of water (200 l) represents an important inertial mass in terms of pressure on the terrace, but also a problem to solve, for structural engineers, in case of an earthquake.

Solving the problem of a building's resistance to a major earthquake becomes more complex as the number of systems with 24 PV/T is higher.

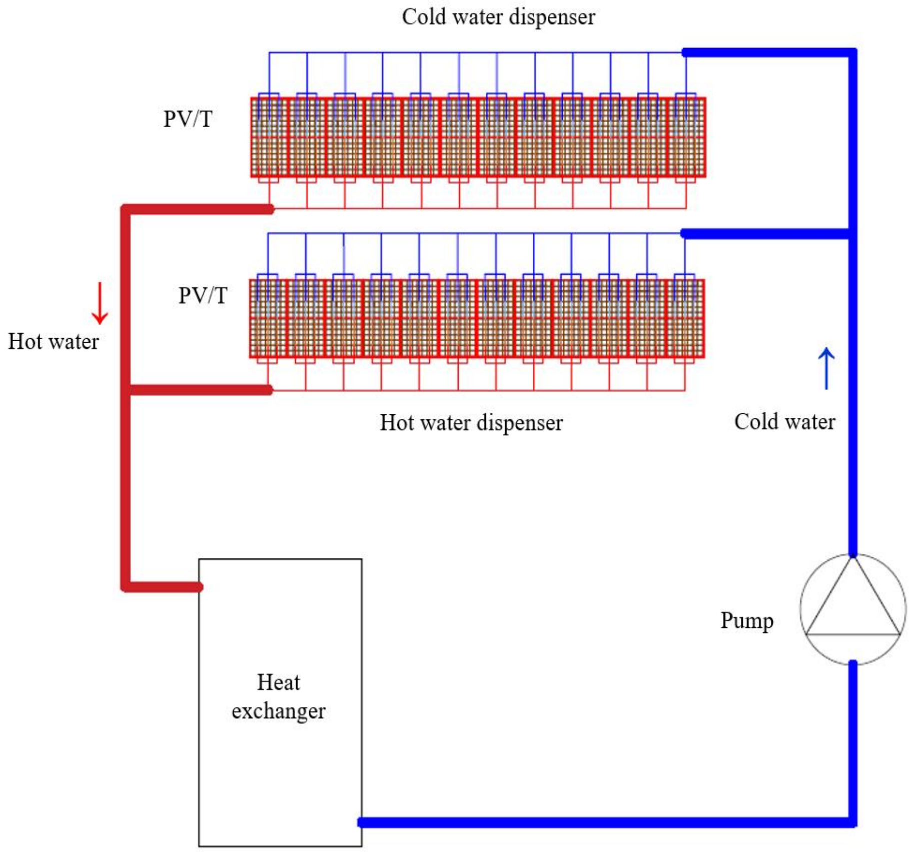

Fig.12. The PV/T system building's integrated [17, 18]

4. CONCLUSIONS

The amount of heat generated depends on several factors such as the amount of the solar radiation available, the panel efficiency, the position and the configuration of the system or the place where the photovoltaic system is installed. An important factor is the material of which the roof or terrace is made, which determines the value of the heat transferred to the environment.
Another factor affecting heat gain and loss is the ambient temperature at which the system is operating. The ambient temperature will impact the generated heat due to the panel efficiency and the system configuration. The ambient temperature also affects the choice of the system components like insulation, dryers and piping. Moreover, the system configuration will determine the amount of heat loss or gain due to the system components and their efficiency.
The heat generated depends on the number of photovoltaic thermal panels installed. However, as we have shown in this paper, the factor that compensates the number of PV/T is given by the amount of water in the installation, which is directly proportional to the number of PV/T and the diameter of the pipes in Cu.
In conclusion the photovoltaic thermal panels (PV/T) represent a viable option to ensure the necessary electricity and heat. They have increased efficiency due to the combination of the two technologies and represent an additional step towards the concept of nZEB (nearly Zero Energy Buildings).
Another conclusion that emerges from the presentation of the constructive models, the input data and the interpretation of the output data, with the help of the mathematical model applied on the 6 cases, the most efficient constructive variant of a water-cooled photovoltaic system is based on 22mm diameter Cu pipes. The constructive model will materialize in an experimental setup to verify, from a practical point of view, the data obtained by theoretical analysis.

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