RESEARCH ARTICLE OPEN ACCESS

Studies of the performances of different thermal photovoltaic modules (PV-Th)

Ines Kanzari, Hatem Oueslati, Salah Ben Mabrouk
Laboratory of Thermal Processes, Research and Technology Center of Energy (CRTEn- LPT)
Po. Box 95, 2050 Hammam-Lif, Tunisia

ABSTRACT
Photovoltaic panels make it possible to transform solar radiation into electrical energy and thermal energy in the form of heat, and this through photovoltaic cells. The disadvantage of a conventional photovoltaic cell is that its performance decreases as the temperature increases. Indeed, part of the solar radiation is not converted into electricity and dissipates in the form of heat which increases the temperature of the cell relative to the ambient temperature.

Hence the discovery of hybrid PV-Th panels that allows the heat transfers fluid to be heated and also to cool the photovoltaic cells and increase their yields.

The purpose of this study is to analyze and determine the performance of each PV-Th module by carrying out various tests on three solar collectors: the PV-Th hybrid panel with PCM, the hybrid PV-Th air panel and the hybrid PV-Th water panel. These hybrid solar energy conversion systems make it possible to obtain simultaneous productions of electrical and thermal energies adapted to various applications in the building (electricity, heating, domestic hot water ...). In this work, we present a study on the thermal behavior of each hybrid panel through the development of thermal mapping and the electrical performance for both PV-Th air and water panels. While the hybrid photovoltaic panel efficiency decreases as the photovoltaic cell temperature increases, the idea is to increase the photovoltaic panel storage capacity using phase change materials (PCMs) placed below the PV-Th air sensor according to a well-defined study.

Keywords - electrical efficiency; solar energy; thermal efficiency; the hybrid PV-Th panel

---

Date of Submission: 05-02-2020 Date Of Acceptance: 20-02-2020

I. INTRODUCTION

This paper presents the design and the development of a new photovoltaic (PV) system using phase changing materials that is recommended to improve the energy efficiency of the module by storing energy losses. As part of a project aiming at the integration of photovoltaic systems in buildings, Mei and al.[1] presented a dynamic model of a solar PV-Th air panel integrated into the facade of a building. This project was carried in Mataro public library in Spain. PV panels were integrated on the facade and roof of this public library Mataro on 1997 by Teulades Multi-Funcional (TMF) [2]. The southern facade of the building, considered comprises from top to bottom, solar air collectors, PV panels connected in series and separated from a double interior glazing by a 14 cm air space, and a brick wall. The facades are composed of cellular concrete and metal cladding. PV modules are composed of poly-crystallin cells encapsulated between two layers of glass. Air is drawn into the base of the air gap at the back of the PV panels. The unidirectional model of the facade has been validated through experimental measurements. The results presented showed that the air ventilated solar collector covers 12% of the heating bills in sunny sites (Barcelona) but covers only 2% of heating bills in sites located further north (Strasbourg). On the other hand, it is necessary to modulate these results because the heating needs differ according to the sites. The theoretical and experimental study in steady state of a PV-Th solar collector with air ventilated naturally or mechanically was presented by Tiwari and al [3]. The PV module is composed of photovoltaic cells bonded to each other by means of a layer of EVA and protected by a layer of glass.

This composent has been integrated into a test bench made of tiltable steel. Fans have been fixed at the entrance of the air gap between the Tedlar and a wooden insulating layer for forced ventilation of the PV modules on the back. The electrical energy produced is stored in an electric battery. This analysis has shown that the additional recovery of the thermal energy produced allows an improvement in the overall efficiency of the air PV-Th system of about 18%. Tiwari and Sodha [4] propose the comparative parametric study of four types of solar air collectors similar to the system previously presented. These systems are differentiated by the presence or absence of a glazing and a support in Tedlar. The thermal models produced were validated experimentally on the test bench. The results obtained show that the glass-free air component without Tedlar is the most efficient and has the highest overall efficiency increase (thermal and electrical). This glazed system could be used for various applications such as heating and lighting of buildings. Sarafraz and al. [5] conducted an experimental study to evaluate the thermal properties of water and the electrical performance of a solar photovoltaic panel cooling system composed of multi-walled carbon nanotubes. It is also filled with a phase change material (PCM) of carbon nanotubes and multiwall paraffin's. The Nano fluid (MWCNT / WEG50) was introduced into the lines, while the Nano-PCM was in the cooling jacket. Nonylphenol ethoxylates at a volume of 0.1% were used to increase the stability of Nano fluid and to decrease the surface tension and attraction forces within the nanofluid mass. The results showed that an increase in mass concentration and cooling increases the production of electricity while the increase in the mass of the Nano fluid causes a decrease in the thermal power. S.C.Solanki and al. [6] have studied the internal performance of a solar heater system integrated with an air line and they proved that the thermal, electrical and overall efficiency of the solar heater obtained at indoor condition is 42%, 8.4% and 50%, respectively**.** Lin and al [7] used PCMs for floor heating to improve air conditioning inside the building. Al-Waeli and al. [8] studied the effect of adding the SiC nanoparticles added in paraffin as a PCM on the effectiveness of PV-Th systems. The system studied reduces the temperature of PV cells to 30°C and therefore increases its power outpoor from 61.1W to 120.7 W.

Several methods have been used for the thermal regulation of PV panels and to cool PV cells such as fans used to force the air inside the panel in order to maintain a higher outlet temperature.

Yun and al. [9] presented a ventilated wall formed by a PV system, they noted an increase of 2.5% in the electric power supplied by the PV system.

The integration of Phase Change Materials (PCM) at the back of the photovoltaic panels is a perfect way to cool the PV cells, to store solar energy and to release it when it's necessary [10].

Alkilani and al. [11] studied the variation of the air temperature in the air panel with phase change materials. The system consists of a solar air collector and an extractor to circulate the air inside the collector. The PCMs used are cylindrical tubes which enclose paraffin and aluminum powder.

Chaichan and al. [12] used paraffin by adding aluminum powder to improve the thermal conductivity of MCP.

Esakkimuthu and al. [13] introduced PCM (HS-58) in an air solar panel and evaluated the heat storage characteristics and the air flow at the inlet and outlet during the charge and discharge phases. He valued the use of this system to store a maximum of heat and extended the duration of using the air sensor in darkness.

Brown and al. [14] presented a new PV system with PCM coupled with a network of pipes filled with water to use the energy stored by PCMs. They found that the use of PCM can improve up to 7 times the amount of heat released by the PV panel used without PCM.

Thermal powers of the system were evaluated at various local times and at different temperatures. The purpose of this document is to compare three PV modules: the PV-Th air hybrid panel with PCM, the PV-Th Hybrid air panel and the PV-Th Hybrid water panel in order to order to improve the thermal efficiency of the PV-Th air panel.

For the air conditioning of buildings, PCMs have been used extensively in buildings, Kissock and al. [15] made PCM test cells constructed with an alkyl hydrocarbon mixture. They compared a control cell and PCM cell to highlight the increase in thermal capacity of the PCM cell. They gived the evolution of the temperature in the two cells during three days.

II. DESCRIPTION OF THE EXPERIMENTAL TESTS DONE ON THE THREE PANELS:

The purpose of this document is to compare three PV modules: the PV-Th hybrid panel with PCM, the PV-Th Hybrid air panel, and the PV-Th Hybrid water panel. The three modules were monocrystalline YINGLI provided by the CRTEn where measurements were made.

The weight is 19Kg, The size is 1640x990x40mm , the output cable is symmetrical and long 's 1m, made of a double insulating layer, halide-free and resistant to UV radiation, and the IP-65 connection box with diodes by pass protection. The frame is an anodized aluminum alloy - type 6063 T6, high conductivity of the glass and thickness of 3.2mm with solar cells that are 60 monocrystalline cells (156x156mm).

During experimental tests, the temperature of the fluid at the inlet (Te) and at the outlet (Ts) is measured. We also measure the temperature of the photovoltaic cells Tc and the temperature of PCMs: T_{PCM}. The efficiency, electric power and voltage of the panelare also measured to see the electrical and thermal performance of each PV-Th panel.

II.1. A case of the PV-Th air panel:
II.1.1. Material and methods

We start with the hybrid air solar collector, which consists of a transparent cover, an absorber painted in black and a perfect insulated back support (Fig.1). The PV cells are bonded to the absorber by means of an adhesive layer chosen for its good properties of thermal conduction and electrical insulation.

The solar radiation is perpendicular to the surface of the panel (which allows a maximum absorption of solar energy) and it is necessary to orient the panel to the south, so in our case the angle of inclination of the panel, was measured to 39°.

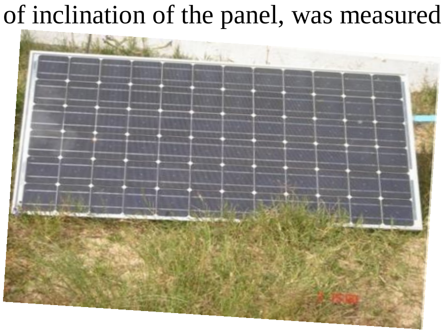

Figure 1: The Hybrid PV-Th Air panel

The acquisition of the data was ensured by a series of thermocouples connected to an HP34970 acquisition chain. The HP-VEE software [16] carries out the piloting and processing of the tests. In order to complete the experiment, eight thermocouples were placed on the system, and distributed as follows: 1 thermocouple at the input of the panel to measure the input temperature (Te), 1 thermocouple at the panel output to measure the temperature of the outlet (Ts), 2 thermocouples at the absorbing plate to measure the temperatures (Tabs1, Tabs2), 2 thermocouples at the glazing to measure the window temperatures (Tv1, Tv2), 1 thermocouple at the level from the back of the panel to measure the ambient temperature in the shade (Ta). A pyranometer placed at the same inclination as the panel to measure sunshine, an anemometer and with an accuracy of 0.01 m / s is placed, at the point of measurement, perpendicular to the flow. The tests we have done measure the temperature of each element of the PV-Th panel and the photovoltaic module, they also measure the air temperature in the PV-Th panel and the air temperature at the inlet and outlet of the panel. The flow and the voltage of the PV-Th panel and the PV module were taken during the same test period. So, the hybrid module studied contains a photovoltaic module (hot wall) to produce electricity and an air thermal module (cold wall) to cool the rear surface of photovoltaic cells and heat the air circulating in the canal. The electrical efficiency of the panel shown in figure 2 depends on the temperature of the photovoltaic cell, when the temperature of the solar cell increases the electrical efficiency decreases.

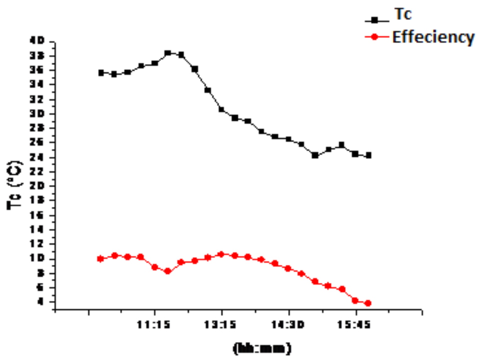

Figure 2: Influence of Cell Temperature on Electrical Efficiency

II.1.2. Results by the infrared camera

Infrared thermography allows visualizing on an image the temperature of the materials which are in the field of observation [17].

The results of the thermal readings are given in the form of thermal images representing the apparent temperature distribution, in degrees Celsius (° C), at the surface of the panel 's sections. The temperature scale chosen to describe the variation of the temperature at the surface of the examined section is a color scale which associates the red-white color at the highest temperatures (potentially problematic areas) and the color blue at the lowest temperatures (areas a priori healthy).

The figure 3 is a photograph of the hybrid air panel. The locations of the 13 positions of this panel are indicated on this picture as well as their identification number. These numbers have been inscribed on the picture by means of different colors corresponding to various visual states of the photovoltaic cells.

According to figure 3, the top part of a hybrid panel with an infrared camera is in good condition and is free from any installation defect. The result indicates that the problem areas are located on the right side and the left side of the bottom half of the panel.

In order to study the possibilities of the thermography to highlight the defects of installation of the panel, the analysis of the thermal images collected on this panel was carried out based on the observations made on the photovoltaic cells.

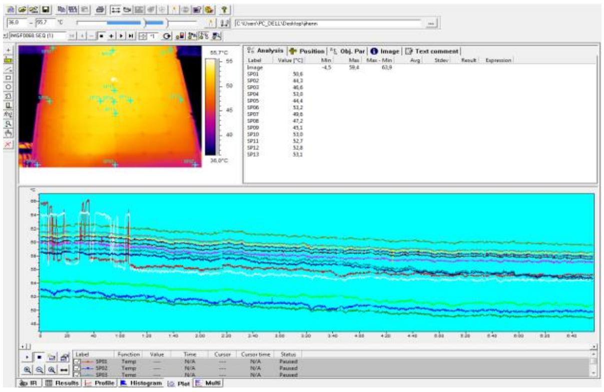

Figure 3: Image of the part below a hybrid panel with an infrared camera in the presence of spectrum.

Figure 4 is the thermal image of the bottom half of the collector collected at 1:00 pm. The surface temperature is between 24.5ºC and 32ºC, a variation of 8.5ºC. This variation is wide and does not allow appreciating the relative importance of one anomaly compared to another.

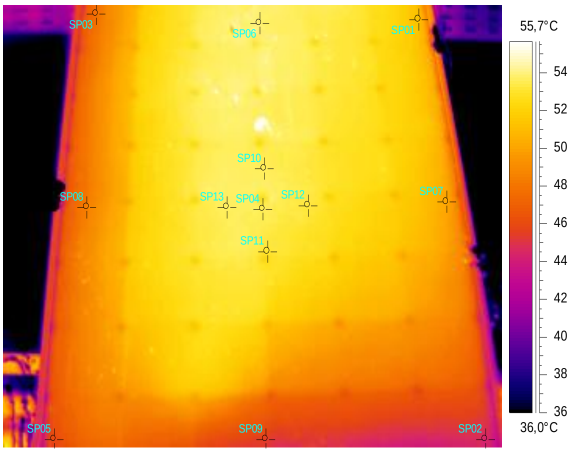

Figure 4: Image of the part below a hybrid panel with an infrared camera

So visually and in order to better show the thermal anomalies and highlight them according to their importance, the temperature scale of the image of the figure (3) has been reduced by keeping fixed the maximum value of the temperature (55,7ºC) and the minimum value (36ºC). The image of this figure has a temperature range of 36 ºC, and 55.7 ºC so a difference of 19.7 ºC. This figure shows that the highest temperature is observed within the zone between the centered positions, SP04, SP10, SP11, SP12 and SP13. A hot zone also appears on the right side of the panel, at position SP01 and on the right of SP07. This result is in agreement with the observations made on this panel which indicates a malfunction of photovoltaic cells at these locations. However, figure 4 also shows that the locations of photovoltaic cells that were considered problematic by the measurements were not all detected by thermography. This can be explained by the fact that defects in the cell are sometimes small. In some cases, the anomaly found on the cells is an importance of the heat losses which does not necessarily lead to a panel operation.

II.1.3. Thermal analysis of the right side

The hottest surface is to the right of the two positions SP01 and SP07. The photovoltaic cells of this portion of the panel is likely problematic and it is highly likely that there is a large void at this location.

SP07 is located in an area where the temperature is higher than the average temperature. The measurement report also mentions the importance of heat losses because the panel is free and not isolated at this location and a malfunction of the photovoltaic cell, as shown in the photograph of the panel.

Position SP01 is also on the perimeter of an area where the temperature is higher than the average. The measurement report mentions a loss of air and a malfunction of the cell. The photograph of the cell taken from this location shows a crack and a vacuum comparable to that observed on position SP07.

The SP02 position is in an area which temperature is lower than the average temperature. The panel at this point has a priori worked well. This is in keeping with the measurement ratio due to less hot air and large convection cooling capabilities.

II.1.4. Thermal analysis of the left side

The surface temperature at positions SP08, SP03, SP05 is slightly lower than the average temperature. The measurement indicates that the photovoltaic cells of the panel are good or acceptable. The temperature of the surface at position SP05 is lower than the average temperature. This can be interpreted as a good operation of the panel. The measurement report also indicates that the cell's operation of this panel is good due to less hot air and large convection cooling capabilities. The temperature of the surface at positions SP08 and SP03 is lower than that recorded at positions SP07 and SP01, even if the operation of the panel extracted from these two positions is qualified bad. This can be logically explained by the fact that the cells at positions SP08 and SP03 are more problematic than the one extracted from positions SP07 and SP01.

II.1.5. Thermal analysis of the centered side

The surface temperature at positions SP04, SP10, SP11, SP12 and SP13 is higher than the average temperature. However, according to the measurement report, the functioning of the panel in these places is good and no loss of air was observed during the measurement. There is therefore a disagreement between the thermal readings and the actual panel state.

SP09 is located in an area where the temperature is lower than the average temperature. The panel at this point is a well made. This is in keeping with the measurement ratio due to less hot air and large convection cooling capabilities.

The temperature at position SP06 is comparable to that recorded at positions SP04, SP10, SP11, SP12 and SP13. However, the measurement report indicates that the operation of the cell is acceptable and no air loss has occurred during the measurement.

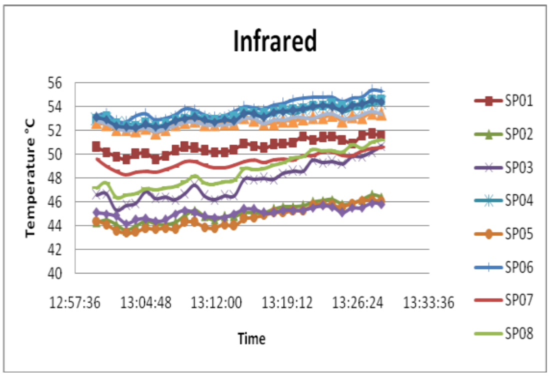

Figure 5: Variation of the temperature in terms of time for different positions

The curves of temperature variations at different positions (Figure 5) consist of three parts: the first part corresponds to the lower part of the panel at the three positions SP02, SP05, SP09 with low temperatures, the second part corresponds to the right and left panel part at the four positions SP01, SP07 on the right of the panel and SP03, SP08 on the left of the panel with low temperatures, the third portion corresponds to the panel centered portion at the six positions SP06, SP04, SP10, SP11, SP12 and SP13 with higher temperatures. The variations of the spectra at the two positions SP01, SP07 show some fluctuations, so we can see defects in these positions conformed to what we perceive visually.
Infrared thermography as a non-destructive radiometric measurement technique is used to detect problems and defects in the hybrid PV-Th air module. The infrared camera helps us locate symptoms and offer recommendations.

II.2. Hybrid PV-Th water panel Case

II.2.1. Material and methods

The second panel studied is the hybrid PV-Th water panel: the production of domestic hot water is carried out in the Thermal Processes Laboratory (LPT) from which the second solar system studied is composed of the photovoltaic hybrid PV panel used previously cooled by a serpentine tube which is glued or welded on the absorber sheet placed on the rear part of the photovoltaic module, a storage tank for domestic water and a hot water circulation pump. A data processing system consisting of an HP34970A acquisition chain with its measurement panels connected to a computer is used. As for the flow of water circulating in the installation, it is taken by a flow meter.

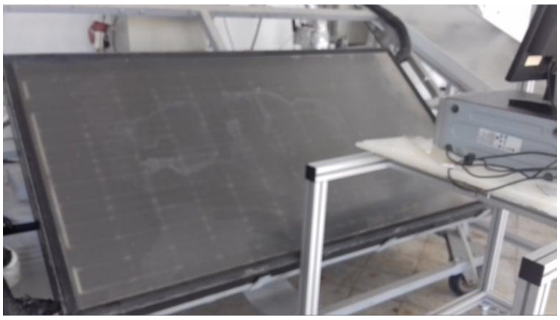

Figure 6: Image of the PV-Th water panel realized in LPT

Figure 7: Solar Thermal Collector Test Bench

II.2.2. HP-VEE aquisition software [16] :

The data acquisition system consists of an HP 34970A type chain. It ensures the conversion and scaling of the electrical signals delivered by the measurement panels and it is controlled by a program that ensures the acquisition of the data necessary for the evaluation of system performance.

The acquisition program was realized using the language that provides a development environment. A program on HP VEE [16] consists of procedures and functions requiring a declaration of variables and respecting a given syntax. The particularity of HP VEE [16] compared to other programming languages is that it has predefined objects constituting subroutines. The combination of these objects constitutes effective programs to satisfy the user's need. These predefined elements can connect to each other according to certain rules.

The program is designed according to the standards for the flat solar collector test.
It is as follows:

- At the start of the program the acquisition chain initializes the different probes, the anemometer, the flow meter and the pyranometer at a measurement frequency equal to 10s.

- After entering the temperature of the setpoint, the program always takes the final values given by the acquisition chain and measures the difference Ts - Te (this difference must not exceed 0.1 ° C). The program also measures sunlight G which must be superior to 800W/m².
- Once the difference is stable, in general this stability is reached during 15min, the program proceeds to the recording of the acquired data for 90 successive values and finally stops the recording automatically.

Before placing our PV-Th water panel in the test stand, we made a simple IV test without introducing water into the water circuit, that is to say the photovoltaic cells do not undergo the test.

Contrarely to the previous case, it is observed that in the course of time the electrical efficiency increases from a value of 7% at 10:30 to a value of 9.39% at 11:40, this is explained by the influence of the circulation of water at primary circuit that heats up by absorbing the heat of the PV cells, hence the cooling of the latter and the increase in yield.

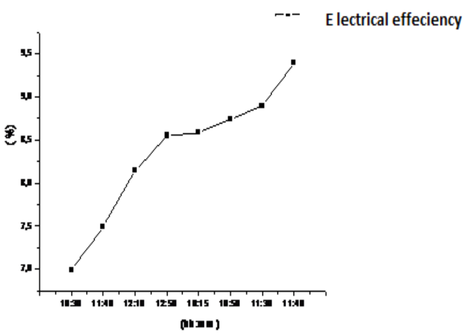

Figure 8: Variation of electrical efficiency

II.3. Case of a PCM panel:
II.3.1. Experience

The same tests are repeated at the addition of the PCM placed below the PV-Th air panel to have the new solar system that will present us the hybrid PV-Th air panel with PCM.

The solar system is composed of the following elements: the same air PV-Th panel used in the previous part, an extractor placed above the panel and thermocouples (type K) to measure the different instantaneous temperatures.

The latent thermal storage solar collector consists of coverage of photovoltaic cells considered as a glass in this simulation to determine the thermal aspect, spherical nodules that contain a Phase Change Material (solid-liquid) melting temperature 27 °C. The thermal characteristics of a nodule "AC27" are given in the table 1, an extractor allowing the circulation of air, a thermal insulation around the different phases and a box placed above panel and which allows to place the nodules in rows and also allows the passage of air between these nodules. This solar system makes it possible to store the solar energy for a predefined duration and to destock it following the movement of air which circulates between PCMs.

During the day, the panel openings are closed and solar radiation passes through the cover formed by photovoltaic cells, arrives on the nodules that change their physical state (from solid to liquid) when its internal temperature reaches 27 ° C and starts to store energy.

At night and in the absence of solar radiation, the extractor starts: the air circulating between PCMs makes it possible to release the thermal stored energy towards the outside environment.

Figure 9: Set of nodules placed in the convergent case

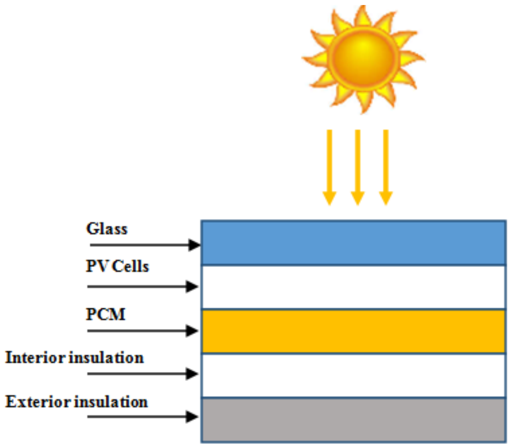

Figure10: The different layers that make up the new solar system

In this work, and while starting from the fact that the yield of the air hybrid photovoltaic panel decreases when the temperature of the photovoltaic cells increases, the idea is to increase the capacity of storage of the photovoltaic panels with the help of Phase Change Materials (PCMs) placed under panel according to this pre-written study.

II.3.2. Characteristics of the used PCM

The shell of a nodule is a mixture of black colored polyolefins 0.002 mils thick containing a phase changing material made of $CaCl_2 6H_2O$ with additives (to prevent super-cooling and dehydration) and a melting temperature of 27 ° C. . The nodule has a lifespan of over 20 years and withstands 10,000 cycles without mechanical failure

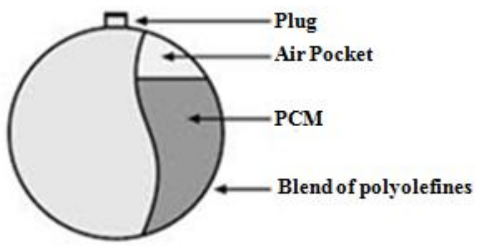

Figure 11: Conditionning of PCM in nodules [18]

Figure 12 shows the evolution of the air temperature at the output of the PV-Th panel with PCM, which varies linearly as a function of the absorber temperature formed by the PCM according to the relation:

$$T_s = 0.81\, T_{PCM} + 5,8 \qquad (1)$$

T_s: outlet temperature(°C); T_{PCM}: temperature of PCM(°C)

From where we note that for a fixed air flow rate, we can estimate the temperature of the air at the panel outlet according to the PCM temperature.

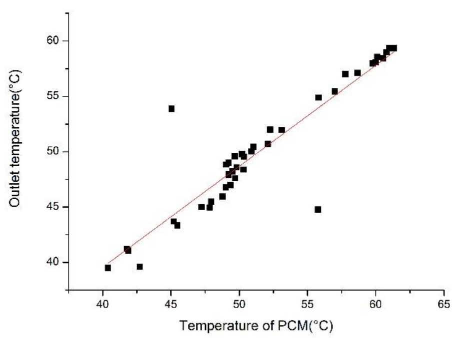

Figure12: Variation of the panel's air outlet temperature according to the temperature of the PCM

III. THERMAL EFFICIENCY STUDY OF THE THREE PANELS:

$$\eta = \frac{Qu}{Qr} = \frac{qm * Cp * \Delta T}{G * Sv} \qquad (2)$$

With:

Qu: The useful power, which allows to heat the flow of heat transfer fluid (qm) from the inlet temperature Te to the outlet temperature Ts (W); Qr: received solar power (W), qm: mass flow rate (kg / s); qm = ρ * Vs * Se

Vs is the air velocity at the panel outlet (m/s) ρ is the air density(1.2Kg/m^3); Se: panel input section (m²); Se = L *l = 515 mm * 40 mm = 0.0206 m²; Cp is the heat capacity (1600 J / Kg°C for air); ΔT is the Temperature Variation (Ts-Te) (°C); G is the solar illuminance (W / m²); Sv is Glass area (m^2).

It can be seen that for a constant fluid velocity, the thermal efficiency of the panel depends on the difference in the temperature of the fluid. That is, as the temperature difference increases, it causes an increase in thermal efficiency. The total yield is the sum of the thermal and electrical efficiency. The circulation of air inside the panel improves the thermal efficiency of the PV-Th panel while taking heat from the photovoltaic cells, hence the increase in thermal efficiency as well.

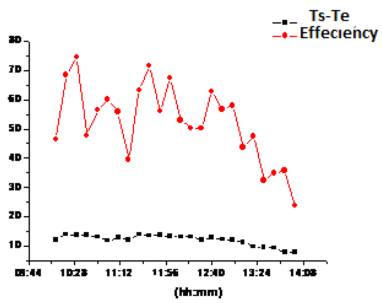

Figure 13: Thermal efficiency variation of PV-Th air panel

The thermal efficiency curve of the PV-Th water panel is plotted from the instantaneous yields:

$$\eta = \frac{m\, Cp(Ts - Te)}{A.G} \qquad (3)$$

η: Instantaneous thermal efficiency of the sensor (%); m: Mass flow rate of the coolant (Kg / s) ; A : solar collector surface (m^2).

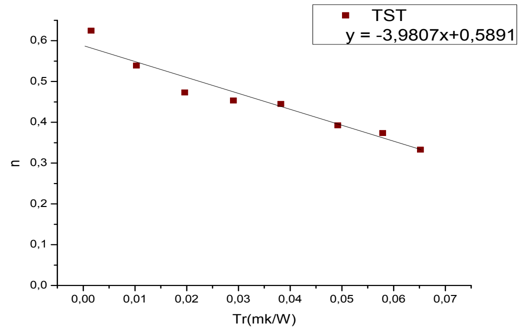

Figure14: Thermal efficiency curve of PV-Th water panel

The evolution of the yield (η) according to Tr is a straight line of equation:

$\eta = -3.9807\ Tr + 0.5891$ (4)

$T_r = \frac{(Tm - Ta)}{G}$; $Tm = \frac{Te + Ts}{2}$

Ta: ambient temperature (° C)

With (-3.9807) corresponds to the thermal losses of the panel, and (0.5891) corresponds to the optimal efficiency η_0..

It should be noted that the reduced temperature is that reported by the flow of light, the variation of the thermal efficiency is inversely proportional to this temperature Tr.

Let's go to the third panel realized and studied in LPT where we used the same air PV panel used previously and where we inserted PCM in the form of nodules which were placed in a box placed under panel and consequently we realized a new air heating system with energy storage in the form of heat.

The average PV-Th panel efficiency with PCM is the rational of the amount of heat released during the discharge phase (from 9 to 16h) on the heat energy captured by the solar system during the charging phase (from 16h to 9h the next day).

η' = (ΣQuantity of absorbed heat) / (ΣQuantity of dissipated heat) (5)

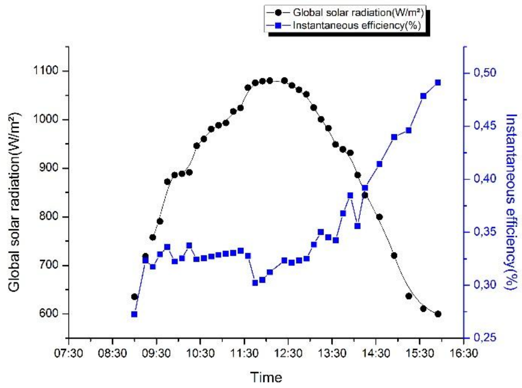

Figure15: Variation of the instantaneous efficiency of the PV-Th with PCM panel in charge / discharge mode and sunshine according to time of time

IV. CONCLUSION:

The goal set in the beginning of this work was achieved: the realization of a new PV-Th panel with PCM and while starting from the fact that the yield of hybrid photovoltaic panel decreases with the increase of the temperature of the photovoltaic cells, the idea is to increase the photovoltaic panel storage capacity using phase change materials (PCMs) placed under PV-Th panel studied and the cooling of PV cells using the PV-Th air panel.

To achieve this goal, three types of experiments were set up to compare the three PV modules: the PV-Th hybrid panel with PCM, the PV-Th Hybrid air panel and the PV-Th Hybrid water panel.

In the first experiment, a test bench made it possible to estimate the conditions to have a good thermal and electrical efficiency, we also used the technology of the thermography using an infrared camera to detect the fluctuations at the level of the photovoltaic cells that have a direct effect on the operation and performance of our panel.

The assembly of a photovoltaic panel and a solar thermal panel in the same module has been established. The advantage of this type of installation is to be able to use the fluid of the thermal part to cool the photovoltaic cells to improve the efficiency.

Thanks to the infrared camera, we knew the defects in our air PV panel and the problems in the PV cells.

In the second experiment; the hybrid PV-Th water panel has been studied, the principle used for the panel test being to expose it to solar irradiance and to measure continuously the temperatures at its inlet and its outlet, the flow of the fluid coolant that passes through it and the incident solar irradiance. The acquisition of the different variables is carried out using an HPVEE program.

In the third experiment, this work enabled us to establish the validity of the concept of PCM coupling with the PV-Th air panel. It has been presented during two different phases: a charging phase where all the new panel openings are closed and the latter begins to store the energy, a discharge phase where the extractor starts to release the thermal energy stored in the PCM.

According to the various tests carried out on these different modules of the hybrid panel, it can be seen that each module is complementary to the other: The photovoltaic module represents the absorber of the thermal module and enables it to reach high temperatures exploitable in the premises, the thermal module cools the PV cells and improves their efficiency. The new PV-Th air panel with PCM transmits solar radiation to PCM storage and improves the performance of PV air panels.

The comparison between the thermal and electrical efficiencies of the three panels enabled us to value the use of the chosen PCMs and integrated into the hybrid photovoltaic panel.

This work constitutes an opening towards other researches: the use of other PCM, the creation of other panels where we have a coupling between the thermal aspect after the storage of the energy and the photovoltaic aspect of the panel and the installation of these panels in buildings according to well-studied positions.

Journal Papers:

[1]. M. Li, D. Infield, U. Eicker, V. Fux, "Thermal modelling of a building with an integrated ventilated PV facade", Energy and buildings, 2003, vol. 35, pp. 605-617.
[2]. TFM. Multi-service and multi-technical company that takes care of the maintenance of the buildings and the operation of the installations.
[3]. A.TIWARI, M.S. SODHA, A. CHANDRA, "Performance evaluation of photovoltaic / thermal solar air collector for composite climate of India. Solar Energy Materials and Solar Cells", 2007, vol. 91, n° 1, pp. 17-28.
[4]. A.TIWARI , M.S. SODHA, "Parametric study of various configurations of hybrid PV/thermal air collector: Experimental validation of theoretical model Solar", Energy 2007, vol. 32, n°13, pp. 2223-2241.
[5]. M. M. Sarafraz, M. R. Safaei, A. S. Leon, I. Tlili, T. A. Alkanhal, Z. Tian, M. Goodarzi and M. Arjomandi, " Experimental Investigation on Thermal Performance of a PV/T- PCM (Photovoltaic/Thermal) System Cooling with a PCM and Nanofluid", Published: 4 July 2019.
[6]. S.C. Solanki, S. Dubey, A. Tiwari, " Indoor simulation and testing of photovoltaic thermal (PV/T) air collectors", Applied Energy, 2009; 86: 2421-2428.
[7]. K. Lin, Y. Zhang, X. Xu, H. Di, "Experimental study of under-floor electric heating system with shape- stabilized PCM plates", EnergyBuild. 37 (2004) 215–220.
[8]. H.A. Al-Waeli Ali., "Evaluation of the nano fluid and nano-PCM based photovoltaic thermal (PVT) system: an experimental study, Energy Convers". Manage. 151 (2017) 693–708.
[9]. G.Y. Yun, M. McEvoy, K. Steemers, "Design and overall energy performance of a ventilated photovoltaic facade", Sol. Energy 81 (2007) 383–394.
[10]. N. Zhu, Z. Ma, S. Wang, "Dynamic characteristics and energy performance of buildings using phase change materials: a review", Energy Convers. Manage. 50 (2009) 3169–3181.
[11]. M.M. Alkilani, K. Sopian, S. Mat, M.A. Alghoul, "Output air temperature prediction in a solar air heater integrated with phase change material", European Journal of Scientific Research 2009: 334-341.
[12]. M.T. Chaichan, H.A. Kazem, "Using aluminium powder with PCM (Paraffin Wax) to enhance single slope solar water distiller productivity in Baghdad" – Iraq winter weathers. 5(1) (2015) pp. 251–257.
[13]. S. Esakkimuthu, A.H. Hasabou, C. Palaniappan, M. Spinnler, J. Blumenberg, R. Velraj, "Experimental investigation on phase change material based thermal storage system for solar air heating applications", Solar Energy 2013; 88: 144-153.
[14]. M.C. Brown, B. Norton, S.J. McCormack, "Heat retention of a photovoltaic/thermal collector with PCM", Sol. Energy 133 (2016) 533–548.
[15]. J.K. Kissock, J.M. Hannig, T.I. Whitney, M.L. Drake, "Early results from testing phase change wallboard", IEA annex 10, phase change materials and chemical reactions for thermal energy storage first workshop, 16-17 April 1998.
[16]. HP-VEE software : HP VEE/Visual Programming Language, http:// www.hp.com/, 2019 (accessed 13.10.2019).

Theses:

[17]. Atef Mazioud, University Paris-Est. Center for Studies and Research in Thermal, Environment and System.

Books:

[18]. Cristopia Energy System. Manuel technique. Vence 5 France, 2000