# Chapter 102

## Application of energy generation hybrid solar panels in a university student house

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**Eluan Oliveira Nascimento**
**Paulo Roberto Duailibe Monteiro**

**Eric Serge Sanches**

**José Ernesto Viqueti Fassarela**

**Carlos Henrique Ventura do Rosário Oliveira**

**ABSTRACT**
This paper presents the study of technical and economic for the supply of electricity and water heating, using hybrid solar panels to house students from the Fluminense Federal University. The application of hybrid solar panels proved attractive to replace a large number of electric showers present in the facility. Electricity meters were installed in the student's house for one week and the annual profile of consumption and demand was obtained by a comparative and extrapolatory methodology of the measurement result with the monthly electric bills of the university fields. The study evaluated several models of hybrid solar panels available in the world market and selected the one that presented the best cost benefit. At the end are presented the reduction of consumption per year for ten years and the savings achieved with the application of the hybrid solar panel

**Keywords:** Renewable energy, solar energy, solar power, hybrid panels, PVT panels

## 1 INTRODUCTION

The federal, state, and municipal governments are finding it difficult to pay the electric power costs of their public buildings due to the strong economic crisis that Brazil is facing. One of the solutions to mitigate the problem is the generation distributed through renewable energies, that is, the public building generating the energy that consumes.

Solar energy is the form of energy that has as its main source the light and heat emitted by the sun, and also, being the form of indirect energy for other technologies like hydraulics, wind, biomass, fossil fuels, and ocean energy. The planet Earth receives annually about 1.5 x $10^{18}$ kWh of energy from the sun, which is capable of supplying ten times the consumption of the planet, this way, the sun is an inexhaustible source of energy [1].

The use of solar energy for natural lighting and heating environments is a free resource, only depending on the architecture and construction techniques, being called passive solar heating [2].

Solar radiation is the radiant energy emitted by the sun, it can be used for both thermal energy generation, thus conducting the heating of liquids or gases, and power generation [2].

Solar thermal energy consists of the energy incident on a body that can absorb this energy in the form of heat. For this system, in the market, the use of solar collectors, which are equipment used to heat fluids (liquid or gaseous), is widespread. These fluids are stored in boilers, until their final use, which is showers, swimming pools, and turbines, widely used in the southern and southeastern regions of Brazil [2].

The conversion of solar radiation into electrical energy is performed by semiconductor devices that use the photovoltaic effect, which is the conversion of photons contained in sunlight into electric energy using solar cells. The use of photovoltaic systems is widely used in the northeast and north of Brazil, in off-grid systems (isolated), where there is no electricity provided by the distribution company. The uses of these systems in a distributed generation are increasing, with connection to the grid (on-grid systems) [3].

Brazil is privileged to receive large amounts of energy from the sun and also to have silicon in its territory, which is used to produce solar cells. Thus, the country has the potential to reach a large-scale use of alternative solar energy with low environmental impact. The use of solar energy can generate several benefits both for the environment and for the economy, because it is clean energy, without emission of pollutants, and it is a system of rapid recovery of investment, thus generating cost reduction and profit making. It is still a system that has little maintenance and a long useful life.

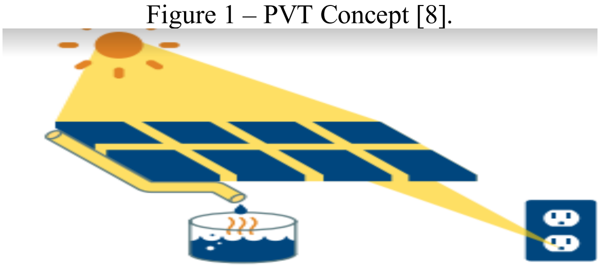
Nowadays Photovoltaic Thermal (PVT) panels are the solution to optimize the solar caption, joining in a single panel a photovoltaic module to generate electricity and a collector to generate thermal energy, increasing the efficiency of the system [4].

The object of this study is to verify the energy saving in applying PVT panels in a student house of the Fluminense Federal University.

## 2 HYBRID PANEL

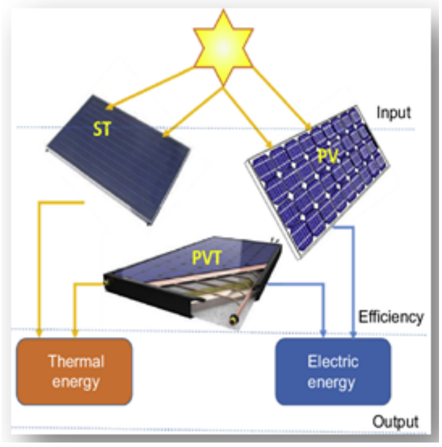
The biggest problem faced in the generation of electric energy with traditional photovoltaic panels is the losses in electricity generation, since only 20% of the solar energy in the modules is converted into electricity, and 80% is transformed into heat, thereby causing the panels to heat up, thus reducing its efficiency and its useful life [5]. To solve this problem the hybrid panel was created (see Figure 1), known worldwide as a Photovoltaic Thermal (PVT) panel, where the idea is the generation of electricity, traditionally realized by photovoltaic panels (PV), and the generation of thermal energy with the heat generated by the solar thermal collector. In this way, the problem of loss of efficiency of the panels is solved, thus increasing the conversion power of the PV modules and also the generation of thermal energy that is used to heat fluids (liquids or gases) [6 -7].

Figure 1 – PVT Concept [8].



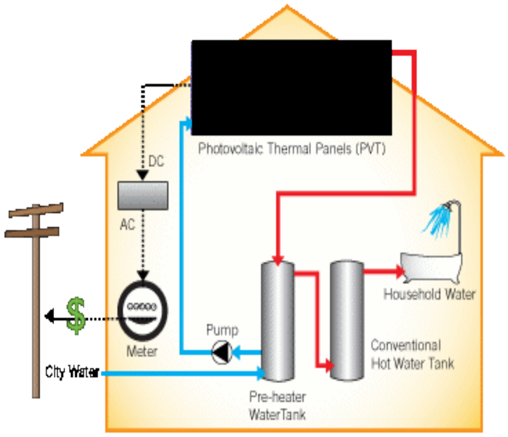
The PVT panels consist of a solar thermal collector placed behind a solar photovoltaic (PV) array, according to Figure 2, so that the solar energy is incident on the PV module first, generating the electric energy, and the remaining heat is transmitted to the coupled solar collector. PVT system has low installation cost when compared to solar collectors and photovoltaic system [9].

Figure 2 - Solar collector junction with photovoltaic panel (*Future Trends for Energy Solar*, 2016, modified by authors).




The PVT panels combine two generation systems and can be connected to the distribution grid if it complies with the existing regulations. The thermal reservoirs can use pumps or thermo fission. The system needs equipment for DC to AC power conversion, as it is used in any typical photovoltaic systems, protection devices, and load controllers, in case of isolated systems (see Figure 3).

Figure 3 - Scheme of a hybrid system (Apropédia, 2014, modified by authors).




## 3 CASE STUDY

The object of study is the student house of the Fluminense Federal University. In this house 176 low-income students are benefiting from a university program, thus helping them to stay during the undergraduate course.

The accommodation is 2000 m² in size and has a total installed load of approximately 621 kW, with a mean daily consumption of 557 kWh measured during one week in June with an energy analyzer.

In the student house, there are 27 washing machines, 27 drying machines, and 71 electric showers, which represent a load of 450,90 kW, with an estimated daily energy consumption shown in Table 1.

Table 1 – Daily energy consumption of some equipment.

| EQUIPMENT | POWER (kW) | TIME (h) | CONSUMPTION (kWh) |
|---|---|---|---|
| Electric Showers | 5.4 | 0,8 | 306.72 |
| Washing Machines | 0.5 | 1 | 13.50 |
| Drying Machines | 2 | 2,4 | 129.60 |

Only the electric showers consume daily 306.72 kWh, which represents 55% of the total consumption of the student house. So the PVT system will need to generate in its thermal unit the equivalent of 306.72 kWh that is consumed by the electric shower and the photovoltaic electric unit will need to generate 250.28 kWh to be consumed by the rest of the installation.

## 3.1 SYSTEM CALCULATION

It is necessary to calculate the water heating system to meet the water consumption requirement of the installation: the size of the thermal reservoir and the amount of thermal energy to be generated.

For the calculation of the electrical system, it is necessary to determine the required electrical demand and the inverters that are used for the connection to the system.

It is also necessary to define the Number of Hours of Full Sun (NHFS) to be used. Consulting the data of the "Centro de Referência em Energia Solar e Eólica" (CRESESB) [10], it is observed that June, when in Brazil is a cold month, the student house receives the least amount of solar radiation.

The value of the NHFS to be used is the average of three locations defined by CRESESB in June [10], thus ensuring that the system will always be able to generate more than the necessary energy for the whole year and generate electric credits for the University that can be used in its others buildings.

$$\mathrm{NHFS} = \frac{3.22 + 2.81 + 2.92}{3} = 2.98$$

Brazilian market does not have a PVT panel, then based on an international market procurement that resulted in models shown in Table 2, the panel of Solimpeks PowerVolt [11] was chosen for reference of this work, since it is one of less expensive and it has the proportion of electric and thermal generation adequate for this case study.

Table 2 – Hybrid panel models.

| MODELOS | ELECTRIC POWER (Wp) | THERMAL POWER (Wp) | PRIZE (€) |
|---|---|---|---|
| CGA Tec | 240 | 1050 | 450.00 |
| PowerTherm | 180 | 680 | 300.00 |
| PowerVolt | 200 | 630 | 300.00 |
| DualSun | 250 | 570 | 545.00 |
| DualSun | 280 | 570 | 590.00 |
| Millenium | 350 | 1200 | 575.00 |

The chosen panel can generate, according to the datasheet, 630 Wp referring to thermal power, and 200 Wp of electric power. Table 3 presents the data of the chosen module.

Table 3 – Technical data of the PowerVolt module.

| PARAMETER | VALUE |
|---|---|
| Electric Power | 200 Wp |
| Thermal Power | 630 Wp |
| Open Circuit Voltage | 45.2 V |
| Short Circuit Current | 5.6 A |

The equations for the system are [12]:

$$V_m = \sum V.t.f \quad (1)$$

$$E_C = \frac{V_m \cdot \omega_s \cdot H_s \cdot (T_h - T_c)}{3600} \quad (2)$$

$$N = \frac{E_{ar}}{P_{panel} \cdot NHFS.\eta} \quad (3)$$

Where:

$V_m$ = water consumption (m³)
V= flow rate (m³/s)
t = use time (s)
f = use frequency
$E_C$ = energy consumption (kWh)
$\omega_s$ = specific weight of water, 1000 kg/m³
$H_s$= specific heat of water, 4.18 kJ/kg ºC
$T_h$ = hot reservoir temperature (ºC)
$T_c$ = cold reservoir temperature (ºC)
N = number of panels
$E_{ar}$ = array energy generation (kWh)
$P_{panel}$ = panel power (W)
η = panel efficiency (as the system is already oversized for NHFS, the efficiency is 100%, thus neglecting losses of wiring and chemical transformation)

Using Equation (1) to calculate the thermal reservoir to supply the daily consumption of the showers, it is obtained the values shown in Table 4.

Table 4 – Thermal reservoir calculation.

| PARAMETER | VALUE |
|---|---|
| Number of persons | 176 |
| Daily frequency of baths | 2 |
| Consumption per bath | 50 liter/person |
| Daily consumption | 17600 liter |
| Thermal reservoir capacity | 20000 liter = 20 $m^3$ |

As the consumption volume should be less or equal to the size of the thermal reservoir, it chooses four thermal reservoirs of 5 $m^3$, since a reservoir of 20 $m^3$ is not available on the market.

To calculate the system thermal energy that will be demanded, equation (2) is used. Considering that the water ambient temperature is received at 23ºC from the public supply and that the system warm temperature must be 55ºC because it is the working temperature for the thermal reservoir, the results are shown in Table 5.

Table 5 – Daily thermal energy consumption

| PARAMETER | VALUE |
|---|---|
| Thermal reservoir capacity | 20 $m^3$ |
| Hot temperature | 55 ºC |
| Cold temperature | 23 ºC |
| Thermal energy consumption | 743.11 kWh |

To calculate the thermal system, equation (3) is used to determine the number of hybrid panels required, taking into account that the thermal system has no losses, according to shown in Table 6.

Table 6 – Panel number calculation.

| PARAMETER | VALUE |
|---|---|
| Energy consumption | 743.11 kWh |
| Panel power | 0.63 kW |
| Efficiency | 1 |
| NHFS | 2.98 |
| Panel number | 395.82 |

A water mixing device is used and it is not needed to carry out work in the building's water installation. The hot water pipe is passed through the outside of the building. The piping size between modules and reservoirs should be ¾” for plumbing and especially for the hot water flux.

Applying equation (3) to determine the number of panels to meet the electricity consumption of 250.28 kWh of the student's home, the results are shown in Table 7.

Table 7 – Electric calculation.

| PARAMETER | VALUE |
|---|---|
| Energy consumption | 250.28 kWh |
| Panel power | 0.2 kW |
| Efficiency | 1 |
| NHFS | 2.98 |
| Panel number | 419.93 |

Based on the design of the electrical and thermal system, it is necessary 432 Solimpeks PowerVolt panels, for a better array.

The PVT modules generate electricity in direct current, so it is necessary for grid inverters or grid-tie inverters that are responsible for DC/AC conversion. It must have Maximum Power Point Tracking (MPPT) taking advantage of the greater capacity of PV array generation, manual or automatic network disconnection, operational data logging, and DC and AC protection (against islanding, overload, and overvoltage).

The inverter is calculated using the relation (4) of the reference [13].

$$0.7 \text{ x } P_{ar} < P_{inv} < 1.2 \, x \, P_{ar} \qquad (4)$$

Where:

$P_{ar}$ = maximum power of the array (W)
$P_{inv}$ = nominal power of inverters (W)

Thus, applying the relation (4), we obtain the following considerations:

$$0.7 \text{ x } 200 \text{ x } 432 < P_{inv} < 1.2 \, x \, 200 \, x \, 432$$

$$60{,}480 < P_{inv} < 103{,}680$$

As the price of inverters in this power range is high, it is better to use four lower-power inverters, thus reducing the investment cost, then:

$$15{,}120 < P_{inv}/4 < 25{,}920$$

Thus it is used a 20 kW/220V inverter that has 1 MPPT. The nominal characteristics of the modules are an open circuit voltage of 45.2 V and a short circuit current of 5.6 A.

With these characteristics, each inverter has 108 boards, so it is used 18 boards in series divided into 6 strings in parallel, resulting in an array that has 813.6 V (18 x 45.2 V) of open circuit voltage that is less than the maximum DC voltage of the inverter which is 1000 V. The current for these 6 strings is 33.6 A (6 x 5.6 A).

With a current of 33.6 A, it is possible to define the conductor to be used by the DC unit. The ideal conductor is 6 mm² which supports up to 36 A. Considering a distance of 120 m and a maximum allowable voltage drop of 3%, using equation (5), results that the conductor of 6 mm² meets the required voltage drop, as shown in Table 8.

$$S = \frac{2 \,.\, \rho \,.\, D \,.\, I_n}{0.03.\, V_{DC}} \quad (5)$$

Where:
$\rho$ = cooper resistivity ($\Omega$ mm$^2$/m)
D = distance (m)
$I_n$ = nominal current (A)
$V_{DC}$ = DC voltage

Table 8 – Voltage drop in cable DC

| PARAMETER | VALUE |
|---|---|
| Cooper resistivity | 0.0172 Ω mm²/m |
| Voltage | 813.6 V |
| Current | 33.6 A |
| Distance | 120 m |
| Voltage drop | 3% |
| Conductor section | 5.68 mm² |

The inverter has a DC switch integrated, anti-islanding protection, overcurrent protection, and under and overvoltage protection.

Considering that the three-phase power P of the inverter is 20 kW, the phase-to-phase voltage V is 220 V and the power factor cosθ is 0.92, the nominal current $I_n$ of the AC cable is obtained by applying the equation (6).

$$I_n = \frac{P}{\sqrt{3} \text{ x } V_{pp} \text{ x } \cos\theta} \quad (6)$$

Thus:

$$I_n = \frac{20{,}000}{\sqrt{3} \text{ x } 220 \text{ x } 0.92} = 57.05 \text{ A}$$

For the $I_n$ calculated the conductor must be 16 mm² which supports up to 68 A. Applying the equation (5) to calculate the allowable voltage drop, considering a distance of 50 m between the DC inverter and the connection with the concessionaire network, results in the value shown in Table 9.

Table 9 – Voltage drop in AC cable.

| PARAMETER | VALUE |
|---|---|
| Cooper resistivity | 0.0172Ω mm²/m |
| Voltage | 220 V |
| Current | 57.05 A |
| Distance | 50 m |
| Voltage drop | 3% |
| Conductor section | 14.87 mm² |

Thus, the 16 mm² cable meets the voltage drop requirements of the system. The three-phase AC circuit breaker should be 63 A, to be less than the cable maximum current (68 A), and also greater than the calculated nominal current (57.05 A).

It can be defined as a bidirectional meter of 100 A.

## 4 ANALYSIS AND INVESTMENT RETURN

The hybrid system always generates more electric energy than requested, since the monthly consumption of the student house is 16,710 kWh (30 x 557), however, 7,508 kWh (30 x 250.28) needs to be supplied by the electric system, considering that the consumption is constant and the rest is supplied by the thermal system.

Figures 4 and 5 show respectively the monthly thermal and electric energy generation, considering the average of the places for use of the NHFS defined monthly by CRESESB.

Figure 4 – Monthly thermal energy generation.

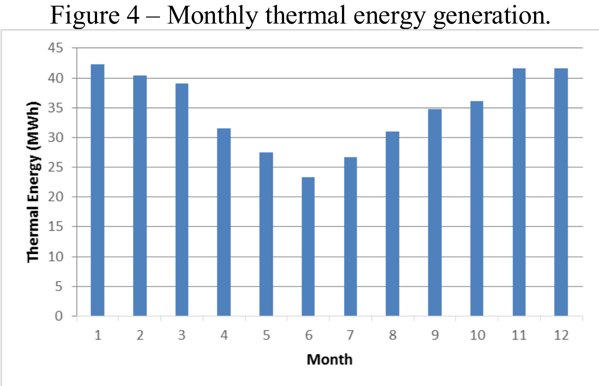
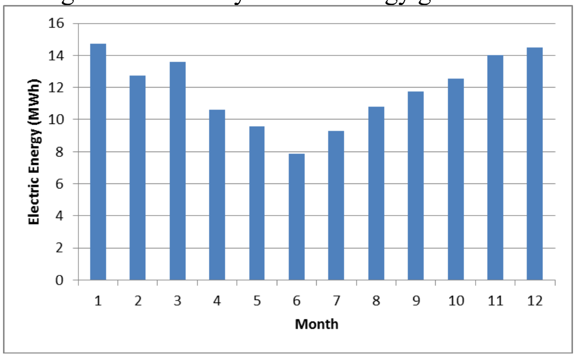


Figure 5 – Monthly electric energy generation.




The electricity excess generated is injected into the concessionaire network, generating an energy credit for the University.

This PVT system generates 86.4 kW (0.2 x 432) for electrical demand and caters to student houses during the year. Only in the cold month of July, the generation is close to the facility necessity, since the consumption in July is 7,508.4 kWh and the system provides 7,724.16 kWh (0,2 x 432 x 2.98 x 1 x 30).

Table 10 shows the annual electrical summary of the installation and the profit that it generates since the concessionaire must pay for the credits of the distributed generation.

Table 10 – Electrical energy summary.

| PARAMETER | VALUE (MWh) |
|---|---|
| Annual consumption | 90.10 (360 x 0,25028) |
| PVT annual generation | 139.50 |
| Credit | 49.40 |

It is necessary 111.65 MWh/year to meet the thermic water system for the shower. The hybrid system generates 433.7 MWh/year, thus attending the students' houses.

Based on Table 11, the total investment would be € 188,970, without considering the import taxes, because there is no hybrid panel for buying in Brazil.

Table 11 – Financial investiment.

| ITEMS | INVESTMENT (€) |
|---|---|
| Modules | 129,600 |
| Inverters | 41,424 |
| Reservoir | 15,184 |
| Installation | 29,490 |
| Freight | 3,000 |
| Miscellaneous | 1,340 |

For the return on investment, it was considered the following variables:

• The system depreciation of 0.6% over the years,

• An increase in electric tariffs of 4% over the years.

Table 12 – Return on capital.

| YEAR | GEN. ANNUAL ENERGY (MWh) | ECONOMY (€) | CUMULATIVE RETURN (€) |
|---|---|---|---|
| **1** | 135.7 | 36,343.10 | 36,343.10 |
| **2** | 134.9 | 39,015.04 | 73,913.14 |
| **3** | 134.1 | 41,883.43 | 112,751.50 |
| **4** | 133.3 | 44,962.70 | 152,901.10 |
| **5** | 132.5 | 48,268.36 | 194,406.20 |
| **6** | 131.7 | 50,789.64 | 237,312.40 |
| **7** | 130.9 | 53,461.60 | 281,667.20 |
| **8** | 130.1 | 56,294.15 | 327,519.40 |
| **9** | 129.3 | 59,297.88 | 374,919.50 |
| **10** | 128.5 | 62,484.13 | 423,919.90 |

Based on the University's installation actual, it can be considered 20% for the peak consumption and 80% for the off-peak consumption. The value of the peak tariff is € 0.7242/MWh and the off-peak tariff is € 0.1552/MWh (based on June 2017). Thus, it can be observed that the return on investment will occur in 6 years.

## 5 CONCLUSION

The use of hybrid panels offers advantages over current technologies for power generation, as it can generate both heat and electricity, having the advantages of decreasing the solar panel's installation area and consequently the reduction of the initial investment compared with the separate use of photovoltaic panels and collectors, or only photovoltaic panels to meet the demand of student housing. The disadvantage is that Brazil has not this system in the national market for sale.

As the hybrid system can generate thermal energy with the heat coming from the photovoltaic panels, heating the water, the electric showers of the installation can be deactivated, thus reducing the cost of electric energy and generating great savings in student housing.

The system, in addition to generating savings in electricity, provides credits to obtain a discount on the electricity bill at any other University campus. The PVT arrangement is a smaller system but generates more electrical energy, than those necessary to meet the demand of the showers for thermal energy. It is still seen that the time of investment return for this application is small or similar to the implantation of previous technologies but has a lower initial value to be spent during the implementation phase of the unit.

Thus, the hybrid system is a great alternative generation solution to be studied in places where it is necessary to use heat for water or in places where it is necessary to use electric energy to attend to others electricity necessities of the installation.

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