Study on the integrated use of photovoltaic plants (PVT) for the production of electrical energy and heat using heat pumps (PN-PT)

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Abstract

Every year, the use and application of photovoltaic systems in residential buildings is increasing for the purpose of producing electricity, especially in isolated areas or for those that lack energy. Photovoltaic systems to produce electricity are safer and more economical systems. Albania's total energy problems include those related to renewable energies, both on the supply side and on the consumption side. In this paper, the topic of integrated photovoltaic systems of energy and heat production is addressed. The theoretical and experimental analysis of the behavior of the integrated Heat Pump - PVT system is very important to increase the efficiency of the use of renewable energies and therefore contribute to the decarbonization of the environment. The research carried out offers not only the increase in the rate of use of renewable energies, but also the optimization of integrated PN-PVT schemes, which can be used in the housing sector.

Key words: *Photovoltaic, systems, residential buildings, energy, biomass*

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Methodology

- Obtaining data from various studies and reports of meteorological and statistical data in the region of Tirana.
- Advice and guidance from the subject leader.
- Using Polysun software for simulating schemes.

Main sources of energy

- Solar energy
- Wind energy
- Energy from biomass
- Energy from biogas
- Geothermal energy
- Power plants
- Water energy (hydro power plants)

Albania's potential for renewable energy

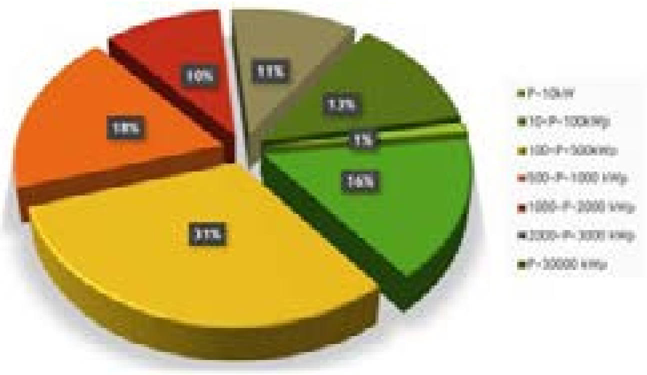
The territory of Albania lies in the western part of the Balkan Peninsula on the eastern coast of the Adriatic and Ionian seas, thanks to this geographical position, Albania belongs to the Mediterranean climate zone with hot and dry summers, long sunny days, and mild winters.

Albania has a good solar energy regime. Also, the intensity of the rays during these days is similar to the countries that have started to use solar collectors on a large scale for heating sanitary water.

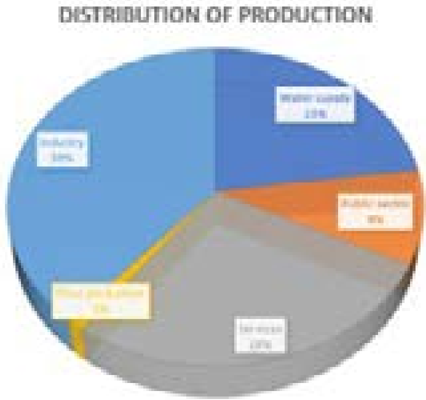
In the territory of our country, we have a considerable energy potential from solar radiation, where many areas are exposed to a radiation ranging from 1185 kWh/m2 per year to 1700 kWh/m2 per year.

The integration of solar thermal energy for the supply of warm water in the household and service sector was among the measures developed by the National Action Plan, approved by the Albanian government in January 2016.

Solar panels for hot water are one of the most promising technologies for reducing electricity and wood consumption, with a significant contribution to reducing greenhouse gas emissions.



Grouping of consumers according to the required production capacity of energy from photovoltaic plants.



Distribution of production capacity by sector in kWp for consumers over 500kWp

The influence of temperature on the electrical performance of the photovoltaic module

The operating temperature plays a central role, because both the electrical efficiency and the power output of a photovoltaic module depend linearly on the operating temperature.

The higher yield of crystalline silicon cells will result in a higher electrical yield and a higher electrical-thermal ratio of the panel than in the case of amorphous cells.

Experimental measurements for the liquid fluid panel and the air collector panel for both cases with amorphous cells and crystalline silicon cells found that at zero temperature, for the liquid collector, the efficiency of the prototype with crystalline cells was 55% and the prototype with amorphous cells 60%, while for the air collector the prototype with crystalline cells was 38% and the prototype with amorphous cells 45%.

The effect of temperature on the electrical yield of a photovoltaic cell / module can be obtained using the basic equation:

$$P_m = I_m V_m = (FF) I_{sc} V_{oc}$$

PVT systems and their construction

The combined photovoltaic panel represents a combination of the photovoltaic panel intended only to produce electricity, with the solar thermal panel.

It is found in various constructive realizations. So, it is produced with or without protective glass. Depending on the cooling fluid, the PVT panel can be air-cooled, liquid-cooled or combined cooling.

Depending on the movement of the fluid stream, the PVT panel is unidirectional or bidirectional.

The PV panel itself depending on the material of the photovoltaic cells, can be:

- Silicon in crystalline form
- With a thin layer, which are: o As amorphous; o CdTe, o CIGS
- With very thin film, which are technologies still in the experimental stage, before they become commercial.

Heat pump (PN) integrated PVT systems in buildings

The object of this study are PVT systems integrated with PN in buildings, with the aim of determining the optimal schemes of PN integrated with the use of renewable energies, primarily solar.

Studies and realizations have proven that PVT systems can be integrated with PN in various residential and service buildings.

There is interest in the use of PVT systems, even integrated in buildings, both in the case when they will be separate, and in the case that they are combined. In the latter case, the use of materials and energy production indicators are more useful.

In these cases, the heat pump is only integrated with industrial processes, in contrast to the integration of the heat pump in buildings, where the integration is done with solar PVT systems.

PVT systems produce both electricity and thermal energy. The latter, being of low potential, can be used for: The heating of the environment; UNGS.

Principle scheme of PN-PVT operation

PVT panels, when integrated into PN systems for use in buildings, have relevant design methodologies. The main parts of this system are:

1. PVT panel; - PN.
2. Thermal storage.
3. Control and management system.

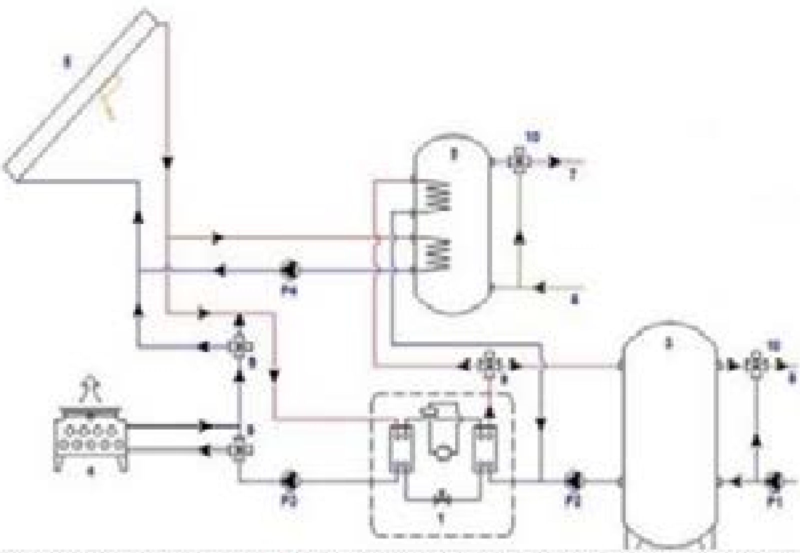
Combining PN with PVT is a useful way to obtain warm water used in buildings for heating and or sanitary water.

PN integration with PVT systems can be:

a. Direct- when the solar panel serves as an evaporator for PN.

Such a system is simple and compact. In this case the combined system can only be used for heating, but it cannot be used for cooling, since the panel cannot play the role of a condenser.

b. Indirect – when the solar panel does not serve as a PN evaporator.

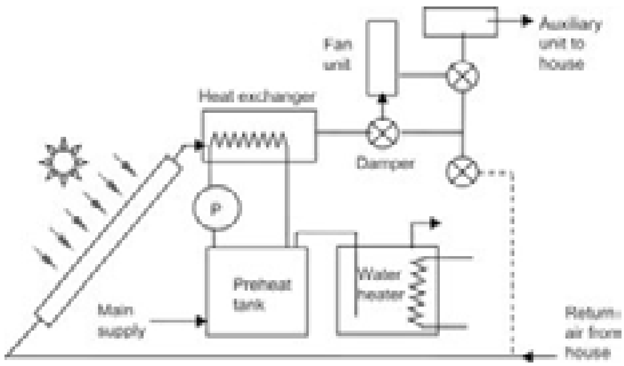


1-HP/Refrigerator, 2-DHW tank, 3-Inertial tank, 4-Cooling tower, 5-PVT, 6-Inlet pipe, 7-The outlet pipe, 8-Water pipe for heating, 9-3 way valves, 10-3 mixing valves, P1, P2, P3, P4-Pump

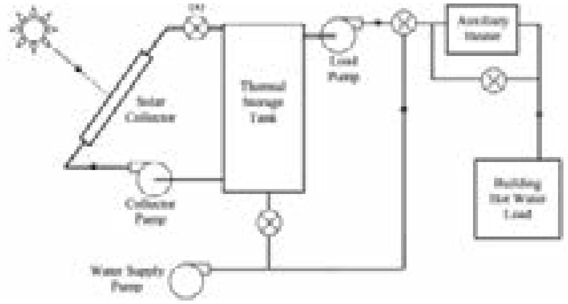
Both subsystems are individual but combined. This combination can consist of their connection in:

- Parallel. In this case, the PN is put into operation when the PVT system does not meet the demand for heating. Even though in the scheme the case of PN work with external air source is given, it is also possible to PN scheme with other sources such as geothermal ones etc.
- Seri. In this case, when the PVT does not meet the energy demand, the PN is put into operation, where the accumulator serves as an evaporator for.
- Parallel, but only of evaporators or as it is otherwise called the scheme with two energy sources. In this case, when the PVT panel does not meet the demand for heating through the accumulator, the second evaporator of the heat pump is also put into operation. PN works with two evaporators connected in parallel.

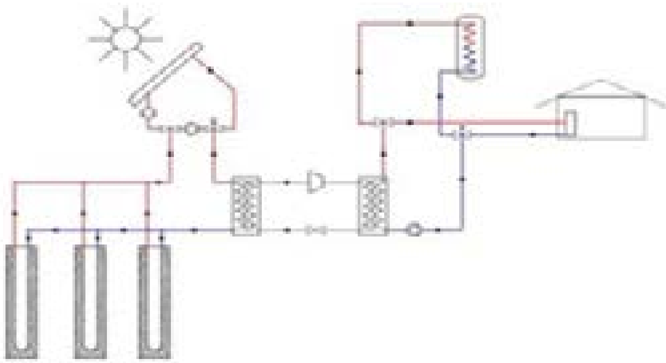
DX EXPANSION TYPE (DIRECT EXPANSION) INDIRECT



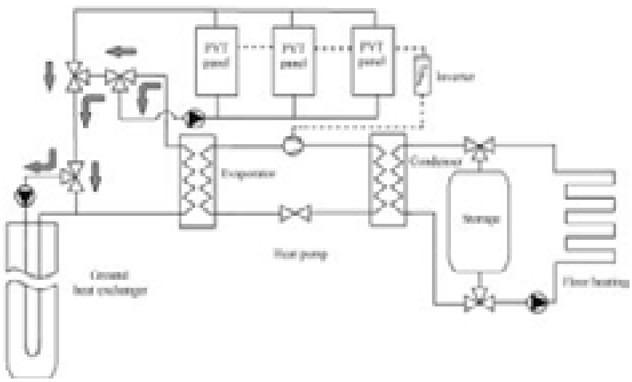
DX EXPANSION TYPE (DIRECT EXPANSION)



INTEGRATED PN SCHEME WITH PVT& GEOTHERMAL)



HEAT PUMP WITH THREE INTEGRATED SOURCES WITH PVT PANELS



PN and PVT system evaluation indicators

PN performance indicators

The efficiency of the PN in heating or cooling is expressed through the performance coefficient, respectively εn or εf :

$$\varepsilon_n = COP = \frac{Q_1}{W_K} = \frac{\dot{Q}_1}{\dot{W}_K}$$

$$\varepsilon_f = EER = \frac{Q_2}{W_{cikli}}$$

Electrical and thermal efficiency of the PVT system

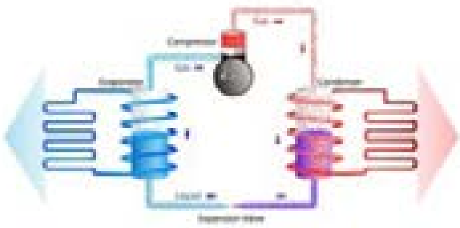
The total electrical and thermal efficiency of the PVT system is expressed as the sum of the thermal and electrical efficiency of the panel:

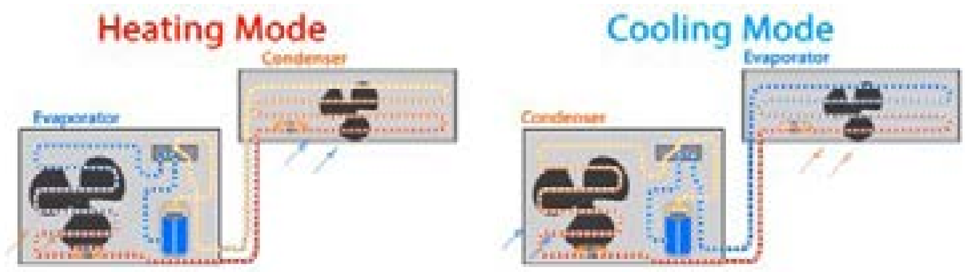
$$\eta_{PVT} = \eta_e + \eta_t \qquad \eta_{PVT} = \frac{\eta_e}{\eta_{el,ref}} + \eta_t$$

where ηe,ref, is the reference electrical efficiency, 0.413 can be obtained

Heat pumps

A heat pump is a system that serves to transfer heat from a lower temperature source to a higher temperature source. Most modern heat pumps use the reverse thermodynamic cycle.





The photovoltaic / thermal hybrid system has the following applications:

- Air heating system;
- Water heating system;

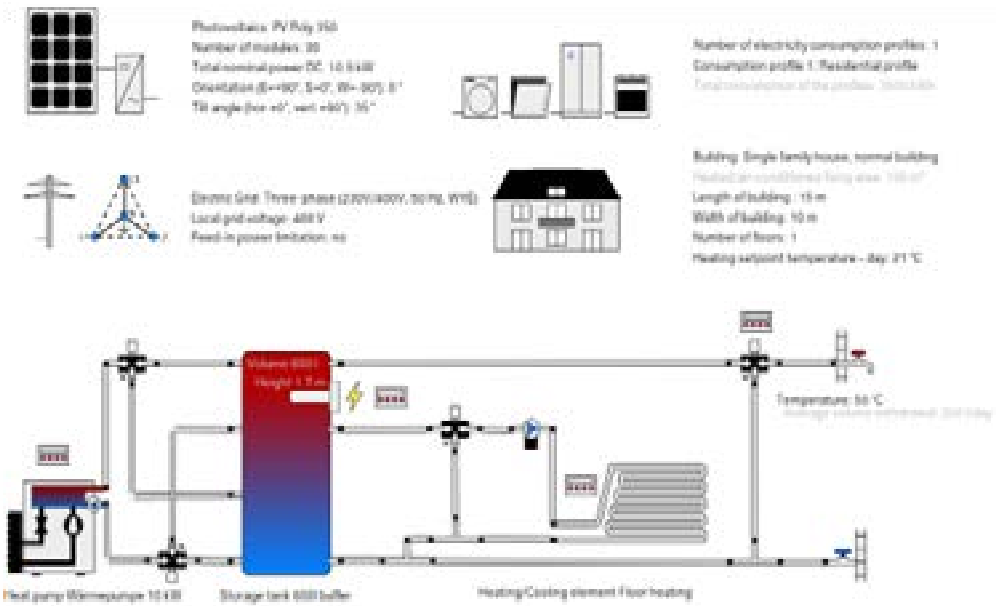
1.Air PVT system

PVT air collectors are used to produce electricity and heat air at the same time. Hot air is used for space heating and/or drying purposes.

2. PVT systems with water

The solar water heating system consists of a collector, an insulated tank and pipe connectors. The solar panel of the solar water heater collects solar energy with a black absorber. The heat collected by the absorber is transferred to the water flowing through the absorber and stored in the tank.

FIRST SIMULATION CASE: SPACE HEATING + DOMESTIC HOT WATER
(PHOTOVOLTAICS + HEAT PUMP)



Functions:

- Heating/Cooling system with Fan Coil.
- Production of UNGS (hot sanitary water); • Production of thermal energy from the PVT panel.
- Production of electricity from the PVT panel.

This type of scheme is mostly used in residential buildings with a high degree of thermal insulation with an area ranging from 150 to 350 m2.

These typologies, in terms of plant engineering, need UNGS (domestic hot water), electricity, heating and cooling, all of this in support of energy saving, environmental protection and CO2 reduction.

To achieve these goals, there should be combinations of water-to-water heat pumps, air-to-air heat pumps combined with PVT panels.

The use of solar energy, to have an optimal yield utilization of PVT panels (Combined Photovoltaic and thermal hybrid panels together) is done with a solar fraction of 40-60%.

Overview of system data (annual values)

Total system fuel and/or electricity consumption [Etot]	-9202.3 kWh
Total electricity consumption [Ecs]	5903 kWh
Total energy consumption [Quse]	9112 kWh
Seasonal performance factor (SPF-SHP)	3.8
Primary energy factor	0.3

Overview of photovoltaics (annual values)

Total gross area	53 m^2
Total rated power DC	0.5 kW
Performance report	76 %
Annual specific yield	1439 kWh/kWp
Savings e CO2	8103 kg

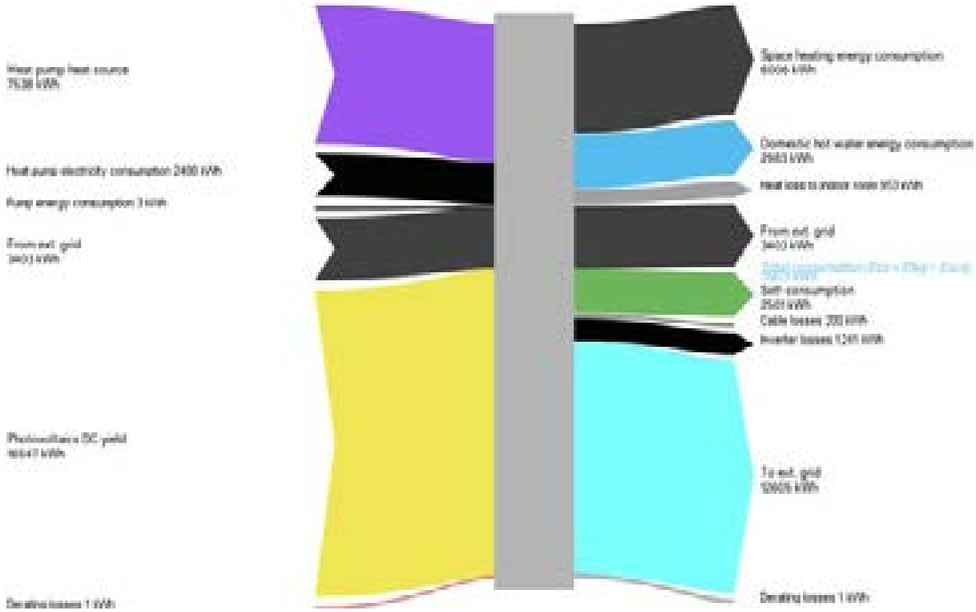
Overview of electricity (annual values)

Annual consumption	5903 kWh
Self-consumption	2501 kWh
Self-consumption part	16.6 %

Heat pump overview (annual values)

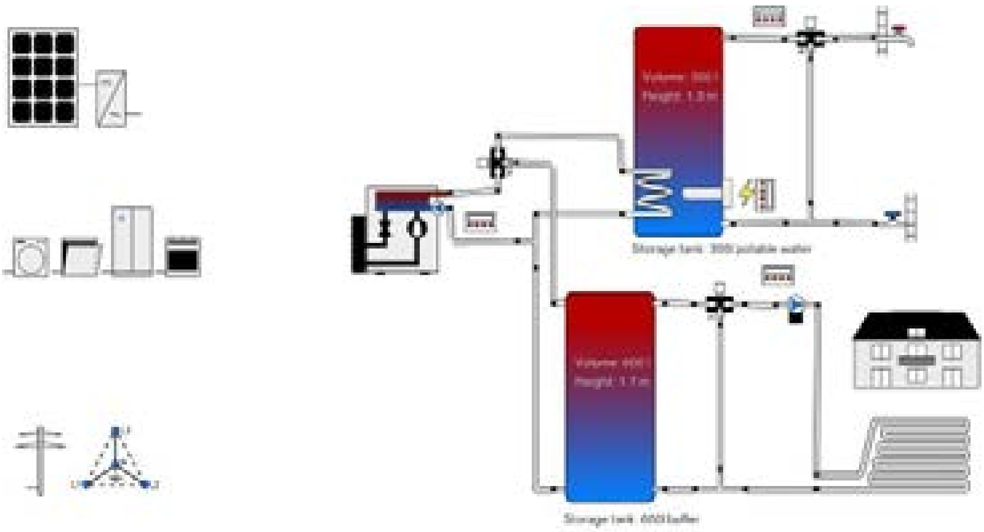
Seasonal performance factor for the air-to-water heat pump	4.1
Total electricity consumption during heating [Eaux]	7538 kWh
Total energy savings.	2400 kWh

Energy flow diagram (annual balance)



The second case of the simulation

Space heating + domestic hot water (photovoltaics + heat pump + two accumulators)



The functions of the scheme are:

- Heating/Cooling system with Fan Coil with P.N.
- Production of hot sanitary water + P.N.
- Production of thermal energy from the PVT panel.
- Electricity production from PVT panel.

In this scheme, the heat pump is integrated, which must meet the needs for ensuring the temperature of the UNGS accumulator and through the diversion by means of 3 (three) way valves, having command from the monitoring and control system, provides heating or cooling in the villa.

Overview of system data (annual values)

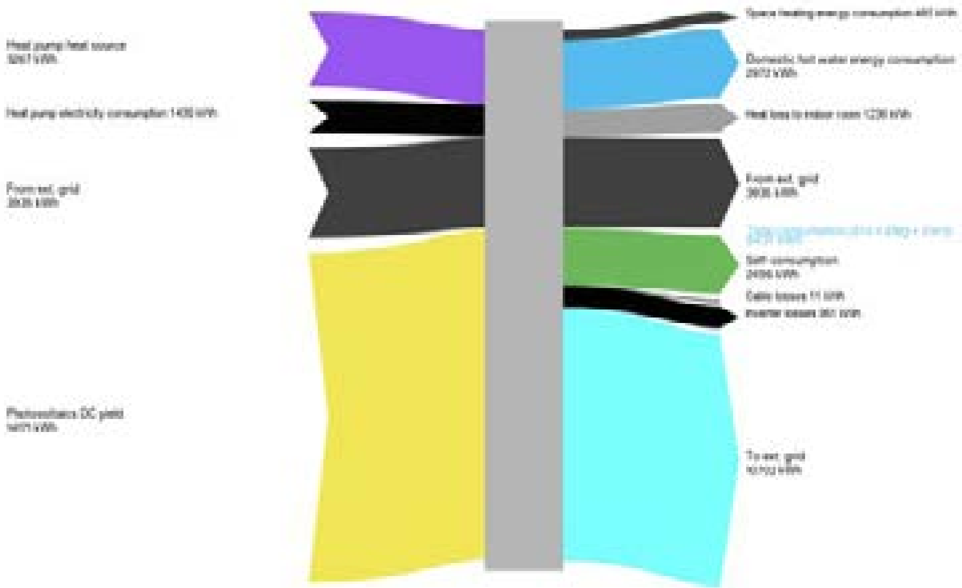
Total system fuel and/or electricity consumption [Etot]	-6767.5 kWh
Total electricity consumption [Ecs]	6431 kWh
Total energy consumption [Quse]	3515 kWh
Seasonal performance factor (SPF-SHP)	2.5
Primary energy factor	0.49

Overview of photovoltaics (annual values)

Total gross area	69.2 m^2
DC power output [Qpvf]	14170.9 kWh
AC power output [Qinv]	13198.2 kWh
Performance ratio	77.7 %
Annual specific yield	1466 kWh/kWp
CO2 savings	7080 kg

Overview of electricity (annual values)

Annual consumption	6431 kWh
Self-consumption	2496 kWh
Share of self-consumption	18.9 %
Self-sufficiency rate	38.8%
Heat pump overview (annual values)	
Seasonal performance factor for the air-to-water heat pump	3.3
Total electricity consumption during heating [Eaux]	1430 kWh
Total energy savings	3267 kWh



Conclusions

Albania has great potential in terms of solar energy, which we can use to obtain electricity as well as thermal energy, through simple plants.

The integration of PVT Plants with Heat Pump can be realized both in the residential sector and in the service sector. It can also be used in other sectors (industry, agriculture), where there is a demand for low potential energy, which makes it suitable for wide use.

The use of PVT plants has many advantages in increasing the efficiency of buildings, and optimizing energy, since the thermal energy generated by them can be used both for heating sanitary water and for heating homes.

Simulations for the plant were performed with Polysun, but they can also be performed with TRNSYS, as well as with any of the other software in the first group, especially when the study objectives include fluid flow and heat transfer.

In the analyzed schemes, the electricity and thermal energy produced varies depending on the type and demand of the consumer. It also depends on the temperature and the density of solar radiation.

Increasing the utilization rate of solar energy and ambient energy in plants combined with PN, leads to the reduction of GHG (Greenhouse gas) emissions that cause the greenhouse effect.

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