MARUEEB project
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Master Degree in Innovative Technologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders (MARUEEB)

Junior Intensive Course

ENERGY EFFICIENT BUILDINGS

Solar assisted heat pumps

(and old concept to be used in innovative renewable solar cogeneration systems, for coupled space heating and refrigerated-photovoltaic electricity generation purposes with solar Hybrid PV-T panels)

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Research Group

Augmentation techniques for ***E***nergy, ***R***efrigeration and the ***E***nvironment
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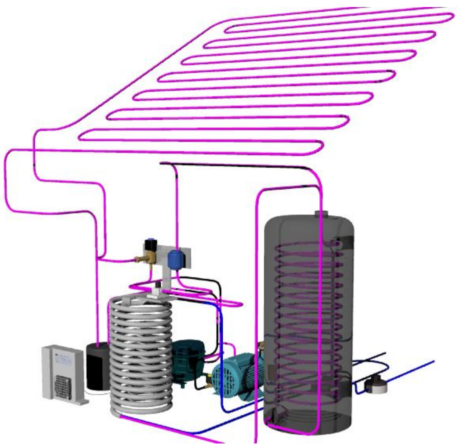
Main topics:

- Integrated Solar assisted heat pump (ISAHP) design;
- ISAHP dinamic simulation ;
- ISAHP economic analisys.



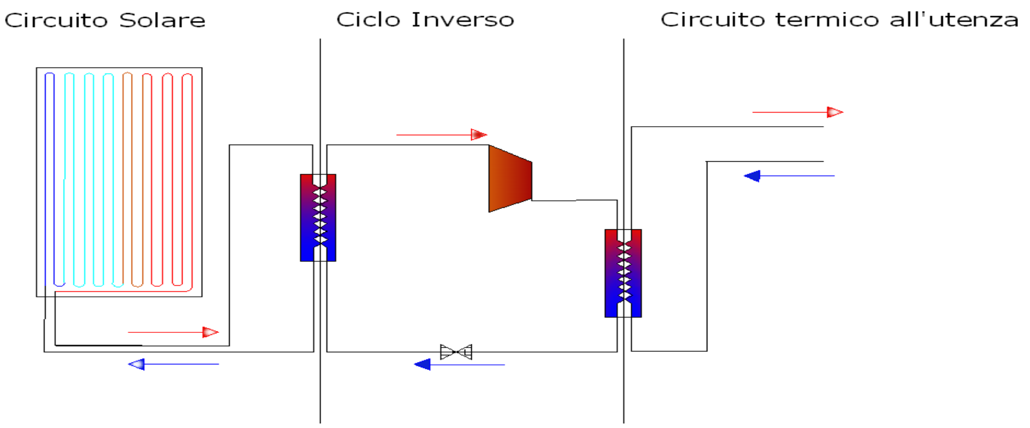
SAHP (acronym of Integrated Solar Assisted Heat Pump) is a first demonstration prototype proving the concept and the feasibility of an idea of full exploitation of the solar energy for production of thermal energy for low temperatures (near environmental temperature), based on the innovative use of inverse cycle systems (refrigerators), working in the heat pump mode and coupled to plain, bare solar panels with additional frontal Photo Voltaic panels..

The thermal solar panels currently commercialized are based on a consolidated and reliable technology, that finds however several limits due to the high surfaces involved for the solar plant and due to installation costs. Furthermore, a great amount of the solar energy available by irradiation is lost because of the thermal losses towards the environment during operation. Such losses are intrinsic in the working principle, since the panel temperature must always be greater than that of the user water tank, thus allowing the solar panel to hardly collect, on a mean annual operation period, the 50% of the available incident solar energy.

The basic idea of ISAHP-PVT is to use refrigerated solar hybrid panels as a component of an heat pump system (see the figure, where traditional thermal solar panels work side-by-side with the new prototype for the same heat duty service), in order to lower the panel working temperature and to carry therefore the exploitation of the solar radiation up to the 100%. The concept is well known in the scientific community since the early years '80, but it had never been actually realized so far, due to the lack of adequate technological and regulation/control capabilities.

The use of variable capacity compressors, of electronic expansion valves and of sophisticated simulation and adaptive control techniques make nowadays the solar assisted heat pump system to work in optimized conditions, achieving good results both from the solar panel captation efficiency (which can reach mean values of the order the 80% against the above mentioned 50%) and in terms of coefficient of performance of the heat pump system (COP), which can be as high as 6 to 7, against the to-day-values of about 4 as a maximum.

These technologies can be further implemented developing also liquid-cooled photovoltaic solar panels, going towards an efficient and cost-affordable application of renewable solar cogeneration systems, where low temperatures of the PV modules promise higher electricity production efficiencies, and high COP values of the coupled heat pump system promise efficient use of electricity for heating purposes.



The knowledge and technological skills now available are ready for the design and construction of a pilot plant of refrigerated photovoltaic cells, in order to test actual performance in operation and to develop further our knowledge, in a highly international and interdisciplinary framework.

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Traditional solar panel

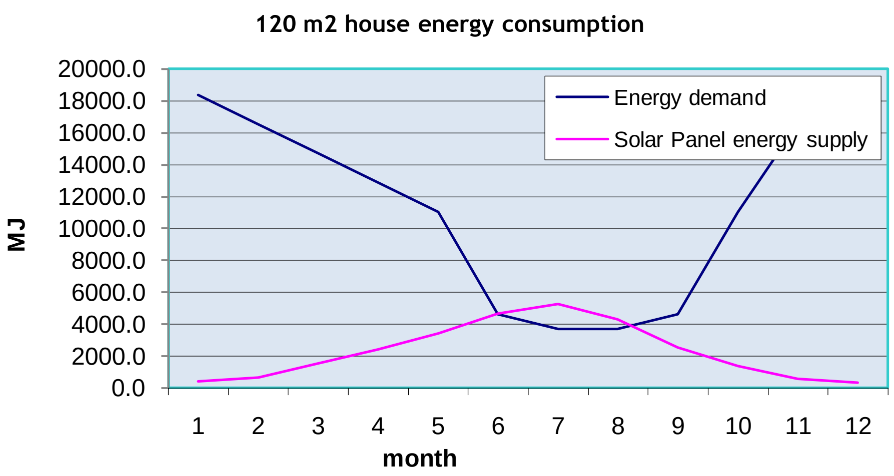
The solar panel efficiency depends on these factors:

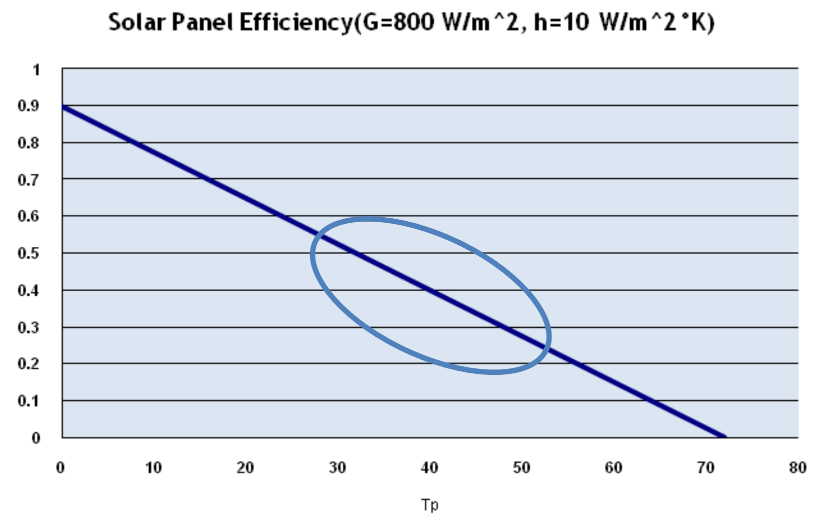
$$\eta = \frac{\alpha \cdot G - h \cdot (T_p - T_a) - \sigma \cdot \varepsilon \cdot (T_p^4 - T_c^4)}{E}$$

G: solar radiation [w/m²]
h: heat transfer coefficient [w/m²K]
T_p: panel temperature [K]

Traditional solar panel are glazed in order to minimize the heat flux dispersion outside the system, however during the summer season the panel temperature grows to very high values (70-80°C), consequently :

- The traditional solar panel have high production costs;
- The working temperature lead to low efficiency energy captation < 0.5;
- In winter season the gap between the solar panel energy supply and the user energy demand is really high.



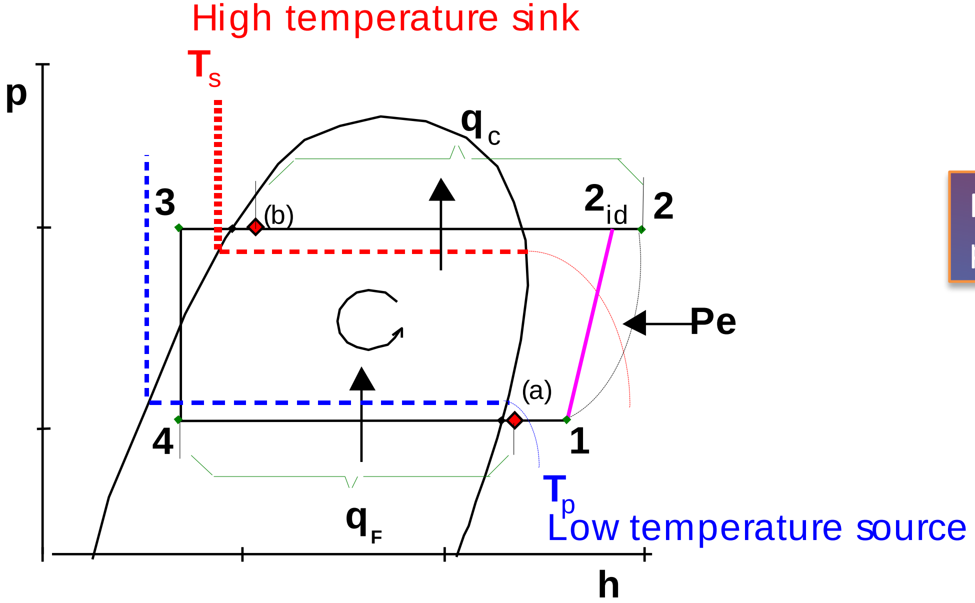


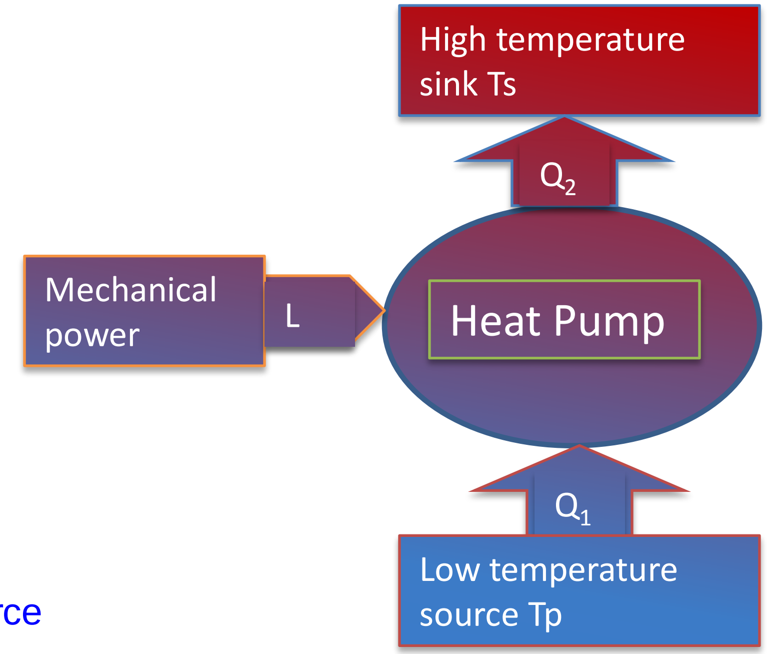
Heat Pump

An heat pump is a machine or device that moves heat from a low temperature heat source to a higher temperature heat sink, using the mechanical work of a compressor.

The main parameter used to measure the heat pump performance is the COP (Coefficient Of Performance).

$COP = Q_2/L \approx 4$ (for commercial heat pumps)



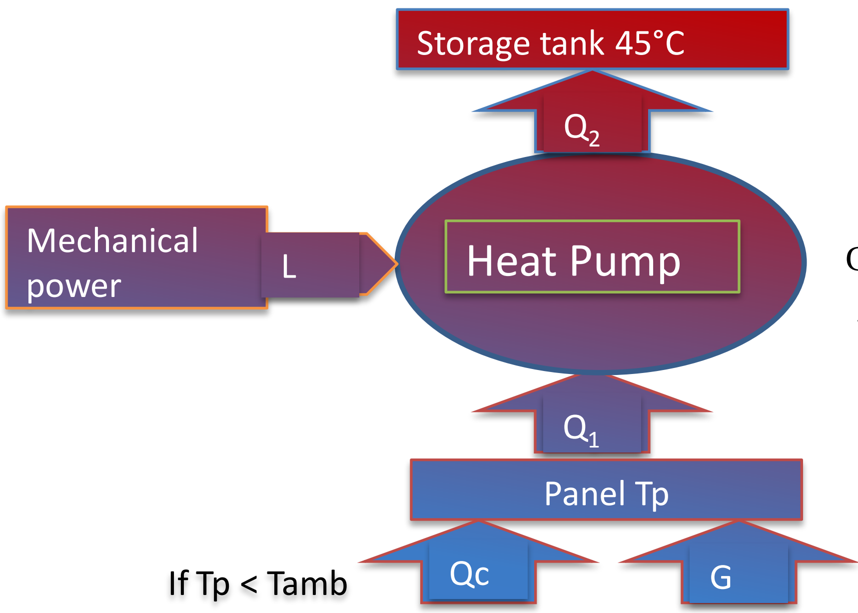


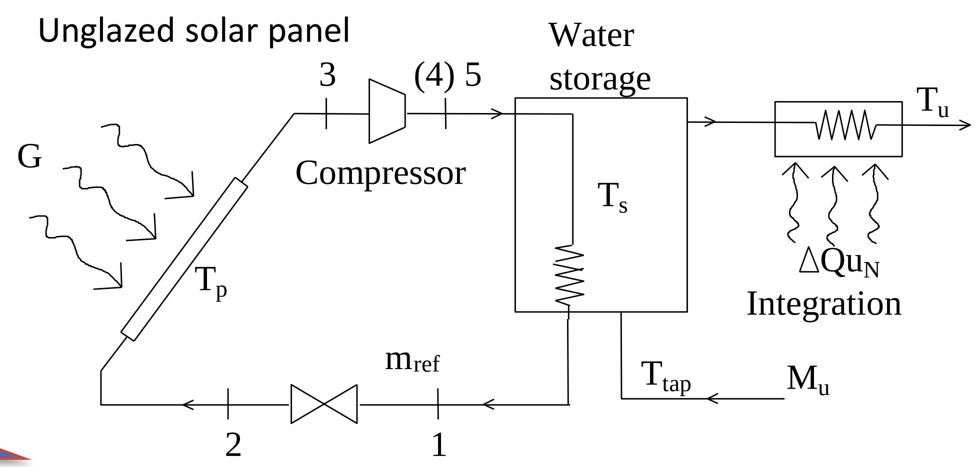
Psipc - ISAHP

(Integrated Solar Assisted Heat Pumps for water and space heating.)

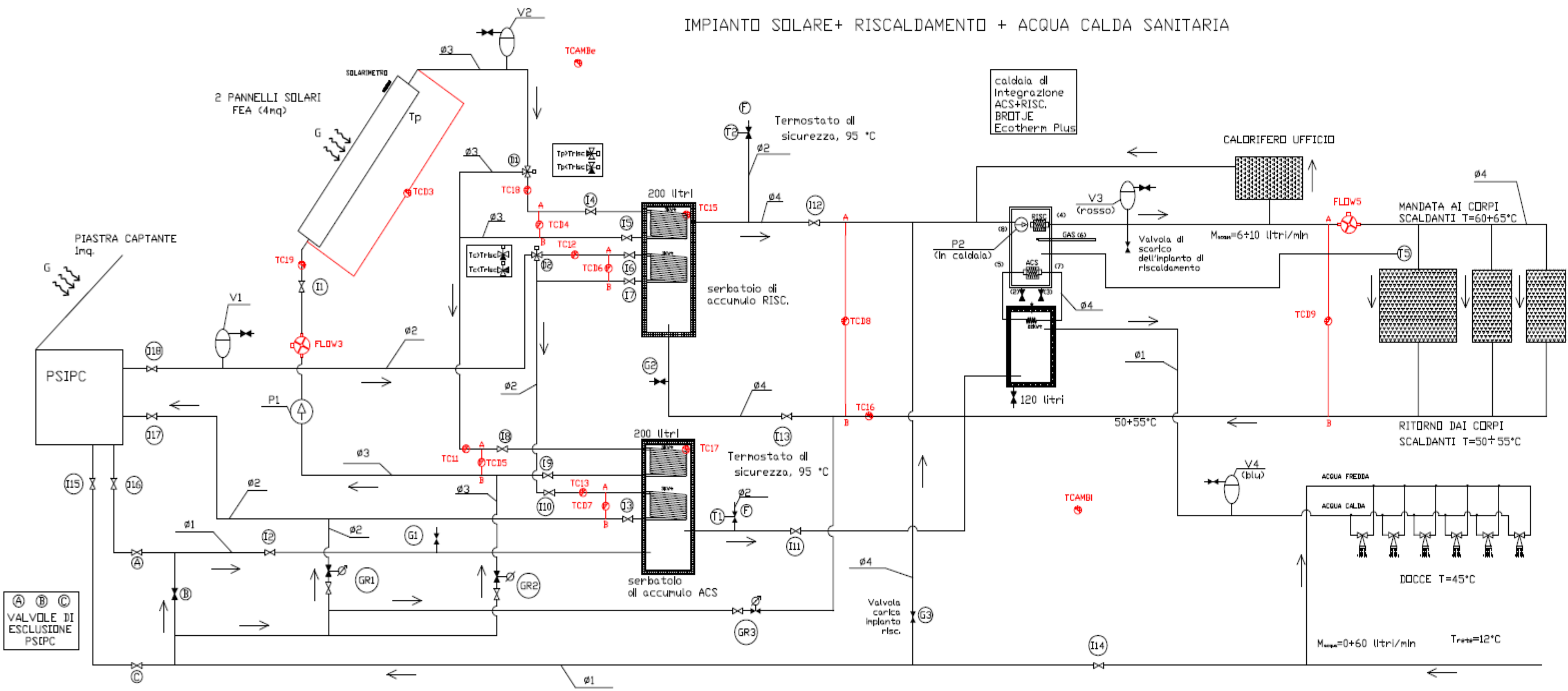
A direct expansion solar assisted heat pump (SAHP) water heater consists of a Rankine refrigeration cycle where unglazed flat plate solar collectors act as an evaporator for the refrigerant.

The condenser is coupled with a water storage thank in order to cover the energy user demand.





Prototype power plant



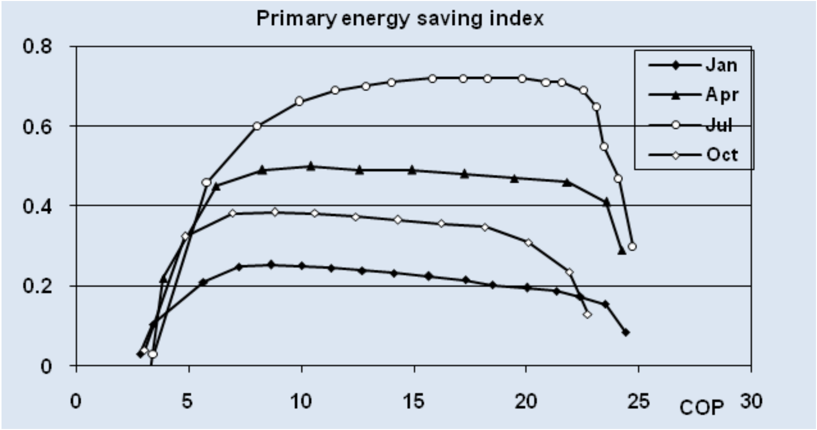
The system test for the prototype plant. It was installed at the University Sport Centre.

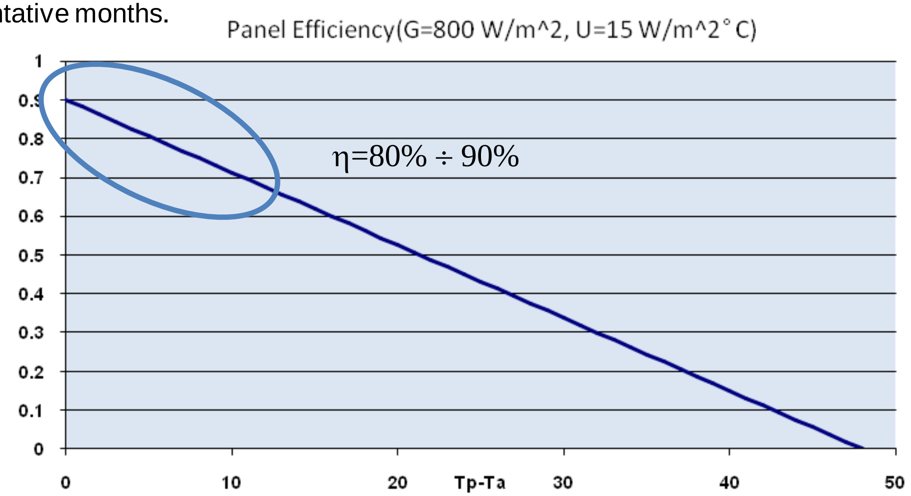
PSIPC Benefit

Advantages in comparison to the traditional system:

- Higher solar panel efficiency, because the solar panel are kept at lower working temperature (0.7-0.9);
- Higher COP (Coefficient of performance) of the heat pump (6 ÷9);
- Lower solar panel cost (bare steel plate, no glass covered).

Primary energy saving index,ξ , as a function of the COP for the four representative months.

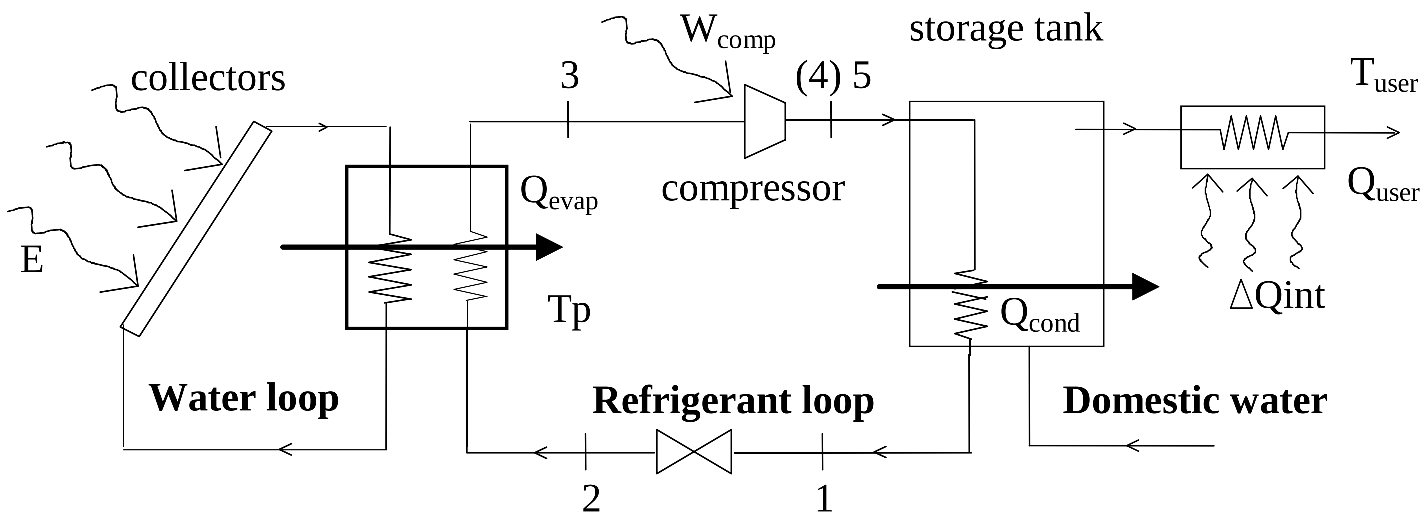




PCEA model

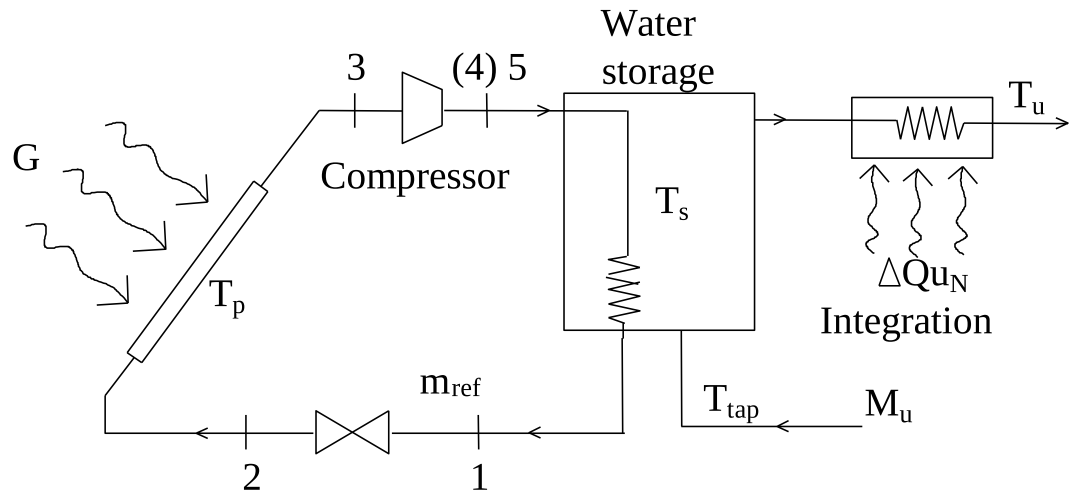
The PCEA plant consist of a **commercial heat pump** combined with a **unglazed commercial solar panel**.

The main difference between the PSIPC plant and the PCEA system is that in the first one the refrigerant directly cross through the collectors, while, in the PCEA model, the configuration prefigures a traditional water loop bare panel plant, coupled, by an heat exchanger, with the heat pump evaporator.

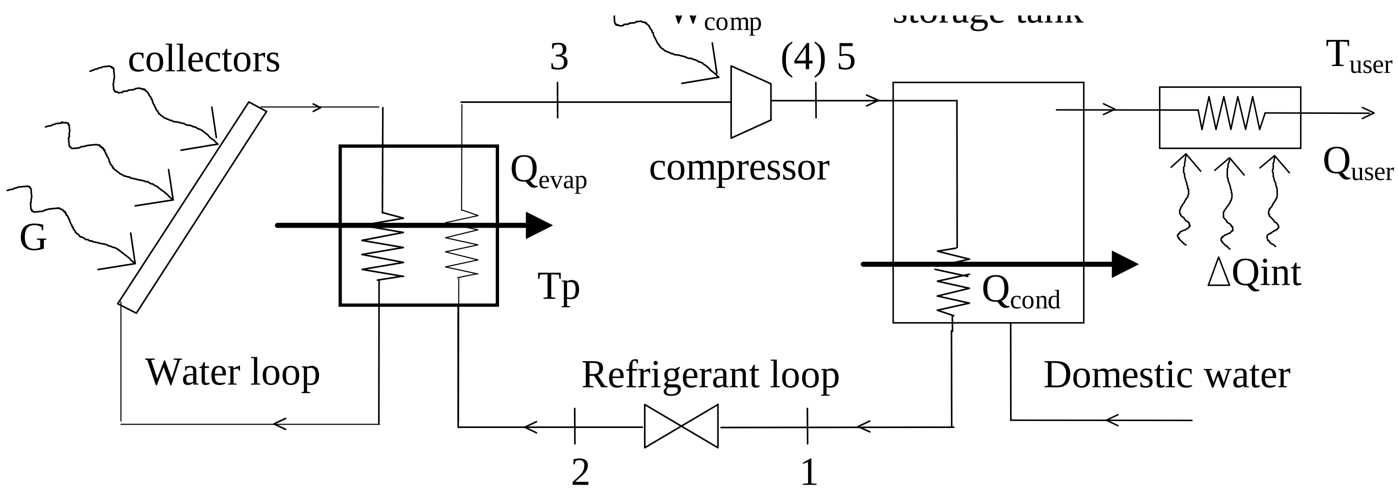


PSIPC vs PCEA

PSIPC plant



PCEA plant



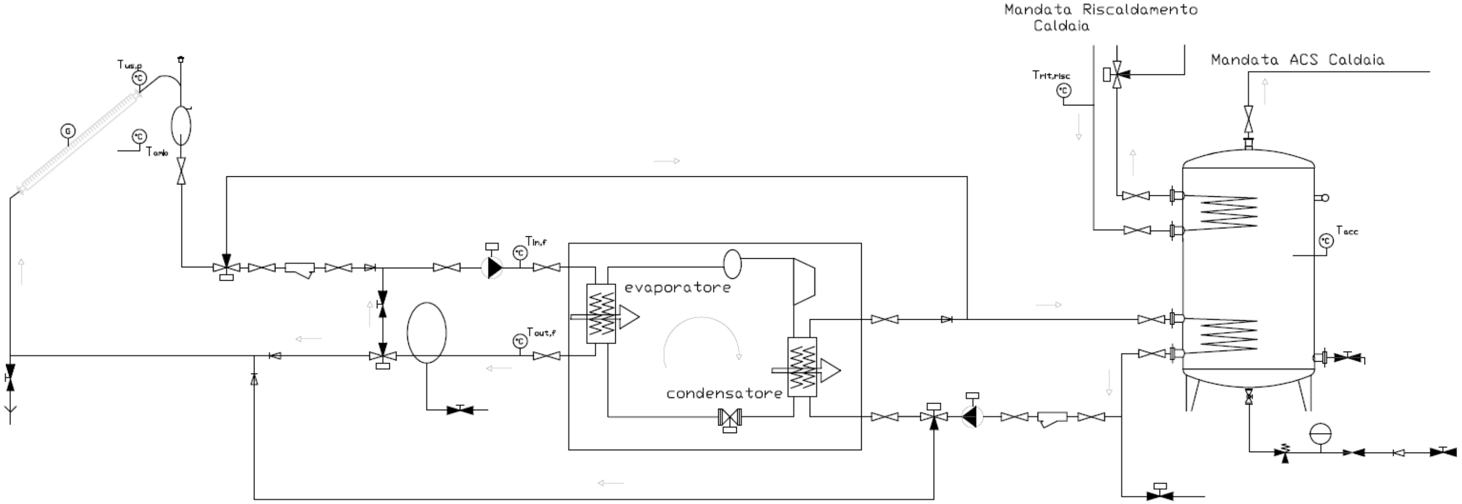
PCEA Benefit

Advantages in comparison to PSIPC system:

• Thanks to the separation between the refrigerant loop and the water loop, the plant layout allows to install the solar panel far from the heat pump machine;

•The power plant can be realized using commercial products (commercial heat pump and solar panel). In this way is possible to strongly reduce the components cost and the time required for the assembly;

• During the summer is possible to exclude the heat pump, so the solar plant can be used in a traditional configuration (By-pass valves).



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Dynamic simulation result

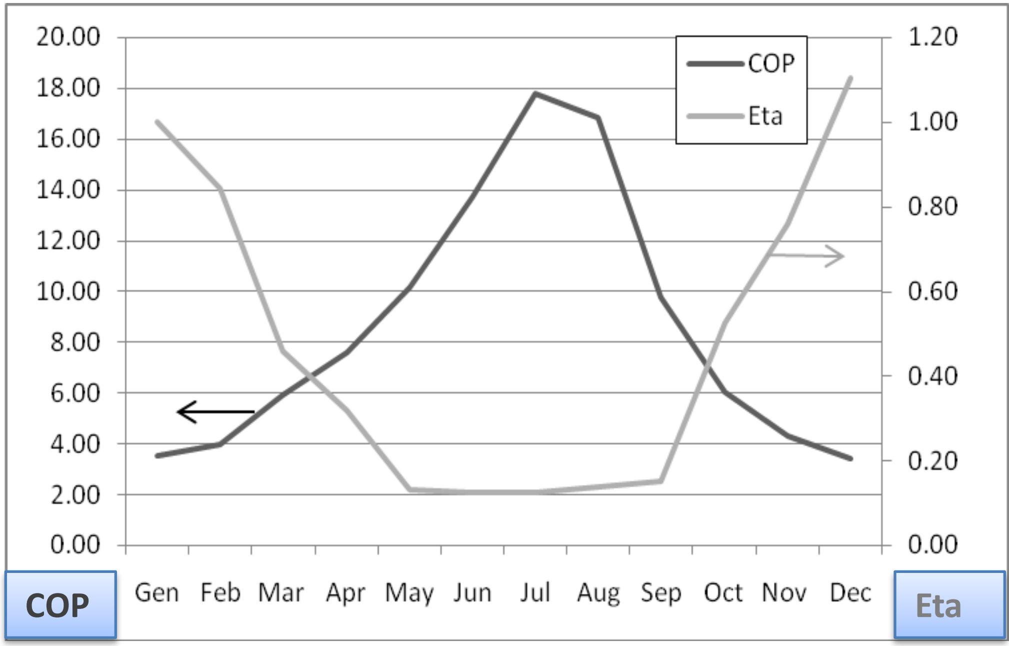
User consumption MJ/Year	Optimal Collector area m2	COP ave	η ave	PBP [Years]	NPV15 [€]
68200	25	5.6	0.38	5	4900

Table 1. Simulation results referred to a PCEA plant installed in a 120 m^2 house in Genoa

In the graph, the values of the COP (black line) and of the solar collector efficiency (gray line) are represented.

- $COP_{min} = 3.2$
- $COP_{max} = 18$
- $Eta_{min} = 0.12$
- $Eta_{max} = 1.1$

$$\eta_{ave} = \frac{\sum_{i=1}^{12} (\eta_i \cdot E_i)}{\sum_{i=1}^{12} E_i} \qquad COP_{ave} = \frac{\sum_{i=1}^{12} (COP_i \cdot Q_{cond\_i})}{\sum_{i=1}^{12} Q_{cond\_i}}$$



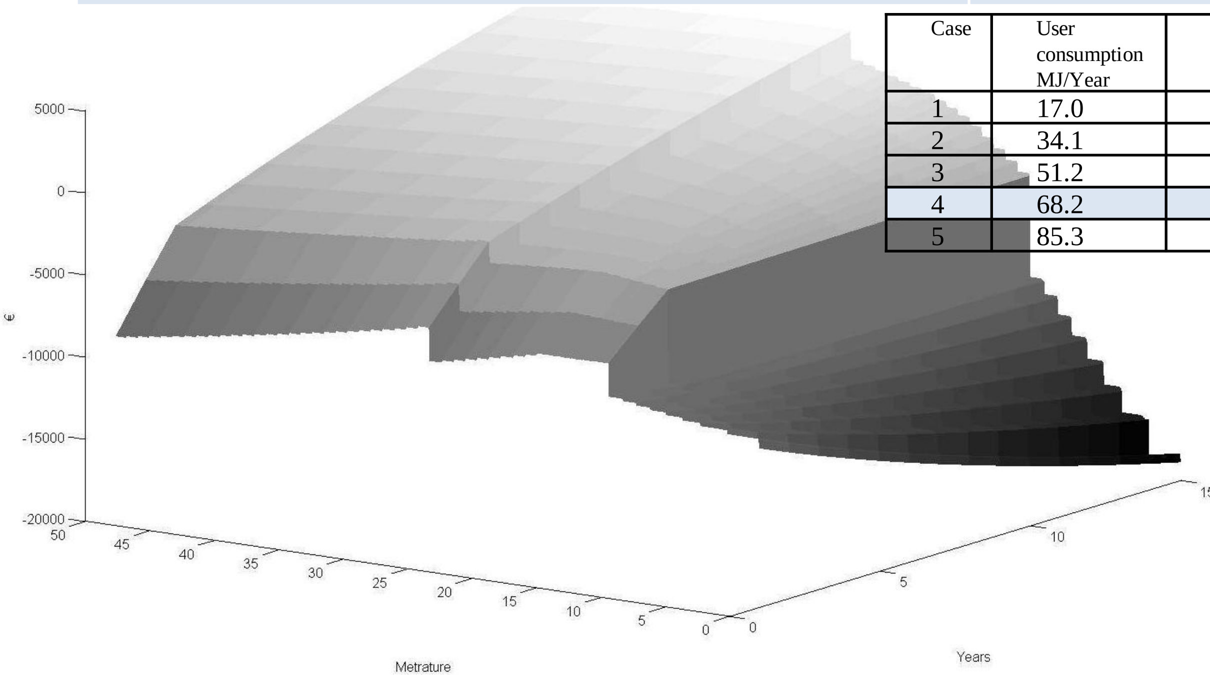
Economical analysis

Economical parameter		Building parameter	
Price of the NG	0,06 €/kWh_t	Climatic zone	D
Price of the electricity	0,16 €/kWh_{el}	S/V	0.35
Price of money	4%	GG	1435
		Energetic performance for winter heating	39.5 kWh/m² year
		Water heating energy consumption	7.9 kWh/m² year

$$NPV_{15} = (CI_{isahp} - CI_{hwh}) + \sum_{k=1}^{15} \frac{\Delta Cf_k}{(1+i)^k}$$

$$NPV_k = 0 \Rightarrow PBP = K$$

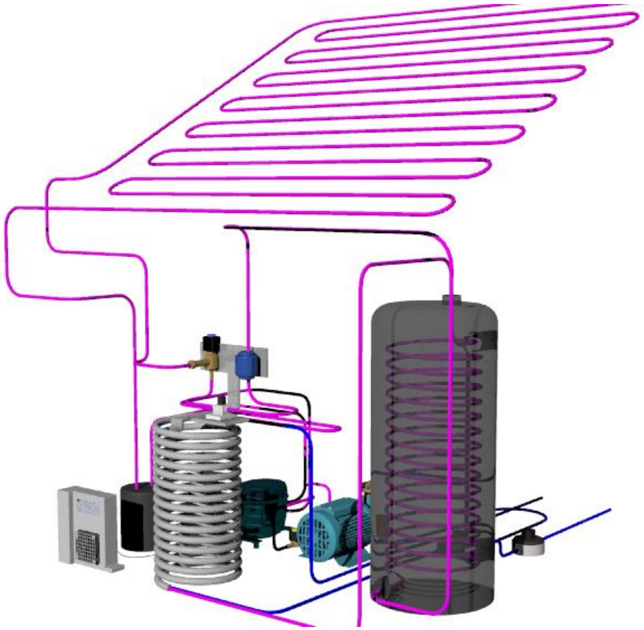
Case	User consumption MJ/Year	Optimal Collector area m^2	COP_{ave}	η_{ave}	PBP [Years]	NPV_{15} [k€]
1	17.0	7	5.7	0.34	> 15	- 0.7
2	34.1	13	5.6	0.37	9	1.4
3	51.2	19	5.6	0.38	6	3.2
4	68.2	25	5.6	0.38	5	4.9
5	85.3	30	5.6	0.38	5	6.7

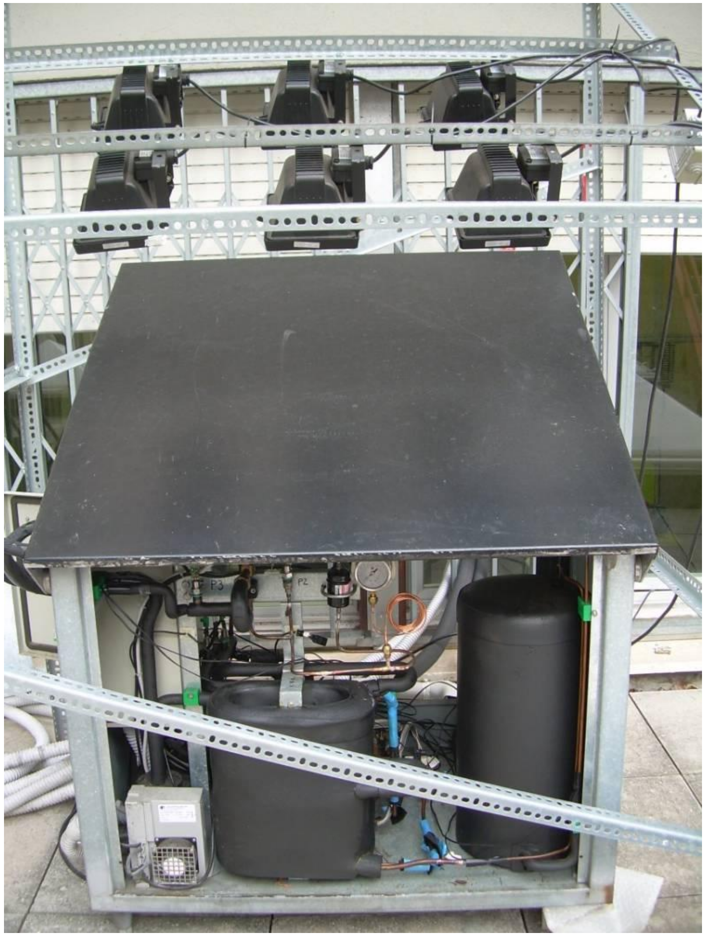


Prototype

The working prototype:

- Bare steel solar panel : 1 m^2
- Variable speed volumetric compressor : 6 cm3
- Pulse Modulated Electronic Expansion Valve
- Light plant : 6 x 400Watt lamps



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