PERSPECTIVES OF SOLAR ASSISTED HEAT PUMPS WITH BARE SOLAR PANEL EVAPORATORS

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INTRODUCTION

Conventional plane solar heating panels offers low efficiencies and suffer of very high investemt costs. The main reason is that the working temperature in the solar panel is strictky coupled to that of the water inside the boiler: this means that high efficiency can be reached only for relatively low working temperatures (not above 50°C) or for very high insolation (near 1000W/m^2). Therefore great heating supply (electrical or gas) is needed for fixed heating service and the mean exploitment coefficient over the year is quite low.

The heating system here presented is based on the concept that the solar panel can work as the evaporator of an inverse cycle operated as a heat pump. The concept is not completely new [14] and has the advantage of decoupling the boiler (that is the condeser) temperature from the solar panel (that is the evoprator) temperature. However if conventional on-off technologies are used to drive the compressor of the plant, not so high coefficients of performance are reached (in the range 2.5-3.5, which is not particularly favourable if compared to actual air cooled heat pumps) and several difficulties are still present to adapt refrigeration capacity to the solar heat rate, which is continuosly changing during the day and with seasonal wether.

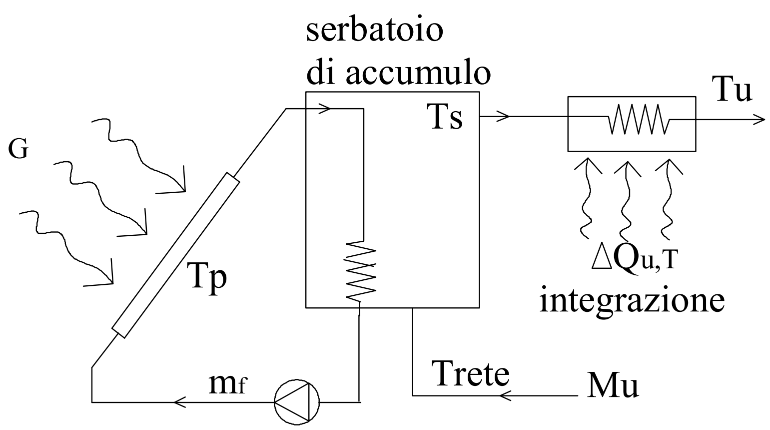

Figure 1. *Sketch of the usual thermal solar panel for hot water applications*.

The simplest reference configuration for a thermal solar water heater is shown in Fig.1, where the main components are evidenced: the solar panel at temperature Tp, the boiler and water storage at temperature Ts, the tap water temperature Trete, the working fluid flow rate mf and the user water flow rate Mu, which must be provided at a useful temperature Tu. An auxiliary water heater (electrical or gas-fired) must be used to satisfay correctly the "useful duty" needed for the user.

The panel efficiency η_p is the ration between the captured mean thermal energy Q_{up} (given to the working fluid) and the global radiation heat flux incident on the panel, GA (G solar insultaion, W/m2 and A solar panel surface, m2):

$$\eta_p = \frac{Q_{up}}{A \cdot G} \tag{1}$$

As well known [1,4,5] η_p is rougthly a linear decreasing function of the temperature difference Tp-Ta, and increases with solar insultaion G. Introducine the non dimensional parameter δ we have [2]:

$$\eta_p = 0.86 - 0.79 \cdot \delta \qquad \delta = \frac{K \cdot (T_p - T_a)}{G} \tag{2}$$

where $K \approx 10 W/(m^2 K)$ is a global thermal conductance between the solar panel fluid and the ambient temperture. Some less efficient correlation, based on lower coefficeint of trasmission and absorption of the solar radiation give [3]:
$\eta_p = 0.7 - 0.75\delta$.

As already mentioned, since in this configuration Tp=Ts, the working fluid can gived useful heat only for $T_p > T_s$. Such a condition makes the panel unusable for the majority of the day, or otherwise ask for very low working tempratures Ts. Typical values of the ratio among the thermal energy given to the user divided for the total solar energy available on the panel (on time scales fo day, monthes or even year) are not higher then 0.5.The new concept is breafly scketched in Fig.2: a proper refrigeration fluid is used to keep the solar panel temperature near to the ambient temperature, giving maximum η_p and giving maximum regulation flexibility to the Ts value, which can be easily adapted to the user (Tu) needs, thanks to the condenser exploitment. A similar innovation has been test for several years as reported in [xxx] adapting a domestic refrigerator to work as a solar assisted heat pump, however heat pump perfprmance coefficients of the order of only 2.6 have been reached. Despite that, the solution offers several very important advantages, such as the highest solar panel efficiency, longer working times of the panel, which could be operatedcontinuosly from sun rise to sun set. Furthermore, much lower panel

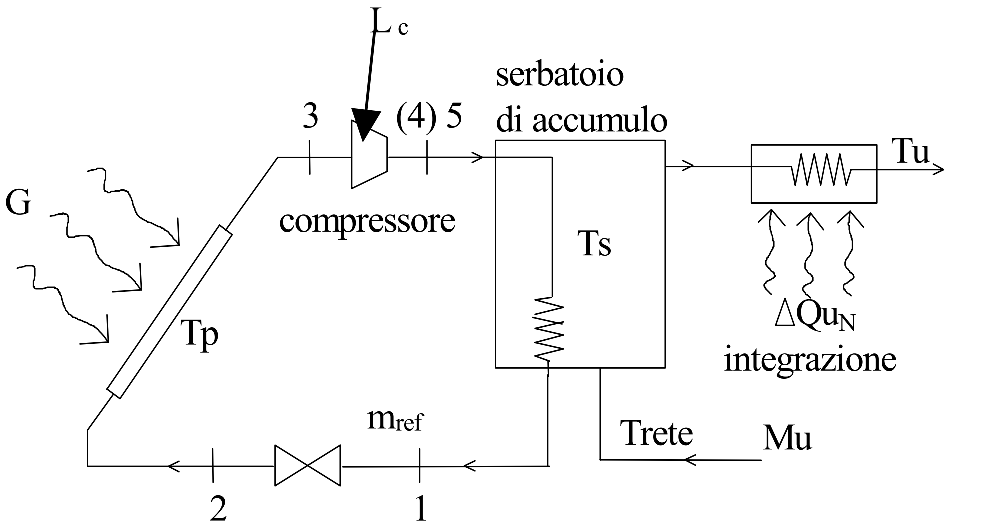

Figura 2. *Sketch of theinnovative solar assisted heat pump system*

surfaces are necessary for given heating needs, thus cutting down the installation and surface costs, with benefits also for the visual impact of the system.

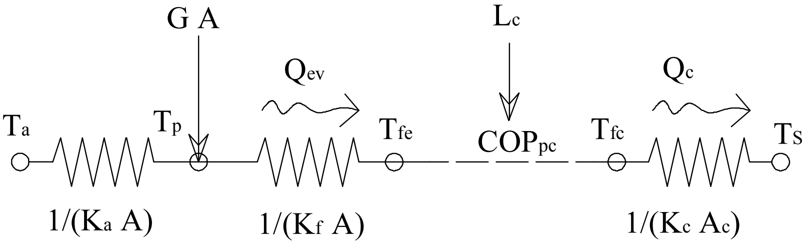

Figure 3.

These advantages are payed for in terms of electrical energy consumption by the compressor and assume we are able to regulate quite well the given compressor power, not only in terms of rotating speed, but also in terms of pressare drops in the expansion valve. Only in recent years such characteristics have been achieved, making similar solutions to be envisaged also in the small refrigeration plants [6,xx].

The basic design concept of fig.]ure 2 can be descriebed, in terms of thermal resistances in steady state, as in Figure 3, together with the thermodynamic cycle of Figure 4.

PERFORMANCE ANALISYS

This paper gives few preliminary results related to the comparison of the two systems, working in the same operatine conditions, in terms of energy consumption (and primary energy) assumine steady state operation. Furthermore, the COP of the solar assisted heat pump is reported too, for comparison with usual air-air or water-air electrical heat pumps.

Significant parameters compared

Given the heating duty, that is a fixed nominal heating rate Q_{uNom} at the working useful temperature T_u, the main performance parameters considered are (T for traditional, N for new):

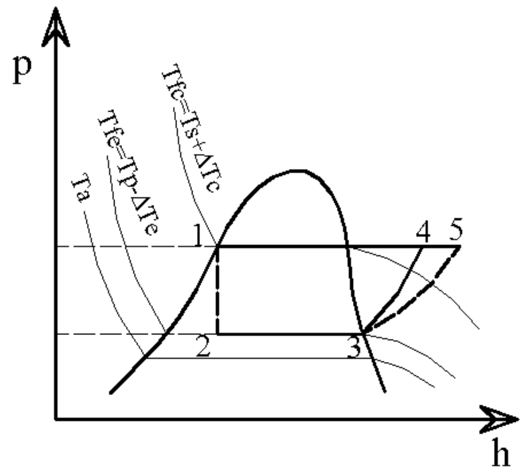

Figure 4.

- **Useful heat rate** (Q_{uT} $=Q_{up}$ for the plane solar panel, while $Q_{uN} = Q_c = Q_{up}+L_c$ for the solar assisted heat pump);
- The **integration heat rate** ΔQ_u needed for each of the two solar plants to fulfill the required useful heat rate Q_{uNom} ($\Delta Q_{uT}=Q_{uNom}-Q_{uT}$; $\Delta Q_{uN} = Q_{uNom}-Q_{uN}+L_c$);
- the **primari energy rate** E_p consumed by each plant ($E_{pT}=\Delta Q_{uT}$; $E_{pN}=Q_{uNom}-Q_{uN}+3*L_c$, with the usual coefficient 3 to convert the compressor electrical energy L_c into primary energy consumption);
- the **COP_{PC} of the solar assisted heat pump** ($COP_{PC}=Q_c/L_c$, with $Q_c=Q_{uN}$), to

perform a comparison with commercial electrical heat pump units for winter heating.

The comparison is performed assuming that the traditional solar panel operates always in its best working conditions and neglecting electrical consumption for water circulation. The compressor of the solar assisted heat pump has a constant compressor efficiency of 0.7, whichever are the operatanig conditions

RESULTS AND CONCLUSIONS

The comparsion is reported in Figure 5. The performance of the innovative solar panel tends towards those of the tradidional one as soon as the compressor work Lc becomes lower and lower. The higher the Lc value, the higher extra-consumption of primary energy, so that the environmental inpact of the refrigeration cycle becames rather high, even if great advantages for the user are reached in terms of reduced integration heat energy.

Also the COPpc values are quite favourable when the Lc value is kept relatively low, showin very interesting perspectives in comparison to usual heat pump heaters [3,7, 8].

Future development ask for dynamic models of the dsolar system, which are expected to given even better performance results, and the design and construction of a prototype to be tested from the point of view of actual reliability, safety and regulation/control capabilities of the reciprocating compressor.

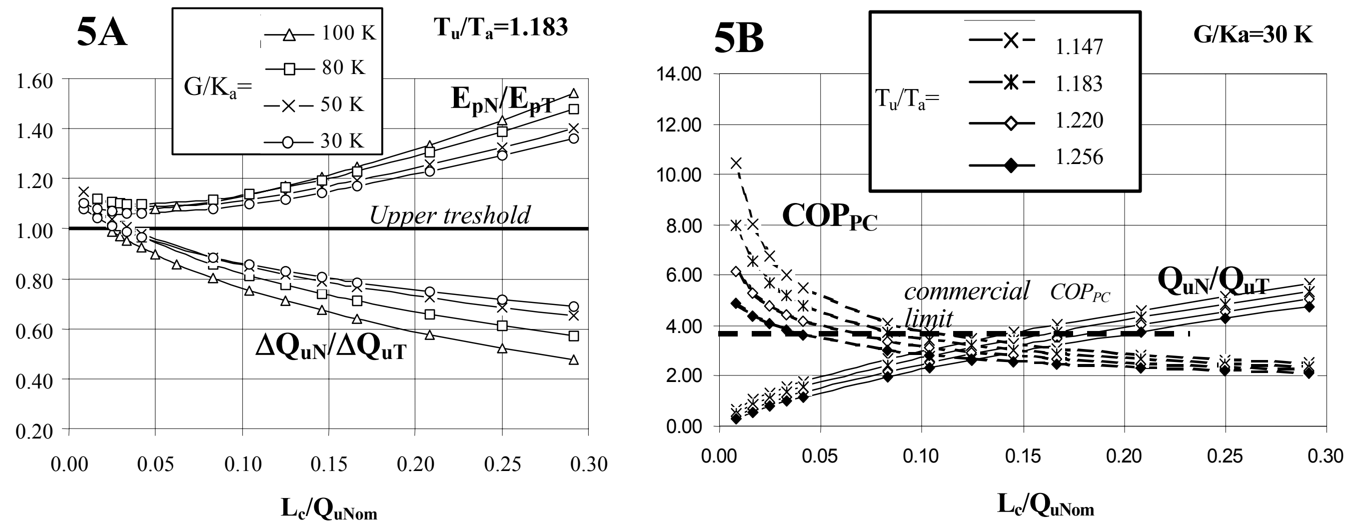

Figure 5. Comparison between the two solar panel solutions (traditiona and solar assisted heat pump) for typical **winter working conditions in Genoa,** as a function of the ratio betweeen compressor power L_c and user heat rate Q_{uNom}

5A Ratio $\Delta Q_{uN}/\Delta Q_{uT}$ between energy integration needed and corresponding primary energy consumption E_{pN}/E_{pT} calculated for different G/K_a values (T_u/T_a=1,183).

5B Ratio Q_{uN}/Q_{uT} between the actual useful heating effects of the two panels and heat pump performance coefficient COP_{PC} for different Tu/Ta values (G/K_a=30K).

The reported mean COP limit for commercial heat pump applications is around 3.8 [3, 8].

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