Increasing Performances of a Thermal Energy Plant

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Abstract: -This paper proposes a domestic heating system driven by solar assisted heat pump in order to increase the system efficiency. A more detailed analysis of quantities that main influence the system performances has been carried out, developing a suitable mathematic model able to describe and control the behaviour of interested phenomena. The use of advanced control and monitoring of several interested quantities has allowed optimising the global system efficiency.

Key-Words: - Solar assisted heat pump, energy plant simulation, energy saving.

1 Introduction

This paper investigates on using solar assisted heat pumps system with high performances to provide the full thermal energy to meet space heating and hot water requirements for domestic houses throughout the year. The project focuses on the domestic housing sector, since this is a major consumer of energy and thus contributor of significant CO_2 emissions.

A new system able to heat domestic space and water has been developed theoretically as a particularly promising application in addition to the generic set of devices known as active solar heaters, or solar assisted heat pumps. It is expected that its widespread application to a variety of sectors over a broad geographical areas would considerably alleviate the greenhouse effect providing at the same time economical space and water heating.

The proposed system uses a solar-assisted heat pump system to provide an efficient method for supplying the thermal energy for space heating and hot water production in buildings [1].

Heat pumps work by extracting thermal energy from a low temperature (T_L) source and upgrading it to a higher temperature (T_H) for space and water heating. For this aim it is necessary that a certain amount of work be done on the system.

The parameter normally used to compare heat pumps efficiency is the coefficient of performance (COP_{HP}) that measures the ratio between the heat output and the energy used. In order to evaluate the actual COP value it's need to define the machine, COP_{HP} , and the plant efficiency, COP_{plant} , as:

$$COP_{HP} = \frac{Q_{COND}}{EC_{SUPPLIED}}$$
(1)

and

$$COP_{PLANT} = \frac{Q_{USERS}}{EC_{SUPPLIED}}$$
(2)

The COP_{HP} of the Carnot cycle expressed through the temperature allows to outline the effect of the temperatures also in the actual heat pumps:

$$\left(COP_{HP}\right)_{Carnot} = \frac{T_H}{(T_H - T_L)} \tag{3}$$

It shows that, for a fixed temperature $T_{\rm H}$, the value of the ${\rm COP}_{\rm HP}$ increases as the lower temperature increases.

For real machines, the characteristic curves, factory provided, show the relationship among the evaporator inlet temperature, the condenser inlet temperature and the value of COP.

The choice of the heating system, as fan coil, radiator or radiant panels, determines the temperature of water supplied by heat pump. The amount of energy consumption can be evaluated through the values of the COP established by the evaporator inlet temperature as below reported:

$$COP_{HP} = 0.9472 \cdot \ln(T_L) + 2.6995 \tag{4}$$

The logarithmic equation (4) of heat pump's COP was determined by the real machines' characteristic curve, factory provided, with a condenser outlet temperature of 45 $^{\circ}$ C..

In order to increase the effectiveness of the heat pump, the thermal system under study uses a solar collector to supply thermal energy to cold the tank of the plant cooled by the evaporator of the heat pump. In this way, the inlet temperature of evaporator and the heating power increases and so the system effectiveness (COP) improves. Fig.1 shows the scheme of the whole thermal plant, with the indication of the sensors, the controllers and the valves necessary composing the system too.

Many parameters must be accurately evaluated to achieve the target, as the water mass flowing through the solar collector in the cold tank, the volume and the shape of tank. The first parameter must be modulated so that the flow mass increases with high solar radiation; on the contrary, with low solar radiation, it is necessary to reduce the flow mass in order to obtain the highest temperature on the top of the tank.

The heat-transfer-fluid is pumped through the collectors to transfer heat from the collector loop to the water in the tank, as shown in Fig.1. Closed loop glycol system must be used for freeze protection.

The flow rate through the solar collector is linked to solar radiation to obtain the wanted temperature of the water to send to thermal plant. A high flow rate is used in solar collector circulation systems when high solar radiation occurs, because heat transfer within the collector improves with flow rate increasing. The major disadvantage of high collector loop flow rates is that thermal stratification in the storage tank may be disturbed by the high flow, even when a heat exchanger is used between the collector and the tank.

In order to evaluating the effectiveness of the plant [2] it is necessary to define and to measure the most relevant parameters, evidenced into the plant scheme shown in Fig.1.



Fig. 1 - Scheme of the rig of the thermal plant and the auxiliary thermal energy suppliers.

The benefit of low flow operation is the promotion of thermal stratification in the storage tank. However, low flow rate is only one factor influencing stratification; so the improving of performances will only be achieved if all factors influencing stratification are considered[3]. High flow systems can have different degrees of stratification, depending on whether there are heat exchangers in the collector loop or the load flow stream. Heat exchangers such as internal coils, full height mantles or external spiral tubing on the wall of the tank, all minimize mixing in the tank and give some stratification, even for high collector loop circulation rates. Maximum performance benefits can only be gained through a fully integrated low flow system design. The most obvious impact is that a smaller low power pump can be used. Smaller tubes lower the thickness and the cost of pipe insulation because the thermal resistance value depends on the ratio of outer diameter to inner diameter and not the absolute thickness of the insulation. Maximum benefit will be achieved in a low flow system if the following load matching principles are incorporated.

Solar heat is collected by means of a roof-shaped solar collector and supplied to hot tank if the temperature is sufficiently high for heating increasing the COP of the plant; otherwise it is supplied to cold tank to increase the COP of the heat pump. On the other hand, the temperature is less then the temperature of the top section of the hot tank, the water flow is driven in cold tank to increase its temperature and to improve the COP of the heat pump and the effectiveness of the heating plant. This is obtained by driving the three-way valve, C4 controlled. The algorithm to control this flow must be analysed, but low flow in pumped circulation systems works well if attention is addressed to minimize mixing in the tanks [4].

The system performance is evaluated through the calculation of heat exchanged between heat pump and the tanks, both the cold tank and the hot one. Moreover it is necessary to evaluate the heat power supplied from the hot tank to users. This energy amount is the actual energy supplied to users so that must be used in effectiveness calculation.

When we consider the domestic hot water, the energy supplied to mains water by hot tank, HTDW, and the energy supplied by solar collector, ADW, we must evaluate a new value of COP:

$$\left(COP_{HP}\right)_{global} = \frac{\left(ADW + HTDW\right) + HC}{EC_1 + EC_2}$$
(5)

where EC1 and EC2 are the electrical power supplied, respectively, to heat pump and to domestic hot water.

The regulation rig has the scope to store the heat from the time the energy is collected to the time it is needed without incurring an unacceptably high loss together with a decrease in temperature. In fact, although the system performs reasonably well for sunny periods during the heating season, it could not give a reliable solution for all year round use, as it would be done by an optimal conditioning.

Under the hypothesis that the errors relevant to the directly measured quantities are statistically independent and uniformly distributed, it is easy to write the analytical expressions of the absolute standard uncertainty in all the indirect measurements [6].

Two auxiliary heaters are available for heating domestic hot water ant heating fluid. The auxiliary inputs should be provided so those not interfere with the operation of the solar part of the tank.

The auxiliary heaters can be used to provide a delivery capacity that varies across the day to match the demand pattern of the user. In winter, the auxiliary controller could be switched to provide a greater volume to match higher hot water demand. In summer, the boost volume could be reduced to allow greater solar contribution. A programmable controller could be used to maximize solar contribution while it is maintaining a delivery capacity across the day that matches a specified pattern. The load pattern could be set by the user or 'learned' by an intelligent controller.



Fig. 2 - TRNSYS scheme of thermal plant

The project requires an overall management and quality control package, modelling techniques to

allow detailed studies of the whole energy system and its optimising.

The work will also involve a complex measurement system (consisting of more than one hundred thermocouples, several flow-meters and a weather station with solar-meter) to monitor in real time and in an extensive period, including the heating and cooling seasons, all quantities influencing the efficiency system.

The performances of the energy supply plant will be calculated on a weekly/monthly basis as well as seasonally and annually.

Besides suitable control strategies will be investigated and developed to optimise the management of various elements of the overall system, i.e. energy collection, energy upgrading and energy delivery.

2 Simulations

In order to design the full size test plant, several extensive simulations have been carried out.

The performances of the energy supply plant have been investigated by means of dynamic simulation code, TRNSYS [5]. It simulates the hourly performances by means of several FORTRAN subroutines, which are linked together in order to model a thermal system. Each subroutine calculates the heat and the mass flow interactions. Simulations performed using average climatic data relevant to Taranto area.

An experimental validation of the developed model shall be carried out by building up and monitoring a full thermal (heating and cooling) energy plant operating under normal occupied conditions.

Once the noisy input data are collected, as returned from the simulated system, they have to be statistically analyzed, so to extract important information about their variance, in order to establish the variance of the simulation results. Finally, the evaluation of the final uncertainty, on the bases of both this information and the knowledge of the model variance has been calculated. Then, the results of these simulations could support the selection and the design of suitable components that well be used in real plant.

Particularly, the greatest attention was devoted to quantities that main influence the COP system and that play leading rule in the control plant as temperatures and flow masses. Then. the measurement of these quantities could be characterized by an uncertainty extremely low [6].



Fig. 3 -Temperatures of the cold tank and the internal air related to outside external air temperatures

Fig. 4 – *Heat Pump's COP with the temperature of the cold tank (grey line) and outside external air (black line) as evaporator inlet temperature.*

3 Results and Conclusion

The simulations carried out shown the capability of heat storage of the cold tank. In Fig. 3 is shown the temperatures of the external air, grey line, the temperatures of a $2,0 \text{ m}^3$ cold tank, black line.

The solar thermal energy collected trough the unglazed roof and the thermal energy exchanged between the outside air and hot sun allow the water mass in the cold tank to have a temperature higher than the external air.

In the Fig. 4 is shown the increase of the COP values, black line, higher the COP of the heat pump exchanging with the external air, grey line.

The simulations carried out shown the capability to increase the efficiency of the heat pump thermal plant and allowed quantifying the dimensions of a lot of components of the full dimension rig, now under construction near the seat of the Engineering Faculty in Taranto. By the use of an aluminum roof in which inside flows HTF, it's possible to increase the temperature of the evaporator so reducing the energy consumption and the green house gas emissions of about the 20%.

The development and the characterisation of an innovative heating system with high performances in terms of efficiency, has been proposed. For this aim complex regulation system has been implemented in order to manage and control all the temperatures of the components, the flowing masses ant the tank capacities of the plant. The main parameters influencing the efficiency of the system have been identified and a lot of quantity of simulation are carried out.

References:

- O1. Comakli O, Kaygusuz K and Ayhan T, Solar assisted heat pump and energy storage for residential heating, *Solar-Energy*, Vol. 51, n.5; Nov. 1993; p.357-366.
- [2] 02. Lampinen MJ and Heikkinen MK, Exergy analysis for stationary flow systems with several heat exchange temperatures, *International Journal of Energy Research*, Vol.19, n.5; July 1995; p.407-418.
- [3] 03. R. M. Lazzarin, G. Longo, F. Piccininni, The use of an absorption heat pump by thermal bathing establishment, *Heat Recovery & CHP*, Vol. 12, n. 4, pp. 365-369, 1995
- [4] 04. N. Cardinale, F. Piccininni, P. Stefanizzi; Economic optimization of low-flow solar domestic hot water plants". Renewable Energy, 28 (2003) 1899-1914
- [5] 05. Klein S. A. et al., A transient system simulation program. Version 15.0, University of Wisconsin-Madison Solar Energy Laboratory, 2000
- [6] 06. S. Bendat, A.G. Piersol, Analysis and measurements procedures, J. Wiley & Sons, New York, 1971