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Dual source heat pump systems: Operation and performance

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ABSTRACT

Dual source heat pump systems comprise of a main cold source heat pump that is supported by an additional heat source. Two arrangements have been studied in detail: air source heat pumps combined with solar collectors; and ground source heat pumps coupled with solar collectors.

In addition to a situation where solar collectors are devoted solely to direct heating, the solar system can be used with the heat pump in either a series or a dual source scheme. When set up in series, a higher COP can be achieved, but there is often a lower free energy fraction. This is due to the lack of direct solar heating, meaning that auxiliary energy is required more frequently.

A careful analysis of all the plant elements, including location, heating and cooling demand, solar collector area, thermal ground probe length, etc. is fundamental for achieving the best outcome in terms of both good primary energy savings and profitable economical performance.

1. Introduction

When considering the possible use of a heat pump, the sensitivity of the system to low and high temperatures should be taken into account. It is also important to consider the temperature lift that the heat pump can achieve in relation to the cold source temperature.

In Fig. 1, the heat pump coefficient of performance (COP) is represented as a function of the temperature lift for a heating temperature of 60 °C. The COP is the ratio between the heating effect and the work necessary to drive the heat pump. Fig. 1 shows indicative COP values that are achievable in theory and practice, according to different sized and technically developed machines.

The profile of the machine capacity is quite similar in most cases, which suggests two key areas that must be considered when designing a heat pump system:

1) Careful selection of the heating system in order to lower heat supply temperature is required before looking for higher level heat sources. It is not logical to operate with systems that need the highest temperature attainable by the machine (usually around 60 °C), when systems are available which can distribute the heat at temperatures lower than 35 °C (i.e. heating panels or all air systems).
2) The most common heat pump source is outside air, but this is the least favourable in terms of thermodynamic properties. Thermal load will increase as external air temperature decreases, resulting in a reduced system capacity and lower COP.

There are other reasons, besides thermodynamic performance, which may make it beneficial to look for alternative sources to the outside air.

The external coils which are in contact with the outside air are often subjected to frosting at low temperatures, leading to the requirement to detect and eliminate frost. Conditions inside the building may become uncomfortable during the defrosting period. Also, air movement within the outside coil produces noise and it may not be possible to control this at an acceptable level. External coils can usually be easily placed, but with poor aesthetic results, and the energy cost of air movement can be considerable.

The main advantage of using air as a heat source is that it is free and immediately available. However, the potential advantages of alternative heat sources can be significant, so it is important that each is fully evaluated at the design stage.

In a dual source system, as the name intrinsically suggests, the main heat pump cold source is aided by another source. Many combinations are theoretically possible [1], but only two arrangements have received full attention and have been studied in detail:

- Air source heat pump and solar collectors;
- Ground source heat pump and solar collectors.

Of course, the two options can be used in different situations according to available storage capacity, or the potential for interaction between the two sources. For example, solar collectors can charge the ground in summer [2].

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Nomenclature

F_R	solar collector heat removal factor
$\tau\alpha$	solar collector effective transmission absorption coefficient
U_c	solar collector heat loss coefficient ($W\,m^{-2}\,K^{-1}$)
Q	solar collector specific power ($W\,m^{-2}$)
F	free fraction

Heat pump systems with more than one source can be classified as:

- Series;
- Dual.

In a series system, the two sources are aligned in series so that the former raises the temperature before that heat is taken from the latter. In a dual source configuration, the heat pump takes heat either from the former or the latter according to the temperature levels [3,4].

The inclusion of more than one source implies a more complex and expensive system, which may need to be justified in terms of either economic performance or energy savings. It is assumed that the COP of the heat pump will be increased by having an additional source. In practice, there are usually some advantages, but it is difficult to evaluate the extent to which such benefits are significant and worthwhile in different applications.

Several mathematical and experimental studies have provided some analysis of the available system options. Discussion of these findings will be presented in this paper, firstly considering the combination of air and solar collectors, before assessing ground and solar systems.

2. Air + solar heat pumps system

The use of a solar source in addition to outside air in heat pump systems has been questioned, as both elements perform poorly during the coldest months. Outside air temperature is lowest during the winter, and solar collectors function inefficiently due to low levels of insolation and cold external temperatures. The performance of the solar collector is relative to direct utilisation of solar energy. However, if thermal levels are lowered to a point that is not suitable for direct utilisation but is high enough for the heat pump evaporator to function, then the solar collector could present a useful addition to the heat pump system and enable increased overall performance levels.

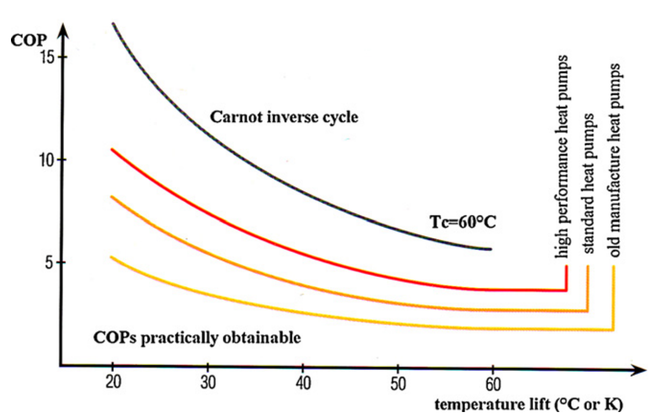

Fig. 1. Theoretical and practical COPs for electric heat pumps as a function of temperature increase.

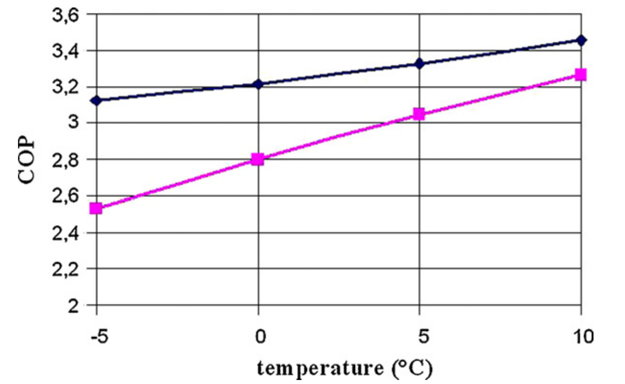

Fig. 2. COP of liquid and air heat pumps as a function of cold source temperature.

In this simple example, a flat plate solar collector is considered with the following parameters: $F_R(\tau\alpha) = 0.85$ and $F_R U_c = 7.5\,W\,m^{-2}\,K^{-1}$. In the case of a low insolation, say of $300\,W\,m^{-2}$ and a working temperature of 35 °C for an outside temperature of 0 °C, the solar collector efficiency would be zero:

$$Q = 300 \times 0.85 - (35 - 0) \times 7.5 \approx 0$$

The same collector, operating at a temperature of 5 °C, which is an excellent value for the heat pump, could provide instead:

$$Q = 300 \times 0.85 - (5 - 0) \times 7.5 \approx 200 \quad Wm^{-2}$$

In this scenario, the solar collector would be useful with an efficiency of 66%, whereas it would be otherwise idle. The operating temperature would also be 5 °C higher than the outside air alone would permit, and there is no need to consider frosting/defrosting cycles. In addition, due to the more favourable heat transfer properties of liquid with respect to a gas at the same temperature of 5 °C, the behaviour of a liquid heat pump is more than 10% better than for an air source heat pump, in respect of both COP and capacity. A possible example is shown in Fig. 2, where the COP is given for liquid or air cold source as a function of temperature.

As an alternative to series or dual source systems, it is also possible to install the heat pump and solar collector in a parallel arrangement. In this situation, the solar collector provides direct heating when possible, and the air source heat pump aids the solar collector when insolation levels are low. Auxiliary heating would be required at low outside air temperatures, as the heat pump capacity is poor in this case.

An overview of a potential parallel system is shown in Fig. 3, taken from an interesting paper by Kaygusuz [5]. The system incorporates a storage tank to store heat when solar energy is available and supply exceeds low levels of heating demand.

Attempting to predict the performance of the three system types is not straightforward. The parallel set-up is the simplest to assess, as the solar collector control is bound to the minimum supply temperature and the heat pump will operate according to the ambient temperature set by the thermostat. When the internal temperature falls below that required by the thermostatic control, the heat pump will function. When the heat pump alone cannot achieve the desired temperature, supplementary energy will be provided by electric resistance heating or an auxiliary boiler.

In a series system, there is a requirement to predefine the temperatures at which the transfer from direct solar heating to use of the heat pump occurs, and vice versa. It is essential to select the two temperatures with care, as direct solar heating could be prevented if the range is not adequately wide. For example, in a case where the solar collector could provide a temperature of 28 °C, this would be too low even for a radiant floor heating system. If the solar system is then devoted to the heat pump, it would take a