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ENERGY EFFICIENT OPERATION OF A HEAT PUMP SYSTEM

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Abstract: As the operating conditions of a heat pump system are the result of multiple interactions between the building and the heat pump system but also between heat pump and its thermal source its efficiency is the result of an adequate design and sizing process preceded by an accurate heat loss and heat gain calculation concerning the building: the appropriate capacity of the heat pump must be correlated with the energy use of the building and the bin method was used for this purpose. On the other hand the source and the sink temperature variation affect the annual performance of the heat pump as a heat generation system.

Key words: Heat Pump System Operation, Energy Efficiency.

1. INTRODUCTION

Heat pumps used in the built environment are just a component of a system also consisting of the building, and the thermal source and denoted as BHPTS (**B***uilding*-**H***eat* **P***ump*-**T***hermal* **S***ource*). The energy efficient operation of such systems depends on several factors as (1) the sizing of the heat pump capacity, (2) the operation conditions of the BHPTS, (3) the performance of the heat pump itself and (4) the efficiency of the heat pump-driving energy. The previously mentioned factors will be analyzed in order to put in evidence their impact on the energy efficient operation of BHPTS system.

The coefficients of performance COP of the heat pump considered as equipment are usually higher then the system COP [1]. When buying a heat pump the consumer usually do not think what other money must be paid for losses not included in the technical documents accompanying it but present on the electricity bill. On the other hand manufacturers strive to deliver more and more performing equipments to resist on the market, but finally all of these equipments using electricity depend on the price of the kWh and on the conversion efficiency of different kind of primary energy sources into electricity. Considering all these efforts it is interesting to evaluate what field is more important to develop.

2. THE BHPTS SYSTEM

2.1 Building-Heat Pump Correlation

The bin method [2] has been used for the evaluation of the heat pump performance in the case of a given building characteristic i.e. its heat loss rate. As the traditional possibility to adapt the energy produced by the heat pump to the building energy use is its cycling operation the heat pump is working only part-load and the integrated capacity which is given in the manufacturer's documentation is reduced to the adjusted capacity. The losses resulted from a cycling operation of the heat pump, the shaded area shown in Figure 1, have as an effect the lowering of its capacity. In the actual example a heat pump of 34 kW-capacity (given for a standard ambient temperature of 10 ^{o}C) will provide a reduced (adjusted) power compared with its integrated capacity. The integrated capacity is represented in Figure 1 by the upper curve and the adjusted one by the lower curve. As can be noticed the heat pump energy losses depend on the building characteristic which is determined by the envelope insulation and by the internal heat gains. The better the building insulation the lower the heating load and the lower the adjusted capacity of the heat pump.

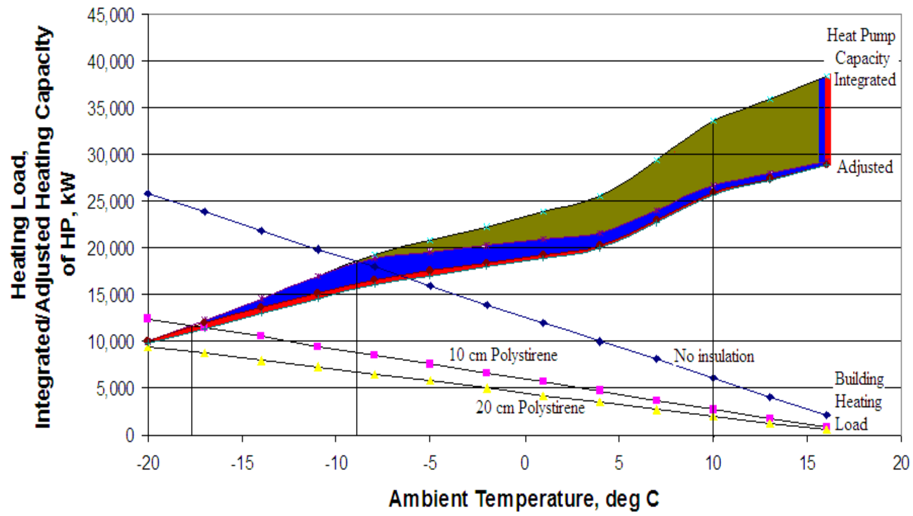

Fig. 1 The balance point for three different building loads

This reducing of the integrated capacity leads to losses depending on the insulation level of the building:

- for the envelope insulated with 20 cm of polystyrene the balance-point temperature is about -21 ^{o}C and it needs no supplemental (back-up) heating system, but losses appear just for ambient temperatures over this very low one
- the 34 kW heat pump is better used in the case of a similar building but only 10 cm of polystyrene insulated: the balance-point temperature became -18 ^{o}C and losses due to the heat pump cycling are a little bit smaller as in the previous case.
- even smaller are the cycling losses for the building with no insulation: the balance-point temperature is increasing to -9 ^{o}C.

In conclusion, by insulating a building envelope the corresponding balance-point temperature will diminish, and so the supplemental heating required. A reduced heat pump capacity can be selected by improving the insulation level of the building envelope. This results in a smaller capital costs and in smaller energy consumption during the system operation, but a supplemental source for heating for temperature under the balance point is necessary. First insulate than choose the heat pump capacity.

What is the optimal heat pump capacity? As can be seen from Figure 2 the smaller the capacity of the heat pump the smaller the losses (shaded surfaces over the balance point). But in the same time the required supplemental heating is increased when smaller capacity heat pumps are selected.

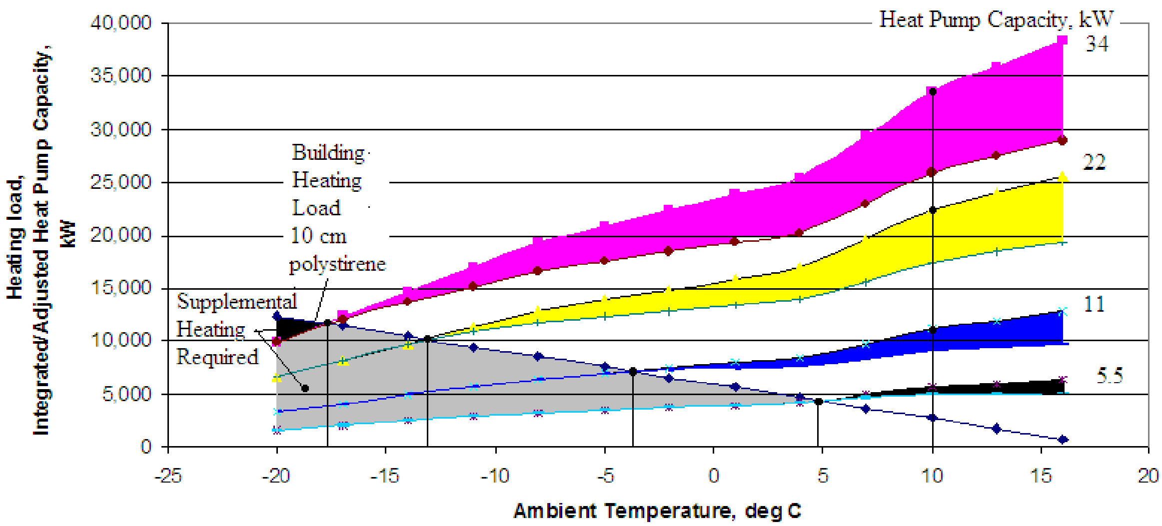

Fig. 2 The influence of the heat pump capacity on the energy losses and on the supplemental heating required

All the above mentioned losses have as a result a decreasing of the coefficient of performance (COP) calculated on an annual basis. The COP of the heat pump HP plus the auxiliary boiler consumption AUX (used to cover the building loads under the balance point temperatures) is decreasing compared with the COP of the heat pump as equipment. When considering the losses specific for the cycling operation together with the supplemental heating required for a given building, the optimal HP capacity is 22 kW for a building not insulated, but only 11 kW if a 10 cm-polystyrene insulation was performed, and 5.5 kW for a 20 cm-insulation, as shown in Figure 3.

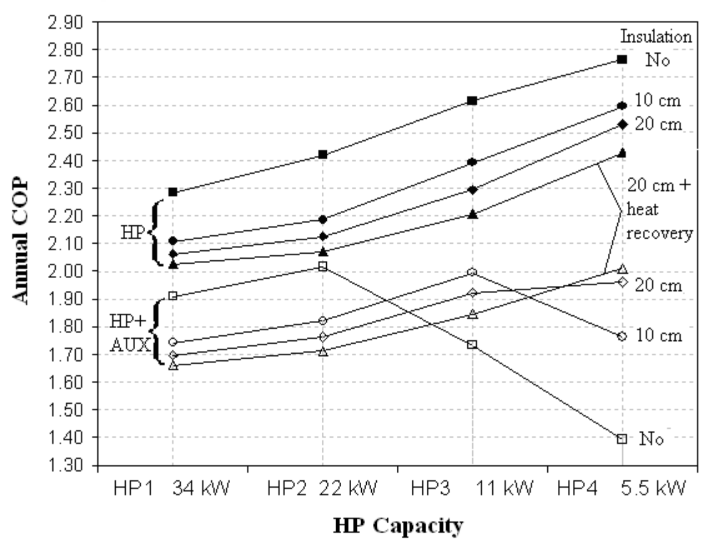

Fig. 3 The maximum COP is specific for a given building and for a heat pump capacity

The coefficient of performance COP can be evaluated considering the operation of the circulating pump too. The electricity used for the operation of the circulating pump, acting the water through the hydronic circuit of the building, added to the other consumptions of the system will diminish the COP describing the whole system, and the system COP is lower than the heat pump COP.The flow rate through the building loop will affect the temperature of the water leaving the building loop LWT, and a correlation with COP can be established [3], as can be seen from Figure 4. The heat pump COP is considerably higher than the system COP especially for low values of leaving water temperatures.

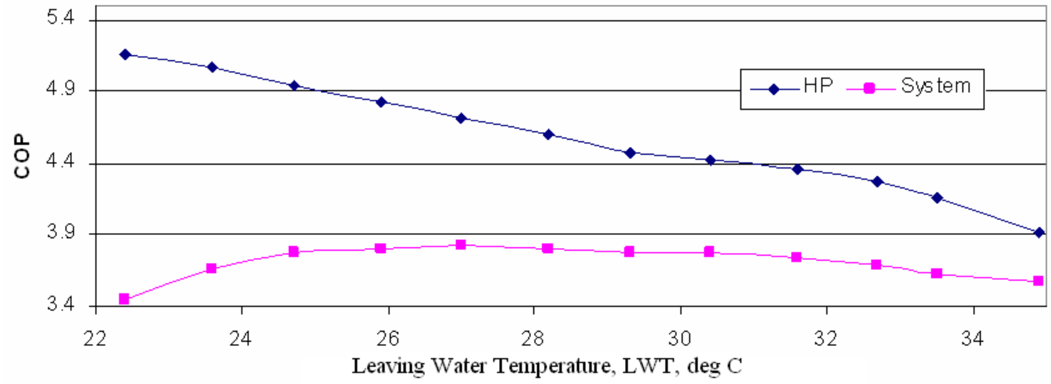

Fig. 4 Heat pump (HP) and system COP correlation
with the building loop return temperature LWT

The annual COP reaches its maximum and for all the analyzed cases is approx. 2. This way, the optimum capacity for the heat pump in a given situation can be selected.

Besides, the HP COP do not show a peak value in the usual temperature range, but the system COP has a peak value for a specific temperature of the water leaving the building loop LWT (the cooling mode is analyzed). For an optimal operation of the system i.e. a higher value of its COP it is useful to keep the temperature of the water leaving the building loop LWT in a specific range. An excessive cycling of the circulating pump will be avoided by this. The thermal capacity of the system depending on the water volume existing in the building loop circuit will affect this temperature range too, and Figure 5 shows the recommended temperatures to be set, for the cooling mode of the heat pump system, in case of a thermal capacity of 8.6 l/kW. A similar analysis should be done for the heating mode of the HP system.

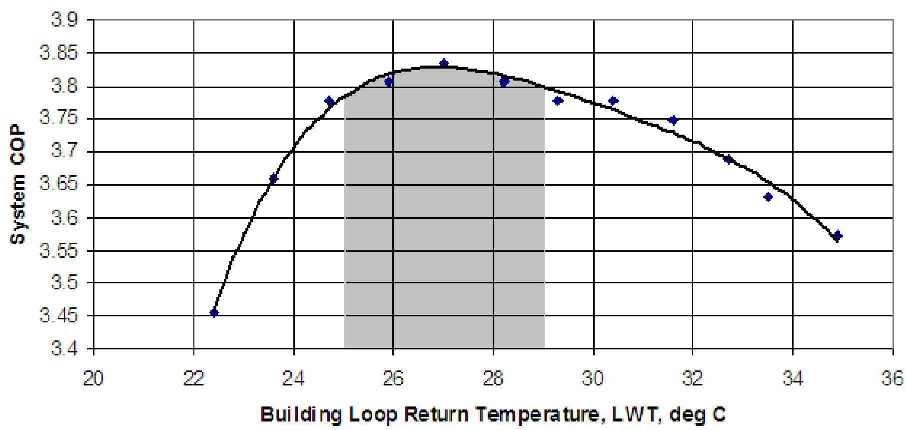

Fig. 5 Peak system COP and start/stop temperatures from the building loop control the excessive well pump cycling

The flow in the building loop is usually 0.045 to 0.054 l/(s.kW), and the building loop pumping power is assumed to be 17 W per kW of installed cooling capacity.

2.2 Heat Pump - Thermal Source Correlation

From the building loop performance perspective higher water flows in the primary loop are always preferable but large values of the flow in this water loop may entail high values of pumping energy. In fact, a significant amount of energy is spent with the fluid circulated between the thermal source and the heat pump. For the case of water-water heat pumps, even if the pump power in the primary circuit is less than 5 % of the heat pump capacity the annual pumping energy may represent a significant portion of the total energy consumption of a heat pump system, i.e. 15 to 48% (in some cases even more than 100%). Many systems have been designed with specific water flows of the primary circuit in the range 0.036 to 0.054 l/(s.kW) but typical values are 0.018 to 0.031 l/(s.kW). Adding the circulating pump energy consumption with the building loop component consumption a BHPTS system COP results different from heat pump performance. As shown in Figure 6 higher flow rates increase system COP. But at some point, additional increase in primary circuit water flow results in a greater increase in circulating pump energy consumption that the resulting decreases in heat pump consumption.

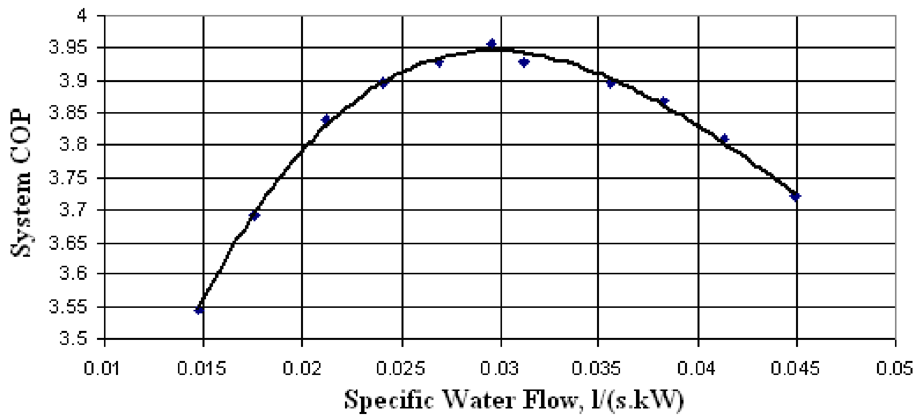

Fig. 6 The system COP correlation with the specific water flow in the primary circuit

The sizing of the system including thermal source, pump, heat exchanger, and piping will be based on the larger of these optimum flows. The operation of the system at the lower flow is possible by means of a variable speed or by cycling avoiding in this way the constant flow. Using a variable frequency drive (VFD) will bring benefits for the cost of energy. Supplementary cost and efficiency of the VFD together with the decreasing efficiency of the electric motor at part-load operation have to be taken into consideration.

It is considered that a higher temperature of the thermal source has an essential contribution to the system COP and as a result to the heat delivered by the heat pump. In fact, the thermal source temperature has a lower influence on the resulted energy delivered by the heat pump, compared with the increment of the temperature, the so called temperature lift, as shown in Figure 7.

It is rather the temperature lift that has a major influence on an efficient operation of the system. For the space heating purposes lower temperatures are required (less than 40 ^{o}C) but for domestic hot water DHW, and especially to avoid the danger of legionellosis temperatures of 55 ^{o}C and even higher than 60 ^{o}C are necessary. This final temperature is responsible for higher thermal source temperatures to avoid an exaggerated temperature lift generating a lower COP and an inefficient operation of the system.

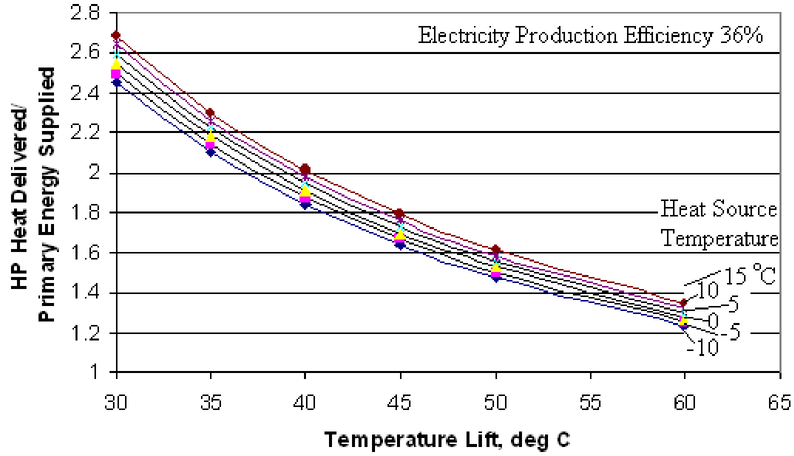

Fig. 7 The energy delivered by the heat pump rated to the primary energy supplied as a function of the temperature lift and having as a parameter the temperature of the thermal source

3. THE ELECTRICITY PRODUCTION EFFICIENCY AND THE HEAT PUMP PERFORMANCE

Usually fossil fuel converted into electricity is represented by an efficiency number of 0.3 to 0.4. Improvements of this figure results in higher HP COP [4]. Figure 8 shows the dramatic improvement in the thermal energy delivered by the heat pump when the electricity production efficiency is improved from a 0.3 to the 0.5 value and this is more evident for a lower temperature lift. Higher efficiency in electricity production allows the use of a lower temperature heat source.

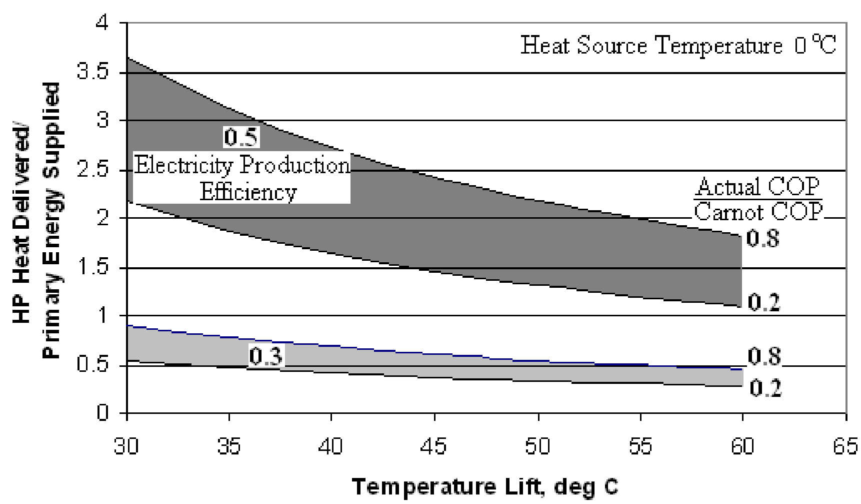

Fig. 8 The influence of the temperature lift and of the electricity production efficiency on the thermal energy delivered by the heat pump

The performance of the heat pump evaluated by means of the actual COP rated to the Carnot COP is very important too: improvements of about 40% can be obtained when this ratio is changed from 0.2 to 0.8 especially in case of higher efficiency of electricity production. Using one unit of primary energy to produce electricity used for the operation of a heat pump the result can vary significantly, i.e. from 0.5 to 3.5 units of thermal energy delivered by this equipment as shown in Figure 9. Improvements for the equipment performance (actual COP/Carnot COP from 0.2 to 0.8), and for the electricity production efficiency (from 0.3 to 0.5) was supposed for a temperature lift of 40 ^{o}C. In such a situation the temperature of the heat source affects very little the thermal energy delivered by the heat pump.

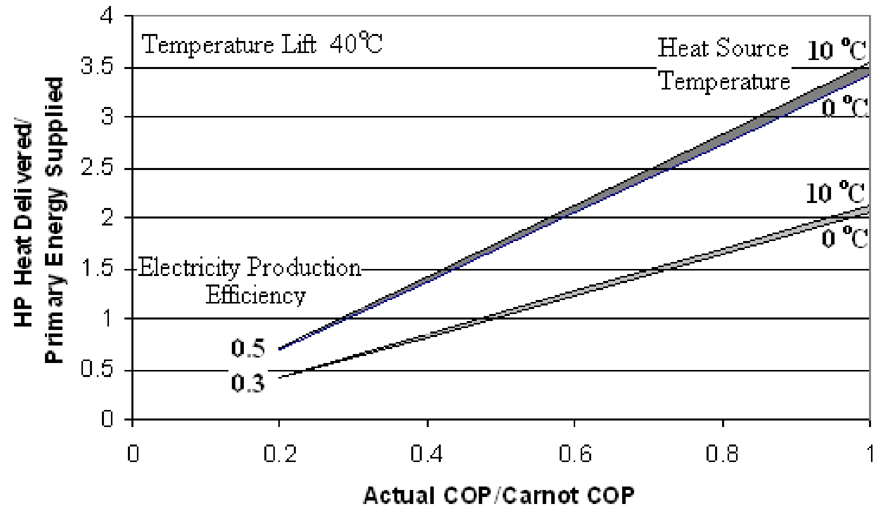

Fig. 9 The heat delivered by the heat pump as a function of its performance and of the electricity production efficiency for two temperatures of the heat source

4. CONCLUSIONS

Heat pumps are considered as a very efficient equipment for air conditioning. However, expenses associated with the excavation or drilling of the ground, and those resulted during the operation do not recommend them as an immediate and attractive alternative. Even if norhern countries and regions with poor energy resources developed this technology since the seventies and continues to promote it a large spreading is still not predictible. Issues for some of the problems related to heat pumps have been found from the practice but these must be disscussed alltogheter as for a system.

Prior to a fizibility study the building must be one with a reduced heating/cooling load. The required capacity of a heat pump strongly depends on the level of insulation of the building. A reduced capacity for the heat pump results in a lower first cost and in a diminished operation cost. A proper sizing of the heat pump, fitted with the building load, will lead to smaller losses associated with the cycling operation. The cost of the supplementary heating, based on the auxiliary source during the operation under the balance temperature point, must be small enough to keep the efficiency of the whole system. The electricity consumed to drive the circulating pumps must be kept too in a reasonable range from an economic efficiency point of vue.

The energy savings in a building with floor heating can range from 20-40% over traditional forced air systems, but the flow rates both in the heat source, heat exchanger and in the building loop one have to be correlated with operation regime. Variable frequency devices VFD became actual as their cost is a small part of the whole system price. The temperature lift is essential for the system COP and it determines the heat source temperature for a required temperature of the water, DHW or hydronic heating.

Improving the technical performance of heat pumps as equipment, i.e. a COP closer to the ideal Carnot COP, will improve too the efficiency of this technology.

The exaggerated cycling operation must be avoided by an appropriate sizing and by the setpoint setting.

In conclusion, the development of heat pump systems depends on a series of factors not only the equipment in it self.

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