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THE SCOP OF AN AIR SOURCE HEAT PUMP: COMPARISON BETWEEN ON-OFF AND INVERTER HEAT PUMP

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Abstract

The paper investigates the seasonal performance of electric air-to-water heat pump comparing an on-off heat pump with an inverter-driven variable speed compressor. Reference is made to a heat pump for domestic space heating installed in Bologna, and the bin-method proposed by UNI/TS 11300-4 is employed in order to investigate the effect of external temperature. The analysis shows that the inverter heat pump performs better than the on-off one, displaying higher values of SCOP about at least 10%.

1. Introduction

Nowadays, air source heat pumps (ASHP) are expected to increase their role in space heating because of different and concurrent reasons [1]. First, there is a need to increase the reduction of greenhouse gas emissions from space heating in order to meet decarbonization. In fact, in Europe, the European system for emission allowances introduced in 2005 is promoting

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the use of greener technologies. Secondly, the coefficient of performance (COP) of ASHP system is improving and electricity driven heat pumps are becoming thermo-dynamically attractive heating systems. A third push is given by public policies and incentives. In [2], a general analysis of the Italian energy system in performed, focusing on the possible energy, environmental, and economic effects that the utilization of individual heat pumps for winter heating can produce.

In the recent literature, some papers investigate the role of an inverter in order to increase the behavior of heat pumps, with reference to the whole heat pump system or to the single heat pump unit [3-8]. In some papers, attention is paid to ground source heat pumps, not considering the possible onset of convection in the soil [9, 10]. Some papers treat experimental validation of heat pumps [11].

In the present paper, we investigate electric air-to-water heat pump performance specifically related to climatic conditions of the place where the heat pump is installed, i.e. the municipality of Bologna, Italy. The analysis is carried out using easily available weather data and using the bin-method proposed by UNI/TS 11300-4 [12]. Two different types of heat pumps (on-off and inverter-driven variable speed compressor) are compared. The main aim is the evaluation of seasonal performance of the heat pumps electric air to water and to establish comparison between different types of heat pumps.

2. Setting of the Model

We employ the bin-method proposed by UNI/TS 11300-4 [12], assuming the weather data available for the town of Bologna, Italy, in order to compare the behavior of two different heat pumps. Attention is paid to two electric air-to-water heat pumps, one on-off HP and the other one an inverter-driven variable speed compressor HP, combined with auxiliary electric resistances (mono-energetic bivalent operating mode heating system). The auxiliary heat source is an electric resistance, switched on only while satisfying high thermal demand, i.e., when the outdoor air temperature is low, close to the design temperature T_d. For Bologna, $T_d = -5^\circ$C.

Seasonal performance indices analyzed are $\mathrm{SCOP_{on}}$ and $\mathrm{SCOP_{net}}$. As is well known, $\mathrm{SCOP_{net}}$ is defined as the ratio between the thermal energy supplied by the heat pump $E_{T,\,\mathrm{HP}}$ and the electric energy input to the heat pump $E_{E,\,\mathrm{HP}}$:

$$\mathrm{SCOP_{net}} = E_{T,\,\mathrm{HP}} / E_{E,\,\mathrm{HP}}. \tag{1}$$

In $\mathrm{SCOP_{on}}$ performance index, also the auxiliary energy related to the electric resistances for heating is considered, i.e.,

$$\mathrm{SCOP_{on}} = (E_{T,\,\mathrm{HP}} + E_{T,\,R}) / (E_{E,\,\mathrm{HP}} + E_{E,\,R}), \tag{2}$$

where $E_{T,\,R}$ is the thermal energy supplied by the resistances and $E_{E,\,R}$ is the electric energy input to the auxiliary resistances.

Technical data related to the heat pumps under investigation, such as the maximum output thermal power and COP are obtained from product datasheet for different outdoor air temperatures and for different water delivery temperatures. In detail, models Aermec ANK and Aermec ANLI [13] are compared.

We assume that the thermal power requested by the building to the heating system linearly decreases for increasing values of the outdoor air temperature T_e and also assume that no power is requested for $T_e \geq 16^\circ$C, and that hot water delivery temperature is set constant equal to 35°C. Under this hypotheses, the COP varies only on T_e and CR, where the capacity ratio CR is defined as the ratio between the thermal power supplied by the HP at a specific T_e and the maximum thermal power that the HP can supply at the same T_e. The HP values of the COP_D values $(\text{at CR} = 1)$ as well as the thermal power supplied for different values of T_e, are given in Table 1, both for the on-off and inverter heat pump.

Table 1. Data from the HP producer datasheet

On-off HP			Inverter HP	
T_e (°C)	Maximum power (kW)	COP_D	Maximum power (kW)	COP_D
–7	5.09	2.51	5.43	2.86
2	6.15	3.25	5.67	2.96
7	8.67	4.09	8.06	3.92
12	10.24	4.26	9.23	4.37
15	10.83	4.31	9.74	4.56

The heat pump will operate at part load, i.e., below its maximum rated capacity, for long period during the heating season. In order to encounter this aspect, according to the UNI/TS 11300-4 [12], we introduce the fCOP coefficient, namely,

$$\mathrm{f} = \mathrm{CR}/(1 - \mathrm{Cc} + \mathrm{CR\,Cc}), \tag{3}$$

where Cc is a degradation coefficient. The value of fCOP provided directly by the manufacturer and COP at part load (COP_{PL}) is given by

$$\mathrm{COP}_{PL} = \mathrm{f}\ \mathrm{COP}_D. \tag{4}$$

Since the COP variations strongly affect the seasonal performance, a monthly or even daily analysis will be inaccurate: a great variation of T_e may occur during the day as well. Indeed, according to UNI/TS 11300-4, the “bin method” will be employed, i.e., measured hourly mean outdoor air temperature values replace the normal distribution of the out-door air temperature proposed by the same norm. The bin hours, in fact, are defined as the number of hours of the heating season when T_e is included in a defined temperature range called *bin*, i.e., a temperature interval of $1^\circ\mathrm{C}$ centered on an integer value.

For the considered municipality, heating period is 15 October-15 April. The hourly mean air temperature T_e is given by ARPAE, the Regional Environmental Protection Agency for Regione Emilia Romagna [14]. In detail, the data downloaded from the website are then processed in relation to the heating period to obtain bin hours. In Figure 1, bin hours obtained for Bologna, years 2017, 2018 and 2019, are reported. For example, Figure 1 shows that for Bologna 300 bin hours at $9^{\circ}\mathrm{C}$ occurred during 2019: it means that during the mentioned heating season, the hourly mean outdoor air temperature was in the range $8.5\text{-}9.5^{\circ}\mathrm{C}$ for 300 hours.

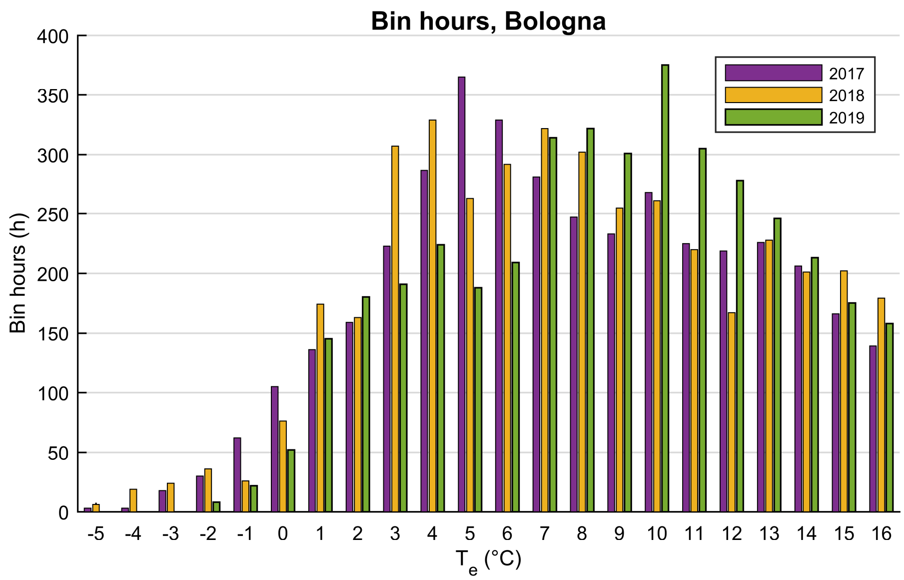

Figure 1. Bin hours for Bologna, years 2017, 2018 and 2019.

The behavior of the heat pumps is analyzed by employing spreadsheets, in which main items were:

The mean hourly outdoor air temperature $T_e({}^{\circ}\mathrm{C})$, bin hours, thermal power P_T (kW) and thermal energy E_T (kWh) requested by the building to the heating system, electric power $P_{,\mathrm{HP}}$ (kW), and electric energy $E_{E,\mathrm{HP}}$ (kWh) to the heat pump, electric energy $E_{E,R}$ (kWh) to the auxiliary electrical resistances.

The spreadsheet allowed us to obtain the COP, evaluated by equation (4), as well as seasonal indices, calculated by employing equations (1) and (2).

3. Results

Let us now discuss the result of the presented analysis. In Figures 2 and 3, the $\mathrm{SCOP_{on}}$ is reported, both for the on-off and for the inverter HP. Figure 2 refers to year 2017, while Figure 3 refers to 2018. The figures show that there is a value of the power requested by the building to the heating system that maximizes seasonal index $\mathrm{SCOP_{on}}$: for example, for and on-off HP (year 2017), the maximum value of $\mathrm{SCOP_{on}}$ is 3.44 for a heating system (heat pump and auxiliary electric resistances) sized to supply a thermal power requested by the building of 7kW.

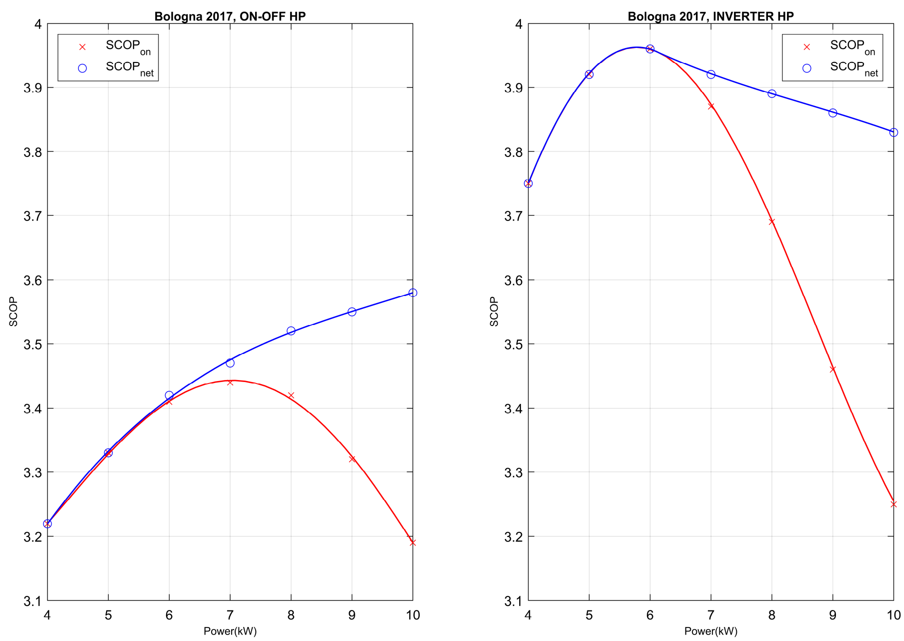

Figure 2. $\mathrm{SCOP_{on}}$ for on-off HP and for inverter HP, year 2017.

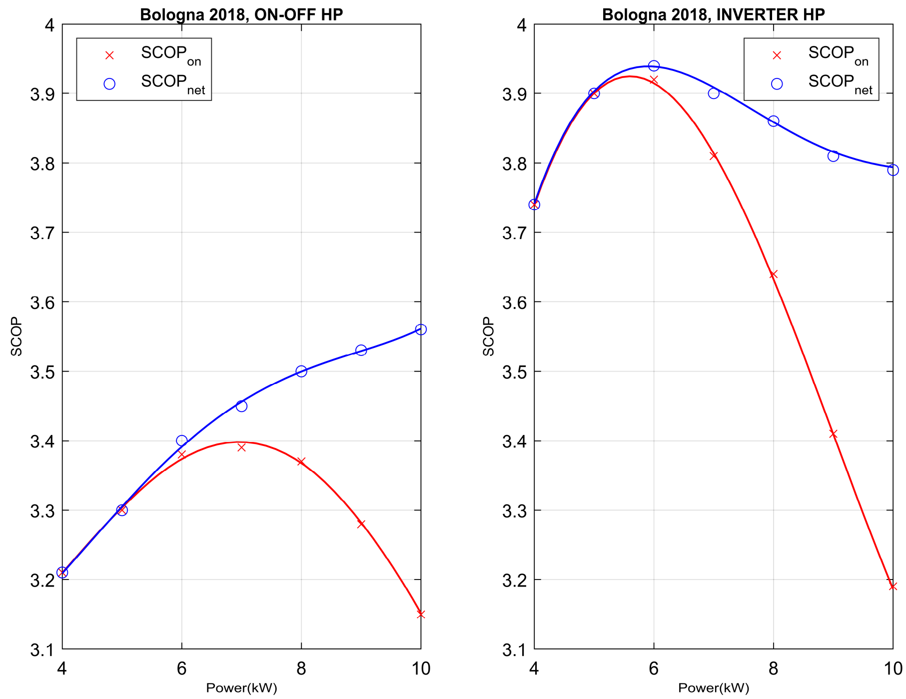

Figure 3. SCOP$_{on}$ for on-off HP and for inverter HP, year 2018.

A comparison between Figures 2 and 3 shows that the climate conditions affect the SCOP. Moreover, both figures underline the influence of heat pump typology on SCOP: inverter heat pump better behaves in all the considered scenarios and SCOP variations are at least approximatively 10%.

4. Conclusions

In the present paper, a comparison between air source heat pumps is presented. An on-off HP and an inverter-driven variable speed compressor HP is done, by employing climate open data available for the municipality of Bologna (Italy). The bin hour method is used, according to UNI/TS 11300-4. The data of the heat pumps are directly available from the producer website.

The analysis show that climate conditions affect the seasonal coefficient of performance of the heat pumps, and especially that an inverter driven heat pump always behaves better than the on-off one.

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