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EFFECT OF REAL TEMPERATURE DATA ON THE SEASONAL COEFFICIENT OF PERFORMANCE OF AIR SOURCE HEAT PUMPS

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Abstract. In this paper, a transient analysis is performed in order to evaluate how effective climate data affect the determination of the seasonal coefficient of performance of ASHPs. Three Italian cities, characterized by different climates, are considered as reference case studies and the influence of real meteorological data, collected from different years, on the heat pump SCOP is performed. The analysis is carried out by employing the dynamic software TRNSYS. Numerical results show small variations in SCOP, while a significant influence on annual thermal energy demand can be observed. The analysis also underlines the absence of a general correlation between annual thermal energy supplied by the heat pump and SCOP and between HDD and SCOP.

1. Introduction

Currently, the energy demand for heating buildings in the European Union (EU) overlies an important part of the overall energy demand. The important share of energy requested for space heating and air conditioning has direct consequences on greenhouse gas emissions, thus displaying a clear environmental impact. To achieve the goal of reducing CO_2 emissions, a possible solution is the use of heating systems powered by electricity (as heat pumps), combined with a decarbonization of the power grid, using renewable energy sources [1]. The installation of heating systems based on heat pumps is a growing market in the EU, with some differences between countries especially related to the heat pump type [2]. Currently, the majority of installed units are air-source heat pumps (ASHPs) because these systems have a lower installation costs compared with other typologies, such as ground-source heat pumps (GSHPs).

ASHPs are indeed especially effective for space heating in temperate and mild climates, and therefore could be particularly effective in Italy. In the literature, the Seasonal Coefficient of Performance (SCOP) of ASHPs is usually determined by using standard weather data of cities/regions taken from a Test Reference Year (TRY). Reference years can be constructed according to the procedure reported in the standard ISO 15927-4 [3], starting from hourly meteorological data taken from a long time series (10 years or more). Nonetheless, effective ambient temperature may significantly vary every year and, for this reason, the effective energy performance of ASHP systems might underperform (or outperform, of course) the calculated one. In the literature there are a lot of works about dynamic simulation concerning heat pump heating systems coupled to residential and non-residential buildings. Conversely, there are few papers discussing on the influence of real weather condition (i.e. outdoor air temperature, which can significantly vary from a year to another for the same place) on the ASHPs performances [4]-[7]. This kind of analysis could be relevant to prevent the underestimation or overestimation of benefits using a heat pump in terms of affordability and environmental impact of that technology.

In this paper, the results of dynamic simulations will be presented considering three different heat pump systems coupled with the same building, located in three different Italian cities: S. Benedetto del Tronto (Central Italy, 42°58’ North, 13° 53’ East), Milan (North of Italy, 45°28’ North, 9° 10’ East) and Livigno (North of Italy, 46°28’ North, 10° 8’ East). Dynamic simulations have been carried out considering real weather data (i.e. outdoor air temperature and solar radiation) referred to the three abovementioned cities for a period of 8 years (2013-2020). The influence of the weather compensation of supply water temperature set-point on the heat pump seasonal performance will be also analyzed.

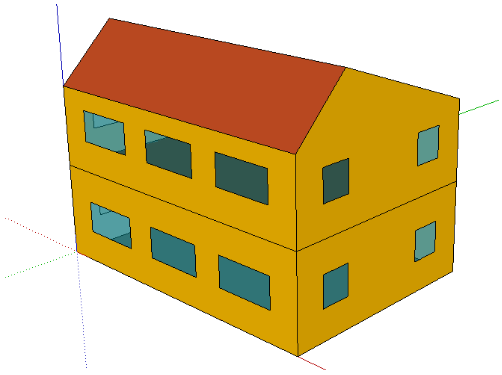

Figure 1. 3D model of the building.

2. Data and setting of the analysis

2.1. Building

The building used for simulations derives from IEA SHC Task 44 [8]. The building considered is SFH45, a single family-house building characterized by two floors with a total floor area of 360m^2 and by a thermal load of 45kWh/m^{2}y in the climate of Strasbourg. Some information about building envelope components is reported in Table 1 and a 3D representation of the building is showed in Figure 1.
The building was modeled through TRNSYS type 56, the multizone building type implemented in TRNSYS [9]-[10]. Analysis will focus only on the heating period since the largest share of buildings' energy demand is still related to space heating.

Table 1. Geometrical and thermo-physical data of the building envelope components. [11]

Assembly	Thickness (m)	U-Value (W/m^{2}K)
External wall	0.318	0.364
Ground floor	0.385	0.241
Floor	0.185	0.235
Roof	0.285	0.694
Internal wall	0.200	0.885

2.2. Heat pumps

Three inverter heat pumps are considered, as reported in Fig. 2: the first heat pump (Ariston Nimbus N50), namely Unit 1, was combined with the building located in S. Benedetto del Tronto, Unit 2 (Ariston Nimbus N70) with that located in Milan and Unit 3 (Galletti Hiwarm Compact 023) with the building located in Livigno. Figure 2 shows the thermal power supplied by the heat pumps, as well as the coefficient of performance (*COP*), as functions of the external air temperature, for different compressor frequency values. That Figure shows that Unit 1 and Unit 2 behave similarly referring both to the thermal power and the *COP*, while Unit 3 displays higher thermal power values. As in [12], the considered heat pumps are selected in order to totally satisfy the thermal energy demand of the building, i.e. to guarantee the set-point temperature for the indoor air of 20°C when the outdoor ambient temperature reaches the winter design temperature, reported in Table 2.

2.3. Heating system

Figure 3 shows the layout of the heating system, consisting of the heat pump, the terminal units, given by 2-pipe three-speeds fan-coils, a circulation pump and a storage of 0.2 m^3. Two heating zones are considered, corresponding to the two floors of the building, and each thermal zone presents a fan-coil.
Each emitter is characterized by an on-board controller, which selects the fan speed on the basis of indoor air temperature. The storage is the same for all considered scenarios, while fan-coils have been sized to satisfy the thermal power required by the single floor of each building. More in detail, for the building in Milan the two fan-coils have a nominal heating capacity of 10kW and 7kW, for the building in S. Benedetto each fan-coil has a nominal heating capacity of 5.5kW, while for Livigno the size of

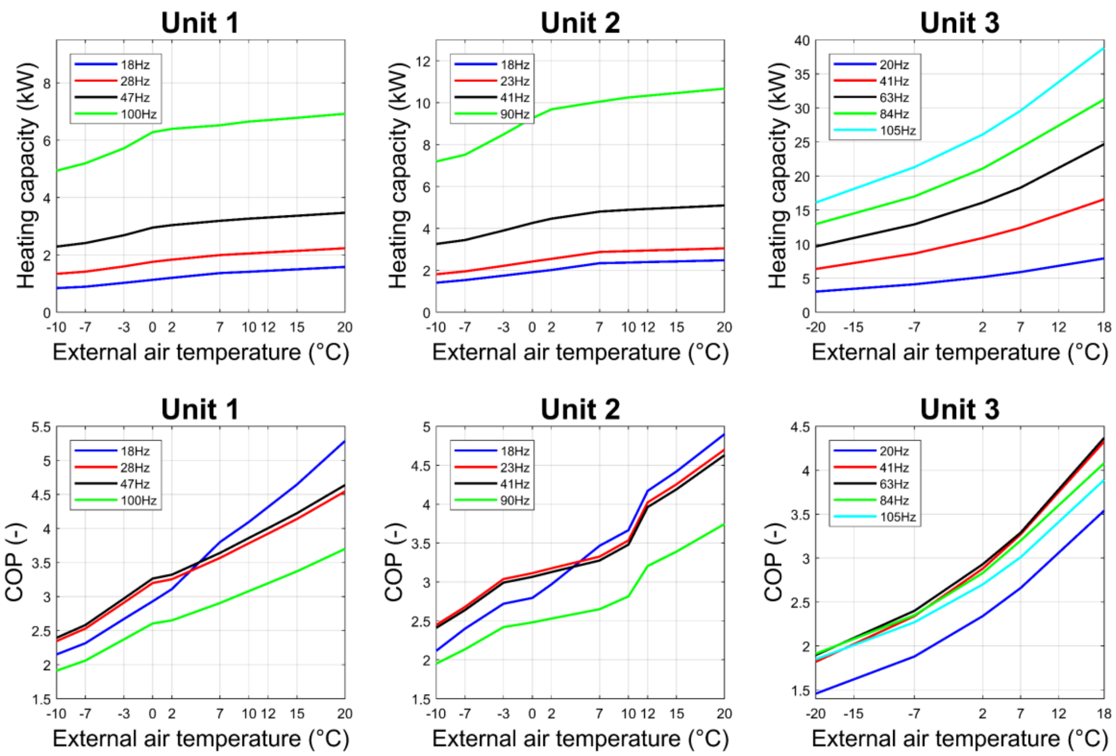

Figure 2. Heating capacity and *COP* of the three HPs used in simulations.

each unit increases due to the higher thermal load. In this location, the nominal thermal power of the fan-coils are equal to 12kW and 10kW, respectively.

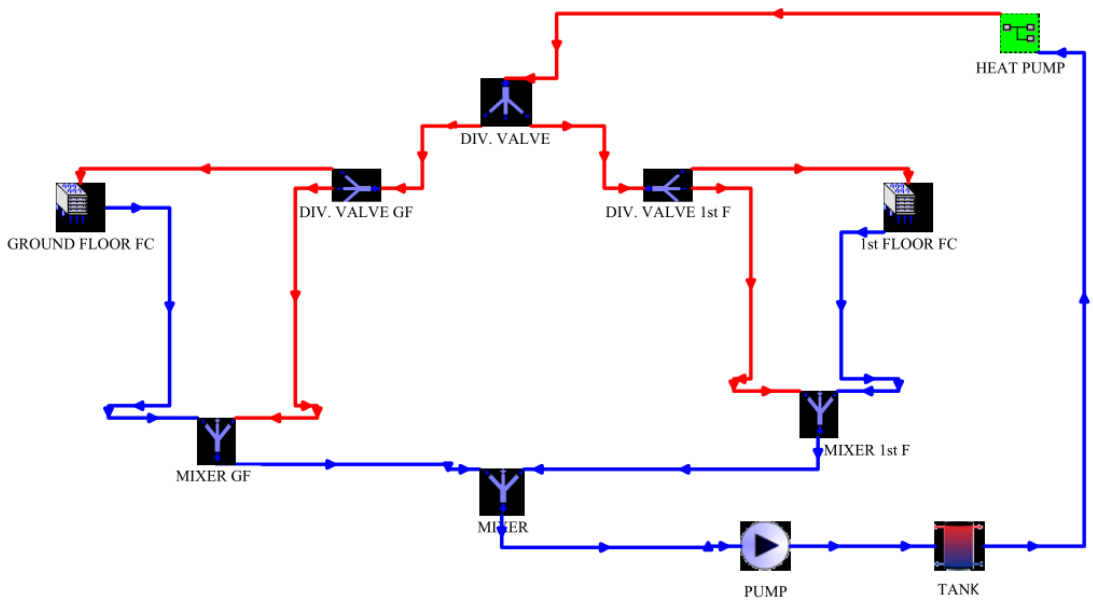

Figure 3. TRNSYS layout of the heating system.

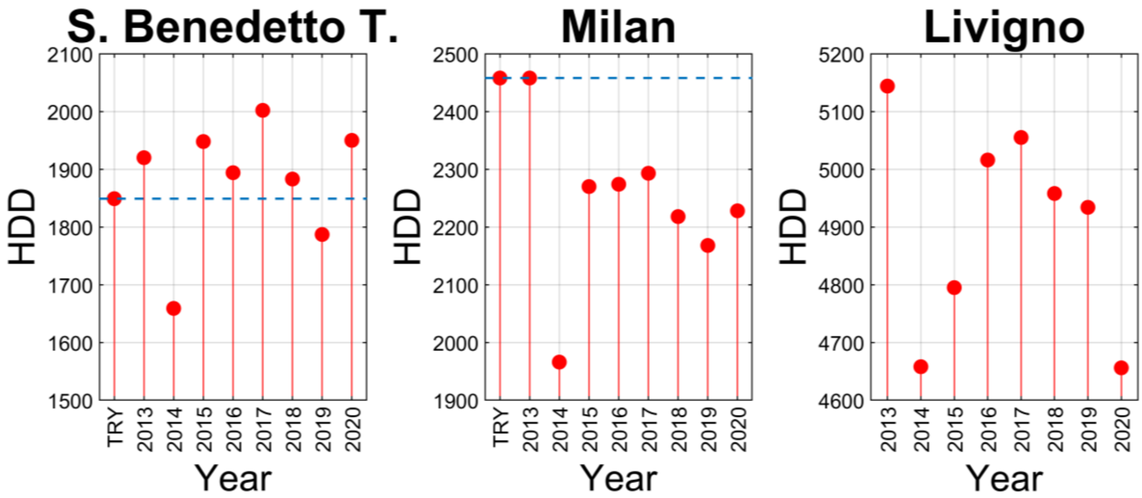

Figure 4. Heating Degree Days (HDD) of the three cities considered (period 10 October - 30 April), for years 2013-2020 and for TRY of S. Benedetto del Tronto and Milan.

2.4. Climatic data

The three locations considered in this work are classified, according to the current Italian law (i.e. DPR 412/1993), in three different climatic zones. Each zone is characterized by a different standard heating season. Table 2 shows the standard heating season, the external winter design temperature, the standard climatic zone and the degree days for the selected municipalities.

Table 2. Heating season, design temperature t_{des}, standard climatic zone and heating degree days (HDD) for the three considered municipalities.

Municipality	Heating season	t_{des} (°C)	Climatic zone	HDD
S. Benedetto del Tronto	1 November – 15 April	-1	D	1593
Milan	15 October – 15 April	-5	E	2404
Livigno	1 January – 31 December	-19	F	4648

The climate data for the three above mentioned municipalities are available in regional services websites: Arpa Lombardia[13] for Milan and Livigno and SIRMIP Marche [14] for San Benedetto del Tronto. In the present analysis, on account of the availability and quality of the data, attention is paid to

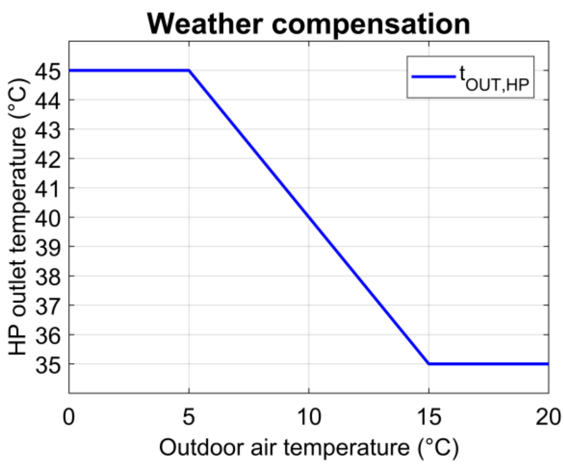

Figure 5. Weather compensation control used in simulations for HP outlet temperature.

8 years (2013-2020). For all locations, external temperature, global radiation on horizontal and relative humidity data are downloaded, as well as data on precipitation, wind direction and speed for Livigno and Milan. The quality of data is good, with less than 5% missing data for most years. The exception is the year 2018 for San Benedetto del Tronto, for which several values of radiation and relative humidity were not present. For this reason, this year was not considered due to a large lack of data.
The open data were used, through Meteonorm software [15], in order to develop the climate files to be used as input for TRNSYS. These climate files display real data, eventually integrated, in case of lack of data, with historical series related to the considered location.
From the open (and reworked) data, the value of the real heating degree days (HDDs) for each location and each year was obtained, considering a base temperature of 20°C, as is shown in Figure 4.

2.5. Setting of the analysis

Annual simulations are carried out, taking into account the same building and the different heat pumps presented in previous sections. The operating period of the heating system is assumed as explained in Table 2. The standard period corresponding to the climatic zone of each municipality is considered for simulations.
First, a simulation is carried out for each year of the considered period and for each location, considering a water supply temperature from the heat pump fixed at 45°C and a temperature difference with respect to the return of 5°C. Then, further simulations are also carried out, with reference to the same years, but assuming a climatic compensation, i.e. considering a decreasing water supply temperature from 45°C for an external temperature below 5°C up to 35°C for an external temperature above 15°C. The compensation curve is shown in Figure 5. The simulations were carried out considering a time step of 30 s.
Attention is focused on the thermal energy supplied by the heat pump and its electric energy use, both evaluated on a seasonal basis, and the seasonal performance factor of the heat pump (*SCOP*), defined as

$$SCOP = \frac{ET}{EE}$$

where *EE* (kWh) is the total annual electric energy supplied to the heat pump and *ET* (kWh) is the total annual thermal energy provided by the heat pump to the plant.
The influence of the heat pump defrost cycles on the seasonal energy performance of the unit has been neglected. The climatic data are, as already discussed, mostly complete and the integration with experimental radiation data, in addition to the ambient air temperature, helps to obtain a more accurate simulation of the behavior of the building.

3. Results and discussion

In Figure 6, the main results of the present analysis are shown for the fixed HP water outlet temperature; for Milano and San Benedetto del Tronto simulations considering the test reference year (TRY) are reported as well.
The figure shows an important variation along the years in SCOP and thermal energy supplied by the heat pump to the building, especially with reference to San Benedetto del Tronto and Milano.
In detail, let us discuss the case of S. Benedetto del Tronto. The simulations indicate an important variation in terms of thermal energy supplied from the heat pump to the heating system, with a value referred to TRY of 4800 kWh/year and a maximum value for the year 2013 (5674 kWh/year, increased by 18% referring to TRY) and a minimum value for year 2020 (3009 kWh/year decreased by 37% referring to TRY). Analysis also shows variations in obtained SCOP, with a value of 3.30 for simulation using the test reference year, a maximum value of 3.52 for year 2014 (+6.7% referring to TRY simulation) and a minimum value of 3.30 for year 2017 (equal to TRY simulation). Moreover, comparing SCOP values and thermal energy demand for San Benedetto del Tronto, Fig. 6 shows that a strict correlation between those two quantities cannot be established; in fact, for example, referring to years 2018 and 2019 SCOP values are similar but thermal energy supplied are very different.

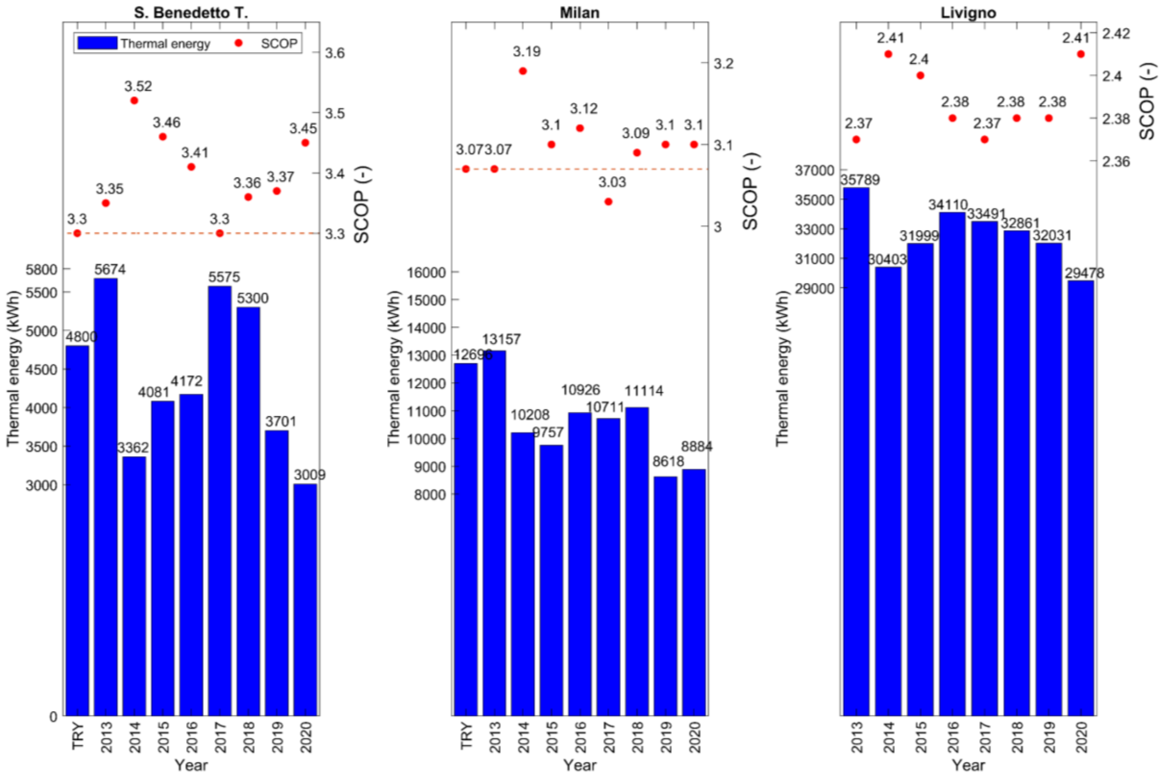

Figure 6. Results of simulations for selected municipalities (annual thermal energy and SCOP), considering an outlet temperature from the HP fixed at 45°C.

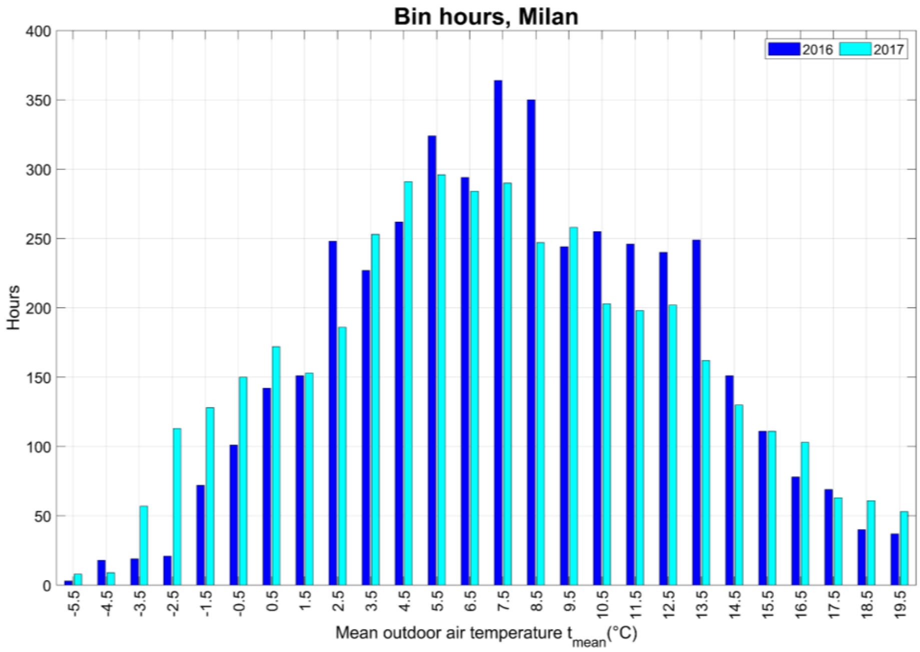

Figure 7. Bin hours for Milan, year 2016 and 2017.

Additionally, there is no correlation neither between HDD and SCOP, nor between HDD and thermal energy supplied.
Similar conclusions may be drawn with reference to Milan and for Livigno, but Livigno has the peculiarity that SCOP value show very little differences (range for Livigno 2.37-2.41, Milan 3.03-3.19,

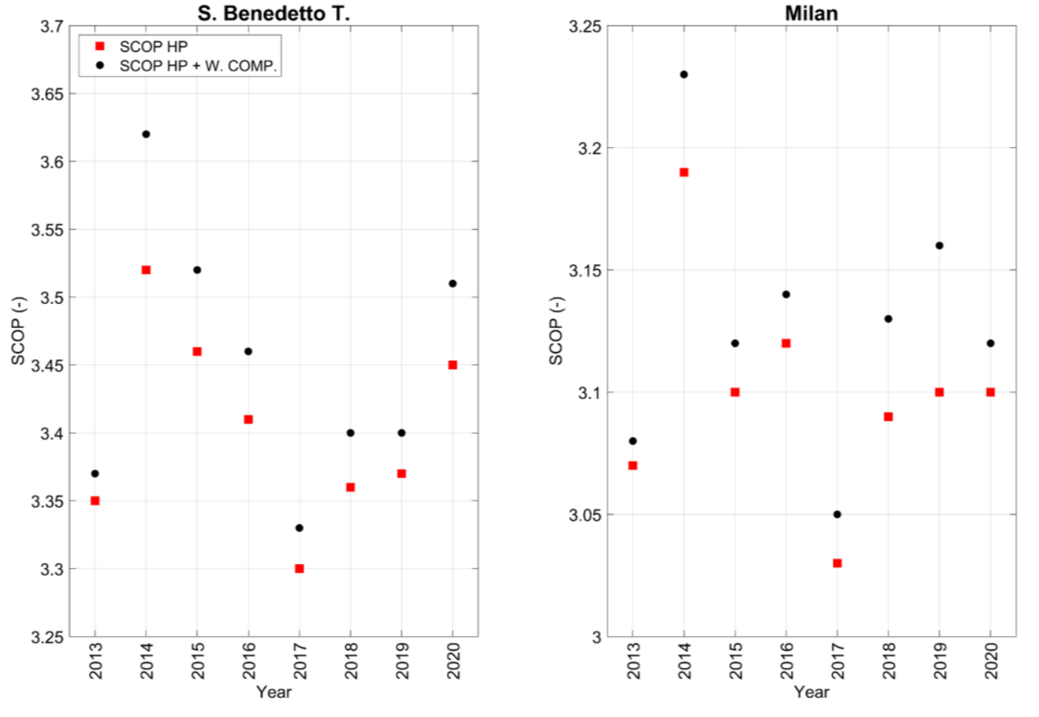

Figure 8. Comparison between HP with fixed outlet water temperature and weather compensation.

S. Benedetto del Tronto 3.30-3.52). In addition, results of simulation for Milan using the Test Reference Year show an annual thermal energy request of 12695kWh comparable to the thermal request of year 2013 (13157kWh).

An explanation of the absence of correlation between HDD and SCOP/thermal energy and between thermal energy/SCOP could be related to the number of hours in correspondence of which the heat pump is active at a given outdoor air temperature. In Figure 7, the number of hours in correspondence of which the outdoor air temperature is in a range of $(t_{mean} \pm 0.5)°C$ is reported, for year 2016 and 2017 and referring to Milano. It can be noticed that for several hours during 2017 the outdoor air temperature is lower than 1°C. For these values of outdoor air temperature, HP's *COP* are smaller than for higher outdoor air temperatures and this may display a relevant impact on SCOP.

Finally, simulations considering the weather compensation for S. Benedetto del T. and Milan are performed. The obtained results are shown in Figure 8. In the comparison with the case avoiding weather compensation, no substantial differences are noticed in terms of thermal energy supplied by the HP for heating; on the contrary, some little benefits may be noticed in terms of SCOP, both for Milan and S. Benedetto del Tronto, especially for years characterized by higher outdoor air temperature during heating season.

4. Conclusions

In the present paper, the effect of real weather data on the seasonal performance of HPs has been investigated. Simulations were done with TRNSYS and show little differences between different years, showing small variations in SCOP (less than 7%) but significant variations on annual thermal energy demand (up to 37%). The analysis also underlines the absence of a general correlation between annual thermal energy supplied by the heat pump and SCOP and between HDDs and SCOP.

Moreover, the use of weather compensation for the considered building does not offer significant benefits for the reduction of energy consumption, while is linked to only a slight increase of SCOP.

Further research might investigate the importance of real temperature data on the heat pump seasonal performance including the effect of defrost cycles. In fact, energy losses linked to defrost cycles could significantly affect the heat pump seasonal performance [16]. In future investigations we wish to double check how defrost energy losses are usually less relevant on seasonal energy performance for HPs installed in places characterized by cold and dry winters like Livigno and more relevant for HPs installed in places characterized by a humid climate.

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