Hourly Dynamic Calculation of the Primary Energy With Heat Pump Generation System (EN 15316-4-2): A Case Study in Italy

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Abstract

With the aim of reducing greenhouse gas emissions, more and more heat pump generators are being used in the residential space heating sector to replace traditional condensing gas boilers. This paper discusses the application to an Italian case study of the new draft of EN 15316-4-2, which provides a methodology for the calculation of the energy performance of heat pump systems used for domestic hot water preparation or space heating purpose. The case study involves a two-storey residential building equipped with several modulating air-to-water heat pumps.

Two different daily profiles for heating were considered: continuous heating mode (heating system on 24 hours a day) and intermittent heating mode. Hourly building energy need for heating, calculated according to EN ISO 52016-1:2017, were used as input.

The seasonal coefficient of performance (SCOP) of heat pumps analysed with an intermittent profile are 45.77 % higher on average than those in continuous heating mode, even if, in the intermittent system configuration, there is always an amount of missing energy.

Finally, the results show that oversizing the heat pump leads to low SCOP and high non-renewable primary energy; while undersizing the heat pump leads to high SCOP but non-negligible missing energy values.

1. Introduction

The need to reduce greenhouse gas (GHG) emissions related to building energy production has led Europe to implement policies to reduce energy demand while promoting the use of renewable energy sources to replace fossil fuels.

Residential space heating is one of the sectors most responsible for producing greenhouse gas; one of the most feasible solutions to decarbonise this sector is to electrify consumption by using heat pumps to replace gas boilers. (Famiglietti et al., 2021; Lin et al., 2021).

In the regulatory field, the European Committee for Standardisation (CEN) has approved a set of standards for the implementation of the EPBD (Energy Performance Building Directive) (European Parliament, 2018). These interconnected standards define calculation methodologies for the energy consumption and performance of buildings.

In this package of standards are EN ISO 52016-1:2017 (European Committee for Standardization, 2017) and the new draft of EN 15316-4-2 (European Committee for Standardization, 2018).

Specifically, EN ISO 52016-1 (European Committee for Standardization, 2017) introduces an hourly methodology for calculating the energy need for heating and cooling, while EN 15316-4 deals with the calculation of system energy requirements and system efficiencies according to the different types of generation system.

In the literature, different studies show how the use of the dynamic hourly method defined in UNI EN ISO 52016-1 (European Committee for Standardization, 2017) allows a more accurate assessment of energy needs than a semi-stationary model (Di Giuseppe et al., 2019; van Dijk, 2018) and how the hourly energy needs for heating calculated with the aforementioned standard is comparable with that obtained with TRNSYS (Summa et al., 2022; Zakula et al., 2021).

Regarding the application of the new draft of EN 15316-4-2, there are some studies concerning boilers (Mattarelli & Piva, 2014) and solar thermal

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panels (Teodorescu & Vartires, 2016), but not heat pump systems.

To this purpose, this works aims to apply the calculation algorithm provided by the new draft of EN 15316-4-2 (European Committee for Standardization, 2018), concerning heat pump generation systems, on an Italian case study, using as input the hourly energy need for heating, calculated according to EN ISO 52016-1 (European Committee for Standardization, 2017).

2. Methods

2.1 EN ISO 52016-1:2017

The calculation algorithm of EN ISO 52016-1:2017 (European Committee for Standardization, 2017) provides the values of the following hourly parameters: indoor air temperature, mean radiant temperature, operative temperature, surface temperature of building elements and the energy needs for heating and cooling.

These parameters are determined for each thermal zone by providing input of climatic data defined on an hourly basis.

To determine the surface temperatures of the building elements and, consequently, all other parameters, the calculation algorithm provides the procedure for spatial discretization of the capacitive nodes and resistive layers of the opaque and transparent elements based on the thermoelectric analogy.

Transparent elements are discretized by two capacitive nodes and one resistive layer, and opaque elements by five capacitive nodes and four resistive layers.

2.2 EN ISO 15316-4-2

The calculation algorithm of the new draft of EN 15316-4-2 (European Committee for Standardization, 2018) provides as output the following hourly parameters: the total electrical energy, the energy from the cold source, the coefficient of performance (COP) of the heat pump, and the energy not supplied by the heat generator.

The algorithm also provides the amount of energy supplied by back-up systems (electrical resistance) if the heat pump is not able to supply the required energy.

All these parameters are calculated separately for heating and domestic hot water.

The hourly profiles of outdoor temperature, indoor operative temperature, energy needs for heating, and domestic hot water, and the water flow temperature according to the system must be provided as input.

Finally, data concerning the heat pump must be entered, identifying its technology, the source and sink type.

The services the heat pump is used for, the presence of any back-up systems and its power and COP at full load, declared by the manufacturer, must also be specified.

3. Case Study

The case study is a two-storey residential building (Fig.1) with a bathroom, a storage room, a kitchen and a living room on the ground floor and two single rooms, a double room, a bathroom and a hallway on the first floor.

The stairwell and attic are unheated thermal zones. The net floor height is 2.70 m, while the net floor area is 129.64 m^2. The thermo-physical characteristics of the building elements are shown in Table 1.

Aiming at evaluating different climatic contexts, the case study focuses on three Italian locations: Milan, Rome and Palermo. The input hourly climate data were calculated according to UNI 10349 (Ente Nazionale Italiano di Unificazione, 2016). The analysis was carried out for the winter period in order to evaluate the behavior of the heat pump for the heating season only.

Two daily profiles for heating were considered, both with a set-point temperature of 20 °C: (i) the first ON 24h/24h and (ii) the second intermittent with a number of working hours equal to the maximum allowed by Presidential Decree 412/93 (Presidente della Repubblica, 1993) depending on the climatic zone considered (Tab.2).

As an evaluation of the operation of the only heat pump for heating is intended, the production of domestic hot water, the thermal storage and back-up heater have not been considered. Four modulating air-to-water heat pumps (AWHP) were analysed, with increasing powers of 2.3 kW, 4.6 kW, 5.8 kW and 8.3 kW, values declared according to UNI EN 14511-1:2018.

The hourly profile of water flow temperature for the heat pump was determined through a climatic curve as a function of the air outside temperature and the design temperature of the location considered. Furthermore, distribution, emission and regulation efficiency were not taken into account as assumptions.

4. Results

Using the hourly energy needs for heating calculated according to EN ISO 52016-1 (European Committee for Standardization, 2017) as input values, the electrical energy, the thermal energy from cold external source (air) and the COP of the heat pump per hour were determined using the new draft of EN 15316-4-2 EN 15316-4-2 (European Committee for Standardization, 2018).

Moreover, the primary renewable and non-renewable energy was calculated based on the energy sources used. The comparison between the different heat pumps was made using the SCOP, which is calculated as the ratio between the supplied energy and the respective electricity consumption during the heating season.

Fig. 2 shows how the SCOP are, on average, 45.77 % higher in the case of intermittent use of heating system than constant use.

Considering the four heat pumps used, switching from a constant to an intermittent profile, the average SCOP increase for Milan, Rome and Palermo is 20.10 %, 48.53 % and 68.67 %, respectively.

Considering the same heat pump and varying the daily heating profiles of the buildings analyzed, qualitatively the same pattern is observed for each location: (i) in the case of constant use, the load factor decreases to values of 0.30 or less, with consequent reduction of COP, which happens during the hours when heating energy need is reduced; (ii) in the intermittent mode, on the other hand, having a higher power demand for the heat pump, the load factor is higher, with a consequent higher COP.

For this reason, in the case of Rome and Palermo, where the number of hours the system is switched on is lower than in Milan, the average SCOP variation between intermittent and continuous use is higher.

Therefore, a more intermittent system implies a higher power demand in the first hours of operation and a limited number of hours with reduced load factors.

These two aspects result in higher seasonal COP in the intermittent regime than in the constant daily profile for heating.

In order to assess the different behavior of heat pumps, it is not sufficient to analyze only the SCOP. For this reason, it is also necessary to evaluate the possible presence of missing energy, i.e., not supplied by the heat pump ($Q_{H,gen,add}$).

This analysis was carried out for all the locations considered. Since the results obtained follow the same trend for each location, the decision to specifically analyze the results obtained for the coldest location, i.e., Milan, was made.

Table 3 shows the missing energy for each heat pump used and for the two daily profiles of the heating system considered. Moreover, the percentage of missing energy in relation to the energy required by the heat pump ($Q_{H,gen,out,req}$) and the percentage of hours when the missing energy is present compared to the heating period are listed.

Table 3 shows how, in the intermittent system configuration, there is always an amount of energy not supplied by the heat pump.

The SCOP are higher in the intermittent mode but, on the other hand, the heat pumps always return a higher missing energy than in the constant profile, where there is no missing energy, except for the smallest heat pump.

Table 3 also provides useful information for determining the correct heat pump size for the building analyzed. Results show how the AWHP 4.6 kW does not result in an amount of missing energy in the case of constant mode, while, for the intermittent profile, the energy not provided is equal to 2.76 % of the energy required for heating.

Moreover, AWHP 5.8 kW has a similar operation to the AWHP 4.6 kW for intermittent operation but would be oversized for constant daily profile use.

Oversizing or undersizing a heat pump has consequences in terms of both primary energy and missing energy. An undersized heat pump (AWHP 2.3 kW) is characterized by a high SCOP (Fig. 2), but also by significant missing energy values (Table 3). An oversized heat pump (e.g., AWHP 8.3 kW) is characterized by a reduced SCOP, which is reflected in a higher primary energy, while not resulting in missing energy. In fact, Fig. 3 shows that the primary energy is higher in the case of the largest generator, i.e., AWHP 8.3 kW. Furthermore, the increase in primary energy leads to an increase of the non-renewable energy.

5. Conclusion

The new draft of EN 15316-4-2 (European Committee for Standardization, 2018), which provides a methodology for calculation of system energy requirements and system efficiencies for heat pump systems, has so far limited application in the literature. For this reason, in this paper the above-mentioned standard was tested by applying it to a residential building located in three different Italian cities and using the hourly energy need, calculated according to EN ISO 52016-1 (European Committee for Standardization, 2017), as input data.
This application shows that

- the use of an intermittent heating profile brings the heat pump to higher COP than a constant continuous heating mode;
- higher intermittency of the system implies a higher power demand in the first hours of operation and a limited number of hours with reduced load factors. These two aspects result in higher SCOP in the intermittent regime than in the constant on regime;
- in contrast, in the intermittent system configuration, an amount of energy not supplied by the heat pump is always present; this leads to an increase in non-renewable primary energy due to the need for an integrated back-up system (e.g., electrical resistance) or a second generator;
- undersizing the heat pump leads to high SCOP but non-negligible missing energy values.
- oversizing the heat pump leads to low SCOP and high non-renewable primary energy.

These results concern the case studies proposed and the methodologies associated with the standards used. The future development of this work will be to extend the calculation by considering an integrated back-up system (electrical resistance) and a storage system in order to assess their possible impact on the results.

Nomenclature

Symbols

COP	Coefficient of performance (-)
SCOP	Seasonal coefficient of performance (-)
M_s	Surface mass (kg/m^2)
U	Thermal transmittance (W/(m^{2}K))
Y_{IE}	Periodic thermal transmittance (W/(m^{2}K))
EP	Primary energy (kWh)
AWHP	Air-to-water heat pump

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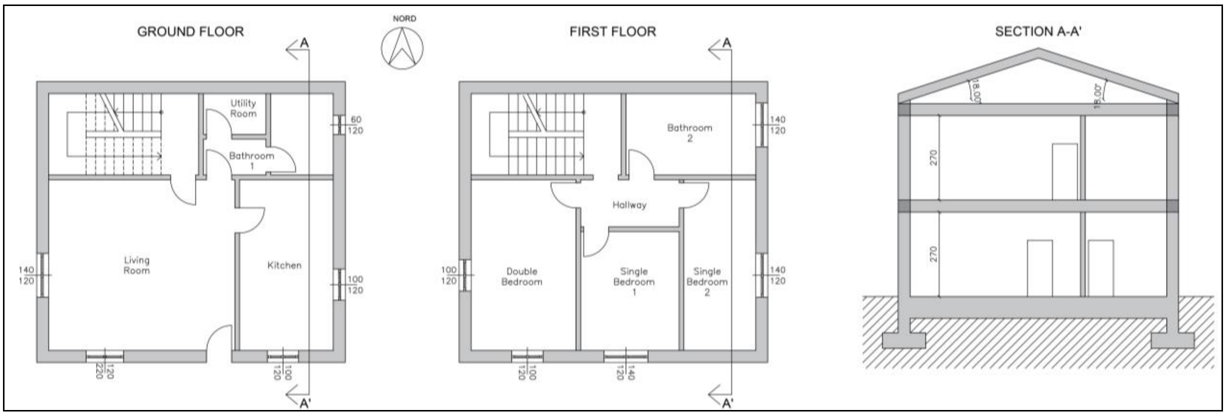

Fig. 1 – Plan view of the ground floor, first floor and section of the case study

Table 1 – Thermo-physical characteristics of the structures

	Thermophysical Parameters	Milan	Rome	Palermo
External Wall	U [W/(m²K)]	0.22	0.24	0.36
	M_s [kg/m²]	227.80	228.86	274.85
	Y_{IE} [W/(m²K)]	0.007	0.007	0.018
Ground Floor	U [W/(m²K)]	0.25	0.27	0.35
	M_s [kg/m²]	1370.60	1370.30	1369.40
	Y_{IE} [W/(m²K)]	0.007	0.007	0.010
Sub-roofing Floor	U [W/(m²K)]	0.24	0.27	0.37
	M_s [kg/m²]	363.60	363.00	362.10
	Y_{IE} [W/(m²K)]	0.038	0.028	0.064
Internal Floor	U [W/(m²K)]	1.13	1.13	1.13
	M_s [kg/m²]	111.60	111.60	111.60
	Y_{IE} [W/(m²K)]	0.673	0.673	0.673
Roof	U [W/(m²K)]	0.70	0.70	0.70
	M_s [kg/m²]	427.20	427.20	427.20
	Y_{IE} [W/(m²K)]	0.120	0.120	0.120
Internal Wall	U [W/(m²K)]	0.35	0.35	0.35
	M_s [kg/m²]	403.80	403.80	403.80
	Y_{IE} [W/(m²K)]	0.039	0.039	0.039

Table 2 – Different daily profiles for heating system, according to the three thermal zone considered.

Climatic Zone	Time Intervals	Heating Period
Milan	6:00-12:00/17:00-23:00	15 October - 15 April
Rome	6:00-11:00/18:00-23:00	1 November - 15 April
Palermo	7:00-10:00/19:00-22:00	1 December - 31 March

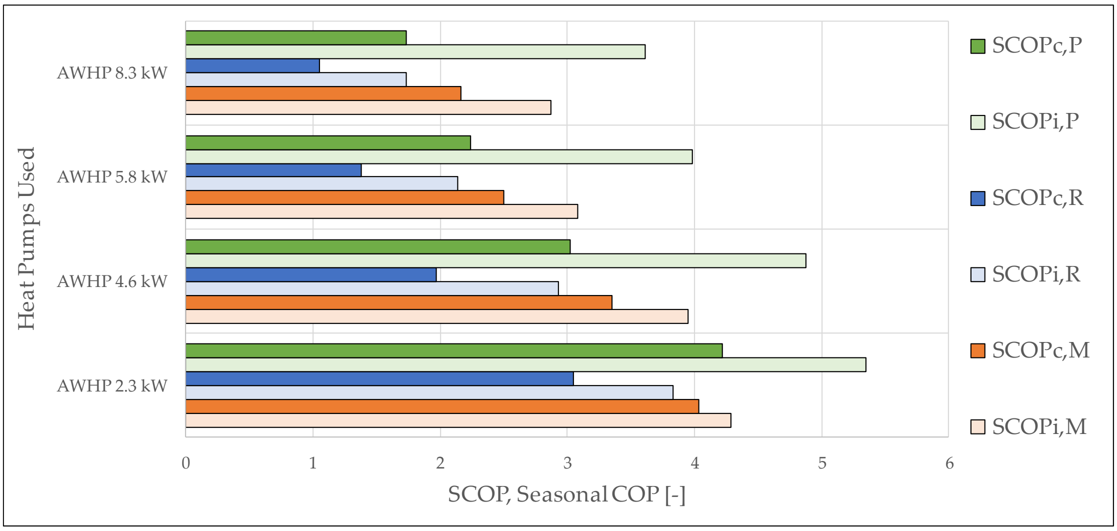

Fig. 2 – Seasonal COP for the three locations, two daily profiles for heating, four heat pumps: c/i:continuos/intermittent heating, P/R/M: Palermo, Rome, Milan

Table 3 – Energy not provided by the heat pump ($Q_{H,gen,add}$); percentage between energy not supplied and energy required for heating ($Q_{H,gen,add}$/ $Q_{H,gen,out,req}$); percentage between the number of hours corresponding to missing energy and the total heating period ($h_{Q,gen,add}$/ $h_{QH,gen,out,req}$)

Milan						
	Intermittent Heating			Continuous Heating		
Heat Pump	$Q_{H,gen,add}$ [kWh]	$Q_{H,gen,add}$/ $Q_{H,gen,out,req}$ [%]	$h_{Q,gen,add}$/ $h_{QH,gen,out,req}$ [%]	$Q_{H,gen,add}$ [kWh]	$Q_{H,gen,add}$/ $Q_{H,gen,out,req}$ [%]	$h_{Q,gen,add}$/ $h_{QH,gen,out,req}$ [%]
AWHP 2.3 kW	641	18.62 %	30,29 %	18	0.51 %	5.20 %
AWHP 4.6 kW	95	2.76 %	3.72 %	0	0 %	0 %
AWHP 5.8 kW	75	2.17 %	3.19 %	0	0 %	0 %
AWHP 8.3 kW	1	0.04 %	0.33 %	0	0 %	0 %

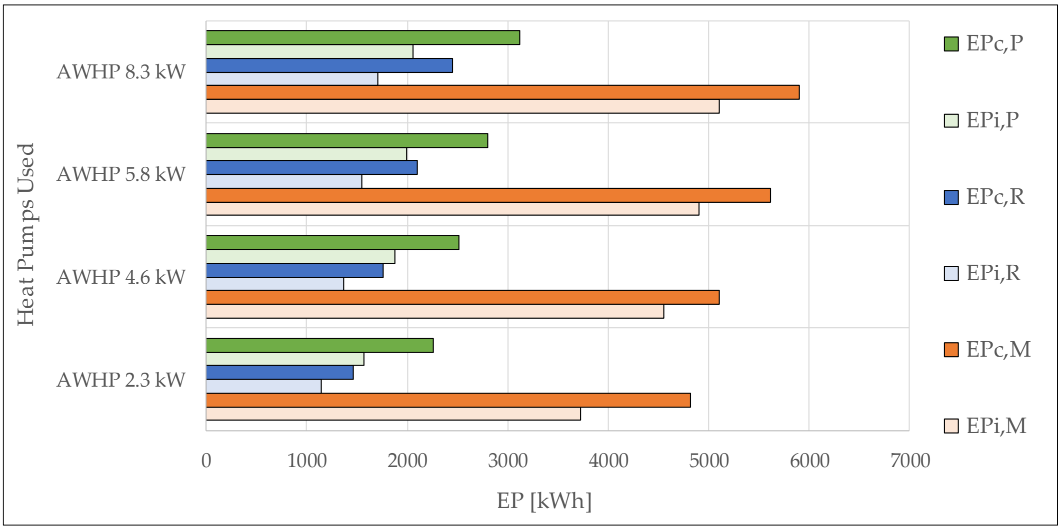

Fig. 3 – Primary energy for the three locations, two daily profiles for heatings, four heat pumps: c/i:continuos/intermittent heating, P/R/M: Palermo, Rome, Milan