15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Operating costs comparison of heat pump vs condensing gas boiler for the residential heating service: an Italian case study

Maurizio Pieve[a*], Raniero Trinchieri[a]

ENEA, Via Anguillarese, 301, Rome 00123, Italy

Abstract

The determination of the running costs of a heat pump is essential to communicate the convenience of its use in place of fossil fuel systems. Such a calculation is the topic of many studies and analyses, usually based on projections of the trend of final tariffs without any subsequent checks. This work proposes a case study in which this gap is filled, presenting a study to calculate the expenditure incurred for heating a residential home in an average climatic zone in Italy during the last seven heating seasons and comparing it with the expenditure that would have resulted for the same service using a commercial heat pump. The methodology for calculating operating costs is illustrated, starting from those sustained with a condensing gas boiler and calculating, with a simplified model and suited assumptions, those that would have occurred with a commercial air-water heat pump operating in the actual climatic conditions during the same heating seasons. The results show a strong dependence of expenditure on the ratio between the two commodities, gas and electricity, with differences in single seasonal expenditure spanning a range between -51% and +12%, due to the occurrence of unpredictable phenomena such as those that occurred with the pandemic and energy crises. As a whole, in the seven years analyzed, a global saving in operating costs of approximately 32% was calculated, which must be taken into account in the analyses for the convenience of a heat pump compared to a fossil fuel system.

Keywords: heat pump; operating costs; economic analysis.

1. Introduction

Understanding the operating costs of a domestic heating system is one of the factors to consider when evaluating the merits of an investment in one system versus an alternative. Recently, especially when investment incentives are available, heat pumps have become increasingly popular as a viable alternative to gas boilers, even condensing ones. In many literature studies, the evaluation of running costs is almost always performed with reference to an estimate of tariffs over the relevant time period based on historical average data or on projections of increases or decreases in macroeconomic variables (e.g., inflation, renewable energy penetration trends, or other factors) [1-2]. Indeed, the evolution of future tariff policy is still subject to a substantial level of uncertainty. The use of actual tariffs is possible only through ex-post analysis, as proposed in this paper, by means of a retrospective *what-if* methodology, which compares the actual expenditure incurred with that which would have been incurred using a different technology, in this case, the heat pump.

2. Method

A domestic household has been considered, located in central-north Italy, in the suburbs of the district of Pisa, 10 km far from it, with the features summarized in Table 1. It belongs to a fairly old class of buildings, since its envelope was built before 1940. Its average historical space heating need is about 43 kWh/m^{2}y.

* Corresponding author. Tel.: +39-050-3153614
E-mail address: maurizio.pieve@enea.it

Currently the space heating service is provided by a 27 kW condensing gas boiler, which serves as DHW supplier as well. In this paper, the space heating service only will be considered.

Table 1. Household and site main features

Type of building	2-story terraced free on two sides, built before 1940
Degree days	1853 (climatic zone D)
Heated volume	712 m^3
Net floor surface area	175 m^2
Building Envelope surface area	324 m^2
Global thermal transmittance U	0.77 W/m^2K

2.1. Gas consumption for the space heating service

The heating seasons were considered as shown on Table 2, where the actual switching on and off periods of the heating system are reported, due to specific weather and climatic conditions.

Table 2. Actual duration of heating seasons

Heating season	On	Off
2018-19	16th Nov	20th Apr
2019-20	4th Nov	20th Apr
2020-21	1st Nov	30th Apr
2021-22	5th Nov	15th Apr
2022-23	5th Nov	22nd Apr
2023-24	4th Nov	28th Apr
2024-25	2nd Nov	12th Apr

A correlation may be obtained between the daily gas consumption for space heating by a condensing gas boiler and the average outdoor temperatures. By monitoring the weekly gas consumption at the gas meter, the gas daily consumption for space heating, domestic hot water production and cooking is obtained, as shown in Figure 1, where the average DHW and cooking consumption, calculated for each season, is highlighted in the lower part of the plot, and can be easily subtracted from the total to determine the consumption for the heating service only. The experimental consumption values were recorded on a weekly basis, with the exception of some measurements, taken over longer intervals. For each monitored interval, the average daily temperature, shown in Figure 2, has been associated [3-4] as well. A validation of the data source was made by comparing data with other sources for the same location [5-6], with a good agreement.

The trends of the outdoor temperature and the natural gas consumption may be merged to get a BES (Building Energy Signature), as showed in Figure 3, which allows to obtain information on the thermal load of the building during the heating season. This technique is consistent with the indications of some international protocols for measuring and verifying consumption [7-8].

Indeed, depending on the design temperature assumed as 0 °C, and assuming a 24 hours per day running of the space heating system, the resulting design thermal load is calculated to be about 4.74 kW (blue line), provided that a conversion factor of 9.63 kWh/m^3 is used for the natural gas, the latter being evaluated from a gross calorific value of 38.52 MJ/m^3 [9-10] and a conversion efficiency of 0.9. If an intermittent heating service of 12 hours per day is set, as for example required by the Italian standard for thermal generators in the climatic zone where the building is located [11], the line with the highest slope, more precisely twice as steep as the blue one, is obtained (red in the same Figure). Depending on the specific heating control system that will be adopted (i.e. the number of hours the system is switched on) and taking into account any inhomogeneities in the comfort of the occupants, it will be possible to choose the most suitable line for sizing a heat pump.

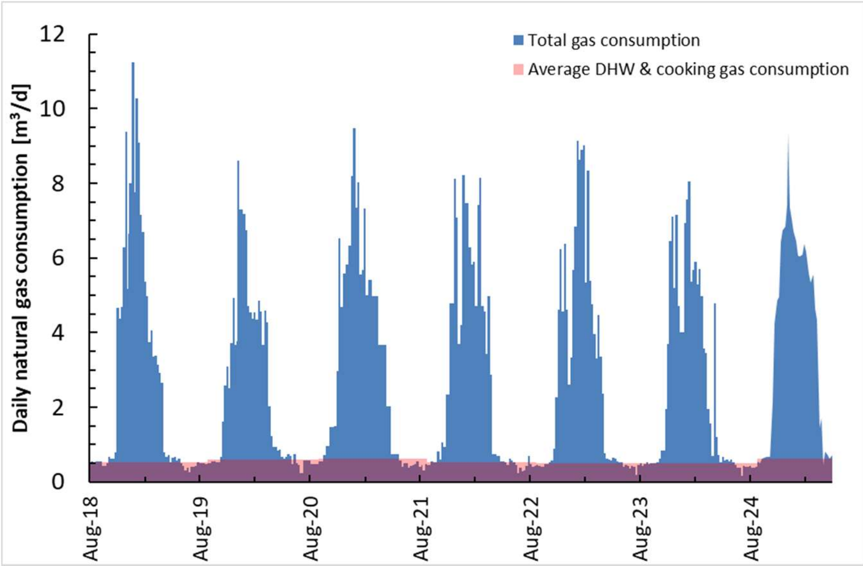

Figure 1. Gas daily consumption for all domestic uses and for DHW and cooking service

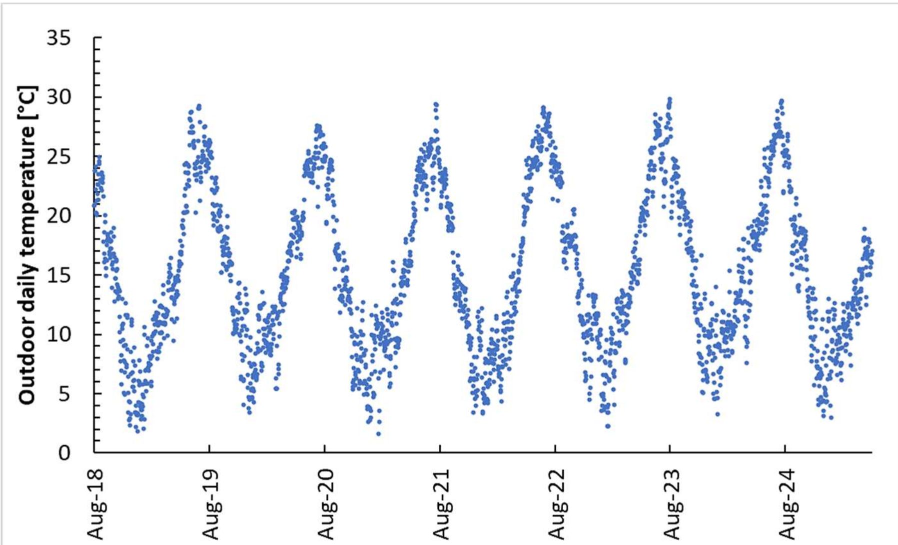

Figure 2. Outdoor daily temperatures between 2018 and 2025

2.2. Electricity consumption

Once a certain gas consumption is fixed, as shown in Figure 1, it can be converted into the electricity consumption for the heat pump's operation: firstly, for each measurement period, the gas consumption is used to determine the thermal energy supplied; secondly, knowing the average outdoor temperature, the heat pump's COP for the same period can be determined. In this way, the electricity consumption corresponding to a given gas consumption is obtained.

In order to get a reference COP value, the technical data sheets of 12 commercial air-water machines belonging to A+ and A++ classes were analyzed when operating in the so-called average conditions and capable of supplying water at 55 °C, so that conditions identical to the current may be guaranteed to the household as regards the heating service. For each machine, the correct sizing with respect to the household needs was verified, and a bivalent temperature equal to 4 °C was assumed.

Since the average outdoor temperature ranged between 3 °C and 15 °C during the observed periods, as Figure 3 shows, a correlation was obtained between COP and outdoor temperature, valid in that temperature range, Eq. (1):

$$COP = 3.018 + 0.071T_{out} + 0.00839T_{out}^2 \quad (1),$$

where T_{out} is expressed in °C.

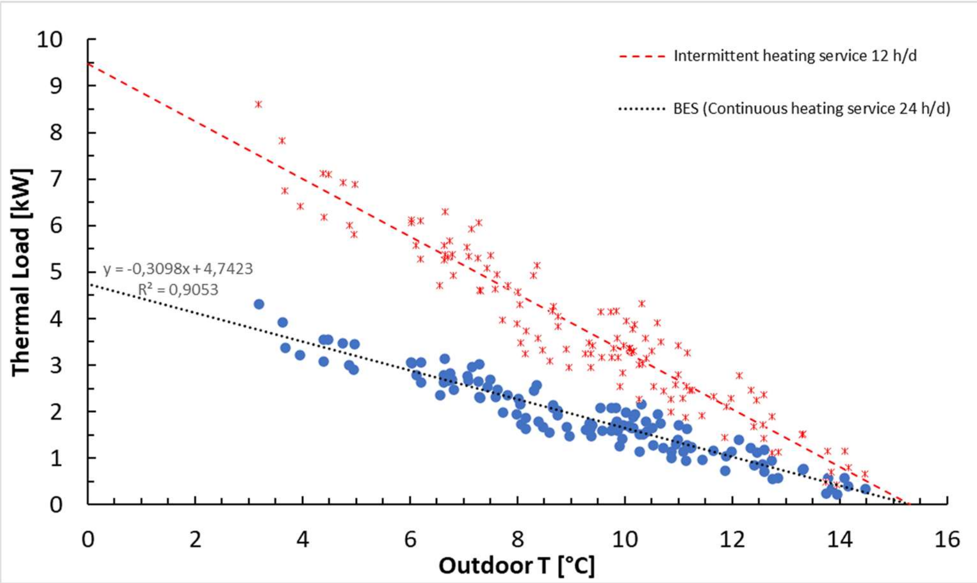

Figure 3. Building Energy Signature

2.3. Heat Pump consumption

The heat pump electrical consumption has to be added to a base electrical consumption, i.e. the consumption of all the others usual electrical appliances and uses, as shown in Figure 4, with base electrical consumption (blue bars) and heat pump further consumption (red bars). This calculation is necessary to carry out a correct calculation of the electricity cost with and without the heat pump, since the tariff does not have an exactly proportional correlation with consumption. A maximum monthly consumption of 985 kWh is observed during January 2019, with a maximum share in the same month equal to 74% of total consumption. Table 3 reports the electrical consumption of each heating season due to the heating service supplied by the heat pump, compared with the electric base consumption. The season is conventionally fixed from May 1st to April 30th of the following year. The average incidence of HP consumption is about 38% on total electrical consumption.

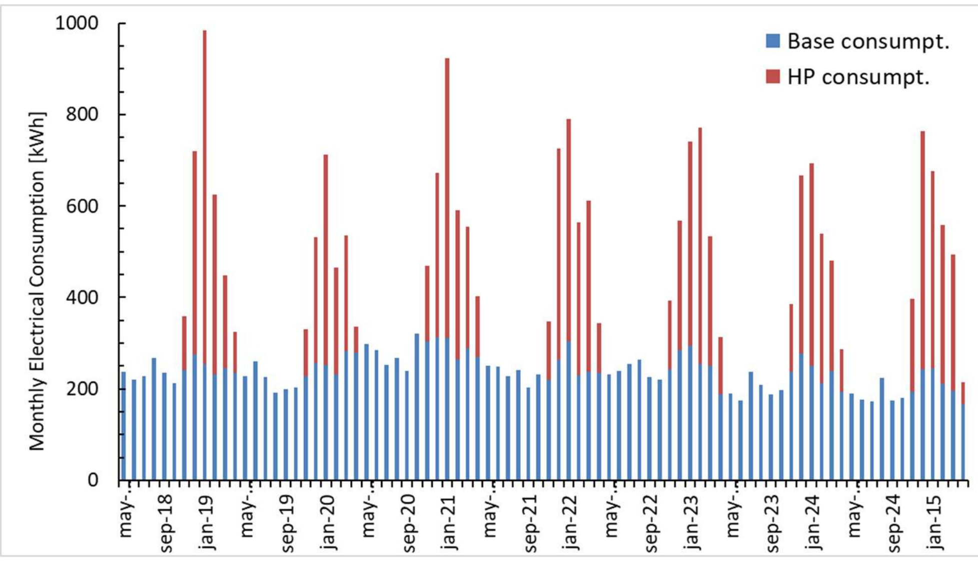

Figure 4. Electric consumption for all uses and for HP operation

Table 3. Electric consumption and share of HP for space heating

Heating season	Base consumption [kWh]	HP consumption [kWh]	% of HP consumption on total
2018-19	2881	1984	40.8
2019-20	2840	1381	32.7
2020-21	3412	1861	35.3
2021-22	2895	1892	39.5
2022-23	2948	1805	38
2023-24	2602	1645	38.7
2024-25	2371	1849	43.8
Overall	**19949**	**12417**	**38.4**

3. Results and Discussion

Once the consumptions have been defined, and the outdoor temperatures as well, the end-user tariffs are to be considered over the examined time range.

3.1. Tariff regimes

The Italian trend of tariffs in the last 15 years can be observed in Figure 5, just to get a reference; they refer to the so-called protected market and more specifically to an annual consumption of 1400 m^3 of natural gas in the Milano region and an electrical annual of 2700 kWh with a 3-kW limiter on the electricity meter [12]. At the end of October 2025, the gas price is about 32% higher than the historical average of the 2010-2020 period, while the electricity final price is around 47% higher.

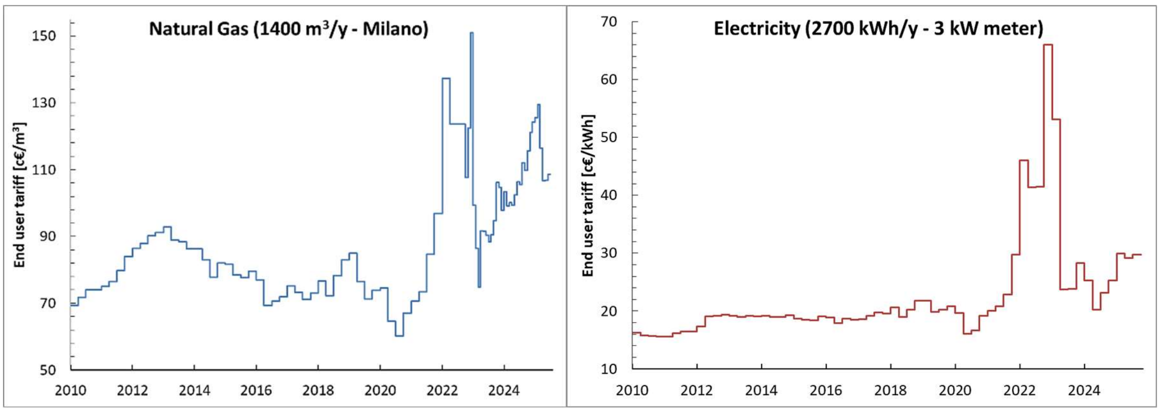

Figure 5. Tariffs trends of natural gas and electricity for domestic households during past 15 years in Italy – Protected markets

When dealing with the specific user, a further detail should be considered, thus slightly more expensive tariffs, both for natural gas, which depends on the regional district where the analysis is performed, and for electricity, because of a greater electricity meter, at least 4.5 kW, which is needed when a heat pump is adopted as primary heating system.

3.2. Potential savings with heat pump

By adopting a retrospective *what if* approach, a precise comparison can be made between the electricity costs incurred without a heat pump (i.e. the electricity consumption due to other usual electrical appliances) and those that would have been incurred with a heat pump, month by month. The running cost of a heat pump for the space heating service is obtained from the difference between the two above calculations. The final comparison between the space heating expenses for the end-user in the examined case is summarized in Table 4. A rather wide range of possible savings is observed, approximately linearly decreasing with the electricity/gas price ratio. The maximum saving, greater than 51%, is obtained for the 2024-25 season, while a loss of more than 12% is experienced during the 2022-23 season, the most critical for both the energy commodities. If the calculation is extended over the entire analyzed period, a 32.3% saving is calculated.

Table 4. Comparison of space heating expenditure with gas boiler and heat pump

Heating season	Gas Boiler exp. [€]	Heat Pump exp. [€]	% saving	Electricity/gas price ratio [(€/kWh$_e$)/(€/kWh$_t$)]
2018-19	734	485	33.9	2.583
2019-20	500	306	38.8	2.638
2020-21	617	357	42.2	2.415
2021-22	1046	774	26	3.019
2022-23	870	978	-12.4	4.765
2023-24	847	433	49	2.286
2024-25	1091	528	51.6	2.097
Overall	**5705**	**3861**	**32.3**	**2.846**

4. Conclusions

An assessment of the running costs for space heating of a single-family home by means of a domestic air-water heat pump has been done, comparing them with the expenses incurred for the same service with a condensing gas boiler over a seven-year period. The monitoring of the gas consumptions, combined with the knowledge of the daily average outdoor temperatures, allowed a precise calculation of the heating needs of the household; a reference COP was deduced by examining 12 suited machines, belonging to the A+ and A++ efficiency classes, capable of supplying water at 55°C, to replicate the actual conditions of the current gas boiler. A maximum single-season economic saving greater than 51% was calculated, while over a 7-year period a saving of 32.3% could have been achieved. A strong dependence on the electricity/gas price ratio is still confirmed as well, that is to be compared with the average actual SCOP of the heat pump.

Acknowledgments

This work was funded by the three-year 2022-2024 MASE-ENEA program agreement plan for the Italian Electricity System Research.

References

[1] Rosenow, J., Barnes, J., Galvin, R., O'Mara, S., Lowes, R., 2025 Total cost of ownership of heat pumps and policy choice: The case of Great Britain, iScience 28, 111784.
[2] Gatti, A., Canevese, S. M., Tagliabue, L., Gelmini, A., Talamo, M. F., D'Oria, F., Croci L., Il costo della transizione energetica per il consumatore finale, RSE 2025.
[3] Aylor, N., Martinez, A., Alexandris, N., Gounari, O., Szabo, S., Chatzipanagi, A., Mercado, L., Falangas, A., Photovoltaics Geographical Information System: Status Report 2024, 2025, https://data.europa.eu/doi/10.2760/2979595, JRC141263.
[4] Weather Station of the Department of Information Engineering, University of Pisa, available at http://meteo.dii.unipi.it.
[5] Weather Station of Guido Cioni, available at https://guidocioni.altervista.org/nuovosito/meteo/stazione-di-pisa/archivipisa/
[6] Weather Station of Alessandro Nerelli, available at https://www.meteopisa.it/index_file/page0002.htm
[7] ASHRAE guideline 14-2014: Measurement of energy, demand, and water savings. Atlanta, GA, USA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2014.
[8] ISO 16346:2013, energy performance of buildings — Assessment of overall energy performance, 2013
[9] Decree of Ministry for Economic Development, 12.07.2007.
[10] Deliberation n. 134/06 of Italian Regulatory Authority for Energy, Networks and Environment (ARERA), 28.06.2006.
[11] Decree of President of Republic, n. 412/1993, 26.08.1993.
[12] Italian Regulatory Authority for Energy, Networks and Environment (ARERA), https://www.arera.it/area-operatori/prezzi-e-tariffe.