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REPLACEMENT OF GAS BOILERS WITH AIR SOURCE HEAT PUMPS: AN ECONOMIC ANALYSIS BASED ON A TRNSYS EVALUATION AND ON THE ACTUAL ENERGY PRICES IN ITALY

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Abstract

In this work, we investigate the replacement of a gas boiler with an electric air-to-water heat pump (AWHP) as a heating generation system for a detached single-family house. Attention is paid to the recent increase in energy prices in Italy. The evaluation of the energy consumption is done via a dynamic analysis performed by employing

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Trnsys. The investment results are economically advantageous only if the thermal energy demand is quite high, and the recent energy price increase (for both natural gas and electricity) leads to disadvantages in replacing the heat generation system in all the considered cases.

1. Introduction

The ambitious European Green Deal aims to achieve 100% GHG reductions by 2050, and many different factors and strategies are driving this change [1]. Among them, heat pumps play a crucial role, especially concerning the buildings sector [2, 3], as well as, for instance, energy communities [4] or green roofs [5, 6]. Concerning heat pumps, a recent study by Valdiserri et al. [7, 8] proposes a method to evaluate the CO_2 emission when a common electric device, such as a heat pump, is connected to the grid, useful for defining a utilization strategy of a heat pump aiming to reduce the dioxide emissions.

Concerning heat pumps, we recently investigated the effect of climate conditions on the SCOP of a heat pump [9-11], for some Italian cases. In renewable energy transition, an important role is paid also by economic growth and non-renewable energy prices in the renewable energy transition [12]. Indeed, in the recent literature, attention is paid also to the economic relevance of a heat pump as an alternative to a gas boiler for residential building heating [13, 14]. In particular, in [13], an energy and economic analysis is presented, comparing heat pumps and gas boilers with reference to the South of Italy, showing that the thermal energy demand strongly influences the competitiveness of the heat pump with respect to a gas boiler.

Recently, an analysis of the impact of the recent and actual variability of the energy process in Italy has been presented. A comparison between air-source heat pumps and gas boilers is done, and the effect of climate conditions is underlined [15]. In the present paper, we aim to deepen the analysis presented in [15] basically from an economic point of view. A comparison between a heat pump and a gas boiler is presented, estimating, for the considered cases, the building's energy demand by employing

Trnsys. Then evaluations on the opportunity to substitute the heat generation are done, with special attention to the effect of climate conditions and building performances.

2. Setting of the Analysis: Building and Heating System

Let us consider two buildings, both characterized by a reference floor of $100m^2$ and displaying same geometric properties and layout (Figure 1), but different envelope components, characterized by different transmittance, as reported in Table 1: building B presents better insulation with respect to building A.

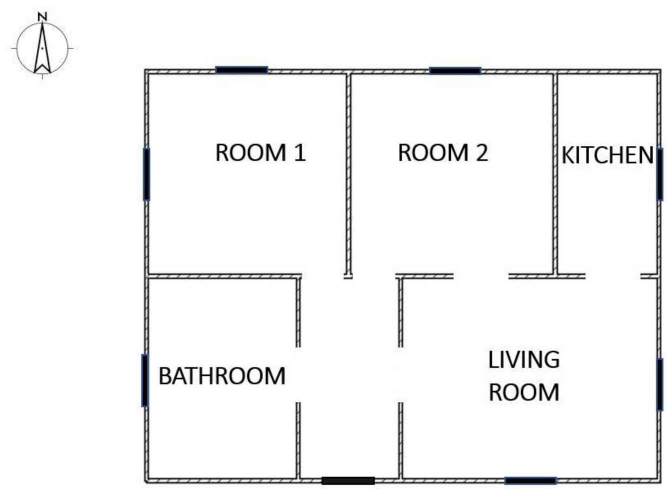


Figure 1. Layout of the buildings A and B.

Table 1. Buildings envelope elements transmittances in $W/(m^2K)$

	Building A	Building B
Windows	1.60	0.90
External walls	1.15	0.60
Internal walls	1.95	1.95

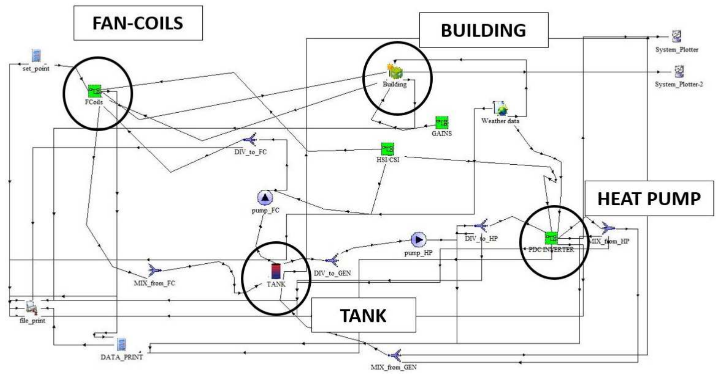
The internal gains are considered as proposed by IEA Task 44 [16], considering the same hourly profile for each day of the heating season.

To determine the buildings' energy demand, dynamic simulations by means of Trnsys software package [17] have been performed, virtually placing the buildings in two different well-known Italian cities, Rome and Milan, characterized by different climates. In Table 2, the annual thermal energy demand for heating (related to the reference floor area of the building) is shown for the two buildings, A and B, in the two abovementioned cities together with the design power for heating (P_{des}) at the different winter design temperatures (t_{des}). It is evident that the climate that characterizes Rome is milder than the Milan climate, in winter.

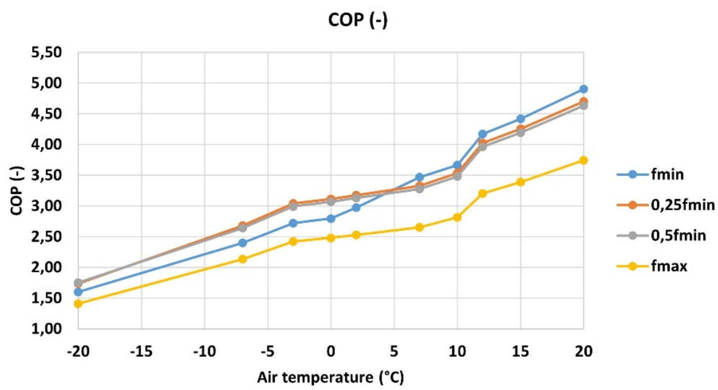
Table 2. Annual thermal energy demand ET for heating (also related to reference floor area, EP) that characterizes the two buildings in Rome and Milan

		Building A			Building B		
	t_{des} (°C)	ET (kWh/year)	EP (kWh/(m^{2}y))	P_{des} (kW)	ET (kWh/year)	EP (kWh/(m^{2}y))	P_{des} (kW)
Rome	0	7858	79	8	3720	37	5.5
Milan	-5	13807	138	10	7472	75	6.5

The heating system employed presents fan-coils as emitters, a thermal storage tank of 0.1m^3 and, as generator, alternatively a gas boiler or a heat pump. Both the gas boilers and the heat pumps have been sized to satisfy totally the thermal power requested by buildings at winter design conditions (reported in Table 2). The gas boilers for all the 4 cases considered (2 buildings, A and B) in the two different climates (Rome and Milan) are characterized by an efficiency of 0.85, and the low heating value of the gas is 9.5kWh/Sm^3. The considered heat pumps are all with inverter-driven variable speed compressors, and present the same COP (Coefficient of Performance, ratio between the thermal power output and the electric power supplied to the thermal machine) trend, but different thermal output power, to satisfy the thermal load at winter design conditions. A scheme of the heating system is reported in Figure 2(a), while in Figure 2(b) is reported the COP trend of the considered heat pumps vs. outdoor air temperature and for different inverter frequencies.



(a)

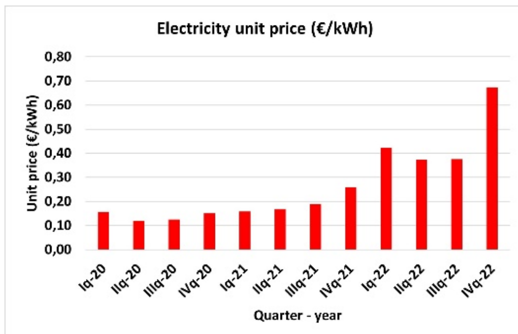


(b)

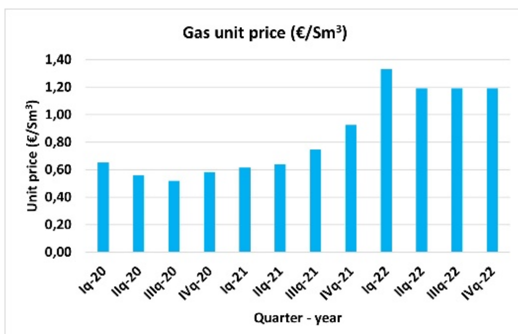
Figure 2. Layout of the heating system coupled with the buildings (a); COP trend vs. outdoor air temperature for different inverter frequencies and for a fixed heat pump water outlet temperature of 45°C (b).

3. Data on Gas and Electricity Prices

The data on gas and electricity prices employed in this analysis have been obtained from ARERA (Italian Regulatory Authority for Energy, Networks and Environment) [18], that is a Regulatory Authority that establishes every three months the gas and electricity prices for customers that have a standard-offer market agreement. In Italy, in fact, household customers for gas and electricity can choose between the standard-offer market, characterized by variable prices and established by the authority every three months, or the free market, i.e., prices are established by the agreement signed between the household customer and the energy provider. At the end of 2021, in Italy, more than 40% of household customers have a standard-offer for electricity and more than 30% for gas. In Figure 3, the unit price of electricity and gas is reported regarding the last three years (2020-2022); energy prices obtained from the Italian Regulatory Agency have been processed as reported in [15]. The figure shows that starting from the last quarter of 2021, both gas and electricity prices show an important increase. Furthermore, considering the last three quarters of the year 2022, the gas unit price is constant: this is obtained as a consequence of the reduction in gas taxes operated by the Italian government in order to contain the huge increase in energy prices.



(a)



(b)

Figure 3. Unit price for electricity (a) and for natural gas (b), years 2020-2022.

4. Economic Analysis

The economic analysis concerns the replacement of the gas boiler as heating generation system with a heat pump, and the parameter analyzed is basically the net present value (NPV), considering a discount rate of 3% and a timeframe of 10 years. Four different cases, considering the two buildings in Milan and Rome, have been analyzed, and for all the four cases, different investment costs for the replacement of the gas boiler with the heat pump have been estimated in relation to the thermal power output of the heat pump, as reported in Table 3. The investment costs consider also economic incentives provided by the Italian government to promote the energy transition.

Table 3. Cases considered in economic analysis

Case	Building	City	Investment (€)
Case 1	A	Rome	2110
Case 2	A	Milan	2450
Case 3	B	Rome	1685
Case 4	B	Milan	1855

The annual energy cost difference for heating the building using a gas boiler with respect to a heat pump in the four cases for the years 2020-2022 is reported in Table 4. The table shows that the major cost difference is obtained for building A which presents poor thermal insulation. It is also evident that for the year 2022, the use of the heat pump with respect to the gas boiler in some cases leads to an increase in annual operational costs, for example for Cases 2 and 4. Therefore, in these cases, there is no convenience of using the heat pump with respect to the gas boiler.

Table 4. Annual cost difference (€) between gas boiler and heat pump for heating (years 2020-2022)

Case	2020	2021	2022
Case 1	423	409	162
Case 2	480	451	–50
Case 3	199	192	72
Case 4	260	243	–25

5. Results and Conclusion

In Table 5, the NPV values for the analysis carried out are presented. The replacement of the gas boiler with the heat pump is cost-effective (i.e., displays a positive NPV) only in some cases. The investment results are advantageous only if the thermal energy demand is quite high, as for building A in Milan.

It can also be observed that the energy price increase (for both natural gas and electricity) of the last year leads to a disadvantage from an economic point of view of replacing the existing gas boiler with the heat pump in all the cases.

Further developments of this study may consider the analysis of other building typologies, such as condominiums, and other economic indicators.

Table 5. NPV of the investment (years 2020-2022)

Case	2020	2021	2022
Case 1	1155	1050	–857
Case 2	1256	1035	–2834
Case 3	–149	–199	–1132
Case 4	150	21	–2048

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