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Opportunities for heat pumps adoption in existing buildings: real-data analysis and numerical simulation

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Abstract

The space heating of buildings represents one of the most important causes of energy consumption in Europe. The necessity to increase the share of renewable energy within the sector is hindered by the difficulty to renew and refurbish the existing building stock. In this context, heat pumps can have an important role in helping increase the renewable share of thermal energy production for the civil sector, in particular in those countries in which the electricity generation mix has large contributions from renewable energy sources. The paper presents a real-data analysis and a numerical simulation to evaluate the opportunity to substitute traditional heat generation systems (natural gas boilers) with air-source heat pumps or hybrid solutions. Three buildings located in Turin (Italy) are taken as case-study, and the hourly profiles of outdoor temperature, water supply temperature and absorbed thermal power are used to simulate four heat generation scenarios, that are compared in terms of primary energy consumption. Results show that (1) the substitution of the traditional natural gas boiler with a heat pump (with backup electric resistance) is always favorable (18% to 32% of primary energy reduction); (2) the influence of water supply temperature of each building on the overall primary energy saving is very high; (3) the adoption of a hybrid system (heat pump and natural gas boiler working alternatively) provides advantages in terms of reduced primary energy consumption only if the required supply water temperature is high. Further studies will investigate the economic aspects and will introduce comparisons with condensation natural gas boilers.

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Keywords: Heat pumps; retrofit; data analysis; existing buildings.

1. Introduction

In Italy, buildings account for about 37% of the total primary energy consumption. About 70% of it is used for space heating and cooling [1]. While the renewable share in the elecitricity generation has constantly grown in the last decade, the generation of thermal energy for space heating purpose is still both inefficient and strongly dependant on fossil fuels [2].

Even if nZEBs do represent a promising scenario to achieve energy efficiency targets, most studies show that the number of new constructed buildings in the next years will likely remain very low, and that the future building stock will be basically constituted by buildings that already exist today [3]. For this reason, much effort is being put into

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finding suitable solutions for balancing deep renovation needs and the necessity to deal with existing buildings in which many constraints coexist.

Heat pumps are one of the key technologies that could be used to increase the renewable share of energy used for space heating in buildings, in particular in countries with high renewable share in the electricity generation mix. The problem of the widespread adoption of heat pumps into the building sector in most of European countries (and in southern Europe in particular) lies in the difficult matching between this generation technology and the heat distribution and emission solutions that are most commonly adopted in existing buildings. In particular, heat pumps are traditionally found in buildings with low temperature heating systems; on the other hand, medium-to-high temperature radiators represent by far the most common heating emission solution in many European countries [4]. Asaee et al. [5] did study the influence of retrofitting air-source heat pumps into existing buildings, but they also introduced some major modifications (notably storage systems and hydronic terminals) that could not be easily implemented within existing buildings without significant economic investment. Similarly, Touchie et al. [6] did simulate the impact of HP retrofitting in Toronto, in which winter climate is very rigid; they design therefore a system in which the HP is mounted over an enclosed balcony, therefore the evaporation temperature would be much higher with respect to the outdoor temperature thanks to solar gains. Though this being an interesting and elegant approach, it is once again not strictly compliant with the necessity to avoid heavy buildings refurbishment and to the general applicability of the approach

The adoption of simple control logics like climatic regulation and thermostatic valves can help decrease the average water temperature of these heating systems [7]. Moreover, detailed analyses of real weather data show that the very-low temperatures that are commonly used as design parameters for heating systems occur rarely even on an hourly basis over a full heating season; if a climatic regulation is adopted in a building, therefore, also the maximum water supply temperature is seldom (if never) reached, and the average one is in fact much lower. These two influences (outdoor temperature and related supply temperature) must be both taken into account as they both affect consistently the efficiency of heat pump units. Madonna et al. [8] presented a detailed simulation tool to calculate the efficiency of a air-source heat pump considering outdoor temperature, defrost cycles and partial load influences on the performance of the unit; however, they considered only one supply temperature for all buildings for being able to compare the different solutions. The proposed qualitative consideration suggests that heat pumps and hybrid systems (i.e. a heat pump and a traditional natural gas boiler working alternatively) could reach average efficiencies much higher than those calculated at 'nominal' conditions [9]. Finally, the overall efficiency of an heat pump must be calculated by taking into consideration the primary energy factor of each electricity generation system [10]; such factor, which is characteristic of every generation mix, is strongly variable on an yearly basis in those countries (like Italy) in which the renewable share in the electricity sector is high. This variability should also be taken into account when evaluating the real performance of a heat pump in terms of consumed primary energy .

This article thus present a detailed analysis of real-data collected from existing buildings to analyze the opportunity for HPs adoption in complete or partial substitution of traditional heating generation systems. A detailed analysis of weather data for the three largest cities in Northern Italy is presented to show that the concern of excessively low temperatures for proper operation of HPs is probably excessive. These data are then used together with real heating data collected from three different buildings located in Turin, Italy, to build a numerical model to compare four different scenarios in which different generation technologies / combination of technologies are adopted. These scenarios are then compared in terms of final primary energy consumption and total CO_2 emissions.

2. Methodology

The aim of the article is to compare different thermal energy generation technologies to provide space heating to three existing buildings located in Turin, Italy. These buildings are heated through traditional natural gas boilers and water radiators are used as heat emission systems. Four different scenarios are proposed for heat generation through different technologies / combination of technologies:

1. **Electric Resistance (*ER*)**: a simple electric resistance is used, with a constant efficiency.
2. **Natural Gas Boiler (*NGB*)**: equivalent to the existing system, a non-condensing natural gas boiler with constant efficiency is simulated.