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A study on the energy performance of a ground source heat pump utilized in the refurbishment of an historical building: comparison of different design options

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Abstract

The European construction sector is facing a major challenge due to the actual impact on long-term energy consumption, caused by the large number of existing buildings. In order to achieve the 2012 energy efficiency directive (2012-27-EU) each European country must draw-up long-term national building renovation strategies. Furthermore, existing buildings, subject to major renovation, also have to meet the European minimum energy performance requirements, in term of energy needs and system efficiency, requested by the 2010/31/EU and 2009/28/CE directives. The aim of the European Commission is to reduce by 27% the actual energy building consumption and to increase the total amount of renewable energy used by 27% by 2030. In Italy, national and regional laws have already implemented these strategies in order to achieve the national energy goals.
The design phase in refurbishment projects is often problematic. The decisions taken in the early stages of the design determine the final result; however, the assessment of the environmental performance only happens at the end of the design process. Moreover, historical buildings present many artistic and architectural constraints that make the process more difficult, especially in the application of envelope refurbishment measures. Therefore, even more than in modern buildings, it is necessary to focus efforts on plant efficiency and exploitation of renewable sources. Currently the application of alternative energy supply systems in common retrofit has not generally been fully explored, in particular for historical buildings. In this context, geothermal energy is becoming all around Europe one of the most interesting sources of renewable energy for heating and cooling by ground-coupled heat pumps. The aim of this work is to compare different system solutions in terms of economic impact and energy needs during a building's operating phase and to evaluate the sustainability of ground-coupled heat pump technology for heating and cooling.

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The test case is an historical single-family dwelling located in Northern Italy and built in 1800 with relevant architectural and artistic features. A range of generation system retrofit options are analyzed in order to evaluate the building's primary energy needs, renewable energy exploitation and actualized return costs in each case. The heating and cooling generation systems compared are heat pumps with different renewable sources (geothermal and external-air) and different control systems (on/off and variable-capacity). Results can be applied in comparable case studies to support refurbishment strategies design.

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Keywords: Geothermal heat pump; renewable sources; energy efficiency; energy retrofit

1. Introduction

European directives in the field of energy efficiency in buildings have boosted the use of renewable sources both in new constructions and in major renovations of existing buildings. In Italy, the laws that have implemented the European Directives 2010/31/EU and 2009/28/CE impose covering a given percentage of primary energy needs with the use of renewable sources in buildings. The aims of European trends are not only the achievement by 2030 of 27% renewable sources utilized in buildings, but also the introduction of Net Zero Energy Buildings in new constructions and renovations in all the member states.

In this context, heat pumps are particularly important, with acceptable costs, since they enable a significant exploitation of renewable energy (air, water or ground) even in case of existing buildings where historical and artistic constraints do not permit the installation of solar or photovoltaic panels for the production of thermal and electric energy from renewable solar sources [1, 2].

In this paper the authors carry out a feasibility study of a ground coupled heat pump technology operating in both heating and cooling in a historical house. The building is part of historical and artistic regional estates bound by the Authority for Cultural Heritage and is undergoing major renovation and seismic consolidation before becoming a private residence. The paper's aim is to deepen the understanding of the use of alternative and innovative generation systems within historical buildings; the objectives are achieved through an energy analysis during the operating phase of the building and a cost-benefit analysis of different system solutions. In particular, the evaluation of the energy savings of several types of systems during the year is carried out in relation to a traditional generation system, named "reference" system. Therefore, the economic evaluation is referred to the sub-system that varies between the analyzed solutions (generation system) and considering the extra costs due to the choice of solutions as more energy efficient.

Nomenclature

E_{res}	Amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps to be considered energy from renewable sources during a year (kWh)
Q_{usable}	Estimated total usable annual heat delivered by heat pumps (kWh)
SPF	Estimated average seasonal performance factor for those heat pumps (ND)
η	Ratio between total gross production of electricity and primary energy consumption for electricity production, calculated in accordance to National Standards (ND)
ΔFC_j	Difference between operating costs (annual cash flow) (€)
f	Inflation (ND)
d	Future trend of a good (ND)
i	Rate of interest of investment (ND)
ΔI	Difference between investment costs and maintenance costs (€)