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Microcogeneration in buildings with low energy demand in load sharing application

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ABSTRACT

The paper investigates the introduction of a MCHP (Micro Combined Heat and Power) system in buildings with low energy demand with respect to the current building stock. A load sharing approach between a multifamily residential building and an office one is taken into account. Dynamic simulations are carried out in order to evaluate the thermo-economic performance of the analyzed system. Particular attention is given to the estimation of the electric load of the different users, as the economic profitability of a MCHP system is strongly influenced by the amount of self-consumed electricity. In order to analyze the influence of climatic conditions, two different geographical locations in Italy (Naples and Turin, having 1034 and 2617 heating degree days, respectively) are considered. The results of this study indicate that the installation of MCHP systems in buildings with low energy demand allows to increase the percentage of self-consumed electricity reducing the bidirectional electricity flow between the users and the external grid, as well as the impact on the grid itself due to the large diffusion of distributed generation systems.

Moreover this study shows that the load sharing approach between users with different load profile leads to better energy, environmental and economic results with respect to a conventional system. The climatic conditions play an important role on the MCHP operational hours and hence on the thermo-economic performance of the system. The primary energy saving of the system located in Turin is equal to 8.8% with respect to 6.2% of the system located in Naples. Also the environmental performance, evaluated in terms of equivalent CO_2 avoided emissions, are better in Turin (8.3%) than in Naples (6.7%). The economic analysis shows acceptable values of the pay-back period in presence of economic support mechanisms. The findings of this study show that the introduction of a MCHP system in load sharing approach leads to thermo-economics advantages even considering the lower heating needs of well-insulated buildings.

1. Introduction

The energy consumption in residential and commercial buildings represents around 40% of total final energy use of European Union, being responsible of 36% of total CO_2 emissions [1].

The European Union through the Directive 2010/31/EU [2] that integrates the 2002/91/EC [3] promotes the energy performance improvement in new buildings and existing ones that are subject to major renovation. Moreover the European Union is aware that the existing building stock represents the most important sector for potential energy savings, through the directive 2012/27/EU [4], and it established that the rate of building renovation needs to be increased.

The introduction of small scale cogeneration (MCHP, Micro Combined Heat and Power) in residential applications is a commonly investigated efficiency strategy to reduce energy use on the plant side. Different studies highlighted the advantages of a MCHP system in a typical residential building.

In Ref. [5] an investigation about the energy, economic and environmental feasibility of a microcogeneration system for residential application was performed by means of dynamic simulations, considering insulated residential buildings. The simulation results showed that the proposed system allows a reduction of primary energy consumption, carbon dioxide emissions and operational costs with respect to the conventional system. Nevertheless, the duration diagram of the space heating load highlights the small operational hours of the MCHP system at full load, that corresponds to maximum efficiency.

In Ref. [6] the authors investigated the performance of a CHP (Combined Heat and Power) system in residential sector in

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Nomenclature

ΔCO_{2eq}	avoided CO_{2eq} emissions (–)
CO_{2eq}	equivalent carbon dioxide emissions (kg)
g	total solar energy transmittance (or solar heat gain coefficient) (–)
PE	Primary Energy (kW h)
PES	Primary Energy Saving (–)
SPB	Simple Pay Back period (year)
U	overall heat transfer coefficient $W/m^2 K$

Acronyms

CCHP	Combined Cool Heat and Power
CHP	Combined Heat and Power
CS	Conventional System
DHW	Domestic Hot Water
IHE	Internal Heat Exchanger
MCHP	Micro Combined Heat and Power
PS	Proposed System
TES	Thermal Energy Storage
wd	week-day
we	week-end day

Canada, namely the feasibility of internal combustion engine based cogeneration system for single detached houses in comparison with traditional practices. They concluded that the performance of the cogeneration system depends on the thermal and electrical loads of the house. Moreover the climate, the duration of the heating season and the constructional characteristics of the house are important parameters.

The application of small scale hybrid CCHP (Combined Cool Heat and Power) systems is also considered in literature for residential and tertiary buildings. For example, in Ref. [7] the performance of a hybrid renewable microcogeneration system that consists of a reciprocating internal combustion engine, a solar device, absorption and electric chiller, was investigated, considering variable electricity prices scenario and three case studies, namely a ten-flat apartment building, an office and a hotel. The authors showed an energy savings of the proposed CCHP system between 20% and 30% with respect to separate production, as well as a pay-back period from 5 to 25 years.

In the near future the building envelope will be more energy efficient with higher level of insulation compared to the present building stock, due to more and more limiting constraints by the EU, that required Member States to implement in the next future nearly Net Zero Energy Buildings regulations. The reduction of the heating demand, due to the improvement of the thermal characteristics of the building envelope, requires a careful assessment of the benefits connected to the installation of MCHP systems in residential or tertiary sectors. In fact, the smaller thermal loads due to more isolated building lead to a reduction of the microcogenerator size, with negative effects on its energy efficiency and specific investment costs [8]. To compensate for this heat load reduction, a load sharing approach can be considered, where a thermal micro-grid is introduced, matching several type of users (residential, commercial, public buildings, etc.) in order to increase the cumulative thermal load and the operational hours of the MCHP system. In fact, as an example, the thermal load of residential users typically occurs in the evenings and early mornings, while for commercial users it occurs during the day time hours. By coupling these two users, a single common energy conversion system can be considered to satisfy their thermal energy requirements, with a higher size with respect to individual equipment. The application of microcogeneration in residential buildings with load sharing strategy has been addressed in some literature works.

In Ref. [9] a microcogeneration unit serving two users, an office building and a residential one, connected through a district heating micro-grid was investigated. Particular attention was paid to the choice of the users, in order to obtain more stable and continuous electric and thermal loads. The operation of the MCHP was governed by a control system, aimed to optimize a thermo-economic objective function. The paper showed how the introduction of a load sharing approach allows to increase the operational hours of the MCHP unit.

The load sharing approach was investigated also for small scale hybrid trigeneration systems. In Ref. [10] an algorithm oriented to optimize synthesis, design and operation of polygeneration systems including thermal energy storages and interconnected by a hot/warm fluid distribution network, serving with heat, cooling and electricity a cluster of buildings located over a small area, was discussed. A Mixed Integer Linear Programming algorithm allowed to optimize the design and operation of the tri-generation system.

In Ref. [11] the authors analyzed the energy performance of a MCHP system serving a cluster of several different buildings in Japan. Absorption and conventional electric chiller were used for cooling demand. Different operation modes and CHP capacities were tested for a cluster of an office building and a residential building. The reduction of primary energy consumption resulting from load sharing was between 1% and 9% when using biogas as primary energy source of the CHP and between 1% and 6% when using natural gas.

The same authors in Ref. [12] analyzed energy-sharing possibilities among four different buildings in Japan (office building, hotel, hospital and shopping center). The comparisons between the separate and shared cases showed that the advantages of energy-sharing cases depend on the type of combined buildings and on the CHP operational strategy.

In Ref. [13] the authors demonstrated the advantages of the load sharing approach and analyzed the energy, environmental and economic performance of two hybrid microcogeneration system in load sharing application.

From the literature review, there are several studies that highlighted the advantages of the introduction of small scale CHP and CCHP systems in residential and tertiary buildings. Very few of them investigated the introduction of a micro-grid to share the loads among different users, but there are no papers that analyze the introduction of MCHP systems, in load sharing approach, in buildings with high level of thermal insulation of the envelope. This new analysis is highly required to assess if the load sharing approach is effective in guaranteeing the energy, emissions and economic feasibility of small scale cogeneration even in buildings with higher level of thermal insulation with respect to the current building stock. A load sharing strategy between a multifamily residential building and an office one is taken into account in this paper. Dynamic simulations are carried out in order to investigate the thermo-economic performance of the analyzed system.

Moreover, the economic profitability of a MCHP system strongly depends on the amount of self-consumed electricity, therefore a further novelty of this manuscript is related to a sensitivity analysis performed with respect to the share of self-consumed