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Energy And Environmental Performance Analysis Of Biomass-fuelled Combined Cooling And Heating System For Commercial Building Retrofit: An Italian Case Study

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Abstract

This study focuses on the operating performance of a biomass boiler (100 kW) coupled with an absorption chiller machine at the service of a commercial building in central Italy. A detailed life cycle environmental assessment (LCA) was performed by comparing the biomass-fuelled system to conventional system, using the SimaPro software. To assess the environmental impact, experimental data, such as energy consumptions and emission factors of the biomass boiler, were used as input data. Biomass-fuelled system was found to have the lowest impact in cumulative energy demand (CED), global warming potential (GWP), and ReCiPe single score method.

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Keywords: Biomass heating and cooling (BHC); Absorption chiller; Life cycle assessment (LCA); Greenhouse gas (GHG) emission; Climate change; Environmental sustainability.

1. Introduction

The building sector is one of the major contributor to both energy consumption and environmental pollution in the EU, accounting for up to 40% of the European primary energy use and being responsible of 36% of European Union's total CO_2 emissions [1]. Several strategies can be employed to reach the energy consumption of the building

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life cycle, including the introduction of renewable energy systems based on biomass conversion technologies. The increase of biomass exploitation can contribute to the achievement of the European targets by 2020, in terms of environmental protection in energy production [2]. Bioenergy actually accounts for nearly 62% of renewable energy in the EU [3] and the European Environmental Agency foresees that the European Union primary energy requirement would be at 1.8 billion toe in 2020, 13% (or 236 million toe) of which would come from biomass contribution [4]. As a feedstock for heating and cooling production, biomass is characterized by several advantages over fossil fuels. It is widespread in many different areas and it can easily be stored, transported, and used in applications on site [3]. From the environmental point of view, biomass is considered to be a carbon neutral energy source, since the amount of the released carbon, during the energy conversion process, is similar to the amount absorbed during its life time [5]. However some environmental issues need to be evaluated in order to compare the overall impact of bioenergy to that of fossil fuels. The air emissions for instance of various pollutants, such as, NOx, CO, and particulate matter, during the use of biomass should be taken into account, representing a relevant environmental issue [6].

Global methodologies such as the Life Cycle Assessment (LCA) are appropriate tools to quantify the energy and the environmental impacts of products and services, and to compare the performance of different products or technologies that provide the same service [7, 8]. Although environmental monitoring is widely carried out by Environmental Agencies in urban areas in order to analyze the burdens and the consequences of combustion processes on human health and the ecosystem, only a few studies in the Literature employed a life cycle approach when focusing on wood biomass heating systems [6]. In particular, these studies evaluate the environmental impact of wood-based heating systems for the household sector, while, to best of our knowledge, no studies on the LCA biomass boiler units in industrial and commercial buildings have been yet reported in Literature.

The aim of the present work is to assess and compare the environmental burden of a biomass heating and cooling (BHC) system for a commercial building, located in Central Italy, with the stand-alone generation, based on fossil fuels. A BHC system satisfies space heating by a biomass boiler and space cooling by means of an absorption chiller coupled to the same biomass boiler. The system was investigated on annual basis, in terms of energy and environmental analysis. In particular, the energy consumption of the building for heating and cooling purposes was monitored during one year from January 2015 to December 2015.

2. Materials and methods

2.1 Case study description

The investigated heating and cooling system was developed in Sant'Andrea delle Fratte, the most important commercial/industrial estate in Umbria, in central Italy, characterized by massif use of fossil fuels for heating and cooling (methane is the most commonly used fuel for heating, whereas small split-units provide cooling), within the SCER (the Italian acronym for Development of a Renewable-Energy air-Conditioning Systems) research project. In the project, co-funded by the Italian Ministry for the Environment, two pilot systems were designed and set up in order to upgrade non-residential buildings with high-efficiency heating and cooling systems, which use a mix of renewable energy sources. In this work only the prototype plant with a BHC system was investigated [9, 10].

The investigated building has different conditioned zones: an exhibition room (318 m^2), offices and restrooms (60 m^2), a dealership (24 m^2), and a mechanic's workshop (about 158 m^2, 7 m high), for a total air-conditioned volume of about 2800 m^3. Before the renovation, mono-split air to air heat pumps were used for cooling in some zones, whereas a methane boiler with fan-coils and radiators provided heating. After the renovation, a boiler, coupled with an absorption machine, provides both heating and cooling, using local wood-based biomass: fan-coils (in the offices) and mixing air distribution systems (in exhibition room and mechanic's workshop) were used; moreover, a 83 kWp photovoltaic polycrystalline plant installed on the roof supplies energy to cover the absorption machine and other electrical appliance needs. The features of the new heating and cooling system are shown in Table 1. The system has been working since June 2013 and the performance has been monitoring via a custom data acquisition system. It can store all the variables registered by several sensors, such as: power and energy supplied to the hot water by the biomass boiler; exhaust temperature and flow/return water temperatures in the biomass boiler; temperature and pressure of the utility buffers; working temperatures and flow rates of the absorption machine, water consumption in