Applied Thermal Engineering 95 (2016) 330–338

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Energy, economic and environmental performance appraisal of a trigeneration power plant for a new district: Advantages of using a renewable fuel

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HIGHLIGHTS

- Trigeneration systems for district heating/cooling have been evaluated in terms of energy and economic performance.
- Two alternative power plant configurations were analyzed: engine fueled by natural gas and renewable vegetable oils.
- The investment for the power plant based on vegetable oils is very convenient.
- The environmental impact of vegetable oil-fired system on local air quality state is minimal.

ARTICLE INFO

Article history:
Received 24 June 2015
Accepted 6 November 2015
Available online 18 November 2015

Keywords:
Thermal power plant
District heating/cooling
Trigeneration
Environmental analysis

ABSTRACT

Renewable energy sources are becoming more and more vital around the word from the last decades, due to the limited reserves of fossil fuels and environmental matters. Starting from this consideration, this paper investigates the possibility to provide a new urban agglomeration in Naples (Italy) with power, heat and cooling, by a modern trigeneration plant. The study was performed for thermal and refrigeration needs of the planned settlements. The analysis was carried out considering two alternative schemes, both based on internal combustion engines: in the first system solution the engines are fueled by natural gas, in the second one, by renewable vegetable oils. Energy and economic evaluations were carried out in order to assess the pay-back period of the investment for the two different systems: the plant configuration based on a renewable energy source was more convenient and profitable. For this power plant solution, finally, an environmental analysis was performed in order to assess the impact of this power system on the territory surrounding the trigeneration plant: the effect on local air quality state was minimal. This environmental analysis was carried out using the Gaussian dispersion model ISC, that determines the pollutant concentrations due to a point emissive source.

1. Introduction

The consumption of energy is an ever-increasing trend mainly due to changes in life styles and significant growth of the population. Petroleum-based fossil fuels presently provide the major portion of the energy supply; but fossil fuels reserves are depleting at an alarming rate around the globe [1]. For this reason the development of innovative technologies for the use of alternative fuels is a stringent necessity, both to meet the energy demands, and to limit the production of carbon dioxides (CO_2), which is directly responsible for global warming. All over the world, about 40% of the total electricity generation is supplied by thermal power plants fueled by coal, and this guess is estimated to rise in the future [2] [3]. Therefore, the improvements of systems to rise the efficiency of coal-fueled power plants is central, because of the limited resources of fossil fuels and the increasing social sensibility to issues related to the air quality state in urban environment. From the viewpoint of sustainable development, the project of new thermal power plants as trigeneration systems that can produce both electricity and district heating/cooling energy would be a noteworthy step toward the better use efficiency of fossil fuels [4]. Besides, due to the increasing demand for energy and severe air pollution regulations worldwide, the study of alternative and renewable clean fuels is strategic in order to save significant amounts of fossil fuels and greenhouse gas emissions [5].

The paper deals with the design of technological systems for a new urban center rising on an old decommissioned industrial area in Naples (Italy). The possibility to plan a new settlement gives the opportunity to study a completely innovative energy plant to provide this converted area with electricity, heating and cooling.

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http://dx.doi.org/10.1016/j.applthermaleng.2015.11.017
1359-4311/

Currently all energy resources have an impact (in different ways and/or in different sites): this consideration leads to a growing necessity to respect the environment with a sustainable development and with a minimal impact. From this point of view, a desirable and feasible solution can be, at least, to increase energy efficiency, choosing more efficient power generation plants and a power plant able to produce both electricity and heating/cooling energy could be a profitable solution [6]. In conventional power plants, a large amount of heat is produced, but is generally not used: cogeneration is the simultaneous production of power and usable heat, starting from a conventional power plant, with a remarkable increase in terms of efficiency [7]. The "cogenerated" electricity and heat can be supplied to individual buildings or building complexes. The source of energy for district heating systems is usually a steam boiler, often fired by natural gas; heat is distributed by circulating piping hot water (or low pressure steam).

Particularly, the idea of the activity described in the present paper is a plant for combined production of power, heat and also cooling: a so called "trigeneration" plant [8]. While cogeneration is based on the use of a thermal engine to generate concurrently electricity and useful heat, trigeneration generally refers to generation of electricity and use of the waste heat for both heating and cooling, starting from the combustion of conventional or alternative fuels or from solar heat collectors. Heating and cooling output can be supplied simultaneously or alternately, depending on demand and type of plant [9,10,11,12].

For the new planning urban agglomeration in Naples, the idea is that office and apartment buildings, hotels and stores could generate their own power and use waste steam for building heating and cooling. This combined plant enables to cover all needs in terms of heat and cooling for the expected buildings of this new district. The project includes a proposal aimed to further reduce environmental impact: the use of alternative fuels feeding conventional engines. In fact, the proposed plant can be fueled by natural gas (in spark ignition engines) and/or renewable energy sources, such as pure vegetable oils (in compression ignition engines) [13,14,15].

The authors studied different configurations to evaluate different solutions, in terms of technical, economic, and environmental validity. The necessity is to satisfy the following requirements:

- Centralization of energy transfer net, serving the expected urban district by flexible plant strategies to reach significant energetic savings and reduction of gas emissions.
- Use of renewable sources replacing fossil fuel (methane).
- Reduction of costs to restore the old industrial area.
- Economic analysis of investment and evaluation of pay-back time.
- Evaluation of impact on local air quality by different plant solutions.

The paper deals with three main aspects of the project:

- Analysis of energetic requirements of the urban area.
- Analysis of technical/economic feasibility of the studied plants.
- Assessment of environmental impact (developed by Gaussian dispersion modeling) caused by installation in surrounding area.

2. Energetic requirements of the urban district

The first step to choose the most appropriate solution for the new urban center expanding on an old decommissioned industrial area in Naples is the evaluation of energy needs, appreciated according to typical values fixed by legislation (D. Lgs. 192/05, D. Lgs. 311/06). For this new urban agglomeration, details on building type and size were defined in order to calculate the heat/cooling load; for the offices, total volume and ventilation flow are 360400 m^3 and 505568 m^3/h, respectively, while for apartment buildings total volume and ventilation flow are 249100 m^3 and 292278 m^3/h, respectively.

Starting from these experimental data and data deduced from legislation, it was possible to build diagrams of heat/cooling load as function of time in the day and month in the year. These diagrams are shown in Fig. 1 and Fig. 2, and all the relevant calculation were performed on the basis of a self-developed software, in which load profiles for different kind of buildings are available, based on real-building data and on the technical and scientific literature. In these figures, cooling loads reflect losses for dissipation and ventilation. Heat loads also reflect hot water flow to be granted to users. The main results in terms of total thermal/cooling energy requests are shown in Table 1.

The total primary energy demand is around 145000 GJ/year, and was calculated starting from the following assumptions: average ef-

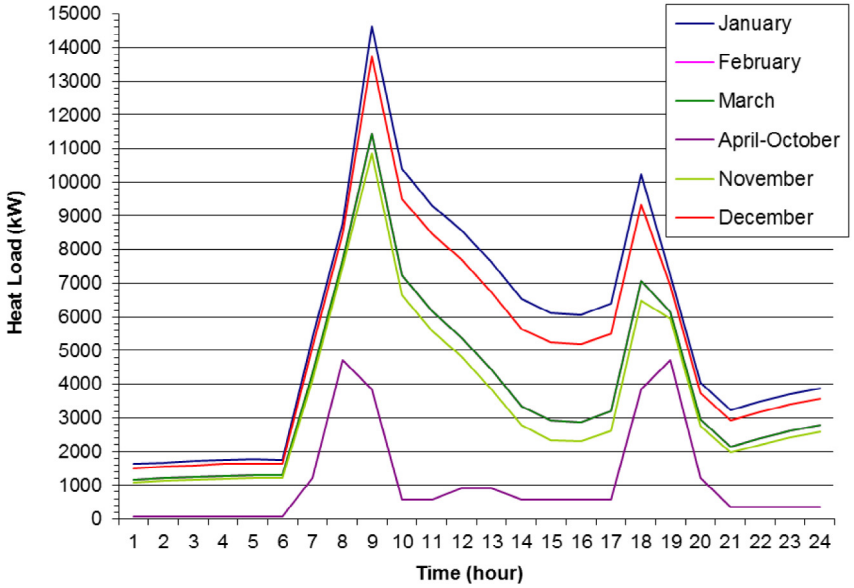

Fig. 1. Heat load as function of time and month.