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Environomic multi-objective optimisation of a district heating network considering centralized and decentralized heat pumps

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ABSTRACT

Concern for the environment has been steadily growing in recent years, and it is becoming more common to include environmental impact and pollution costs in the design problem along with construction, investment and operating costs.

To economically respond to the global environmental problems ahead, progress must be made both on more sustainable technologies and on the design methodology, which needs to adopt a more holistic approach.

Heat pumps and, in particular systems integrating heat pumps and cogeneration units, offer a significant potential for greenhouse gas reduction. This paper illustrates the application of a multi-objective and multi-modal evolutionary algorithm to facilitate the design and planning of a district heating network based on a combination of centralized and decentralized heat pumps combined with on-site cogeneration. Comparisons are made with an earlier study based on a single objective environomic optimisation of the same overall model.

1. Introduction

Heating represents an important fraction of modern society's energy needs and the replacement of existing heating systems with advanced, integrated solutions based on a combination of centralized and decentralized heat pumps (Fig. 1) has the potential to significantly reduce environmental pollution [1,2,3]. The continuing concern for energy efficient solutions has renewed interest in a design approach called *environomic analysis*[1], applied in this case to distributed heating and cooling [4,5,6].

Earlier work concerned the environomic analyses of highly efficient urban heating system using heat pumps and cogeneration units taking into account simultaneously the life cycle and environmental impact while meeting the required heating demand. Traditionally it has been the job of an experienced engineer to find a good solution, a process essentially of guided trial and error, that tends to favor conventional solutions. Curti's work [5,6] improved upon this by performing a single objective optimisation using a genetic algorithm (GA) [7], and minimising the total cost with and without internalisation of the external costs of the major emissions (NO_x, CO_2).

This new work has taken the process one step further by using multi-objective optimisation techniques to simultaneously optimise the separate cost and pollution criteria without combining them.

1.1. Aim of this work

Using the same simulation and superstructure (described below) as in the earlier work this project aimed to:

- reproduce the results of the previous work demonstrating the reduced solution time required with a new multi-objective optimisation algorithm called the *Clustering Pareto Evolutionary Algorithm* (CPEA) [8,9].
- investigate more thoroughly the solution domain using a byproduct of the CPEA.
- demonstrate the advantages of post processing low level optimisation results, rather than incorporating uncertain cost parameters in the optimisation process (and hence requiring multiple optimisation runs to investigate the importance of these parameters).
- look in more detail at the interaction of pollution with system configuration and the tradeoffs between different technology types.

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[1] Environomic is an expression combining environment, economics and thermodynamics.

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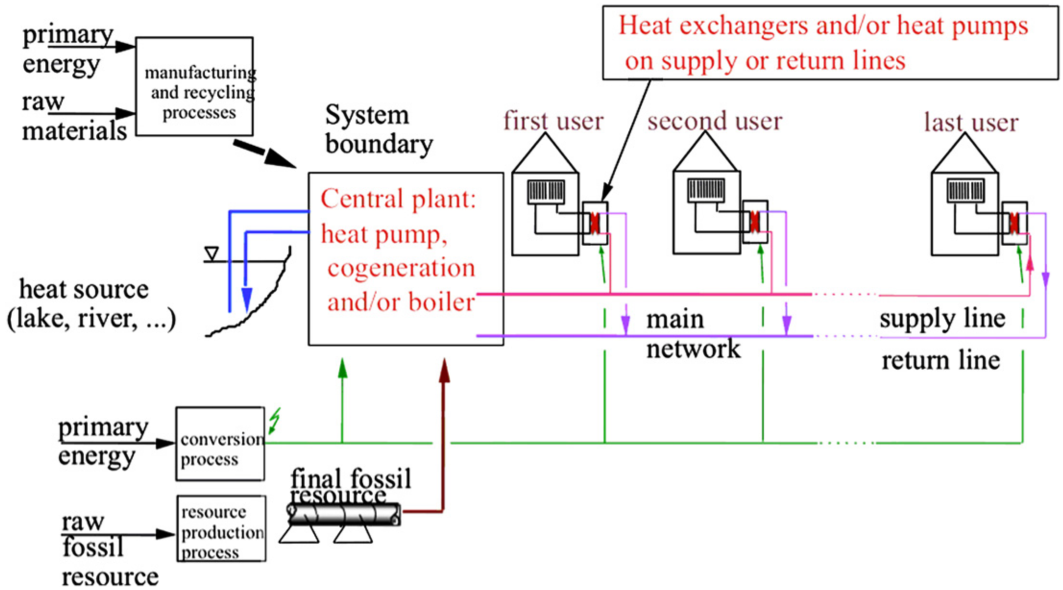

Fig. 1. Schematic layout of the overall network.

The following section describes the system considered and presents results comparing the performance of the new algorithm on the original single objective problem, followed by results and discussion on the results from the CPEA.

2. Description of the district heating system

2.1. Models and superstructure

Clearly, a district heating system must meet the demands of its clients. However, with a heat pump based central plant, adapting the delivery temperature to the most demanding client is frequently detrimental to the overall performance of the system when using centralised heat pump based plant. To avoid this a model was designed that could make use of decentralised heat pumps on the supply or return line of each user. Fig. 1 shows the overall schematic network layout.

The model *superstructure*, consisting of a central plant with a heat pump, two alternative cogeneration systems and an auxiliary furnace is shown in Fig. 2. The *users* are connected to the main network either with a heat exchanger or a local heat pump as shown in Fig. 3. The local heat exchangers and heat pumps may be connected either to the outbound or return lines introducing the potential for further reducing relative network costs. However in the simple network chosen in this paper the heat exchanger RL_HX and the heat pump RL_HP of Fig. 3 are not anymore considered in the user superstructure which is therefore limited to equipment supplied by the supply line only.

The model considers thermodynamic, economic and environmental aspects associated with the entire life cycle of a distributed heating system, beginning with the manufacture of equipment and energy sources, continuing with operation and ending with equipment removal. In [5,6,10] environmental characteristics of the system are internalised through the use of pollution factors that adjust the costs of damage due to pollutant emissions in construction, operation and decommissioning. Unfortunately the pollution factors depend in turn on constants that are either subjective or involve a high degree of uncertainty.

2.2. Central plant

The central plant superstructure consists of a combination of:

- a heat pump to upgrade heat from a low temperature heat source such as a lake
- a gas turbine cogeneration system to produce both heat and electricity
- an internal combustion gas engine cogeneration system producing both heat and electricity
- an auxiliary boiler directly producing heat.

To simplify the problem the network is arranged with users in series, with no branches, and is driven by an electric pump.

The pollution calculations are taken to include the pollution produced during the fabrication of the components, the preparation and transport of the primary fuel sources and the production of the electricity. Any mixture of pollution emission during the production of the bought electricity may be introduced into the model, but for consistency with [5,6] the work presented here dealt with only the *Swiss mix* (the Swiss mix of electricity consists mainly of hydro and nuclear with a low NO_x and CO_2 content).

Electricity could be bought from the national grid, or produced by the central plant for use internally or to supply users of the heating network but could not be sold back to the electricity grid.

2.3. Users

With the exception of the last user each has a superstructure as shown in Fig. 3. They consist of:

- a heat exchanger on the supply line
- a heat pump on the supply line
- a heat exchanger on the return line (except for the last user)
- a heat pump on the return line (except for the last user)
- two heat exchangers for domestic hot water at different temperature levels
- an auxiliary electric water heater for the domestic hot water demand that cannot be met by the hot water exchangers.