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Mapping energy and exergy flows of district heating in Sweden

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Abstract

District heating has been available in Sweden since the 1950s and used more than half of the total energy use in dwelling and no-residential premises in 2013. Energy and exergy efficient conversion and energy resources are key factors to reduce the environmental impact. It is important to understand energy and exergy flows from both the supply and demand sides. The exergy method is also a useful tool for exploring the goal of more efficient energy-resource use. Sankey diagrams together with energy and exergy analyses are presented to help policy/decision makers and others to better understand energy and exergy flows from primary energy resource to end use. The results show the most efficient heating method in current district heating systems, and the use of renewable energy resources in Sweden. It is exergy inefficient to use fossil fuels to generate low quality heat. However, renewable energies, such as geothermal and solar heating with relative low quality, make it more exergy efficient. Currently, about 90% of the energy sources in the Swedish district heating sector have an origin from non-fossil fuels. Combined heat and power is an efficient simultaneous generator of electricity and heat as well as heat pump with considering electricity production. Higher temperature distribution networks give more distribution losses, especially in exergy content. An outlook for future efficient district heating systems is also presented.

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Keywords: District heating, exergy, Sankey diagram, Grassmann diagram, Sweden

1. Introduction

District heating was introduced in 1948 and has been successfully expanded in Sweden since then. The district heating deliveries are mainly used to cover space heating and hot water demands in buildings, but have a low usage

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in the industrial processes. Currently, about 58% of total building heat demands for residential and service sector premises are covered by district heating [1].

Both the exergy concept and Sankey diagrams are used as tools for visualizing energy quality processes in this study. The exergy concept gains insights into its efficiency as well as the quantitative measure of quality, and the diagrams were used for mapping energy and exergy supplies, transformations and uses during 2014. Sankey diagrams together with energy and exergy analyses are presented to help policy/decision makers and others to better understand energy and exergy flows from primary energy resource to end use. The combined methods have been applied for national levels in a country [2-5] and industrial heating processes [6], as well as in company levels in industry [7]. To our knowledge, there is currently no exergy flow analysis available for a national district heating sector. The purposes of this paper are to:

- map energy and exergy flows from primary energy sources to customer usages in the Swedish district heating systems
- show the most efficient heat supply methods in current Swedish district heating systems
- visualize the utilization of renewable energy resources in Sweden.
- give an outlook for more efficient district heating systems in Sweden

2. Method

2.1. Exergy analysis

Exergy is a measure of how far a certain system deviates from equilibrium with its environment, a given state of reference or equilibrium. In this analysis, the average outdoor temperature is used as reference temperature T_0, and 100 kPa as reference pressure.

The exergy of material substances can be calculated as [8]:

$$E = \sum n_i(\mu_i^0 - \mu_{i0}^0) + RT_0 \sum n_i \ln \frac{c_i}{c_{i0}} \tag{1}$$

where n_i is the number of moles of different chemical materials *i*. μ_i^0 and c_i are the chemical potential and concentration of substance *i* in relation to its standard state. μ_{i0}^0 and c_{i0} are the chemical potential and concentration for the substance in the environment in relation to its standard state. R is the gas constant, 8.314 J mol^{-1} K^{-1}.

The exergy factor is defined as the ratio of exergy *E* to energy *Q*. The exergy factor of energy transferred as heat at a constant temperature *T*, i.e., a heat reservoir becomes [8]:

$$\frac{E}{Q} = \left| \frac{T_0 - T}{T} \right| \tag{2}$$

Heat used for space heating and domestic hot water was calculated by Equation 2. The exergy factor of district heat was calculated as [8]:

$$\frac{E}{Q} = 1 - \frac{T_0}{T_s - T_r} \ln \frac{T_s}{T_r} \tag{3}$$

where T_s is the temperature of the supplied heat, i.e., the temperature of the hot water used by the consumer for space heating. T_r is the temperature of the return water.

Table 1 lists some energy forms used in this study. The exergy factors for fuel are based on lower heating values (LHV), which are the data available in Swedish energy statistics. It must be noted that some factors are only approximate due to unknown moister and exact content. The exergy factor for current district heating grid is the average value for Swedish district heating system [9], and the outdoor temperature has a strong effect on the heat at