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Advanced low exergoeconomic (ALEXERGO) assessment of a building along with its heating system at various stages

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ABSTRACT

The present study deals with evaluating the performance of a building heating system along with its main components using advanced low exergoeconomic analysis method. This method combines advanced exergoeconomic with low exergy (LowEx) and is shortly called ALEXERGO. A building heating system is investigated from the energy production to the building envelope stage by stage through the ALEXERGO for the first time by the authors. Based on the results, the generation and distribution stages are found to have bigger exogenous exergy destruction cost rates, meaning that the components in these stages have strong interconnections. The emission (heating) stage has, however, a bigger endogenous exergy destruction cost rate. The generation and emission stages have low improvement potentials while the distribution stage has a big improvement potential. A sensitivity analysis is also made based on the environmental temperature for exergy destruction rates and efficiencies.

1. Introduction

Increasing the energy efficiency in all sectors has been one of the important issues due to the growing concern of environmental problems. In this regard, efficient energy supply for buildings, building complexes and districts has been considered one of main focusing areas based on exergetic principles to coordinate and optimize demand and supply aspects in cities [1]. The Low exergy (LowEx) approach is the concept for the work of ECBCS Annex 49 on energy use and supply structures in the built environment [2]. It has been successfully utilized for analyzing and assessing buildings at various states, such as primary energy production, energy storage, heating/cooling system, building envelope [3].

Exergoeconomic analysis is a combination of exergy and economic analysis methods. It provides the system designer with the information, which is not obtained from conventional exergy and economic assessments. Exergoeconomic analysis method includes cost balances and means for costing exergy transfers and several exergoeconomic variables used in the optimization of the design of thermal systems.

Exergoeconomic is based on the exergy costing principle. A system and its components are investigated for their entire lifetime. All related costs are considered. These are depreciation, return on debt and equity, taxes and insurance, fuel costs and operating and maintenance expenses. The real cost sources in a system include capital investment for each component, operating and maintenance expenses, cost of exergy destruction and cost of exergy loss from the overall system [4].

There are various types of exergoeconomic analysis approaches and methods in the literature. In this context, Rosen and Dincer [5] used several examples to explain general concept of energy, cost, exergy and mass (EXCEM) analysis. In that study, they applied the EXCEM analysis to three components, which were a pump, a steam turbine and a coal fired electricity generator. To calculate cost rates, investment cost and depreciation factor were used. Exergy loss rates of the boiler and the generator turbine were found to be 48.5 MW and 10.2 MW, respectively. Hürdoğan et al. [6] constructed and tested a desiccant cooling system. The EXCEM analysis was applied to the system. Thermodynamic losses, capital costs and their relations were investigated. Electric heater unit, expansion valve, pump, fresh air fan and condenser fan were determined as inefficient unlike other components of the system. Improvement

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potential rates and ratios of thermodynamic loss rate over capital cost varied between 23.72–26.78 kW and 1.14–1.19 MW/US$. Yucer and Hepbasli [7] examined a building heating system by using exergetic and exergoeconomic analysis methods. They combined the LowEx with the exergoeconomic method to investigate the system performance. The stages in the building heating system and the components in these stages were analyzed. The EXCEM analysis was applied to the building heating system. The ratio of thermodynamic loss rate over cost for the generation stage and the steam boiler were calculated as 4.52 W/US$ and 19.77 W/US$, respectively. In another study, the specific exergy costing (SPECO) method was applied to a building along with LowEx method [8]. The exergetic results of the building heating system stages and their cost figures were combined. The exergetic cost coefficients of the generation and emission stages were reported to be 174.67 $/GJ and 256.89 $/GJ, respectively.

In the advanced exergy analysis, the exergy destruction term is divided into certain parts. These are endogenous, exogenous, avoidable and unavoidable. Avoidable/unavoidable exergy destruction concept was presented by Tsatsaronis and Park [9]. Endogenous/exogenous exergy destruction concept was described by Kelly et al. [10]. Morosuk et al. [11] evaluated a LNG regasification and electricity generation system with advanced exergoeconomic and exergoenvironmental methods. They suggested that the focus should be on compressor III and expander II to improve cost effectiveness. Açıkkalp et al. [12] analyzed a trigeneration system by applying the advanced exergoeconomic analysis. The important parameters of the system were exergy efficiency, total exergy destruction, total exergoeconomic factor of the system and electricity generating cost. These were calculated as 0.354, 16.695 MW, 0.069 and 56.249 $/GJ, respectively. The exergy destruction and investment cost values were obtained in four parts (i.e., endogenous, exogenous, avoidable and unavoidable). The results found according to the exogenous part were greater than those of the endogenous part. The improvement potential for the investment flow rate was considered as weak because 88% of them were unavoidable. Açıkkalp et al. [13] also performed advanced exergy analysis of an electricity generation facility. The exergetic efficiency of the system and total exergy destruction rate were calculated to be 0.402 and 78.242 MW, respectively. According to the results of the advanced exergetic and exergoeconomic analyses, the combustion chamber, the high pressure steam turbine and the condenser were the components with the highest potential for improving the system. Those components had the highest exergy destruction cost rates. Keçebaş and Hepbasli [14] compared conventional and advanced exergoeconomic analyses to find potential for energy savings of a geothermal district heating system. The SPECO method was utilized. The conventional and advanced exergoeconomic factors were obtained to be 5.53% and 9.49%. The largest exergy destruction and endogenous exergy destruction cost rates were calculated to be 63.67 $/h and 41.83 $/h. Tan and Keçebaş [15] analyzed a geothermal heating system using advanced exergy and exergoeconomic methods. They determined the improvement potential and cost saving potential of the system were 2.98% and 14.05%, respectively. Keçebaş et al. [16] compared two geothermal district heating system using advanced exergoeconomic method. They concluded that the Sarayköy plant could be operated more economic than the Afyon plant. Khoshgoftar Manesh et al. [17] evaluated a cogeneration system with advanced exergoeconomic and exergoenvironmental methods. In addition to these analyses, malfunction and dysfunction analyses may be applied to various energy systems by considering the thermoeconomic analysis [18,19].

The main objective of this contribution is to apply advanced exergoeconomic analysis to a heating system, which was investigated stage by stage through the LowEx method. In this paper, both the conventional and advanced exergoeconomic analyses are presented in a detailed manner. There are several studies investigating building heating systems by using exergoeconomic analysis. To the best of the authors' knowledge, this is the first attempt that the advanced exergoeconomic analysis and LowEx methods are combined to examine a building heating system.

2. Advanced exergoeconomic analysis

Before making an advanced exergoeconomic analysis, a conventional exergoeconomic analysis has to be done, of which equations are indicated in Table 1.

Endogenous and exogenous parts are described to determine the reasons for the irrevesibilities. The endogenous part presents irreversibilities resulted from the component itself while the exogenous part gives irreversibilities based on other components. The endogenous exergy destruction cost rate, the exogenous exergy destruction rate, the endogenous investment cost rate and the exogenous investment cost rate are calculated as follows, respectively [20]:

$$\dot{C}^{EN}_{D,k} = c_{F,k}\dot{E}^{EN}_{D,k} \quad (1)$$

$$\dot{C}^{EX}_{D,k} = c_{F,k}\dot{E}^{EX}_{D,k} \quad (2)$$

$$\dot{Z}^{EN}_{k} = \dot{E}^{EN}_{k}\left(\frac{\dot{Z}}{\dot{E}_P}\right) \quad (3)$$

$$\dot{Z}^{EX}_{k} = \dot{Z}_k - \dot{Z}^{EN}_{k} \quad (4)$$

where $\dot{E}_P$ is the product exergy and $\dot{Z}$ is the investment cost of the component. For describing the improvement potential of the components, avoidable and unavoidable parts are used. The unavoidable part represents technological and economical limits of the component while the avoidable part indicates improvable potential of the considered component. The rates for the avoidable exergy destruction cost, the unavoidable exergy destruction cost, the avoidable investment cost and the unavoidable investment are calculated from [21]:

$$\dot{C}^{AV}_{D,k} = c_{F,k}\dot{E}^{AV}_{D,k} \quad (5)$$

$$\dot{C}^{UN}_{D,k} = c_{F,k}\dot{E}^{UN}_{D,k} \quad (6)$$

$$\dot{Z}^{AV}_{k} = \dot{Z}_k - \dot{Z}^{UN}_{k} \quad (7)$$

$$\dot{Z}^{UN}_{k} = \dot{E}_{P,k}\left(\frac{\dot{Z}_k}{\dot{E}_{P,k}}\right)^{UN} \quad (8)$$

The avoidable and unavoidable exergy destruction cost rates are divided into the endogenous and exogenous parts, which are defined here as follows [20]:

$$\dot{C}^{UN,EN}_{D,k} = c_{F,k}\dot{E}^{UN,EN}_{D,k} \quad (9)$$

$$\dot{C}^{AV,EN}_{D,k} = c_{F,k}\dot{E}^{AV,EN}_{D,k} \quad (10)$$

$$\dot{C}^{UN,EX}_{D,k} = c_{F,k}\dot{E}^{UN,EX}_{D,k} \quad (11)$$

$$\dot{C}^{AV,EX}_{D,k} = c_{F,k}\dot{E}^{AV,EX}_{D,k} \quad (12)$$

The avoidable and unavoidable costs are divided into the endogenous and exogenous parts, as defined below [21]:

$$\dot{Z}^{UN,EN}_{k} = \dot{E}^{EN}_{P,k}\left(\frac{\dot{Z}}{\dot{E}_P}\right)^{UN}_{k} \quad (13)$$

$$\dot{Z}^{UN,EX}_{k} = \dot{Z}^{UN}_{k} - \dot{Z}^{UN,EN}_{k} \quad (14)$$

$$\dot{Z}^{AV,EN}_{k} = \dot{Z}^{EN}_{k} - \dot{Z}^{UN,EN}_{k} \quad (15)$$