Energy and Buildings 86 (2015) 366–375

Contents lists available at ScienceDirect

Energy and Buildings

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

Artificial neural networking model of energy and exergy district heating mony flows

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ARTICLE INFO

Article history:
Received 14 July 2014
Received in revised form 22 July 2014
Accepted 25 September 2014
Available online 28 October 2014

Keywords:
District heating
Exergy mony flow
District heating plant
Heating costs
Matlab
Heat consumer
Artificial neural networking

ABSTRACT

This paper describes a computation model using an artificial neural network (ANN) for a thermoeconomic analysis of district heating (DH) mony flows (MF). The model will compute the results of the MFs in accordance with an energy method or a caloric method and an exergy method at various DH substations. A heat distributer is unable to ensure the same quality of heat to all consumers due to the length of the network. A consumer nearest to the heat source receives heat of a higher quality than the last consumer. As the DH heat is usually calculated using the MF energy method, the available heat quantity that can actually be converted into another form of energy is not taken into account in the calculation. The above indicated deviations, however, are taken into consideration in the calculation of heating costs in accordance with the MF exergy method, giving a more realistic picture of the heating cost evaluation. Considering the first law analysis of thermodynamics, the amount of energy consumed is calculated disregarding the difference between work and heat. The analysis and design of engineering systems based on only the first law is not adequate [1].

1. Introduction

Thermoeconomics deals with the analysis of the costs related to energy conversions [1]. Cost balances (like mass and energy balances) are used for an economic analysis comparing the cost flows, i.e. monetary values per unit of time [2]. Exergoeconomics is based on the exergy costing principle, which states that exergy is the only rational basis for assigning monetary values to energy streams and to the thermodynamic inefficiencies within the system [3,4]. Energy and exergy analysis are well-established methods, used to investigate thermal systems [5]. The Matlab–Simulink software tool will be used to design a model to provide the results on the quality of heat for the DH substations located at different sites by means of a pre-trained ANN. Training an ANN involves the provision of real data obtained from the DH unit in Slovenija [6]. The data on the heat quality of the DH substations will be used for the calculation of the mony flows using energy and exergy methods. ANN modeling of various energy systems has been recently studied by numerous researchers [7–10].

A DH system is a consumer-, environment- and heat producer-friendly heating system, supported by the European Energy Performance of Building Directive (EPBD) [11]. DH systems have the potential to contribute to the renewable energy targets [12]. DH utilizes heat in an energy efficient way and has the potential to exploit a wide spectrum of low exergy sources like the waste heat and the renewable energy [13]. In many countries, DH has been actively promoted as an important component in the national strategic energy planning [14,15]. A large DH system is cost-effective for both a heat producer and a consumer, as the system can use various heat sources (waste incineration, biomass, waste heat from thermal power plants), contributing to more favorable costs of heating.

The purpose of designing the MF thermoeconomic analysis model is to identify any discrepancies between the energy and exergy heating cost calculation methods, how this impacts a heat consumer and which consumer would pay more or less for heating. Identification of heating cost discrepancies between the consumers is the main objective. The goal of any consumer is that their heating bills comprise the actual energy received to be used or converted into another form of energy.

2. Methods

Initially, a DH model scheme was designed integrating 5 heat consumers. The heat consumers are located in an order, namely from consumer 1, which is nearest to the heat source (a district

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http://dx.doi.org/10.1016/j.enbuild.2014.09.075
0378-7788/

Nomenclature

Abbreviations

ANN	artificial neural networking
EPBD	European Energy Performance of Building Directive
DH	district heating
MF	mony flow

Parameters

C	specific heat, 4.181 kJ/kg K
E	specific exergy, kJ/kg
Ex	exergy power, kW
$\dot{m}$	mass flow rate, kg/s
$\dot{M}$	mony flow
Q	specific energy, kJ/kg
R	correlation coefficient
T	temperature, K, °C
W	power, kW

Subscripts and superscripts

cq	heat consumer
en	environment
er	error
E	exergy method
in	inlet
j	iteration
$MAPE$	mean absolute percentage error
$MEAN$	mean value
MSE	mean square error
n	steps
out	outlet
p	pattern
Q	energy method
RMS	root mean square
t	target value
x	model output

heating plant) to consumer 4 or the last DH heat consumer. Fig. 1 shows the diagram of consumers. The quality of heat supplied to the consumers is conditional upon the ambient temperature. The data on the quality of heat supplied to the selected consumers (Fig. 1) complies with the analysis indicated in Ref. [16].

Consumer 1 receives heat of the best quality and consumer 4 of the worst quality. A median consumer median is a neutral consumer, which means that the energy and exergy MFs are identical. The cost of heating of the median consumer will not be different in the MF thermoeconomic analysis. The monetary value of exergy was obtained by taking into account the monetary value of 0.07 per kW in accordance with the energy method of the median consumer to calculate the equivalent of monetary value in accordance with the exergy method, amounting to 0.3656 per kW. As a result, the DH median consumer is the initial consumer of the MF model.

In order to facilitate the illustration of the results the fact that all consumers consume the same amount of heat at the same time, which, however, varies depending on ambient temperature, was taken into consideration in the model. Using the MF model results obtained the mean values will be computed of the heating cost in accordance with the energy and exergy method and the average deviations in the period analyzed will be indicated.

3. DH MF model

The DH MF model comprises a main model and 6 sub-models. The main model provides the results and integrates the sub-models into a unit, whereas the sub-models compute the desired values. The first sub-model represents an ANN which, using the ambient temperature input data, computes the consumer heat quality. The other subprograms, however, represent the heat consumers. Fig. 2 shows the architecture of the model main program.

3.1. ANN sub-model

The ANNs represent the best model of brain neurons at a microscopic level, whereas as a broad concept, this is a model of a complex system, in which a large number of identical elements react to signals in relation to each other. These are mathematical models that imitate the structure and functionality of biological neural networks. The essential characteristic of the ANNs is that during the learning process they are capable of finding a rule connecting the input data with the output data. When an ANN is trained it also functions in situations it has not encountered in the training process, i.e. it can also resolve the tasks where no solution exists in the form of a sequence of steps (such as in computer algorithms), although a risk of unpredictable functioning exists.

The ANN learning is carried out in three steps (training, volition and test) with the models used from the real world. On the basis of input data, an ANN sets the weights on the connections to be

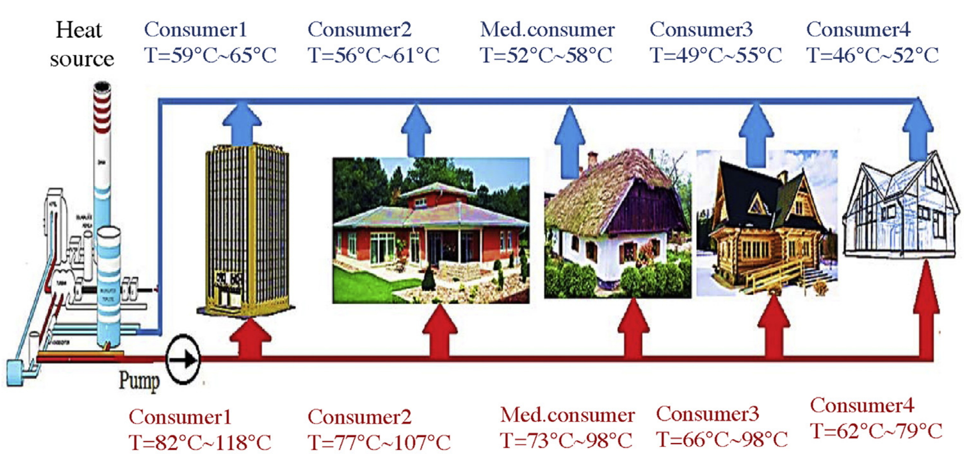

Fig. 1. Consumer model diagram.