Energy Conversion and Management 75 (2013) 74–85

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

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

Development, validation and application of a fixed district heating model structure that requires small amounts of input data

Magnus Åberg *, Joakim Widén

Department of Engineering Sciences, Uppsala University, Box 534, SE-751 21 Uppsala, Sweden

ARTICLE INFO

Article history:
Received 2 March 2013
Accepted 13 May 2013

Keywords:
District heating
Buildings
Energy efficiency
Energy system modelling
CHP
Heat demand

ABSTRACT

Reducing the energy use of buildings is an important part in reaching the European energy efficiency targets. Consequently, local energy systems need to adapt to a lower demand for heating. A 90% of Swedish multi-family residential buildings use district heating (DH) produced in Sweden's over 400 DH systems, which use different heat production technologies and fuels. DH system modelling results obtained until now are mostly for particular DH systems and cannot be easily generalised. Here, a fixed model structure (FMS) based on linear programming for cost-optimisaton studies of DH systems is developed requiring only general DH system information. A method for approximating heat demands based on local outdoor temperature data is also developed. A scenario is studied where the FMS is applied to six Swedish DH systems and heat demands are reduced due to energy efficiency improvements in buildings. The results show that the FMS is a useful tool for DH system optimisation studies and that building energy efficiency improvements lead to reduced use of fossil fuels and biomass in DH systems. Also, the share of CHP in the production mix is increased in five of the six DH systems when the heat demand is reduced.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

The European Union (EU) has set energy efficiency goals of reaching a primary energy use 20% below the predicted level until 2020 [1]. In 2010 the EU launched a recast of the directive on the energy performance of buildings (2010/31/EU), which requires that new residential buildings shall be nearly zero-energy buildings by 2020 [2]. These energy efficiency policies indicate that the domestic demand for heating in buildings will be reduced in the coming years, and that the building energy supply systems need to be adapted to a future lower energy demand. Heat demands in buildings are, in general, large contributors to the total national energy demands. In Sweden about 24 % of the total energy demand was heat for space heating (SH) and domestic hot water (DHW) in 2009 [3]. A significantly reduced heat demand in buildings is therefore an important part in reaching the energy efficiency targets.

In the Northern, Central and Eastern European countries district heating (DH) is a common infrastructure to supply heat for DHW and SH [4]. DH is a local heat distribution system where hot water or steam is produced in a central facility and distributed in an underground pipe network to consumers. Multi-family residential buildings receive 50% of the total Swedish annual DH deliveries [5] and 90% of the Swedish multi-family residential buildings use DH for DHW and SH [6]. An important characteristic of DH is that heat production facilities vary significantly between different DH systems. Heat may be produced in for example heat-only (HO) boilers, heat pumps or combined heat and power (CHP) plants, and the fuels used may be fossil fuels, biomass, household waste or electricity. In addition, waste heat from industrial processes can be utilised as "free" heat in DH systems. These differences on the supply side mean that the environmental impact and sensitivity to energy market dynamics vary significantly between different DH systems. Thus, although DH in many cases causes less carbon-dioxide net emissions than other heating options, it is not by definition a uniform source of energy.

When it comes to energy efficiency improvements in buildings supplied by DH there is a concern, mainly from DH utilities, that deliveries and revenues for Swedish DH companies will be adversely affected [7]. Less heat will be purchased by the existing users and the possibilities to expand and increase the number of customers is limited due to the already high market share for DH. The Swedish DH demand is expected to decrease by up to 20% until 2025 [8] and the DH utilities might need to compensate for this market loss by more cost-efficient heat production, finding alternative use for DH, such as industrial processes, or complementing deliveries of district cooling (DC) [7]. The impact that a reduced heat demand would have on the DH systems has been previously investigated, using cost-optimisation models, for the

* Corresponding author. Tel.: +46 18 4717232.
E-mail address: magnus.aberg@angstrom.uu.se (M. Åberg).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.05.032

current DH systems in the Swedish municipalities Uppsala [9] and Linköping [10,11], which have DH systems with a large share of CHP production. The results for both systems show that heat demand reductions due to building energy efficiency improvements mainly affect high demand periods and reduce use of expensive fossil fuels and heat-only production. In Linköping heat demand reductions mainly affected the heat-only production units in the system and in Uppsala the operation time of the peat fuelled CHP plant was reduced. Evidently, a reduced heat demand due to building energy efficiency improvements might have positive environmental impact on DH system operation and may reduce average heat production costs.

Most studies made until now are for particular DH systems and cannot be easily generalised. In addition, the models for the Uppsala and the Linköping systems mentioned above are complex and detailed and require in-depth knowledge about the DH systems. Stating anything in general, for example for the whole of Sweden, would require a method that provides simple and efficient modelling of DH systems from easily available statistics and data. There are several energy system optimisation modelling tools that have been used for cost-optimisation of DH system operation. Examples include MODEST[12] and MIND [13], in which the predominant models are for individual DH utility systems and require detailed input data for the included system components. On the other hand, there are studies focusing on analysis of the Swedish DH sector on an aggregated national level, but with a very generalised and aggregated approach. MODEST has been used for a cost optimisation study of the Swedish power system and Swedish DH was represented as a part of the model on an aggregated form [14,15]. The HEATSPOT DH simulation model presented in [16] describes all Swedish DH systems separately and presents the results in an aggregated form.

In this paper a general fixed model structure (FMS) for cost-optimisaton studies of DH systems based on linear programming is developed and implemented in MATLAB [17]. The FMS enables modelling of DH systems on the level of heat production processes, but still requires few input parameters, meaning that several DH systems can be modelled in a relatively short time. This gives the opportunity to perform several parallel DH systems optimisation studies and to aggregate the results in order to yield generally valid results for DH. The FMS has unlimited flexibility in time-period length and number of time-periods since optimisations are performed separately for each time-period. This means that for example full-year optimisation on an hourly basis is possible and hourly fluctuations in heat demand and electricity price can be captured. Input data can be approximated from easily available and general DH system information. The FMS model is validated against model results from the MODEST optimisation tool and to test the usefulness of the FMS model, six Swedish DH systems are modelled using data from annual reports and websites. The six models are also used to study the impact of heat demand reductions due to energy efficiency measures in residential buildings on the fuel use and heat production in the studied systems. This impact is measured by the use of different fuels, the electricity-to-heat output ratio of a system and the amounts of generated electricity and heat. Also, in order to yield hourly heat demand input data for the FMS model, a method for approximating heat demands using easily available local outdoor temperature data is developed and validated.

The article is structured as follows. Section 2 describes the FMS, used mathematical relations and the necessary input parameters. In Section 3 the input data for the models are presented as well as the heat demand approximation method. In Section 4 the validation of the FMS DH models is presented and in Section 5 the FMS application and results for the heat demand reduction scenario are described. Discussion and conclusions are included in Sections 6 and 7, respectively. When nothing else is stated, heat demand in this work corresponds to required heat production unit output, i.e. not building heat demand. This means that heat distribution losses are included in the heat demand.

2. The fixed model structure (FMS)

This section describes the structure and the mathematical relations that define the FMS that was developed and implemented in MATLAB. The necessary input data (DH system plants and network, production costs, electricity prices and energy demands) are also presented.

2.1. General model structure

An overview of the fixed model structure is shown in Fig. 1. The structure consists of 17 nodes (boxes) representing the components of the system. The arrows that interconnect the nodes represent the different energy flows in the system (fossil fuel, bio fuel, waste, heat/steam and electricity). The node column to the far left in Fig. 1 consists of three fuel nodes for three fuel categories (fossil fuel, biomass and waste). The fuels are categorised so that all fossil fuels used in DH systems (for example oil, coal and natural gas) and all biomass fuels (for example treetops and branches, wood pellets, bio oil and wood chips) are represented collectively in single nodes. This limits the complexity of the model and facilitate the process of collecting input data. Domestic household waste is represented in a separate node because waste is associated with a negative fuel cost due to the reception fee paid to Swedish DH companies for waste treatment.

The second node column from the left in Fig. 1 consist of fuel-to-energy conversion nodes. These nodes represent the heat production units of the system. The conversion nodes are categorised in correspondence with the fuel categories. This means that one node does not necessarily represent one single boiler, depending on whether there is more than one HO boiler or CHP plant using a similar fuel within the system. In some systems this also means that one single conversion node represents several production units. The ‘‘Heat pump’’ node in the mid-right node column is also a conversion node representing a heat producing unit that uses electricity from the electric grid for heat production. This node can be used to represent electric heat pumps and electric HO boilers. The IWH node in the figure represents possible utilisation of industrial waste heat (IWH).

To the right in Fig. 1 the distribution nodes, heat demand node and electricity market nodes are shown. Electricity can be both sold and purchased on a market. There is no electricity demand node since the local electricity demand does not have to be met by local electricity generation, as is the case for the DH demand. Also, possible district cooling demands are for simplicity not included in the FMS since it is in general small compared to the heat demand. The ‘‘Heat Waste’’ node is an end node that represents the possibility to waste heat, which can be useful when electricity is generated in CHP plants or household waste is incinerated while heat demand is low.

2.1.1. Linear programming

To find the cost-optimal operation of the system in the general model it is formulated as a linear programming (LP) problem. Linear programming is generally used to find the maximum or minimum value of a linear function constrained by linear relations. A linear program consists of an objective function that is to be minimised or maximised under certain given constraints. The objective function can be described as

Download English Version:

https://daneshyari.com/en/article/7166128

Download Persian Version:

https://daneshyari.com/article/7166128

Daneshyari.com