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Review

Integration of storage and renewable energy into district heating systems: A review of modelling and optimization

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ABSTRACT

The building and infrastructure sector is accountable for 46% of the total worldwide energy consumption. Most traditional energy sources such as coal or petroleum are among the non-renewable types and most likely to be depleted in the forthcoming decades. To address the current energy crisis, use of renewable energy such as solar sources and a considerable increase in energy efficiency are proposed as the potential solutions. District heating systems (DHS), in particular, has recently received more attention due to several advantages in energy production, distribution and consumption for the space heating.

This paper reviews the recent advancements in the energy production, modelling and optimization of the DHSs. A classification of energy sources is presented in terms of their sustainability and ease of integration to a DHS. Current modelling methods are further compared with respect to computational limitations, level of precision as well as the degree of certainty in the output level. Moreover, the recent studies of DHS are classified in accordance with the optimization objectives, including energy/exergy efficiency, cost, exergo-economic/thermo-economic and green-house gas (GHG) and pollutant production.

Contents

Abbreviations: CPEA, clustering pareto evolutionary algorithm; DHS, district heating system; DH, district heat; DHW, domestic hot water; CHP, combined heat and power; GHG, green-house gas; COP, coefficient of performance; GDHS, geothermal district heating systems; HOB, heat-only boilers; MSW, municipal solid waste; LSDHS, large-scale district heating systems; LTDHS, low temperature district heating systems; SH, space heating; DDM, degree-day method; ANN, artificial neural network; SVR, support vector regression; SPECO, specific exergy and cost method; MILP, mixed integer linear programming; MINLP, mixed integer non-linear programming; NSGA, non-dominated sorting genetic algorithm; GIS, geographic information system; O&M, operation and management; RE, renewable energy; BIGCC CHP, biomass integrated gasification combined cycle combined heat and power plant; GA-ANFIS, hybrid genetic algorithm adaptive network-based fuzzy inference system; MRA-ANN, multi resolution analysis artificial neural network; CFB, circulation fluidised bed combustion; CCGT CHP, combined-cycle gasification turbine combined heat and power plant; NGCC CHP, natural gas combined-cycle combined heat and power plant; APF, advanced pulverised fuel; WtE, waste to energy and; TSP, thermal solar plant; 3GDHS, third generation district heating system; 4GDHS, fourth generation district heating system.

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1. Introduction

Sustainable development is the ability to supply current population needs without preventing future generations to sustain theirs (Brundtland, 1987). Most traditional forms of energy such as coal, petroleum and natural gas are non-renewable sources of energy and will be depleted in a near future (Li et al., 2011a,b). Use of renewable energy and an increase in energy efficiency are two essential solutions to address the current energy crisis (Keçebaş, 2013).

In the building sector, 46% of the total worldwide energy demand can be attributed to heating and cooling (IEA, 2012). In addition to the availability of non-renewable energy forms, environmental impacts associated with power production from these non-renewable energies stresses the development of more efficient and sustainable heating/cooling and energy distribution strategies. District heating systems (DHS) have shown to be a promising technology to address sustainability in building-related energy production and distribution (Laajalehto et al., 2014).

Many countries have already benefited from a rapid growth in the number of the DHS installed in the recent years (Ancona et al., 2014). In many cities, the requirements for space heating (SH) and domestic hot water (DHW) can be entirely supplied by the DHS. Fig. 1 shows the percentage of district heating utilized in Europe by 2012. Many long and short term plans have also been developed to fully take advantage of renewable energy sources. An example is a plan in Denmark to employ100% of the energy demand from the renewable sources (Li et al., 2011a,b). In addition to energy efficiency, DHS helps to minimize a number of safety and fuel transportation issues due to the absence of any combustion system for the space heating at the end-user level. The absence of boilers also elevates the available usable floor area. Moreover, individual users restrain from dependency on installation and maintenance of boilers, furnaces, chillers and/or air-conditioning (Gopalakrishnan and Kosanovic, 2014).

DHS implementation, nonetheless, requires a high level of management, especially in regions with a high share of renewable energy systems, e.g. Germany, Sweden and Denmark, where most end-users have to remain connected to the electrical grid in order to import/export excess electricity during the fluctuation of power and heat demand in the operation period (Gopalakrishnan and Kosanovic, 2014). Furthermore, optimization of costs is necessary to justify fluctuations in heating and electricity consumption in accordance with in-peak and off-peak tariffs from electrical distribution companies (Gopalakrishnan and Kosanovic, 2014).

DHS are extensively reviewed in the past years; Rezaie and Rosen (2012) reviewed DHS in terms of technology and potential enhancements; Lund et al. (2014) discussed 4th generation of DHS (4GDHS); Xu et al. (2014) reviewed available seasonal thermal energy storage technologies; Hepbasli (2010) reviewed energetic, exergetic and exergoeconomic aspects of geothermal DHS (GDHS); Cheng and Hu (2010) discussed municipal solid waste use in DHS; Tabasova et al. (2012) analyzed waste-to-heat impacts on the environment; Harris (2011) reviewed thermal energy storage in Sweden and Denmark; BCS (2008) reviewed waste heat recovery in the U.S.; Novo et al. (2010) reviewed basin thermal energy

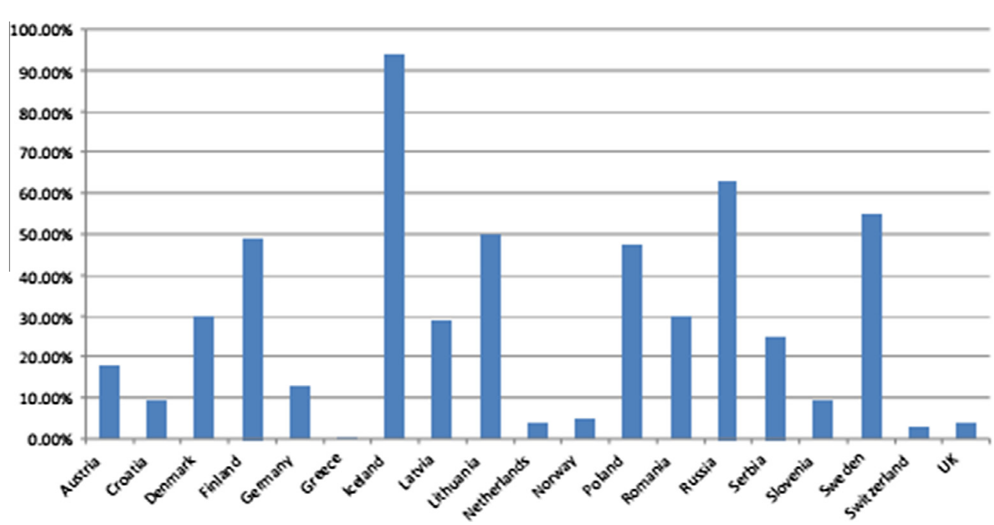

Fig. 1. Share of low temperature heat demand in Europe currently met by DHS (Andrews et al., 2012).