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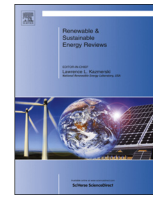

Combined cooling, heating and power systems: A survey ☆

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ABSTRACT

The combined cooling, heating and power (CCHP) system – a typical representative of the decentralized energy system – has been increasingly attracting attention in academia and industries in recent years, thanks to its distinctive advantages of high system and economic efficiency, and less greenhouse gas (GHG) emissions. In this paper, the state of the art of CCHP research is surveyed. First, the development and working scheme of the CCHP system will be presented. Some analyses of the advantages of this system and a brief introduction of the related components are then given in the first part. In the second part of this paper, we elaborately introduce the prime mover and thermally activated facilities. Recent research progress on the management, control, system optimization and sizing will be summarized in the third part. The development of the CCHP system in representative countries and the development barriers will be discussed in the last part.

Contents

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1. Introduction

With the rapid development of distributed energy supply systems [1–4], combined heating and power (CHP) systems and combined cooling, heating and power (CCHP) systems have become the core solutions to improve the energy efficiency and to reduce greenhouse gas (GHG) emissions [5–9]. The CCHP system is an extended concept of the CHP system, which has been widely utilized in large-scale centralized power plants and industrial applications [10]. CHP systems are developed to conquer the problem of low energy efficiency of conventional separation production (SP) systems. In SP systems, electric demands, which include daily electricity usage and electric chiller usage, and heating demands are provided by the purchased electricity and fuel, respectively. Since no self-generation exists in SP systems, they are proved to be of low efficiency; however, in CHP systems, most of the electric and heating demands are provided simultaneously by a prime mover together with a heat recovery system, a heat storage system, etc. Energy demands beyond the system capacity can be supplied by the local grid and an auxiliary boiler. If introducing some thermally activated technologies, e.g., absorption and adsorption chillers, into the CHP to provide the cooling energy, the original CHP system evolves to be a CCHP system [11], which can also be referred to as the *trigeneration* system and building cooling heating and power (BCHP) system. Since there is no need for cooling energy from cooling system generally in winter, the CHP system can be regarded as a special case of the CCHP system. A CCHP system can achieve up to 50% greater system efficiency than a CHP plant of the same size does [12].

A typical CCHP system is shown in Fig. 1. The power generation unit (PGU) provides electricity for the user. Heat, produced as a by-product, is collected to meet cooling and heating demands via the absorption chiller and heating unit. If the PGU cannot provide enough electricity or by-product heat, additional electricity and fuel need to be purchased to compensate for the electric gap and feed the auxiliary boiler, respectively. In this way, three types of energy, i.e., cooling, heating and electricity, can be supplied simultaneously.

Compared with conventional generating plants, the advantages of a CCHP system appear in three-fold: high efficiency, low GHG emissions and high reliability.

First, the high overall efficiency of a CCHP system implies that less primary fuel is consumed in this system to obtain the same amount of electric and thermal energy. In [10], the authors give an example to show that, compared with the traditional energy supply mode, the CCHP system can improve the overall efficiency from 59% to 88%. This improvement owes to the cascade utilization of different energy carriers and the adoption of the thermally activated technologies. As the main electricity source, the PGU has an electric efficiency as low as 30%. By implementing the heat recovery system, the CCHP system can collect the by-product heat to feed the absorption/adsorption chiller and heating unit to provide cooling and heating energy, respectively. By adopting the absorption chiller, no additional electricity needs to be purchased from the local grid to drive the electric chiller in summer, but only the recovered heat is used. In winter, a CCHP system degenerates to be a CHP system. The high efficiency of the CHP system is investigated in [13–20]. In a nutshell, a CCHP system can dramatically reduce the primary consumption and improve the energy efficiency.

The second advantage involved in the CCHP system is the low GHG emissions. On the one hand, the trigeneration structure of the CCHP system contributes to this reduction. Compared with SP systems, if within the capacity limitation of the prime mover, no additional electricity needs to be purchased from the local grid, which is supplied by fossil-fired power plants. It is well known that, even though the penetration of some types of renewable energy, e.g., the wind, tide and solar energy, increases significantly

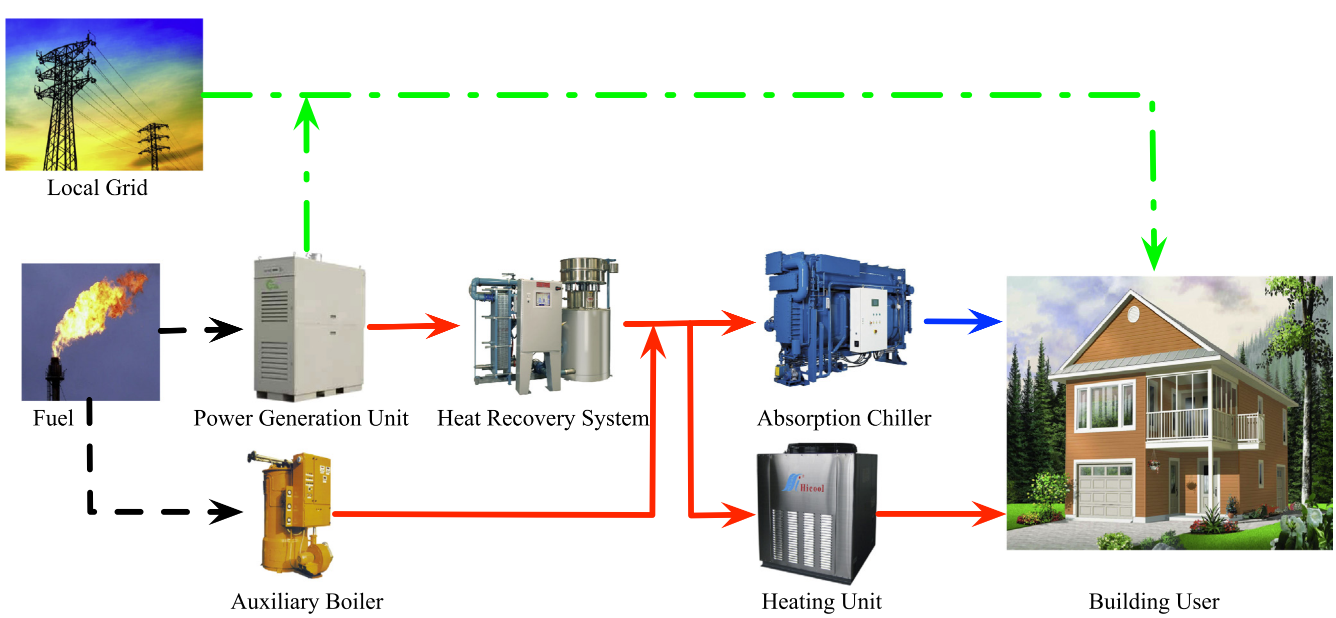

Fig. 1. A typical CCHP system.