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Combined cooling, heating and power: A review of performance improvement and optimization

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HIGHLIGHTS

- A review on combined cooling, heating, and power (CCHP) systems is presented.
- Energetic and exergetic methods to improve CCHP performance are discussed.
- Optimization techniques used to improve CCHP performance are reviewed.
- The most current research and emerging trends in CCHP technologies are presented.
- Gaps in the current CCHP research and development are discussed.

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ABSTRACT

This paper presents a review on combined cooling, heating, and power (CCHP) systems. This work summarizes the methods used to perform energetic and exergetic analyses, system optimization, performance improvement studies, and development and analysis of CCHP systems, as reported in existing literature. In addition, this work highlights the most current research and emerging trends in CCHP technologies. It is envisioned that the information collected in this review paper will be a valuable source of information, for researchers, designers, and engineers, and provides direction and guidance for future research in CCHP technology.

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1. Introduction

Traditional power plants convert about 30% of the fuel's available energy into electric power [1]. The majority of the fuel energy content is lost at the generation facility through waste heat. Further energy losses occur in the transmission and distribution of electric power to individual users. Inefficiencies and environmental issues associated with conventional power plants provide the thrust for developments in "on-site" and "near-site" power generation. Combined cooling, heating, and power (CCHP) systems[1] have the potential to increase resource energy efficiency and to reduce air pollutant emissions dramatically. CCHP systems produce both electric and usable thermal energy on-site or near site, converting 75–80% of the fuel source into useful energy [2]. CCHP systems typically require only ¾ the primary energy separate heat and power systems require [1].

International Energy Agency (IEA) [3] reported in 2007 that CHP systems produce approximately 9% of global power generation. The global capacity of CHP systems is estimated at around 330 GWe[2] [4]. The total installed CHP systems capacities of 37 countries are listed in Table 1. According to IEA's scenario [4], the G8+5 countries[3] have the potential to raise their CHP systems capacity almost 430 GWe in 2015, and over 830 GWe in 2030. In the U.S., the total CHP systems capacity in 2012 is estimated 82 GWe [5]. European CHP systems potential studies indicate that the total capacity in Europe can be raised to within the range of 150–250 GWe by 2025 [3].

The application of CHP systems also has great potential to reduce carbon dioxide emissions: IEA [4] reported that CHP systems can potentially reduce CO_2 emissions arising from new generation by more than 4% (170 Mt/year)[4] in 2015, while in 2030 CO_2 reduction could improve to more than 10% (950 Mt/year) which is equivalent to one and a half times of the total annual emissions of CO_2 from power generation in India. By 2030 the implementation of CHP systems has the potential to reduce CO_2 emissions in the U.S. by 70 Mt/year for buildings and 80 Mt/year for industries [6]. In Europe, CHP systems have been estimated to have been responsible for 15% of greenhouse gas emissions reductions (57 Mt) between 1990 and 2005 [4].

A typical CCHP system for a building consists of a power generation unit (PGU) working together with HVAC (heating, ventilation, and air conditioning) components, such as absorption chillers, cooling towers, and air handling units (AHUs). A variety of PGUs can be used in CCHP systems: micro-turbines, internal combustion (IC) engines, external combustion engines, fuel cells, etc. Fig. 1 illustrates a schematic of a CCHP system. As shown in the figure, Fuel (F_{PGU}) is supplied to the PGU, and it produces electric energy (El_{PGU}) and rejects heat as a byproduct, normally wasted in many applications. This electric energy is used to power appliances and lights in the building ($El_{building}$) and to operate auxiliary cooling and heating components (El_{comp}). If the PGU does not generate enough electricity to satisfy the demand, the difference (El_{grid}) can be imported from the electric grid (EG). El_{PGU} and El_{grid} can be stored using batteries and super-capacitors, when necessary. On the other hand, if the PGU generates more electricity than needed, the excess electricity (El_{excess}) can be exported or sold to the EG in locations where this is option is available. The recovered waste heat (Q_{rcv}) from the PGU is used to produce cooling or heating (Q_{cool} or Q_{heat}) to satisfy the building cooling and heating loads. If the heat recovered from the PGU is not enough to fulfill the thermal energy requirements of the building, a boiler is used to offset the deficit heat (Q_{boiler}). Q_{rcv} and Q_{boiler} can be stored using thermal energy storages if necessary.

This paper presents a review on the methods used to perform energetic and exergetic analyses, system optimization, performance improvement studies, and development and analysis of CCHP systems, highlighting the most current research and emerging trends in CCHP technologies.

[1] CCHP originally stands for combined cooling, heating, and power. In the literature, CCHP is also referred to by various names for slightly different applications such as CHP (combined heat and power), CHCP (combined heating, cooling, and power), BCHP (building cooling, heating, and power), DER (distributed energy resources), cogeneration, and trigeneration. Throughout the study, CCHP is used to refer to applications of combined cooling, heating, and power for Buildings.

[2] Gigawatt-electric (GWe) is one billion watts of electric capacity.

[3] The G8+5 countries consist of G8 (Group of Eight) nations including Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States and 5 nations of the leading emerging economies including Brazil, China, India, Mexico and South Africa.

[4] Megaton (Mt) is one million tons. Gas emissions are often expressed in terms of megatons.