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The Contribution of Thermal Energy Storage to The Energy Efficiency of Combined Cooling, Heating, and Power Systems

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Abstract

Combined cooling, heating, and power (CCHP) is considered a promising technology. Because thermal demand varies strongly with time (and can even be discontinuous), the power generation in CCHP systems can be inefficient and significant heat can be wasted. This paper proposes incorporating thermal energy storage (TES) in CCHP systems (CCHP-TES). TES can balance heating, cooling, and power loads. Authors describe several mathematical models for CCHP system components – TES, heat-recovery devices, auxiliary heating and cooling devices – and for criteria used to evaluate system evaluation performance. Authors assess the impact of adding TES to CCHP systems by analyzing simulated performance of an office building in Beijing, China. The simulation models use heating and cooling load profiles for a whole year as well as for peak summer and winter days. Using the primary energy consumption ratio and energy-savings rate (ESR) as indicators of the different performances of the CCHP system with and without TES, authors found that the ESR of CCHP-TES compared with CCHP is 6.4 % greater under winter operating conditions and 8.7% greater under summer operating conditions. Authors conclude that incorporating TES improves the energy efficiency of CCHP systems. Our research provides guidance for designing and retrofitting CCHP systems to benefit from TES.

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Keywords: CCHP, CCHP-TES, Primary energy consumption ratio (PECR), energy-savings rate (ESR)

1. INTRODUCTION

Combined heating, cooling, and power system is widely used because it`s efficient and reliable. CCHP systems are generally composed of a power system, waste-heat recovery, and auxiliary heating and cooling components. Qu Shilin

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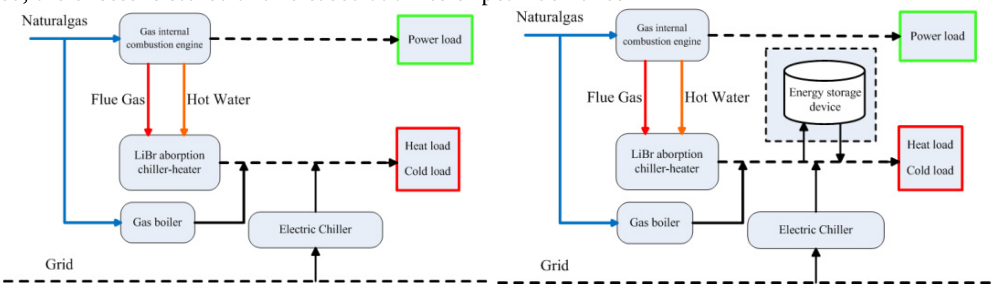
et al. [1] found that the techno-economic performance of CCHP systems is superior to that of other types of systems. Heating, cooling, and power load generally change seasonally, so CCHP systems have to operate under varying load conditions. The asynchrony of heating or cooling and power load compromises the efficiency of electricity generation and results in waste heat. Lei Wang [2] analyzed the performance of a CCHP system with energy-storage devices under full- and part-storage scenarios. To estimate the impact of thermal energy storage (TES) on system efficiency, authors performed a comparative analysis of the energy efficiency of CCHP systems with and without TES.

2. METHODS

Schematic drawings of the two systems, CCHP and CCHP-TES, are shown in Fig.1 (a) and (b) respectively. The systems are composed of a gas internal combustion engine, a lithium bromide (LiBr) absorption chiller-heater, a gas boiler, an electric chiller, and an energy-storage device (a water tank). The high temperature and high-pressure gas produced by natural-gas combustion push the system's generator to generate electricity. At the same time, exhaust is discharged, which the absorption chiller-heater units use to produce cooling or heating. Electricity is purchased from the power grid if the power produced by the system is insufficient. If the recovered thermal energy is not enough to meet cooling or heating demand, the auxiliary heating and cooling device are used for peak shaving. Or, if waste heat is produced, the excess is stored and released at times of peak demand.



(a) System without energy storage device; (b) System with energy storage device.

Figure.1. System Sketch Maps of CCHP and CCHP-TES.

The mathematical model of the internal combustion engine can be simplified as follows [3]:

$$\begin{cases} P_{GE} = p_1 E_{GE} + q_1 \\ Q_{flue} = p_2 E_{GE} + q_2 \\ Q_{water} = r E_{GE} + s \end{cases} \tag{1}$$

where P_{GE} is the gas engine power output (kW), E_{GE} is gas engine fuel input calorific value (kW), Q_{flue} is available residual heat of the flue gas discharged from the gas engine (kW), Q_{water} is the gas engine jacket water residual heat (in kilowatts [kW]), and p_1, p_2 , q_1 , q_2 , r , s are gas engine performance parameters.

Two criteria are used to evaluate the CCHP systems: an absolute index and a relative index [4]. PER (primary energy ratio) is the ratio of primary energy authors used to the energy authors got. This is an absolute index. Authors use ESR (energy saving rate) to compare the primary energy consumption of the CCHP and CCHP-TES systems. Therefore, ESR is a relative evaluation index. For peak summer and winter days, the PECR and ESR of CCHP and CCHP-TES system are analyzed separately.