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# Laboratory research on combined cooling, heating and power (CCHP) systems

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ABSTRACT

Combined cooling, heating and power (CCHP) systems offer the potential for a significant increase in fuel use efficiency by generating electricity onsite and recycling the exhaust gas for heating, cooling, or dehumidifying. A challenge for CCHP system is the efficient integration of distributed generation (DG) equipment with thermally-activated (TA) technologies. The China Ministry of Science and Technology and Tsinghua University launched the 863 Hi-Tech Program in 2007 to focus on laboratory and demonstration research to study the critical issues of CCHP systems, advance the technology and accelerate its application. The research performed at the Building Energy Research Center (BERC) Laboratory focuses on assessing the operational performance and energy efficiency of the integration of current DG and TA technologies; developing and verifying mathematical models of the individual devices and all the systems.

The test laboratory is a flexible test-bed for the configuration of DG (presently a 70-kW natural gas-fired internal combustion engine (ICE) with various heat recovery units, such as an flue gas-to-water heat recovery unit (FWRU), a jacket water heat recovery unit (JRU), liquid desiccant dehumidification systems (LDS), an exhaust-gas-driven double-effect absorption heat pump (EDAHP), and a condensation heat recovery unit (CRU)). In the winter, the exhaust gas from the ICE is used in the FWRU or used to drive the EDAHP directly, and the exhaust gas from the EDAHP is used in the CRU. The water flows from the CRU can be directed to the evaporator side of the EDAHP as the low-grade heat source. The water flows from the condensation side of the EDAHP, in conjunction with the jacket water flows from the JRU, is used for heating. In the summer, the exhaust gas from the ICE is used to drive the EDAHP for cooling directly, the exhaust gas from the EDAHP is bypassed to the exit via automated damper controls. The waste heat of the jacket water is used to drive the liquid desiccant dehumidification systems, to realize the separate control of heat and humidity. The automated damper is used in order to test various configurations and operating modes.

The testing results show that the operating parameters and efficiencies of the overall system depend on different configurations. Under certain combinations of CCHP, the efficiency of the overall system can be as high as 90% (based on lower heating value of the natural gas).



## 1. Introduction

Distributed generation (DG) technology is becoming more reliable and prevalent because of the losses reduction on transmission and distribution lines by placing the generator next to the load. Recent developments in DG technologies have opened new opportunities for relatively small-scale combined cooling, heating and power (CCHP) systems that can be used in buildings. The CCHP system is always the combination of DG with thermally-activated (TA) technologies which could recover the waste heat for cooling or heating. The CCHP, in conjunction with other energy efficient building technologies, will maximize the efficiency of energy use, reduce harmful emissions to the environment, improve power quality and reliability compared with large central power plants [1].

The University of Maryland's Center for Environmental Energy Engineering has worked closely with DOE's Oak Ridge National Laboratory, and carried out a great deal of research. Two different CHP systems are studied, and some test and research results based on these two systems have been reported [2–6]. In China, CHP technology is still a promising energy conversion technology under development for application [7]. Typical examples can be found at the Shanghai Huangpu Central Hospital, Pudong International Airport, the Beijing Gas Company building and Tsinghua University [8,9]. But until now, there have been no reports of any detailed research on their performance. The China Ministry of Science and Technology, cooperated with Tsinghua University, launched the 863 Hi-Tech Program in 2007 to focus on laboratory and demonstration research to study the critical issues of CCHP systems, advance the technology and accelerate its application.

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**Nomenclature**

| | | | |
|---|---|---|---|
| AHP | absorption heat pump | $Q$ | heating/cooling capacity (kW) |
| CCHP | combined cooling, heating and power | $\rho$ | density of water (kg/m$^3$) |
| CHE | condensation heat exchanger | $G$ | volumetric flow rate (m$^3$/s) |
| COP | coefficient of performance | $t$ | temperature (°C) |
| CRU | condensation heat recovery unit | $W$ | electric power (kW) |
| CT | cooling tower | $M$ | mass flow rate of the air (kg/s) |
| DAS | data acquisition system | $r$ | latent heat of vaporization (kJ/kg) |
| DES | distributed energy system | $\omega$ | humidity ratio (kg/kg) |
| DG | Distributed generation | $h$ | enthalpy (kJ/kg) |
| EDAHP | exhaust-gas-driven double-effect absorption heat pump | | |
| FWRU | flue gas-to-water heat recovery unit | *Subscripts* | |
| ICE | internal combustion engine | e | electric |
| JRU | jacket water heat recovery unit | fa | fresh air |
| LR | liquid regenerate unit | o | out door air |
| LD | liquid desiccant unit | s | supply air |
| LDS | liquid desiccant dehumidification systems | in | inlet |
| LHV | lower heating value of natural gas | out | outlet |
| NG | natural gas | | |
| $C_P$ | specific heat (kJ/kg °C) | | |

A laboratory for testing CCHP was commissioned at Building Energy Research Center (BERC) Laboratory. The scope of the facility is to test DG in combination with TA technologies for optimum waste heat recovery and overall energy efficiency. The objectives of the laboratory include collection of performance data on current DG and TA technologies both individually and operated as an integral part of an CCHP systems, development of models of different devices and verification of an system model based on integrated operation.

## 2. System and equipment

The CCHP system in the laboratory (Fig. 1) is the combination of a gas-powered internal combustion engine (ICE) with other heat recovery units, including a jacket water heat recovery unit (JRU), an flue gas-to-water heat recovery unit (FWRU), liquid desiccant dehumidification systems (LDS), an exhaust-gas-driven double-effect absorption heat pump (EDAHP), and a condensation heat recovery unit (CRU). The ICE, JRU, FWRU, EDAHP are all located on the basement of the building, and the liquid regenerate machine and liquid desiccant unit are located on the roof and second floor of the building, respectively.

The 70 kW natural gas-powered ICE, has six cylinders with four strokes, which is designed to operate at a rated speed of 1500 rpm, a rated voltage of 400 V. The high-frequency power produced from the ICE is converted to 50 Hz 3-phase electric power through power conditioning device. In the winter, the exhaust gas from the ICE can either be routed to the FWRU or used to drive the EDAHP directly, and the exhaust gas from the EDAHP is used in the CRU. The water flows from the CRU which recovered the condensation heat of the exhaust gas can be directed to the evaporator side of the EDAHP as the low-grade heat source. The water flows from the condenser side of the EDAHP, in conjunction with the hot water flows from the JRU, is used for heating. In the summer, the exhaust gas from the ICE is used to drive the EDAHP for cooling directly, the exhaust gas from the EDAHP is bypassed to the exit. The cooling tower (CT) is used. The waste heat recovered from JRU is used to regenerate the liquid, and the regeneration stream

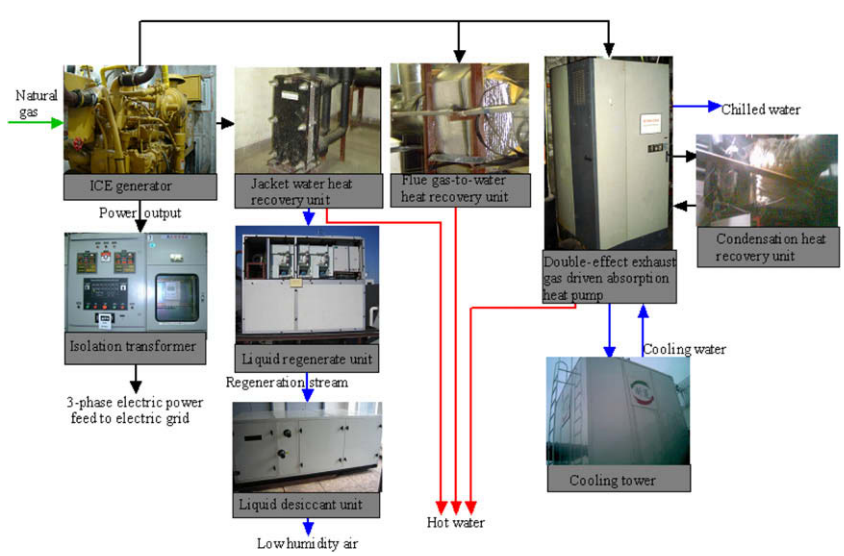


**Fig. 1.** CHP Laboratory at Building Energy Research Center.