Use of BCHP System in a Super High-rise Building in China

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Abstract

According to US Department of Energy, combined cooling, heating and power systems are potentially 70-85 per cent more efficient in utilizing fuels when compared with the 30-51 percent of central power plant. However, Building Cooling Heating and Power (BCHP) system design and application requires detailed system evaluation and optimization analysis. Factors to be considered in design and engineering review for an integrated BCHP system will be discussed and elaborated in this paper with reference to a super high-rise building in Shanghai. In this reference project, the preliminary results of life cycle cost analysis revealed that adoption of integrated BCHP system in a building may have around 4 years simple payback and achieve positive return on the investment after around 11 years.

1. Introduction

Sustainable and green building designs are the trend of building projects all over the world. Due to rapid economic growth, China is now facing the challenge of insufficient power supply and booming infrastructure development. In addition, on top of stringent statutory energy performance requirements in China, Clients' are also demanding for value-added and energy conservation building design to enhance building image and attract potential tenants. As a result, application of integrated building energy saving systems in China is growing to cater for the urgent need of energy saving and environmental protection [1].

Building Cooling, Heating and Power (BCHP) is building energy supply system that produces cooling, heating and electricity simultaneously from a single primary energy source [1]. The goal of using BCHP is to improve system efficiencies or source fuel utilization by availing of the low grade heat that is a by-product of the power generation process for heating and/or cooling production [2]. According to US Department of Energy, combined cooling, heating and power systems are potentially 70-85 per cent more efficient in utilizing fuels when compared with the 30-51 percent of central power plant [3]. However, BCHP system design and application requires detailed system evaluation and facility scheme optimization analysis. Otherwise, BCHP system may be worse than conventional energy supply system, and failure projects have occurred in China [1]. This paper aims to highlight major factors to be considered while carrying out design for an integrated BCHP system with gas engines, absorption chillers, electric chillers, ice storage system, gas-fired steam boilers and geo-thermal heat pump for a super high-rise reference building in Shanghai.

2. Background of the Building and the Integrated BCHP System

The reference building is a mixed use super high-rise building located in one of the fast growth city in China. The building consists of Grade A+ office, luxury 5-star plus hotel, entertainment, retails, conference and cultural venues. The proposed building height will be over 600m and total gross floor area will be around 500,000m^2. The prime building services system design objectives of this building are to achieve highest system efficiency and reduce source energy consumptions. The project team has a common goal to achieve "Gold" rating in LEED Certification of US Green Building Council and "Green 3-Star" award presented by the China Green Building Committee.

At this planning stage, there are two thermal energy centres in the building. They are located at low and high zones of the building respectively. The tentative integrated BCHP system consists of 2 gas engines, 2 absorption chillers, 3 electric chillers, 3 ice chillers, 4 gas-fired steam boilers and 1 geo-thermal heat pump is the heart of the low zone thermal energy centre. A simplified system schematic of the tentative integrated BCHP system is shown in Figure 1 below.

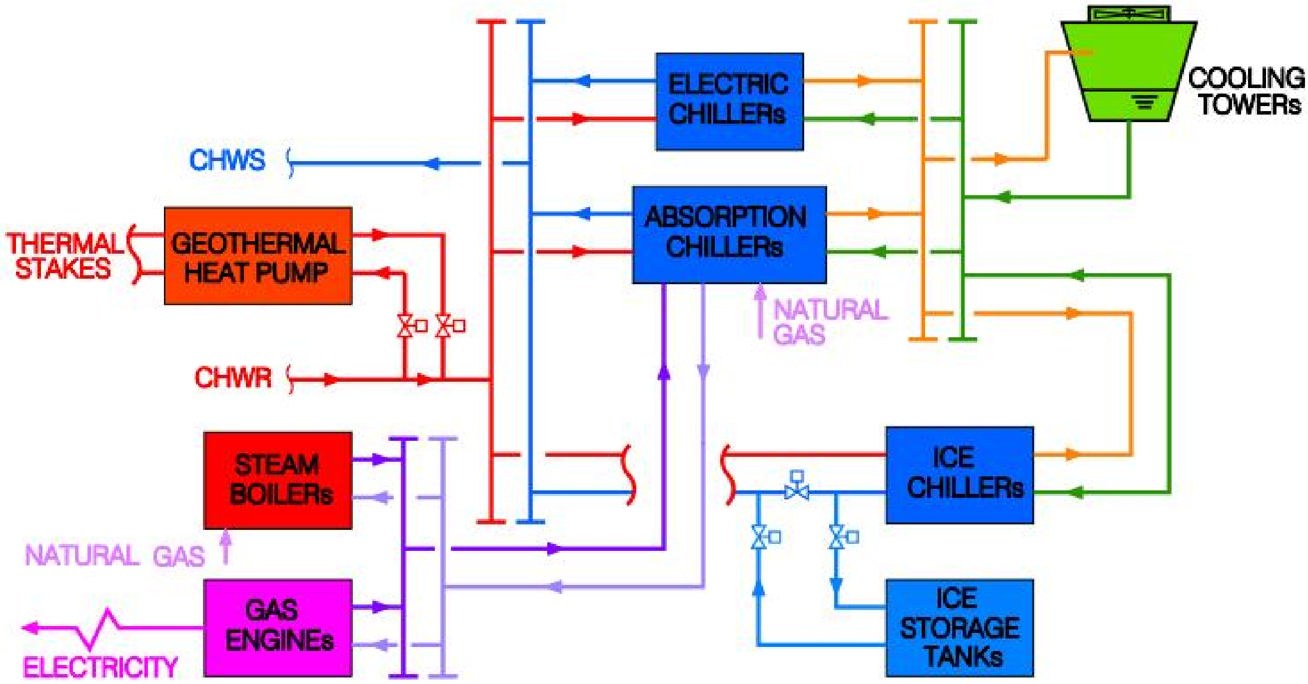

Figure 1 – Simplified Schematic Diagram of an Integrated BCHP System

In principle, gas engines convert natural gas to mechanical energy or directly to electrical energy and produces thermal energy. Absorption chillers or heat recovery devices will then utilize the available waste heat energy to generate cooling and heating energy for the low zone of the building. On top of the above, the BCHP system will integrate with features such as ice storage and geo-thermal heat pump systems to trim down the peak cooling and heating demands.

Based on the latest system design, the ice storage system will consist of ice chillers, insulated storage tanks and associated pumping network. Ice-on-coil type thermal storage tanks will be adopted. The ice chillers will be operated at ice making mode at night (during off-peak hours) with the lowest electric tariff and discharged to offset partial cooling demand during day time to reduce use of electric driven chillers. For the geo-thermal system, ground-loop geothermal heat pumps together with 130 34-metre deep thermal stakes will be adopted to produce chilled water in cooling season or hot water in winter. To achieve highest system efficiency and prevent adverse effect due to close packing of the thermal stakes, the average separation distant between each stake in the reference project is around 4 metres.

3. Major Factors to be Considered in BCHP System Optimization

BCHP system design and analysis involve variables such as type and size of the components, individual component efficiencies, system operation mode, operation strategy, and building demand for power, heating and cooling loads [4]. In addition, electricity and fuel prices shall also be considered while determining operation schedule of system components and carrying out life cycle analysis of the system.

Type and Size of Component

The Heat-Electricity Ratio (HER) and Cooling-Electricity Ratio (CER) are used to describe the energy demand ratios. HER is defined as the ratio of annual total heating demands and annual total electricity demands. CER is defined as the ratio of annual total cooling demands and annual total electricity demands. Study done by C.Z. Li [1] revealed that optimal capacities of power generation unit are influenced by electricity, cooling and heating demand simultaneously. The optimal capacity cannot be achieved only by one kind of energy demands. The common facility scheme designed according to methods of electricity following or heat following cannot realize the advantage of BCHP. In most of the case, cooling demands have more influence on the capacity of power generation unit than heating demands do. The optimal capacity of absorption chiller increases nearly linearly with increasing of CER and it is barely influenced by HER in general. The optimal capacity of gas boiler mainly lies on HER and the optimal capacity of electric chiller mainly lies on CER. In general, the optimal capacities of BCHP system components are mainly influenced by the energy it supplies for in most case.

Although the proposed BCHP system of the reference project is not a big system, it requires proper sizing and selection of equipment so as to meet the basic electrical and thermal requirements of the building. The latest major components of the proposed BCHP system are summarized as follows.

- 2 nos. of 1.2 MW gas engines;
- 2 nos. of 1,300 TR absorption chillers;
- 3 nos. of electric driven chillers (1 no. of 1,000 TR and 2 nos. 550 TR)
- 4 nos. of dual mode ice chillers (ice making - 800 TR, normal cooling – 1,100 TR);
- 26,400 TR-hr ice storage tanks;
- 4 nos. of 12,000 kg/hr gas-fired steam boilers; and
- 1 no. 90 TR geo-thermal heat pump

Individual Component Efficiency

Coefficient of performance (COP) is usually used to evaluate the energy efficiency of systems for cooling and heating production. For BCHP system which involves different types of driving and produced energy, COP is not a good measure of energy efficiency. To compare systems with different types of driving and produced energy, the Primary Energy Rate (PER) is a satisfactory criteria [5]. The PER is defined as the ratio of the required output to primary energy demand. The system with the higher value of PER is considered to be better.

After detailed system review and analysis based on the characteristics of the reference project, the minimum individual component efficiency recommended by the designer are listed as follows for reference.

- Gas engines (electrical efficiency – not less that 35%, thermal efficiency – not less than 28%);
- Absorption chillers (COP not less than 1.3);
- Electric driven chillers (COP not less than 6.2); and
- Ice chillers (ice making – COP not less than 5.1, normal cooling – COP not less than 6.2);

Based on the above, the PER of the integrated BCHP can then be evaluated according to the estimated electricity, cooling and heating demands and operation strategy of the system.

System Operation Mode

For a BCHP system, common operation modes are electric load following, electrically sized, or thermally sized [6]. For the electric load following operation mode, the power generation unit is able to handle the variations on the electric demand. The electrically sized operation mode is a “base loaded” operation. Whereas, the thermally sized operation mode is a “thermal demand following” operation.

As a green feature and pilot scheme, the power generation capacity of the BCHP system in the reference project is far less than the actual building electricity demand. As a result, the gas engines can be operation at designated time period to suit the optimal electrical, cooling and heating demands. As a result, all power supply generated by the gas engines will be consumed by the building equipment and cooling production by absorption chillers will depend on the energy content of waste heat from gas engine jacket water and flue heat recovery units. The waste heat recovery process of using gas engine and heat recovery unit is shown in Figure 2 below.

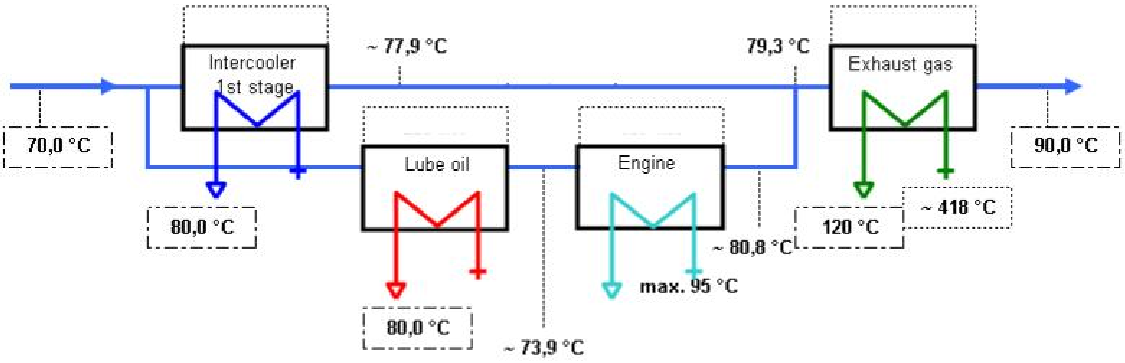

Figure 2 - waste heat recovery process of using gas engine and heat recovery unit

Operation Strategy

An accurate assessment of energy saving potential of BCHP system requires careful accounting of the operation strategy and the coincidence between electric and thermal loads. Besides, the economics of BCHP system is greatly dependent on the local utility rates, particularly electricity and natural gas prices [7]. In principle, BCHP system should only be operated when it reduces operating cost [8].

In the reference project, operation schedule of each integrated BCHP system component is determined according to the overall system operating cost. Unlike natural gas which is charged at a constant unit rate, there are seasonal and off peak variations in electricity tariffs in Shanghai. As peak cooling demand may not be coincident with the peak electricity charge rate, ice storage tanks may not be necessary to release cooling energy during building peak cooling demand. In principle, the integrated BCHP system operation strategy of the referenced building is to operate gas engines and absorption chillers in the first place. In case of insufficient cooling supply, traditional electric driven chillers will be operated before operating ice chillers in normal cooling mode. Ice chillers will be operated at ice making mode only during period of off peak electricity tariff, i.e from 2400 hrs to 0500 hrs and 2200 hrs to 2400 hrs. To achieve lowest operating cost, ice storage tanks will mainly discharge cooling energy during time of peak electricity tariff. A sample integrated BCHP system operation schedule is shown in Figure 3 below.

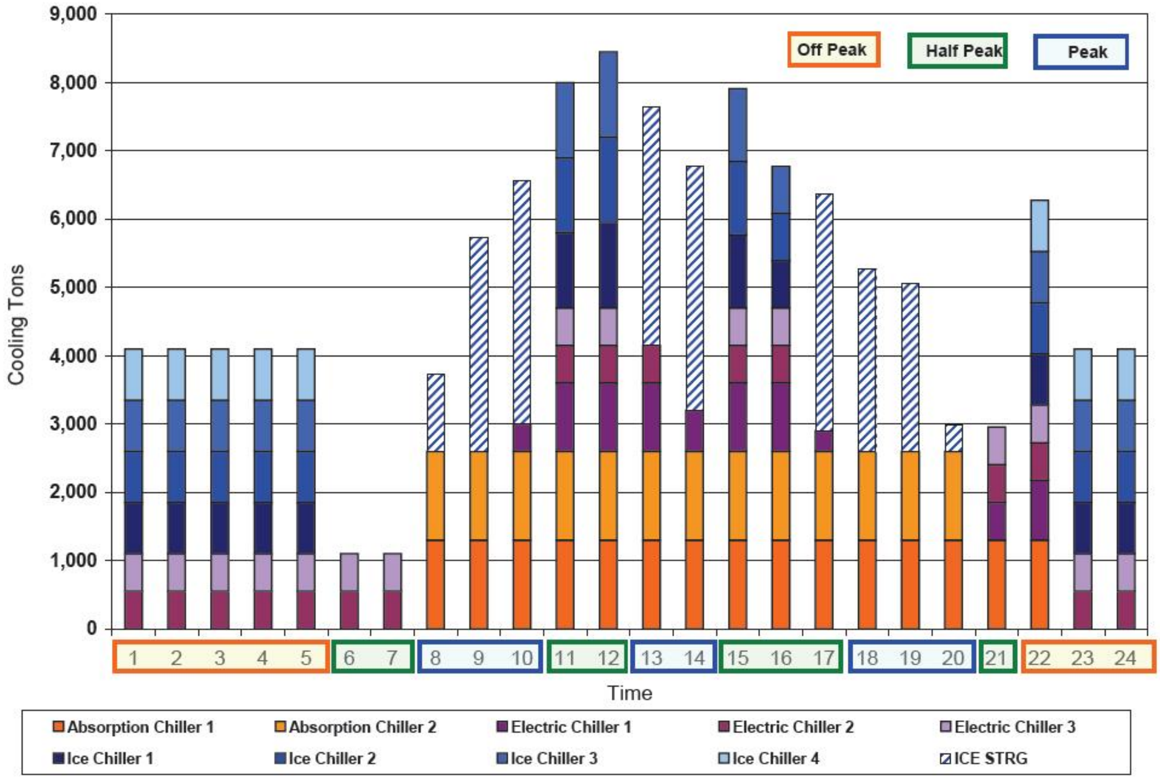

Figure 3 – Preliminary BCHP Operation Schedule of the Reference Project

From the above Figure, both traditional electric driven chillers and ice chillers will be in operation during day-time and night-time. However, ice chiller will be operated at ice making mode during night-time when electric tariff is relatively lower than day-time. For absorption chiller, it will only be operated when gas engine is in operation, i.e. from 0800 to 2200. In addition to operation efficiency, the operation strategy of the integrated BCHP system shall prevent frequent start and stop of major equipment.

Building Demand for Power, Heating and Cooling Loads

Energy consumption profiles will affect the BCHP energy design and performance [8]. There is no standard method or formulas to determine optimal configurations of a BCHP system and energy consumption profiles vary with types of buildings and place to place. Optimal BCHP system configuration can only be based on detailed energy and life cycle analysis.

In an integrated BCHP system like the reference project, the capacity of gas engines is determined according to the estimated electricity demand of the building so that a minimum efficiency level can be achieved. In addition, the cooling effects of ice storage system and geo-thermal heat pump system are also important while determining the capacity of absorption chillers and electric driven chillers.

4. Conclusion

Study of Z.G. Sun [5] revealed that a gas engine driven cooling and heating system save more than 35% of primary energy compared to the conventional separate systems. The potential saving of the integrated BCHP system is not yet available as the system configuration is still subject to review. However, based on the preliminary results of life cycle cost analysis carried out by the designer, the simple payback of the integrated BCHP system will be around 4 years and the system can provide positive return on the investment after around 11 years.

Although application of BCHP system has potential energy saving opportunity. However, optimal plant configuration and system operation strategy require detailed and careful design planning and engineering review according to the energy demand characteristics of each building. With the increasing awareness on environmental protection and green building design, the application of BCHP system will become prominent and mature.

5. References

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