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EVALUATING THE PERFORMANCE OF CCHP SYSTEM IN A FULL PROCESS OF PROJECT

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ABSTRACT

Combined cooling, heating and power (CCHP) is getting more attention for its energy saving. There has been a large number of researchers focus on the system configuration and operating strategies. However, the analysis of the whole process of the system from planning to design and running is relatively few. This paper based on an actual project in China, which has been running for two winters. Based on the background, planning, design and operating of the project, this paper comparing the load results between design and running stages, and it is found that the cooling and heating load in the running time is much smaller than the designed load. But the performance of CCHP is indeed better than the other conventional systems in the same building load situation. Finally, this paper proposed some suggestions for the future CCHP projects in the different stages.

Keywords: CCHP, buildings load, performance, running stage.

NONMENCLATURE

Abbreviations	
CCHP	Combined cooling, heating and power
CDE	Carbon dioxide emission
FEL	Following electrical load
FTL	Following thermal loads
PGU	Power generation unit
PEC	Primary energy consumption
n	Year

1. INTRODUCTION

Combined cooling, heating and power systems (CCHP) as effective energy production systems are widely utilized to provide electricity, cooling and heating. And the use of CCHP systems has been investigated for various kinds of buildings, such as residential buildings [1,2], office buildings [2,3], hotels [4,5], airport [6] and other types of commercial buildings. In order to achieve a high energy efficiency, economic benefits or reduce the greenhouse gas emission, there have been many papers focused on the system configurations and operating strategies.

In the aspect of system configuration, in order to minimize the life cycle environmental impact for a solar-assisted CCHP system which used for a hotel in Beijing, Jiang [7] proposed a life cycle assessment optimization methodology to optimize the configuration in following electrical load and thermal load. And

For a regional energy system, Ligai Kang [8] proposed a new configuration of CCHP system to analysis the annual total cost, operational cost, carbon dioxide emission and primary energy consumption under three loads following.

In the another aspect, P.J.Mago [9] evaluated and optimized two strategies: electric load and thermal load based on: primary energy consumption (PEC), operation cost and carbon dioxide emission (CDE) for a reference building in Columbus, MS, and the building cooling, heating and electric loads form simulated using EnergyPlus. Besides, a hybrid electric-thermal load (HETS) also analyzed and evaluated during its operation, its result showed that the HETS is a good alternative for CCHP system operation since it gives good reduction of PEC, cost and CDE. Jiangjiang Wang [10] proposed an improved operation strategy that the generated electricity of PGU (Power generation unit) is optimized, and four types of building are comparison using the new strategy, the result showed the proposed strategy can achieve more energy saving. For special building, such as a data center, Xu Song [11] evaluated two operation strategies of CCHP system with cool thermal storage.

For some other researches, Pedro J. Mago [3] compared a turbine driven CCHP system for a large office building in Chicago with a reference building using conventional technologies under three different operation strategies: following electrical demand, following thermal demand and following a seasonal strategy. Livio de Santoli [6] use different bioenergy form short chain with a CHP plant to analysis economic sustainability for the Bari airport. Based on the former researches, Sayyed Faridoddin Afzali [12] proposed to use overall optimal partial loads of power generation and novel performance curve to optimize CCHP operation considering energy price, fuel consumption and CO2 emissions factor.

Besides, some new method also used for the design and operation strategy. Jiang [13] use genetic algorithm to optimize design and operation strategy for a CCHP. With a CCHP for hotels, offices and residential buildings in Dalian, Miao Li [14] employed weighting method and fuzzy optimum selection theory to evaluate the integrated performances of CCHP system with various operation strategies.

Summarizing the above-mentioned studies, either configuration or operation optimization, the cooling, heating and electric loads of the reference building from two aspects: simulated form the energy simulate software and Statistics from relevant departments. There is no research on the performance studies of CCHP at a project running, and no comparative analysis between the designed and running project. For a practical project, there are always some unexpected situations that are different form the designed.

This paper focused on a practical project with designed configuration and operation strategy of CCHP, comparison the actual operation data and designed plan values in the cooling and heating loads, cost and benefit, etc. Then, according the results, analyzing the issues encountered during the project and provide guidance for the plan and design of next project.

2. CCHP SYSTEMS MODELS

2.1 Background

In order to achieve the goal of low carbon, natural gas distributed energy as a key development direction in the energy field for China. The project in this paper located in Hunan province, central of China, taking the campus as a dominant. So, the systems in this project used for an architecture group, which contains hotels, commercial and offices based on campus.

2.2 Load prediction

The very first step is to predict the cooling, heating and electrical loads for all CCHP projects. In this paper, TANFGENT, a software based on CAD for design of architectures, used to predict the loads. In addition, the loads optimized because different functional buildings, such as office and hotel can complement for each other. However, not all the architectural details are clear for simulation in the planning and design stage, so the typical building model is used or using the area load index method directly. The results of building load are shown in table 1.

From the table 1 we can get the total cooling energy is 23216 MWh and the heating energy is 10195 MWh in one year for this project. And there is even not considering the lost load caused by the pipes and devices.

2.3 Configuration and operation of CCHP

By analyzing the local resource conditions, electricity, natural gas, solar energy and geothermic energy and so on, the project designed three system schemes, which were compared from the initial investments and energy cost, then selected one. The finally system configuration of the CCHP includes PGU, water source heat pump, centrifugal electric refrigeration unit and a gas boiler.

The system operation strategy is given priority to low-cost technologies for energy supply and try to lengthen it as much as possible according to the economic priority principle. Therefore, the operating strategy of the engineering energy system is the CCHP system should be used for cooling and heating as much as possible under the premise of satisfying the starting condition of the PGU and the power and heat recovery from the PGU can be fully utilized. Secondly, the insufficient power supply of CCHP is supplemented by

Table 1 The results of building load

Building types	building area	Air-conditioning area	cooling load	Heating Load	Operating days		Running period	Running time	Accumulated Load	
	㎡	㎡	(kW)	(kW)	Summer	Winter		（h）	Cooling season （MWh）	Heating season （MWh）
Commercial	18956	10414	1261	883	150	90	9:00-23:00	14	1589	779
Hotel	16141	15162	1226	792	150	90	0	-	2004	938
Office 1	56043	31683	3789	2270	150	90	8:00-20:00	12	4092	1716
School 1	17239	11205	1065	728	105	68	8:00-20:00	12	805	416
Office 2	30000	22500	1710	1170	150	90	0:00-23:00	24	3694	1769
Culture park	45000	40500	3888	1944	150	90	9:00-21:00	12	4199	1470
School 2	25699	14045	1480	770	105	68	8:00-20:00	12	1119	440
Business street	70000	42000	4536	3024	150	90	9:00-23:00	14	5715	2667
Total	279078	187509	18955	11581	—	—	——	——	23216	10195

the heat pump, and finally, considering a gas boiler in the case that the heat pump cannot be guaranteed.

2.4 Economic analysis

The planning period of the CCHP is 20 years and the first and second years are the initial stage of the project, the third and the following year is the normal year. The economic analysis in this project is described from two aspects of cost expense and operating income. The cost expense includes cost of production, employee's compensation, repair charge, management cost, depreciation and amortization expenses. Based on the cost of the normal year, the cost in the first year is 31% and the second year is 78%. The operating income including the sales income of cooling, heating, electricity and hot water, besides, the air-conditioning connection fee from the energy-using units is also included. Same as the above cost, the income in the first year is 33% and the second year is 80%, so the percentages of cost and income for the first and second year are basically flat.

Including the construction period, the static investment horizon calculated before income tax is 9.17 years and after income tax is 11.08 years.

In addition, the uncertainties of the project in this project is studied from two aspects. The first is about the sensitivity analysis of the price of cooling and heating, air-conditioning connection fee, gas and construction investment, and the change rate is 10%. The other is balance of profits and losses, and the results showed the profits and losses will be balanced if the production load in the normal year is more than 80.75%.

3. ACTUAL OPERATION

The actual cooling season is from May to October, and the heating season is from November to March of the second year. The research cycle starts in August of the trial operation and lasts until June of the third year, including a complete cooling season and two complete winters. So, the total energy supply month is 21, except two April.

by the end of the research, PGU was still not running, and the water used in heat pump was purchased as the free water from the nearby river didn't met the requirement. In the early stages of the research, a gas direct-fired engine has been added to provide heating and cooling load, then heat pump used for cooling and gas boiler for heating.

Besides, the project has a long cycle and is interfered by the market easily. Therefore, the unit price of gas, water and electricity purchased and heating and cooling sold is inconsistent during the design stage and actual operation. The result of the unit price between the two stages is showed in the table 2.

Table 2 The unit price at two different times

Stages	Cost			Income	
	Electricity (yuan/kWh)	Water (yuan/t)	Gas (3.48/Nm3)	cooling (0.71yuan/kWh)	heating (0.71yuan/kWh)
Design	0.843	2.83	3.48	0.71	0.71
Operation	0.71	2.73	3.58	0.66	0.66

Measurement cost refers to the proportion of the direct cost to the measurement income. Direct cost is the total amount of water, electricity and gas purchased, and the measurement income is the total of heating and cooling sales. The lower the measurement cost, the smaller the cost, and vice versa. As we can see from Figure 1, the cost is high in the initial operation, up to 1.45, and it's getting better, reducing to a minimum of 0.14.

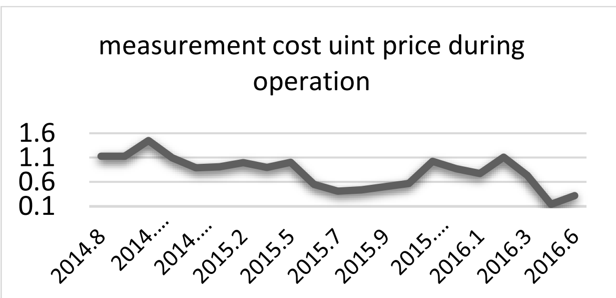

Fig 1 Measurment cost uint price during operation.

4. RESULTS

According to the results of the research, two aspects are analyzed in this paper: one is the load of heating and cooling and the other one is the economic. The predicted load energy during the planning and design phase will be compared with the survey. And the economic means the direct-cost and income will be compared at different seasons in the two stages.

4.1 Capacity of heating and cooling

The project consists of a full summer and two complete winters, one of which and the summer constitute a full year. Firstly, the loads energy of two winters and normal years of the design stage are compared, and then the total energy of a whole year and a normal year are compared.

In consideration of there are two winters in the project's investigation, hence the comparison is made. The results shown in table 3.

From the table 3, we can find the heating energy in the first winter is 11% of the normal winter, and the second winter is 20%.

Table 3 The heating energy of two winters

	Heating energy (MWh)	Percentage of the normal year (%)
First Winter	1116.915	11
Second Winter	2065.839	20
Normal Winter	10195	100

The cooling energy is complete only in one summer, so this summer is compared with the normal year of design stage. The result is shown in table 4.

Table 4 The cooling energy result

	Actual operation MWh	Normal summer MWh	Percentage of the normal year (%)
Cooling energy	2853.92	23216	12.3

The start time of this system was beginning in Aug, leading to this full cooling season is between the first and second summer. And from the table 4, we can get the ratio of this summer to normal summer is 12.3%. Comparing with the heating energy, the ratio about cooling energy is between the first winter and second winter.

4.2 Economic analysis

The economic analysis in this paper just about the performance of the CCHP, comparing the cost and income. Therefore, the cost just about cost of production and does not include the employee's compensation, repair charge, management cost, depreciation and amortization expenses. And the income just about the sales income of cooling and heating, because the electricity and hot water are not available, and the air-conditioning connection fee is not included.

This paper analyzed the cost and income of the first whole year from the actual operation and the normal year from the design. The first whole year consists the full summer and the first winter. The results are shown in table 5.

Table 5 The economic analysis in cost and income between two stage

	Kinds	Designed			Actual			Ratio
		Amount	Unit price (yuan/)	Total cost (ten-thousand yuan)	Amount	Unit price (yuan/)	Total cost (ten-thousand yuan)	(%)
Cost	Electricity (kWh)	7626300	0.84	642.9	1178193	0.71	83.65	
	Gas (Nm3)	3944500	3.48	1372.69	215390	3.58	77.11	
	Water (t)	130500	2.83	36.93	17898	2.73	4.89	
	Total			2052.51			165.65	8.07
Income	Cooling (kWh)	24330000	0.71	1727.43	2853920	0.66	188.36	
	Heating (kWh)	10637000	0.71	755.23	1116915	0.66	73.72	
	Electricity (kWh)	10614200	0.843	894.78				
	Hot water (t)	55600	26	144.56				
	Total			3521.99			262.08	7.44

Notes: the ratio is the total expense in actual operating divided by the design

From the table 5 we can see the actual operating data is much smaller than the designed both in aspects of cost and income. Moreover, the unit prince of each parameter is also different between the actual operation and design stage. In the aspect of cost, the total cost of the first year in the actual operation is 8.07% of the normal year in the design stage. Comparing with the first year of the design stage, which is 31% of the normal year, the actual operation is less than 1/3. In the other aspect of income, the ratio is 7.44%, which is much bigger difference than the 33% of the design stage. Although the total expense of income is greater than the cost in the actual operation, compared to the designed, the cost is more, and the income is less.

From the results of load and economic analysis in actual, the load is 12.3% of the normal year of design, the cost is 8.07% and income is 7.44%. Because there is no partial load analysis in the design stage, the paper can't predict how much the first-year load will be in the normal year. From the actual operation data, the cost is greater than the income, which shows that the performance of the CCHP in the initial stage of actual operation is relatively poor. This paper summarized three reasons for this result: the first is about the building load, which is predicted by typical buildings or even directly determined by indicators, there is no partial load analysis according to the progress of the project and the building group is mainly school, resulting the load required at the coldest and hottest time is not big. The second is the problem encountered in the actual project: the PGU is not running, resulting in no sales of electricity and hot water, a small part of revenue. Besides, the shortage of free water sources in nearby river has led to the purchase of water, which has increased cost. The last one is the market volatility, although there is sensitivity analysis, the most influential electricity price is not, and the price exceed 10% between two stage.

5. CONCLUSION

This paper focused on an actual project with a configured CCHP system, analyzing the design and operating situation to evaluate the performance of the system. The results of the comparison are from two aspects: load and economy. The following conclusions are obtained:

The project was running for 22 months during the research, two winter and one summer, the first winter is 11% of the normal winter, and the second winter is 20%. And the summer is 12.3% of the normal summer. From this, we can get the load of the building in operating is much bigger than in the design stage, so more reasonable approach to be need to predict building load for regional buildings. Besides, there is no partial load analysis, resulting in a large investment of the equipment at the beginning of the project.

In the aspect of economic, due to the large load forecasting, the operation performance of the system is not at the optimum point. The analysis of market fluctuation is miscalculated, leading cost increase and income decreases in the actual operation. The misestimation of resource nearby the project, so the free water is not used, increasing one cost, and the system configuration is different from the actual design, which is also an important reason for reducing energy performance.

Although the actual operating performance is almost 1/3 of the designed, with the continuous improvement of the regional and increasing load users, free water source can be used, it is believed that the performance of the system will be greatly improved. The correct method of load predicting, the availability of resource analysis, the implementation of system configuration and the comprehensive analysis of market economy has an important impact on the performance of CCHP. These must be taken seriously in the next project.

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