Research on Benefit Analysis of CCHP-WSHP System in Vehicle to Building

Xin Zhao1, Hailin Mu1*, Nan Li1, Zhaoquan Xue1 and Xiuye Yang1

1Key Laboratory of Ocean Energy Utilization and Energy Conservation of Ministry of Education, Dalian University of Technology, Dalian, Liaoning, 116024, China

1hailinmu@dlut.edu.cn

1Corresponding author’s e-mail: mhldut@126.com

Abstract. This paper proposes a combined cooling, heating and power (CCHP) system, which comprehensively uses water source heat pump (WSHP) system and vehicle to build (V2B) mode. The CCHP-WSHP-V2B could efficiently solve the problems when a CCHP or a WSHP operates independently. And it can acquire better system performance. In this mode, the CCHP system can flexibly exchange electricity with electric buses and coordinate electricity demand. The water source heat pump can supplement the cooling load and heating load of the system. Furthermore, a case study based on a hotel building is established and studied to verify the effectiveness of the model. The results of the case study show that the primary energy saving ratio, carbon dioxide emission reduction ratio, and annual total cost saving ratio comparing with the separate production system are 36.09%, 43.06%, and 25.47%, respectively.

1.Introduction

Combined cooling, heating and power (CCHP) system is famous for their cost-saving, low emission and energy-efficient[1-3]. For higher energy and environmental requirements, we need to further improve the performance of the CCHP system[4]. A large number of scholars try to improve the efficiency of CCHP system. Li et al. proposed a CCHP system with a heat pump. By optimizing the heat ratio, the heat pump can be flexibly operated according to requirements[5]. Cardona et al. proposed an analytical optimization model for analytical CCHP systems with heat pumps, and optimized the system with the goal of economic optimization[6]. Luo et al. presented a real-time operation strategy based on variable load. To improve CCHP's traditional operating strategies to achieve higher energy efficiency[7].

In recent years, with the rapid development of electric vehicles, V2G is also booming, and V2B is an extension of V2G[8]. Zhao et al. found that electric trucks provide V2G services, which can bring additional revenue to the vehicle owner and the grid[9]. Lance et al. found that when electric buses are connected to the grid in V2G mode, electric buses can achieve certain profits[10]. Thomas et al. analysed the impact of V2B and V2G energy decisions on electric vehicles with the different mileage requirements[11].

This paper proposes a combined cooling, heating, and power system with water source heat pump in V2B (CCHP-WSHP-V2B). V2B is connected to an electric bus for two-way power exchange with the CCHP system. The WSHP is used to supplement the cooling load and heating load of the CCHP system. The optimization goal includes primary energy saving ratio, CO2 emission reduction ratio and
annual total cost saving ratio. A hypothetical hotel building in Dalian city of China is used as a case study to prove validity of this method.

2. Methodology

2.1. CCHP-WSHP-V2B system

The CCHP-WSHP-V2B system consists of a power generation unit, water source heat pump, heat exchanger, boiler, absorption chiller, and electric bus, which is shown in figure 1.

![Figure 1. Structure and energy flow of CCHP-WSHP-V2B system.](image)

The electricity energy balance in the object system is expressed as:

\[ E_{\text{grid},i}^{\text{w}} + E_{\text{bd},i}^{\text{w}} \cdot \mu_{\text{bd},i} + E_{\text{wshp},i}^{\text{w}} \geq E_{\text{wshp},i}^{\text{w}} + E_{i}^{\text{w}} / \mu_{\text{be},i} \]

(1)

\[ E_{\text{pgu},i}^{\text{w}} = E_{\text{pgu},i}^{\text{w}} \cdot \eta_{\text{pgu}} \]

(2)

where \( E_{\text{grid},i}^{\text{w}}, E_{\text{bd},i}^{\text{w}} \cdot \mu_{\text{bd},i}, E_{\text{wshp},i}^{\text{w}}, E_{\text{pgu},i}^{\text{w}}, E_{i}^{\text{w}} / \mu_{\text{be},i}, F_{\text{pgu},i}^{\text{w}} \) and \( \eta_{\text{pgu}} \) represent electricity purchased from the grid, the electricity of electric bus discharge, electricity consumed by the WSHP, the electricity generated by the PGU, the electricity load of buildings, the electricity of electric bus charge, the natural gas consumption for the gas engine and the gas engine efficiency in period \( i \), respectively.

The heating balance in the object system is expressed as:

\[ Q_{\text{hr},i}^{\text{w}} + Q_{\text{bd},i}^{\text{w}} = Q_{\text{hr},i}^{\text{w}} + Q_{\text{wshp},h,i}^{\text{w}} \]

(3)

\[ Q_{\text{hr},i}^{\text{w}} = F_{\text{pgu},i}^{\text{w}} \cdot (1 - \eta_{\text{pgu}}) \eta_{\text{r}} \]

(4)

\[ Q_{\text{bd},i}^{\text{w}} = F_{\text{bd},i}^{\text{w}} \cdot \eta_{\text{bd}} \]

(5)

\[ Q_{\text{wshp},h,i}^{\text{w}} + Q_{\text{be},i}^{\text{w}} \eta_{\text{be}} = Q_{\text{bd},i}^{\text{w}} \]

(6)

where \( Q_{\text{hr},i}^{\text{w}}, Q_{\text{bd},i}^{\text{w}}, Q_{\text{be},i}^{\text{w}}, Q_{\text{wshp},h,i}^{\text{w}}, Q_{\text{bd},i}^{\text{w}}, \eta_{\text{r}}, \eta_{\text{bd}}, \eta_{\text{be}} \) represent the heat from the heat recovery system, the heat from boiler, the heat from heat exchanger and the heat driving the absorption chiller in period \( i \), respectively.

The cooling balance in the object system is expressed as:

\[ Q_{\text{wshp},c,i}^{\text{w}} + Q_{\text{ac},i}^{\text{w}} \cdot \text{COP}_{\text{ac}} = Q_{i}^{\text{w}} \]

(7)
where $Q_{cw,i}^{wshp}$, $Q_{cw,i}^{ac}$, $Q_{ci,i}$ and $COP_{ac}$ represent the cooling provided by WSHP, the cooling provided by AC, the cooling load of building and the coefficient of performance of the AC in period $i$, respectively.

$$SBS_B \cdot \alpha_{B_{min}} \leq E_{B,i} \leq SBS_B$$  \hspace{1cm} (8)

where $SBS_B$, $E_{B,i}$, and $\alpha_{B_{min}}$ represent the maximum storage capacity of smart battery system, the battery storage and the minimum percentage of storage in period $i$, respectively.

2.2. Objective function

Based on the previous discussion, the primary energy saving ratio can be illustrated as:

$$PESR = \frac{F_{ip} - F_{total}}{F_{ip}}$$  \hspace{1cm} (9)

$$F_{total} = \sum (F_{pgui,i}^{cw} + F_{b,i}^{cw} + E_{grid,i} / \eta_{grid})$$  \hspace{1cm} (10)

Where $F_{ip}$ and $F_{total}$ represent the total energy consumption of SP and CCHP-WSHP-V2B system all year round respectively.

The carbon dioxide emission ratio can be illustrated as:

$$CDER = \frac{CDE_{ip} - CDE}{CDE_{ip}}$$  \hspace{1cm} (11)

$$CDE = \mu_1 \sum (F_{pgui,i}^{cw} + F_{b,i}^{cw}) + \mu_2 \sum E_{grid,i}^{cw}$$  \hspace{1cm} (12)

Where $CDE_{ip}$ and $CDE$ represent the carbon dioxide emission of SP and CCHP-WSHP-V2B all year round respectively, $\mu_1$ and $\mu_2$ represent the emission conversion factors of electricity from grid and natural gas respectively.

The annual total cost saving ratio can be illustrated as:

$$ATCR = \frac{ATC_{ip} - ATC}{ATC_{ip}}$$  \hspace{1cm} (13)

$$ATC = P \times \sum N_i C_i + \sum C_f (F_{pgui,i}^{cw} + F_{b,i}^{cw}) + \sum C_e E_{grid,i}$$  \hspace{1cm} (14)

Where $N$ and $C$ represent the install power of equipment and the initial capital cost of each kind of equipment, respectively; $C_f$ and $C_e$ represent the gas price and the electricity price, respectively. $P$ represents the capital recovery factor[12].

3. Case study

3.1. Building information and load simulation

In order to better verify the superiority of the system, take an imaginary hotel in Dalian as an example. The hotel covers an area of 10000 m², with a floor height of 3.5 m and a total height of 21 m. From the simulated load, two typical full-day load data are selected and sorted as the typical daily hourly load in summer and the typical daily hourly load in winter, which is shown in figure 2.
Figure 2. Typical loads of daily electricity, cooling, and heating.

3.2. Results and discussions

The characteristic parameters of CCHP-WSHP-V2B and SP are listed in Table 1. The cost parameters are presented in Table 2 and Table 3. The emission parameters are presented in Table 4.

Table 1. The characteristic parameters CCHP and SP[13-15].

| System            | Variable                        | Symbol     | Value |
|-------------------|---------------------------------|------------|-------|
| CCHP–WSHP-V2B     | Electric efficiency of GE (PGU) | $\eta_{pgu}$ | 0.3   |
|                   | Boiler efficiency               | $\eta_{b}$  | 0.8   |
|                   | COP of absorption chiller       | $COP_{ac}$  | 0.7   |
|                   | Heating exchanger efficiency    | $\eta_{he}$ | 0.8   |
|                   | COP of water heat Source Heat Pump cool | $COP_{wshp,h}$ | 3.5   |
|                   | Electric bus discharge efficiency | $\mu_{bd}$ | 0.9   |
|                   | Electric bus charge efficiency  | $\mu_{bc}$  | 0.9   |
|                   | Electric bus min storage       | $\alpha_{B \text{, min}}$ | 0.2   |
| SP system         | Boiler efficiency               | $\eta_{b}$  | 0.8   |
|                   | COP of electric chiller         | $COP_{ac}$  | 3.2   |
|                   | Heating exchanger efficiency    | $\eta_{he}$ | 0.8   |

Table 2. The cost parameters of system.

| Facility                  | Gas Engine +heat recovery | Water Source Heat Pump | Boiler heating exchanger | Absorption chiller | Charge station |
|---------------------------|---------------------------|------------------------|--------------------------|--------------------|---------------|
| Price(yuan/kw)            | 9800                      | 2200                   | 500                      | 200                | 1200          | 850           |

Table 3. The unit price of electricity and natural gas.

| Facility (yuan/kWh)       | 00: 00-05: 00 | 05: 00-08: 00 | 08: 00-11: 00 |
|---------------------------|---------------|---------------|---------------|
Table 4. The emission of electricity and natural gas.

| Facility    | symbol | CO₂ emission (kg/kWh) |
|-------------|--------|-----------------------|
| Natural gas | μ₁     | 0.201                 |
| Electricity | μ₂     | 1.110                 |

The optimal scheduling diagram of CCHP-WSHP-V2B system, which is shown in figure 3. (a) represents the optimal summer power dispatch. It can be seen that electric buses can share part of the electricity load pressure. (b) represents the optimal summer cooling dispatch. It can be seen that the WSHP can share part of the cooling load pressure. (c) represents the optimal winter power dispatch. Compared with the summer, the electric buses have delay in discharging to the system. (d) represents the optimal winter heating dispatch. It can be seen that the WSHP can share part of the heating load pressure.

Table 5 shows each evaluation indicator of the CCHP–WSHP-V2B system, including primary energy saving ratio, CO₂ emission reduction ratio and annual total cost saving ratio.

Table 5. Annual saving ratio of CCHP–WSHP-V2B system compared with SP system.

| Evaluation | PESR (%) | CDER (%) | ATCR (%) |
|------------|----------|----------|----------|
| Value      | 36.09    | 43.06    | 25.47    |

4. Conclusion
This paper analyses the operating mechanism of the CCHP system based on the V2B model, and adds the charging behaviour of electric buses to the system. Electric buses can freely choose to exchange power with the cogeneration system, which not only helps the system to peak load, but also saves the system a certain cost. WSHP can cool and heat, which reduces the waste heat of the system and reduces energy consumption. The case analysis results (primary energy saving ratio 36.09%, carbon dioxide emission reduction ratio 43.06%, annual total cost saving ratio 25.47%) can clearly show the effectiveness, environmental protection, and economy of the hybrid system. This way of connecting
the electric bus with the CCHP system in the V2B mode can provide some valuable insights for the design of future smart communities.

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