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Large-scale Gas Absorption Heat Pump Applied for Distributed Heating: a Preferred Alternative to Gas Boilers

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Abstract

Boilers are the main heating methods in building and industry fields at present. In the process of carbon neutrality, the replacement of gas boilers with high energy consumption and carbon emission is of vital importance. However, recent electric heat pumps are confronted with application problems such as difficulties in electrical power expansion, lower heating capacity of single unit, higher investment and operating costs, making it difficult to directly replace fuel boilers. Gas-fired absorption heat pump is a new heating technology with high efficiency and low carbon emission. It can be driven by high-grade heat of natural gas combustion, and recover low-grade heat from the ambient air, ground or waste water. Therefore, the gas efficiency can far more higher than boilers. In this paper, large-scale gas absorption heat pump with new configurations were designed and built, using self-developed vertical falling film generator with winding tube type, solution-spray absorber with plate type, and integrated multistage centrifugal pump. Moreover, intermediate evaporation and absorption processes were introduced to improve the internal heat recovery under higher temperature lifts, and enhance heat utilization of exhaust gas. Performance testing were carried out to replace conventional gas boilers. Results showed that the heating efficiency was over 1.4, and the maximum heating capacity was nearly 1200kW. Moreover, benefits from the strategy of absorption heat for defrosting during normal operating, the defrosting time was less than 15 minutes, and did not have significant impacts on the return water temperatures. The consumption of natural gas and carbon emission is reduced by more than 37% compared with conventional gas boilers, and the payback period is only 3.6 years. It was proven that the proposed large-scale gas absorption heat pump has significant advantages in distributed heating, and is a preferred alternative to gas boilers.

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Keywords: Gas absorption heat pump; Space heating; District area; Carbon emission reduction.

1. Introduction

Under the background of the global climate change, countries are setting carbon peak and neutrality targets, in order to significantly reduce greenhouse gas emissions and facilitate the transition to sustainable energy systems. The building sector is a major contributor to climate change, accounting for approximately 31% of global CO_2 emissions when including indirect emissions from electricity and heat[1]. In recent years, driven by urbanization and rising living standards, energy consumption in buildings has grown rapidly in developing economies[2]. In China, heating demands account for 41% of building loads[3][1], representing the primary sources of building energy consumption. Furthermore, the global energy crisis poses new challenges for the transition to clean energy. It is crucial to integrate renewable energy into the power grid and build efficient heating networks.

In China, building space heating can be classified into three levels: centralized heating, distributed heating

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and household heating. For centralized heating, the heating area is usually above 0.5 million square meters, and the main method adopted is the combined heat and power generation of thermal power plants. For household heating, wall-hung gas boilers and electric heat pumps are currently the main forms. As for distributed heating, the heating area is commonly between 0.02 to 0.5 million square meters, including residential communities, shopping malls, office buildings, schools, hospitals, hotels, etc. In these distributed areas, gas boilers are widely used to provide flexible space heating. The installed heating capacity of gas boilers in distributed areas is mostly between 1 and 25 MW, which can hardly be replaced by existing electric heat pumps with single-unit heating capacity less than 200 kW, due to huge land occupation and renovation investment.

Gas heat pumps are potential alternatives to gas boilers for distributed heating, as they can utilize existing gas pipelines without the need for power capacity expansion, thus significantly reducing the investment in renovation. In accordance with technical form, gas heat pump can be classified into gas compression heat pump and gas absorption heat pump. Gas compression heat pump occupies a gas engine to produce power and drive the compression heat pump, and its heating capacity is limited by the combination of gas engine and compressor, usually lower than 100 kW. Gas absorption heat pump uses a “thermal compressor” to provide the driving force, which mainly consists of the generator and absorber. The combustion heat of natural gas is used to regenerate the refrigerant for the absorbent in the generator, while the refrigerant can recover low-grade heat from the ambient through the evaporation process, and release heat through condensation and absorption processes. Limited by the reliable gas generator and solution pump, the heating capacity of conventional gas absorption heat pump using air-source is lower than 85 kW under the mild working condition of 15℃ ambient temperature and 41℃ heating temperature. Therefore, the current gas heat pump, whether it is compression type or absorption type, is in low heating capacity, and is not applicable to distributed heating scenarios in China.

Currently, gas-fired absorption heat pump (GAHP) technology is evolving towards higher energy efficiency, broader operating temperature ranges, and enhanced system integration. Regarding working fluids, although research into novel pairs such as ionic liquids is emerging, the ammonia-water pair remains the primary commercial choice[4], particularly dominating cold-climate heating applications due to its superior thermophysical properties. State-of-the-art GAHP technologies have significantly improved primary energy efficiency by incorporating Generator-Absorber Heat Exchange (GAX) cycles and deep flue gas condensation heat recovery techniques. Experimental studies demonstrate that pre-commercial units based on the ammonia-water cycle can stably achieve a Coefficient of Performance (COP) exceeding 1.4 under rated conditions, with even higher seasonal efficiencies under part-load operations[5, 6]. To address cold climate demands, a “hybrid” strategy—utilizing GAHPs for base loads and gas boilers for peak shaving—has been proven to significantly enhance economic viability, with field tests demonstrating energy savings of 40%–50% compared to conventional systems [6, 7]. Furthermore, GAHPs exhibit significant potential for deep decarbonization; recent research confirms that these systems maintain efficient and stable operation with hydrogen-natural gas blends of up to 30%, thereby aligning with the requirements of future low-carbon energy networks [8].

Compared with electric heat pumps, large-scale gas absorption heat pumps have significant application advantages in specific fields in China, including smaller floor area, lower noise, the ability to utilize the existing gas pipelines of existing gas boilers, and no need for power capacity expansion. This provides users with additional options, allowing them to choose more suitable heat pump products based on local energy costs and the current status of the heating station.

In this paper, large-scale gas absorption heat pumps with maximum heating capacity of 1200 kW were developed, using self-developed vertical falling film generator with winding tube type, and integrated multistage centrifugal pump. Moreover, intermediate evaporation and absorption processes were introduced to improve the internal heat recovery under higher temperature lifts, and enhance heat utilization of exhaust gas[9-11]. Therefore, the system can operate efficiently under lower ambient temperature of -20℃ and higher heating temperature of 60℃, which is a preferred alternative to large-scale gas boilers that are widely used in distributed areas in China.

2. System Description

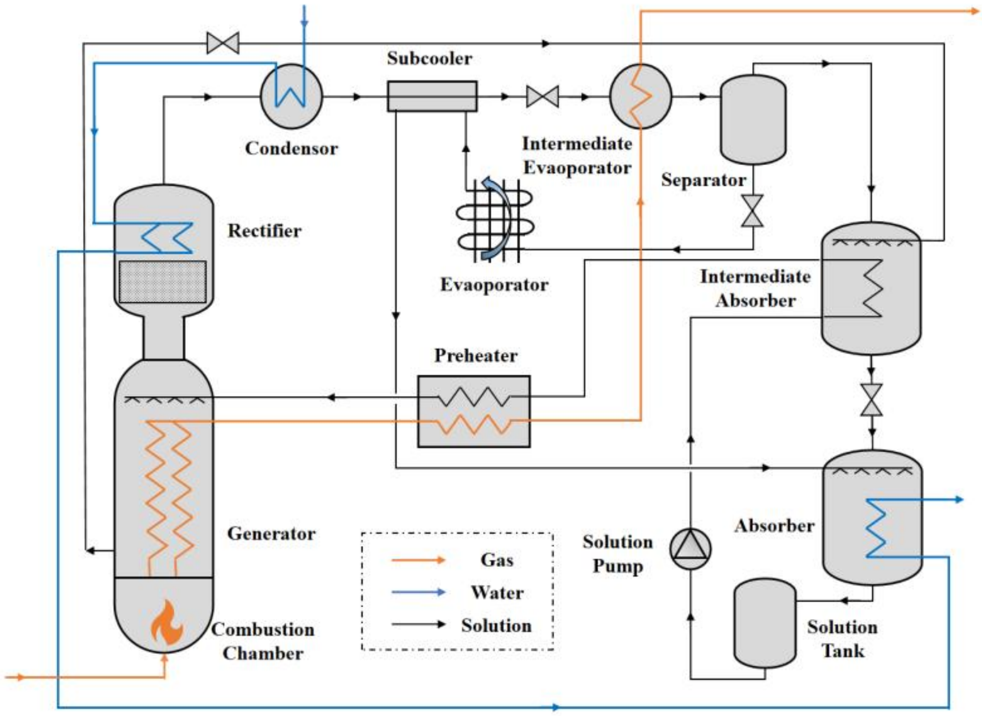


Figure 1. Schematic diagram of the proposed gas absorption heat pump.

The gas absorption heat pump system is shown in Figure 1. Natural gas burns in the combustion chamber, and the high-temperature flue gas flows through the generator to provide driving heat. And then, it passes through the preheater and intermediate evaporator, and release sensible and latent, respectively. Resulting from the cascade recovery of exhaust heat, the outlet temperature of the flue gas reduces to 30℃. On the other hand, return water passes through the condensor, rectifier and absorber in sequence, and the temperature is gradually rising. The proposed system has double low-grade heat sources: ambient heat from the air is utilized in the evaporator, while waste heat of the flue gas is recovered in the intermediate evaporator. Ammonia vapor produced by the intermediate evaporator is absorbed in the intermediate absorber, at much higher intermediate pressure, and the released absorption heat is used to preheat the strong solution, in order to improve the system performance at low ambient temperatures.

The MW level gas absorption heat pump unit is shown in Figure 2. It can provide 1200kW heating capacity at 15℃ ambient temperature and 41℃ heating temperature, and 1000kW heating capacity at -15℃ ambient temperature and 49℃ heating temperature, with 4300mm × 3000mm × 4300mm in size. The gas absorption heat pump unit has the following characteristics.

- Natural gas combined with air-source, and heating efficiency is 60-80% higher than gas boilers.
- Moving parts are only the solution pump and fans, with electricity power lower than 30 kW.
- Efficient recovery of exhaust heat, with outlet temperature of flue gas lower than 30℃.
- Absorption heat for defrosting during normal operating, with defrosting time less than 15 minutes.
- Free of gas compressor, with noise level of the equipment below 60dB within 10m.
- Fully premixed column-type surface burner, with NO_X emissions below 30mg/Nm^3.
- Components and pipelines all 304/310s stainless steel, with corrosion-resistant and highly reliable.
- Portable design, convenient for transportation and easy to install and dismantle.
- Remote monitoring and intelligent control, automatic operation with no personnel on-site.

Figure 2. The MW level gas absorption heat pump unit.

The return water passes in sequence through the condenser, rectifier and absorber, and are heated to the target temperature. Therefore, the heating capacity Q_H consists of three parts: condensation heat Q_C, rectification heat Q_R and absorption heat Q_A. They are calculated by Eqs. (1)-(4):

$$Q_C = m_W \cdot c_{p,W} \cdot \Delta T_{WC} = \rho_W \cdot V_W \cdot c_{p,W} \cdot \left(T_{WC,out} - T_{WC,in}\right) \tag{1}$$

$$Q_R = m_W \cdot c_{p,W} \cdot \Delta T_{WR} = \rho_W \cdot V_W \cdot c_{p,W} \cdot \left(T_{WR,out} - T_{WR,in}\right) \tag{2}$$

$$Q_A = m_W \cdot c_{p,W} \cdot \Delta T_{WA} = \rho_W \cdot V_W \cdot c_{p,W} \cdot \left(T_{WA,out} - T_{WA,in}\right) \tag{3}$$

$$Q_H = Q_C + Q_R + Q_A = \rho_W \cdot V_W \cdot c_{p,W} \cdot \left(T_{SW} - T_{RW}\right) \tag{4}$$

where m_W and V_W are the mass and volume flow rates of the circulating water; ρ_W and $c_{p,W}$ are its density and specific heat; $T_{WC,in}$ and $T_{WC,out}$ are the water inlet and outlet temperatures of the condenser; $T_{WR,in}$ and $T_{WR,out}$ are the water inlet and outlet temperatures of the rectifier; $T_{WA,in}$ and $T_{WA,out}$ are the water inlet and outlet temperatures of the absorber; T_{SW} and T_{RW} are the supply water and return water temperatures, T_{SW} is equal to $T_{WA,out}$, and T_{RW} is equal to $T_{WC,in}$.

The heating efficiency COP_H is calculated based on Eqs. (5) and (6):

$$COP_H = Q_H / Q_{NC} \tag{5}$$

$$Q_{NC} = V_{NC} \cdot q_{NC} \tag{6}$$

where Q_{NC} is the combustion heat of natural gas, V_{NC} is its volume flowrate, and q_{NC} is its calorific value.

It should be noted that the electricity consumption of the unit is less than 3% of that the heating capacity, hence it is not concluded in the calculating of COP_H. And it is more fair when compared with heating efficiency of the gas boiler.

3. Results and Discussion

Four MW level gas absorption heat pump units are used in Weihai since January 2025, to replace the gas boiler and provide space heating for 95,000 m^2 of buildings. The basic operating conditions of the unit are shown in Table 1. The two typical full-day operation conditions are shown in the following Figure 3 and 4.

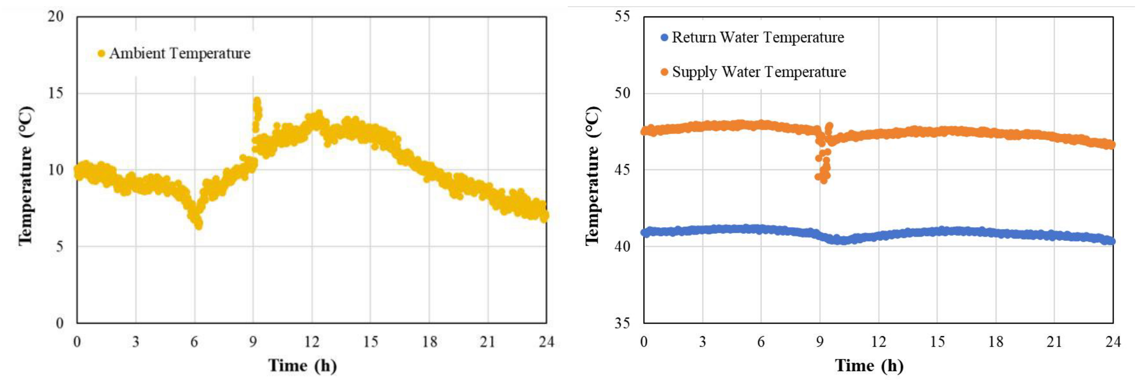
Table 1. Basic operating conditions of the gas absorption heat pump unit

Parameters	Values
Return Water Temperature	38℃
Supply Water Temperature	45℃

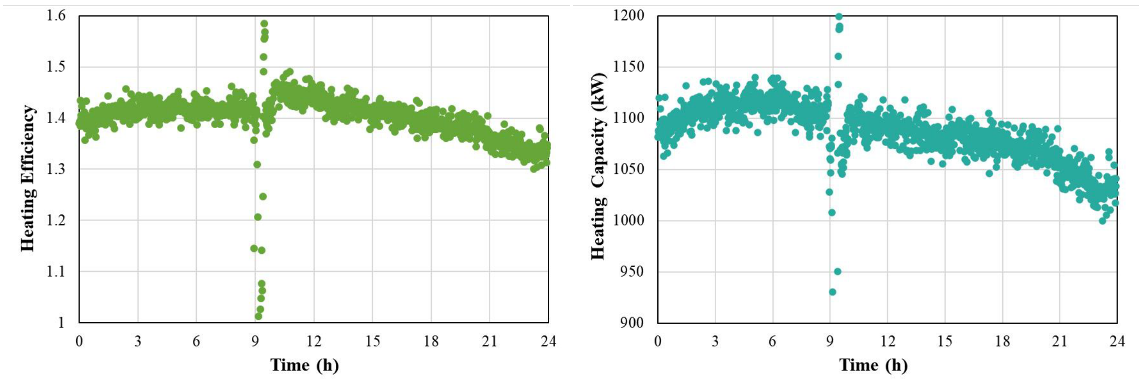
Ambient Temperature	-5°C
Exhaust Gas Temperature	25°C
Generation Temperature	157°C
Evaporation Temperature	-11°C
Condensation Temperature	42°C
Absorption Temperature	48°C
Generation/Condensation Pressure	1.72MPa
Absorption/Evaporation Pressure	0.28MPa
Heating Capacity	1122kW
Gas Efficiency	1.32

It is shown in Figure 3 that on Feb. 27, the ambient temperature varied from 6°C to 14°C, temperatures of the return and supply water were 41°C and 47°C, respectively. The heating efficiency was between 1.3 and 1.5, and the average value was 1.41. The heating capacity was between 1000kW to 1150kW, and the average value was 1082kW.

It is shown in Figure 4 that on Jan. 12, the ambient temperature varied from -3°C to 2°C, temperatures of the return and supply water were 44°C and 51°C, respectively. The heating efficiency was between 1.28 and 1.4, and the average value was 1.34. The heating capacity was between 900kW to 1050kW, and the average value was 972kW.

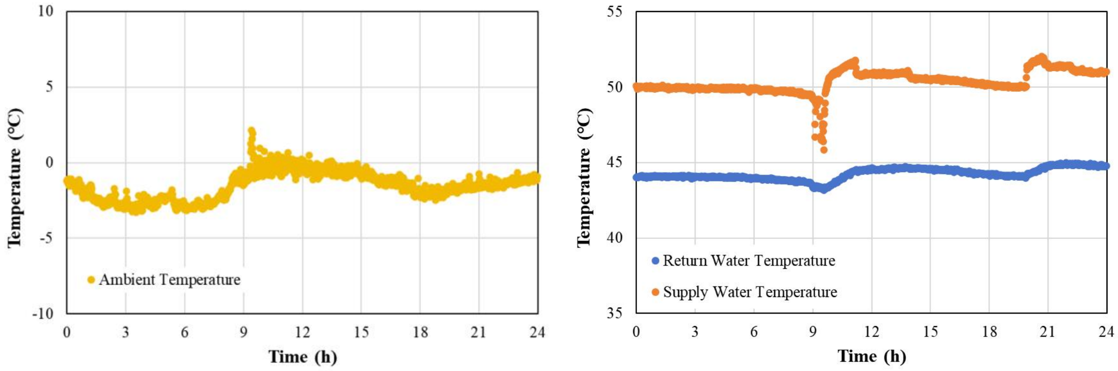


(a). Operating condition.

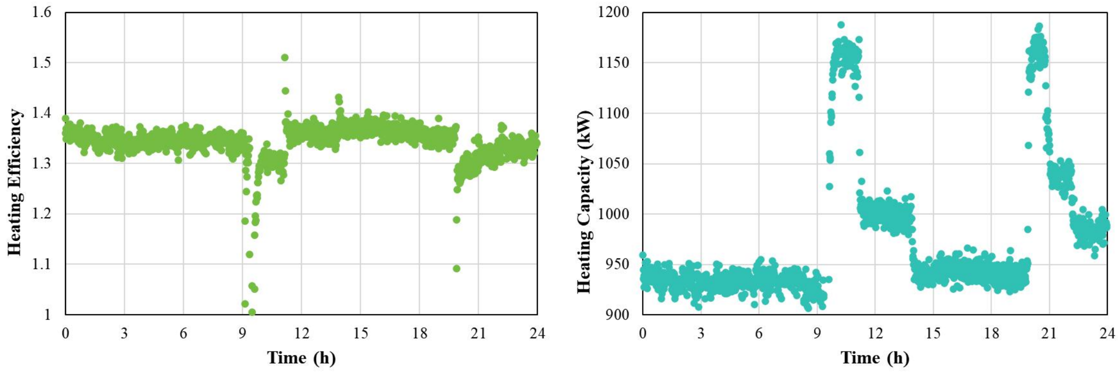


(b). Performance.

Figure 3. Operating condition and performance on Feb. 27, 2025.



(a). Operating condition.



(b). Performance.

Figure 4. Operating condition and performance on Jan. 12, 2025.

It should be noted that Weihai is close to the sea and has extremely high humidity, consistently above 80%. As a results, evaporators of the gas absorption heat pump units were prone to frosting up within 24 hours. Therefore, the units were set to defrost at 9 o'clock every day. It is shown in Figure 3 and 4 that, benefits from the strategy of absorption heat for defrosting during normal operating, the defrosting time was less than 15 minutes, and did not have significant impacts on the return water temperatures.

Comparison of natural gas consumption between the gas boilers and the gas absorption heat pumps is shown in Figure 5. During the winter heating period in 2024-2025, the total natural gas consumption of the gas absorption heat pumps was reduced by 354216 Nm^3, which was 37% lower than that of the gas boilers in 2023-2024. It should be noted that the average ambient temperature in winter of 2024-2025 is 1.1℃, which is 0.7℃ lower than that of 2023-2024. Moreover, the corresponding carbon emission reduction amount was 708 tons, demonstrating a significant effect in decarbonizing heating.

The economic performance of the gas absorption heat pump is shown in Table 2. The total construction cost is 4.6 million yuan, which includes 3.7 million CNY for equipment expenses and 0.9 million CNY for construction costs. The annual operating costs were reduced by over 1.3 million CNY, and the payback period is only 3.6 years.

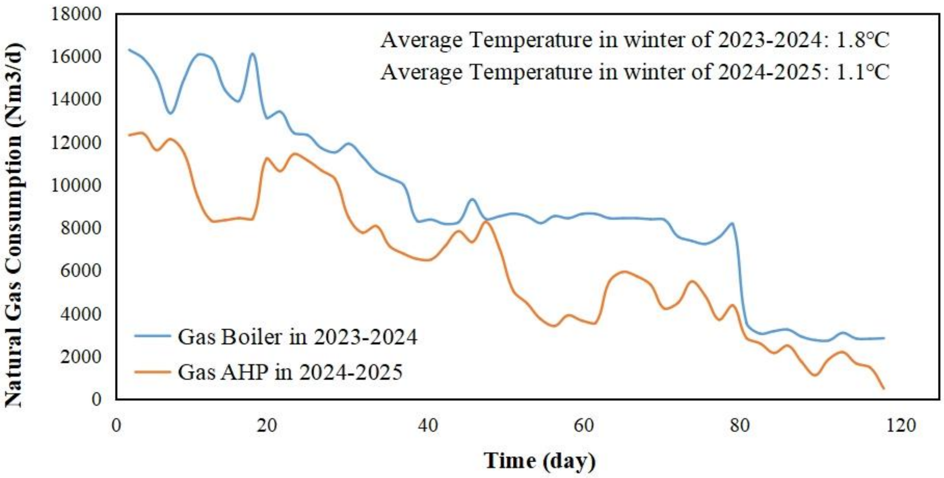


Figure 5. Comparison of natural gas consumption.

Table 2. Economic performance of the units

Parameters		Values
Investment Cost	Heat Pump Units	3.6 million CNY
	Pipeline Construction	0.6 million CNY
	Gas renovation	0.3 million CNY
	Accessories	0.1 million CNY
	Total	4.7 million CNY
Operating Cost Saving		1.3 million CNY
Payback Period		3.6 years

4. Conclusions

In this paper, large-scale gas absorption heat pumps with maximum heating capacity of 1200 kW were developed, using self-developed vertical falling film generator with winding tube type, and integrated multistage centrifugal pump. Moreover, intermediate evaporation and absorption processes were introduced to improve the internal heat recovery under higher temperature lifts, and enhance heat utilization of exhaust gas. Four MW level gas absorption heat pump units are used in Weihai since January 2025, to replace the gas boiler and provide space heating for 95,000 m^2 of buildings. The main results are shown below.

- The heating efficiency was over 1.4, which was 55% higher than that of the gas boilers, and the maximum heating capacity was nearly 1200kW, during the winter heating period of 120 days.
- The consumption of natural gas for the same heating power was reduced by 354216 Nm^3, which was 37% lower than that of the gas boilers.
- The carbon emission reduction amount was 708 tons compared with gas boilers, demonstrating a significant effect in decarbonizing heating.
- The total construction cost is 4.6 million yuan, which includes 3.7 million yuan for equipment expenses and 0.9 million yuan for construction costs. The annual operating costs were reduced by over 1.3 million CNY, and the payback period is only 3.6 years.

It was proven that the proposed large-scale gas absorption heat pump has significant advantages in distributed heating, and is a preferred alternative to gas boilers.

5. Outlooks

Currently, gas absorption heat pumps are mainly driven by natural gas and coupled with ambient heat acquisition, with the proportion of renewable energy reaching up to 40%. However, in the subsequent system design and application, more low-carbon energy gases such as hydrogen, ammonia, and biogas can be adopted, enabling the system's proportion of renewable energy to reach 100%, providing greater support for the carbon neutrality strategy.

Acknowledgements

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