Study on technical route and business mode of electric heating in rural areas of North China

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Abstract. In 2017, after the conversion of coal to gas and coal to electricity in parts of northern rural areas, there was a shortage of gas supply and power supply, reflecting the lack of overall planning and scientific management of rural clean heating. Based on the field case analysis and research in a rural area of Hebei Province, this paper studies the technical route and business model of electric heating in rural areas of North China. The research shows that the electricity consumption per unit area in the heating season is about 53~133 kWh, the electricity cost per unit area is about 23~45 yuan, and the initial investment of equipment are mostly more than ten thousand yuan, which is beyond the user's tolerance. Thus the single electric heating technology is not economically viable in rural areas. This paper proposed a combined technical scheme to carry out coal-to-electricity transformation according to local economic and resource conditions, which can solve about 68% of the coal-to-electricity demand in the village. It is necessary to coordinate and plan in a unified manner, and the business model uniformly organized and implemented by integrated energy service providers has great feasibility.

1. Introduction

Clean heating is an important measure of promoting the revolution of energy production and consumption, as well as improving the rural lifestyle. At present, there are two main technical forms for implementing clean heating reform in rural areas, namely “coal to electricity” and “coal to gas”. Considering China's tight natural gas resources, weak supply support capacity, inadequate infrastructure construction, safety hazards and pollutant emissions during the use of natural gas, it is more likely to use the “coal to electricity” approach in rural areas far away from the gas source and with relatively weak infrastructure conditions [1]. In 2017, the rural areas in North China accelerated the pace of coal-to-electricity transformation [2], and the total scale of renovation was about 2 million households, accounting for 36% of the total renovation of clean heating in North China.

However, with the increasing scale of electric heating, the Beijing Power Grid in the winter of 2018 and the Hebei South Network may have short-term power supply shortages. In fact, the winter heating load is similar to the summer air conditioning load, and can be utilized by flexible peak shaving, which can alleviate possible short-term supply pressure and enhance system flexibility [3].
2. Typical test case analysis for electric heating

2.1. Case scenario
Taking the “coal to electricity” technical test carried out by the Development and Reform Commission of Hebei Province in a local rural district as a case, the winter heating situation of the test village has certain universality and representativeness in the rural areas of North China. Forty-nine percent of the actual heating area of the villagers is below 60 square meters, as shown in Figure 1. The average outdoor temperature in the recent three heating seasons is about 2 degrees Celsius. The lowest temperature is minus 15 degrees Celsius. The current heating quality is poor, with burning coal as the main heating method, and the average indoor temperature in the heating season is about 12 degrees Celsius. The heating furnace is mainly composed of four types of small coal stoves, radiators, floor radiation and air conditioning heating. Each household consumes one to two point five tons of coal per year, and the annual heating cost is one thousand to two thousand and five hundred yuan.

![Figure 1. The distribution of household heating area by households in the experimental village.](image)

2.2. Test process and data

| Heating technology       | Test heating household (households) | Total area (m²) | Facility power (kW) | Investment (yuan/m²) | Power consumption (kWh) | Average indoor temperature (°C) |
|--------------------------|-------------------------------------|-----------------|--------------------|----------------------|-------------------------|--------------------------------|
| Combined heat pump       | 6                                   | 607             | 28                 | 180                  | 7297                    | 14.8                           |
| Hot air heat pump        | 1                                   | 50              | 2                  | 170                  | 619                     | 14.7                           |
| Hot water heat pump      | 1                                   | 90              | 5                  | 200                  | 1394                    | 14.7                           |
| Phase change heat storage| 1                                   | 80              | 12                 | 210                  | 2518                    | 15.3                           |
| Carbon crystal           | 4                                   | 74              | 12                 | 125                  | 1659                    | 14.2                           |

The electric heating technologies selected by the test are combined heat pump, hot air heat pump, hot water heat pump, phase change heat storage boiler and carbon crystal technology [4-5]. The test was conducted during the period from February 8 to March 9 in 2018, a total of 30 days. The average outdoor temperature during the test period was 3.5 degrees Celsius. The lowest temperature was minus 7 degrees Celsius, and the average daily temperature for the coldest day was minus 1.5 degrees Celsius. The highest temperature was 19 degrees Celsius, and the average daily temperature was 11.1 degrees Celsius for the warmest day. The indoor temperature after electric heating during the test was set to be 14~16 degrees Celsius. According to the local survey, the residents are satisfied with the indoor temperature of 15 degrees Celsius. It is estimated that for every one degree Celsius decrease in indoor temperature, the heating energy consumption is reduced by 7%.

The test data records are shown in Table 1.
2.3. Calculation method of heating power consumption

The annual heating energy consumption per unit area is calculated by the data of the test period. The daily heating energy consumption per unit area is multiplied by the number of annual heating days, and then multiplied by the temperature difference correction coefficient. This is because the heating energy consumption is proportional to the temperature difference between indoor and outdoor temperature. The specific calculation method is added as follows.

\[ Ea = \frac{Et}{Sa \times Dt} \times Da \times \frac{\Delta Th}{\Delta Tt} \]  

\( Ea \) represents the annual heating electricity consumption. \( Et \) represents the heating electricity consumption during test. \( Sa \) represents the total heating area. \( Dt \) represents the number of heating days during test. \( Da \) represents the number of annual heating days. \( \Delta Th \) represents the average temperature difference between indoor and outdoor during the whole heating period. \( \Delta Tt \) represents the average temperature difference between indoor and outdoor during test.

The average temperature difference between indoor and outdoor during the whole heating period equals to the indoor average temperature minus outdoor average temperature, which is 13 degrees Celsius. The indoor average temperature is 15 degrees Celsius, and the outdoor average temperature is 2 degrees Celsius according to the average temperature provided by Meteorological Observatory during the period from November 15, 2017 to March 15, 2018.

According to the local heating habits, when the average daily temperature exceeds 10 degrees Celsius, in order to save electricity, the villagers will stop the heating equipment. According to the data provided by the Meteorological Observatory, the number of days with daily average temperature of the test area less than 10 degrees Celsius from November 15, 2017 to March 15, 2018 is 115. Then \( Da \) equals 115.

3. Technical route analysis of electric heating based on test

3.1. Comprehensive technical solution for electric heating in the test village

Based on the above test results, the electricity consumption per unit area in the heating period is calculated to be about 53~133kWh for different electric heating technologies by the above calculation method, which is shown in Table 2. According to resident peak and valley electricity price, which is 0.52 yuan for peak electricity price and 0.31 yuan for valley electricity price, and the valley electricity time is from eight o'clock in the afternoon to eight o'clock in the morning, the heating electricity cost per unit area is calculated to be about 23~45 yuan. In terms of the initial investment of heating equipment, the current "coal to electricity" equipment subsidy upper limit is 7400 yuan per household. Assume that the maximum subsidy is deducted, in addition to the hot air heat pump and carbon crystal, which have lower cost and users can afford, for the rest of various types of technology, user self-raised expenses are more than 10000 yuan after considering government subsidies, which is beyond the user's tolerance according to local survey. The comprehensive comparison of the feasibility of various types of "coal to electricity" technology is shown in Table 2.

| Heating technology             | Investment (yuan/household) | Power capacity (kW) | Power consumption (kWh/m²/annual) | Operation cost (yuan/m²/annual) | User paid (yuan/household) | User tolerance | Grid capacity expansion need |
|--------------------------------|-----------------------------|---------------------|---------------------------------|-------------------------------|---------------------------|----------------|-----------------------------|
| Combined heat pump             | 18000                       | 4.6                 | 53.0                            | 22.55                         | 10600                      | no             | yes                         |
| Hot air heat pump              | 9000                        | 2                   | 55.2                            | 23.52                         | 1600                       | yes            | no                          |
| Hot water heat pump            | 18000                       | 4.6                 | 68.9                            | 29.32                         | 10600                      | no             | yes                         |
| Phase change heat storage      | 21000                       | 12                  | 132.5                           | 41.07                         | 13600                      | no             | yes                         |
| Carbon crystal                 | 3125                        | 2.5                 | 104.9                           | 44.63                         | 469                        | yes            | yes                         |

Table 2. Comprehensive technical feasibility comparison for various electric heating technologies based on test data.
In order to meet the heating needs of different residents, on the basis of the test, combined with the visits, seminars and site surveys of the village residents, the “coal-to-electricity” clean heating solution with various technical route optimization combinations shown in Table 3 was proposed, by finding the best match between the cost of electric heating technologies and the economic tolerance of residents. The comprehensive scheme adopts the combined technical scheme of heat pump hot air blower, carbon crystal and air source heat pump. Under the current subsidy of 7400 yuan per household, it can solve about 68% of the coal-to-electricity demand in the village.

Table 3. Comprehensive solution for the "coal to electricity" technology for the test village.

| Heating area       | Heating technology                              | Investment (yuan/household) | User paid (yuan/household) | Annual Operation cost (yuan/household) |
|--------------------|-------------------------------------------------|-----------------------------|---------------------------|---------------------------------------|
| Below 60m²         | Hot air heat pump                               | 9000                        | 1600                      | 1411                                  |
| 60~80 m²           | Hot air heat pump and carbon crystal             | (9000+2500)                 | 1600~4100                 | 1411~2304                             |
| 80 m² above        | Hot water heat pump                             | 18000                       | 10600                     | 2304~3518                             |
| Mostly no one      | Hot air heat pump                               | 9000                        | 1600                      | <1000                                 |

3.2. Electric heating technology route promotion suggestions

Based on the above case analysis, for areas with low government equipment subsidies (such as Hebei), a single electric heating technology has certain limitations. It is impossible to meet the residents' problems in terms of economy, heating targeting, tolerance and local distribution network capacity. In order to achieve the comprehensive optimal goal of low government subsidy investment, small power consumption, and high user satisfaction, we should adopt a combined technical solution to transform “coal to electricity”, which must be tailored to local conditions, coordinated and unified, and requires comprehensive energy service providers to unify the implementation [6-7].

In addition, the heating mode with “photovoltaic + heat source” can alleviate the pressure on rural residents to use heating electricity to a large extent, and further improve the economics of “coal to electricity” technology [8]. In the “Implementation Plan for Solar Heating in Rural Areas of Hebei Province”, it is proposed that the “solar photovoltaic + heat source” heating technology pilot can use two kinds of business models: bank loans and enterprise investment. The bank loan model is adopted, and the residents' income is relatively high, which greatly relieves the pressure on heating and electricity charges, but needs to pay 10%-30% of the initial investment. With the corporate investment model, residents' income is low, but there is no need to pay for initial investment.

4. Prospect of business mode for electric heating in rural areas

4.1. Virtual power plant and demand response business

From the view of power grid operation, considering the rural house building has a certain heat storage capacity, a large number of electric heating equipment constructed in rural areas can be regarded as various interruptible and controllable flexible load. What’s more, there are local household photovoltaics, village-level photovoltaic power plants and energy storage devices. Then such a village can be treated as a small virtual power plant unit. If such small units in a larger area can be coordinated and controlled, a large-scale virtual power plants can be formed, which are of great significance for improving the balance of power supply and demand, as well as grid flexibility. For example, after 2-3 years, the control capacity of 10 million rural coal-to-electricity units will be formed, with 4 kilowatts per household. The operation control areas in North China will form a load-side adjustment capacity with a total capacity of 40 million kilowatts. According to the construction and operation experience and implementation data of the non-work air conditioning flexible load peaking system in Jiangsu Province in 2015-2017, the monitoring system is running stably, the
province has access to more than 1600 non-workers to the monitoring platform, and the flexible peaking potential exceeds 0.32 million Kilowatts, effectively alleviating the short-term supply of electricity during the summer peak season.

4.2. Cloud platform service business
With the continuous advancement of rural coal-to-electricity work in North China, such as the annual transformation of 3 million to 4 million households, according to the government subsidy standard of 8500-20000 yuan per household, it can actually form a clean heating integrated energy service of 30-60 billion yuan per year. Considering the implementation of this business requires grid companies to carry out different levels of capacity expansion and operation, as well as the operation and maintenance of local agricultural power companies, so they can give full play to the resources advantages of State Grid Corporation, coordinating e-commerce, provincial and municipal integrated energy companies, Yingda and, rural power companies and other related units, formulate the best economic and technically optimal technical solutions and equipment standards, optimize the construction of photovoltaic projects, build an internet operation and maintenance cloud platform, and conduct integrated energy services.

5. Conclusions
In this paper, a field case test for electric heating was conducted in a rural area of Hebei Province for 13 households. Five kinds of electric heating technologies were applied, which were combined heat pump, hot air heat pump, hot water heat pump, phase change heat storage boiler and carbon crystal. Based on the filed test, the combined electric heating technology schemes are proposed for the whole test village with 520 households, which can solve about 68% of the coal-to-electricity demand in the village. The comprehensive scheme adopts the combined technical scheme of heat pump hot air blower, carbon crystal and air source heat pump, according to various income level and living area. In can be shown that, economics is the biggest obstacle facing the current rural electric heating, a single electric technology is impossible to solve all the heating demand, a combined technical solution must be tailored to local conditions, which requires comprehensive energy service providers to unify the implementation.

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