Research on the influence of coal to electric heating on regional power grid in Northern China

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Abstract. North china has been implementing large-scale coal-to-electricity action, for air pollution reduction and rural household indoor environment improvement. This cause electricity fluctuations and load increase. This paper characterizes patterns of three dominated electric heating equipment in Beijing-Tianjin-Tangshan region (BTT), which are thermal storage electric heating radiators (TSEHRs), air-to-water heat pumps (AWHPs), and low temperature air-to-air heat pumps (AAHPs), and estimate their impact on the power grid system of BTT. Due to physical properties, TSEHRs keep operating as a direct-acting electric heating radiator during the daytime, consequently, caused a high electricity consumption up to 144.3 (kWh/m²); AWHPs had to uninterrupted operate to keep heating each currently in-use room, and electricity consumption was 65.6 (kWh/m²); electricity consumption of AAHPs fell to 29.7 (kWh/m²), benefited from separate installation and intermittent operation. Based on those patterns, the impact on power grid system of large scale adoption in BTT were estimated: daily peak-valley ratios of the typical daily load curve, which respectively turned into 42.5%, 22.4% ,21.8% from original 26.5%, and the load increase rates of the original monthly maximum load throughout the year, respectively were 101.5%, 9.0%, 2%.

1. Introduction

China has a long-term coal-based energy structure especially in rural areas of north [1]. The total annual household energy consumption in rural areas of north China was 178.7 million tons of standard coal equivalent (tce), equal to 5.2×10⁹ GJ, of which scattered coal and raw biomass account for 60.8% and 38.5%, 108.5 million tce and 30.6 million tce respectively. Meanwhile, coal is the primary fuel for space heating: 74.4 million tce of scattered coal and 11.4 million tce of raw biomass are used for space heating, they together account for 85.2% of total heating energy consumption [2]. The combustion of scattered coal and raw biomass in traditional coal stove not only generates large amount of pollutants (e.g. PM_{2.5}, PM_{10}, NOx, SOx), but also have low-efficiency [3]. The amount of pollutants emitted by traditional coal stove is 4 to 10 times of that emitted by large coal-fired boiler [4], with the same amount of coal burning, which are the most important factor causing air pollution [5]. Therefore, the replacement of scattered coal and biomass, and seeking for coal-free heating methods in rural areas of north china is significant for air pollution reduction and rural household indoor environment improvement. For this reason, Chinese government has been implementing large-scale “coal-to-electricity action” since 2013 [6],[7]. There are a variety of electric heating equipment, which are generally divided into two types:

- direct heating type, such as electric heater, electric heating plate, thermal storage electric heating radiators (TSEHRs). Due to high electricity consumption and low efficiency, electric heater and other direct heating equipment without thermal storage function are not recommended. TSEHRs, as shown in Figure 1, by using valley electricity to heat the thermal storage body, and blowing out the heat to supply heat for room [8];
the other type is heat pump, mainly air-to-water heat pumps (AWHPs) and low temperature air-to-air heat pumps (AAHPs), as shown in Figure 1. The indoor units of AWHPs usually are radiator, radiant floor. AAHPs are similar to split air conditioners, except that the indoor unit is installed near the floor for heating human active areas.

![Electric heating equipment: (a) TSEHRs; (b) AWHPs; (c) AAHPs.](image)

Additionally, the power grid has an obvious typical daily load characteristic in winter and monthly fluctuation of power demand during the whole year. Taking the example of Beijing-Tianjin-Tangshan region (BTT) Power Grid, as shown in Figure 2. The typical daily load curve in winter is saddle-shaped with 2 peaks reaching at 12:00 and 18:00 respectively. Original daily peak-valley ratio is up to 26.3%; the monthly fluctuation of power demand during the whole year has a large seasonal difference and the maximum of it is about 64.8 GW. There are two peaks reaching in summer and winter respectively. Summer peak generally occur in July or August, and winter peak generally occur in December [9].

![Figure 2. (a) Typical daily grid load curve in winter of BTT grid; (b) Monthly maximum power demand curve of BTT grid.](image)

The load of electric heating equipment has obvious seasonal fluctuation. As electric heating equipment are put into use in winter, it will cause load increase which can largely affect the stability and capacity of power grid systems. Gao Ze, Chen Dengming [10] conducted power grid planning and design research from the perspective of load forecast, distribution transformer capacity allocation and electrical safety, but does not consider the real time-varying power load of coal-to-electric equipment. Liu Yanru [11] conducted electricity demand forecast after coal-to-electricity, including typical daily load characteristic in winter and monthly fluctuation of power demand during the whole year. The load of electric heating equipment per household is assumed as 6~9kW. However, the basic data of electric heating equipment is not based on the actual power load, and there is no analysis of the load characteristics of different electric heating equipment. Therefore, it is necessary to conduct detailed test on the dominated electric heating equipment to analyse their typical load characteristics and the impact of coal-to-electricity on the regional power grid.

This paper has two goals:
- to characterize load patterns of three dominated electric heating equipment, which are TSEHRs, AWHPs, and AAHPs;
- to explore and estimate their impact on the power grid system of BTT grid.

2. Method
Twenty-four rural residential houses in suburban Beijing were selected, including three houses using TSEHRs, seventeen houses using AWHPs and four houses using AAHPs. We tested the following data: 1) indoor temperature; and 2) outdoor temperature; and 3) energy consumption of heating equipment under non-intervention condition from January 25, 2019 to February 19, 2019. To obtain those data, automatic power recorders (Tianjian Hua Yi Co., China) and temperature loggers (WZY-1A) were used. Figure 3 shows the test devices.

Figure 3. Test devices: (a) electric power recorder; (b) temperature logger.

Through recording instantaneous electric power of heating equipment, we can get power load characteristics pattern and total energy consumption. Indoor Temperature provides reference for selecting typical households, so it can avoid comparing the power consumption of equipment in different indoor conditions. We select three households using different heating equipment, with a same indoor temperature range, for analysis. The heating area of the three households are 58.3 m², 64.5 m², 54 m². We choose the average daily load curve as the typical load curve for each equipment. Then use the average heating area of rural household of north China, which is 59.0 m² [2],[3], and lowest typical outdoor temperature of each month, to calculate the heating energy consumption of each household and the highest power demand of each month. Eventually, under the assumption that total rural households use one electric heating equipment, taking BTT Grid as an example to estimate the impact of increased heating power load on the grid, which includes: 1) typical daily load curve and 2) monthly maximum power demand curve. The total number of rural houses in BTT area, including Beijing, Tianjin, Tangshan, Qinhuangdao, Langfang, Zhangjiakou, Chengde, are 7.6 million [12].

3. Results and discussion

3.1. Representative power patterns and energy consumption

3.1.1. TSEHRs

In household 1, power load starting to raise after 18:00 since occupants turn on TSEHRs. After 21:00, it enters to a stable operation state of night time heat storage, and the load reaches to the maximum. During 3:00 to 4:00, as the thermal storage capacity reaches maximum, the load begins to decrease. After 4:00, TSEHRs enter a low-power operation state, and the load stays low and stable. However, since the thermal storage property of the brick cannot be completely controlled, it is not guaranteed that the thermal energy stored during the night can be precisely emitted. So the TSEHRs are still operated at a relatively low power state during the day time to maintain the indoor temperature. The electricity consumption up to 144.3 (kWh/m²) during test period. Figure 4(a) and (b) show the daily instantaneous electric power of TSEHRs during the test period and that during a typical day.

Figure 4. Results of household 1: (a) daily instantaneous electric power of TSEHRs; (b) instantaneous electric power of TSEHRs on a typical day (February 11).
3.1.2. AWHPs

In household 2, AWHPs stay in a stable intermittent operation state throughout whole day, and the average load curve is stable and without fluctuation. This is because the indoor units are radiators or radiant floor, so the AWHPs has to operate without interruption in order to support the heat demand of every in use room. The electricity consumption is 65.6 (kWh/m²) during test period. Figure 5(a) and (b) show the daily instantaneous electric power of AWHPs during the test period and that during a typical day.

![Figure 5](image)

**Figure 5.** Results of household 2: (a) daily instantaneous electric power of AWHPs; (b) instantaneous electric power of AWHPs on a typical day (February 7).

3.1.3. AAHPs

In household 3, three AAHPs are installed separately in two bedrooms and one living room, so that occupants can turn off the AAHPs of a certain room which they stop using. As it is shown in figure 6(a) and 6(b), the load of living room is relatively high during 19:00 to 23:00, which is the period when living room is frequently used, and reaches the peak at 9:00. Same as living room, as shown in figure 6(c) and 6(d), when the bedroom is not in use during the day time, the AAHPs were turned off or operate at a low power state. Overall, the maximum load appears at 22:00, and between 10:00 to 18:00 the load is low. The electricity consumption is 29.7 (kWh/m²) during test period. Figure 6(e) and (f) show the total daily instantaneous electric power of AAHPs during the test period and that during a typical day.

![Figure 6](image)

**Figure 6.** Results of household 3: (a) daily instantaneous electric power of AAHPs in living room; (b) instantaneous electric power of AAHPs in living room on a typical day (February 1); (c) daily...
instantaneous electric power of AAHPs in bedroom; (d) instantaneous electric power of AAHPs in bedroom on a typical day (January 30); (e) total daily instantaneous electric power of AAHPs; (f) total instantaneous electric power of AAHPs on a typical day (January 30).

3.2. The impact of increased heating power load on the grid

3.2.1. Typical daily load curve

Typical daily load curve before and after using electric heating equipment in BTT Power Grid are shown in figure 7(a). Due to the high load during the night time opening of TSEHRs, the maximum load increase from 53.6 GW to 93.3 GW. The maximum load transfers from 6:00 to 11:00, and a new ultra-high peak is formed. The peak-valley ratio increase to 42.5%. Since the power of AWHPs is stable throughout the day, the load on the whole day increase. The maximum load increase to 63.0 GW, and the peak remain at 6:00, and the peak-valley ratio dropped to 22.4%. The maximum load of the entire power grid after using AAHPs increased to 56.8 GW and it was transferred to 9:00. Due to the large power consumption at night, the peak-valley ratio has been reduced to 21.8%.

3.2.2. Monthly maximum power demand curve

Figure 7(b) depicts that the maximum power demand in winter after using TSEHRs, AWHPs and AAHPs, rise to 130.6 GW, 70.7 GW, 65.9 GW from the original 53.7 GW. The load increase rates are 101.5%, 9.0%, 2% respectively, which means its needed to add new power plants to meet the power demand.

Figure 7. Electricity curves before and after using electric heating equipment in BTT Power Grid: (a) typical daily load curve; (b) monthly maximum power demand curve.

4. Conclusion

Three dominant electric heating equipment are tested to investigate the load patterns. Field measurements of indoor temperature and instantaneous power load in representative households in rural Beijing, China, from January 25 to February 19 were conducted. Electricity consumption and patterns of each equipment were observed. Depending on the load patterns, taking BBT power grid as an example, the impact on the power grid system was estimated. AAHPs can be separately installed, not only have the potential to reduce heating energy consumption, but also has the lowest impact on the power grid. The results obtained from this study provides new insights into the coal-to-electricity action, and could also provide guidance for heating replacement decision making and power grid system upgrading.

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