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Communication

Energy saving and emission reduction of China's urban district heating

Xia Chen [a,b], Li Wang [a,b,*], Lige Tong [a], Shufeng Sun [a], Xianfang Yue [a], Shaowu Yin [a], Lifang Zheng [a]

[a] School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China
[b] Beijing Engineering Research Center for Energy Saving and Environmental Protection, Beijing 100083, China

HIGHLIGHTS

- ► Replacing urban district heating with heat pump heating.
- ► Impact of heat pump heating on heating and power generation sectors.
- ► Potential of energy saving and emission reduction for heat pump heating.
- ► China should adjust current urban heating strategy.

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ABSTRACT

China's carbon dioxide (CO_2) emission ranks highest in the world. China is committed to reduce its CO_2 emission by 40% to 45% from the 2005 levels by 2020. To fulfill the target, China's CO_2 emission reduction must exceed 6995 million tons. Energy consumption and CO_2 emission of China's urban district heating (UDH) are increasing. The current policy implemented to improve UDH focuses on replacing coal with natural gas to reduce energy consumption and CO_2 emission to some extent. This paper proposes that heat pump heating (HPH) could serve as a replacement for UDH to help realize energy-saving and emission-reduction goals to a greater extent. The paper also analyzes the impact of this replacement on the heating and power generation sectors. The results show that replacing coal-based UDH with HPH decreases energy consumption and CO_2 emission by 43% in the heating sector. In the power generation sector, the efficiency of power generation at the valley electricity time increases by 0.512%, and the ratio of peak–valley difference decreases by 16.5%. The decreases in CO_2 emission from the heating and power generation sectors cumulatively account for 5.55% of China's total CO_2 emission reduction target in 2020.

1. Introduction

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas. Its rapid increase in emission rate is attributed to the increase in civil and industrial activities over the last few decades (Kerr, 2007; Karl and Trenberth, 2003). Global CO_2 emission from energy consumption reached 30,313 million tons (Mt) in 2009 (EIA, 2012). In the same year, the total CO_2 emission from China was 7707 Mt (EIA, 2012), which accounted for 25.3% of global CO_2 emission. China is the world's largest emitter of CO_2. The pressure on China to reduce CO_2 emission is increasing (Guo et al., 2010; He et al., 2010; Jiang et al., 2010).

CO_2 emission from urban district heating (UDH), which has an average annual growth rate of 10.3%, was responsible for 4.4% of China's total CO_2 emission in 2009 (Wang et al., 2011). Coal is the main energy source of UDH in China (Shang and Wang, 2009; Xu, 2010a, 2010b). Coal combustion is one of the main sources of urban air pollution (Hu et al., 2010; Xu, 2010a, 2010b). UDH in China is exerting increasing pressure on energy, environment and economy.

The urban population density in China is very large. Most buildings in UDH regions are high-rise buildings. The extension of cogeneration to urban areas is also limited partly because of the limited coverage of heat and electricity supply. Most power plants in China are coal-fired, small-scale stations. Such small-scale stations are being eliminated gradually, but large-scale stations are far from the cities to be of much use for UDH. Moreover, preferential policy for thermoelectricity is lacking in China.

To reduce inhalable particle and SO_x pollution from coal-based UDH, China has been vigorously developing natural gas-based UDH for years. The current policy to improve UDH focuses on the replacement of coal with natural gas, which is effective in reducing CO_2 emission to some extent. In regions 41°N latitude

* Corresponding author at: University of Science and Technology Beijing, School of Mechanical Engineering, Xueyuan Road No.30, Beijing 100083, China.
Tel.: +86 10 62334425; fax: +86 10 62329145.
E-mail address: liwang@me.ustb.edu.cn (L. Wang).

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south of China, the replacement of coal-based UDH with natural-gas-based UDH is expected to decrease CO_2 emission by as much as 63.5% in 2020. This reduction is expected to account for approximately 7.9% of the total CO_2 emission-reduction target for China by 2020 (Wang et al., 2011). However, the replacement of coal-based UDH with heat pump heating (HPH) driven by electricity generated by natural gas is capable of decreasing CO_2 emission by 83.7%. This reduction constitutes approximately 10.5% of the total CO_2 emission-reduction target for China by 2020 (Wang et al., 2011).

The electric power industry in China has been developing rapidly. In 2009, electricity generation in China was approximately 3681.2 TW h, presenting a 492.6% increase compared with the electricity generated in 1990 (AREPSC, 2010; CSY, 1997–2011; Hu et al., 2012). The peak–valley difference of China's power supply is a conspicuous contradiction. Its concrete manifestation is that the load at valley electricity time from night to early morning is low, whereas the power supply at peak electricity time is deficient. The power generation is imbalanced, and the power network operation cannot be carried out under the most economic and steady conditions. The ratio of peak–valley difference in China ranges from 25% to 30%, and in some provinces and cities, the difference is close to 50%. China encourages the use of valley electricity to alleviate power utility pressure. Some cities have implemented policies on the time-of-use power price to facilitate peak load shifting. HPH can improve the primary energy ratio and decrease energy consumption as well as CO_2 emission for the heating sector. Replacing coal with heat pumps driven by electricity also benefits the power generation sector. The replacement can effectively improve power generation efficiency and reduce the ratio of peak–valley difference and requirements of load adjustments.

Thermal power is the main source of the Chinese power structure. Coal is the main energy source of thermal power in China, and it will be used for a long time. In this paper, we comprehensively analyze the feasibility of replacing UDH with HPH driven by electricity generated by coal in China. We also estimate the corresponding potential for energy saving and emission reduction both in the heating and power generation sectors

2. Methods

The application of HPH is restricted by ambient temperature in winter. The lowest outdoor temperature for the normal operation of household heat pumps produced in China at present ranges from -10 °C to -15 °C. In this paper, we consider that the region covered by the Northern China power grid, Northwest China power grid, and Central China power grid is feasible for replacing UDH with HPH.

Based on the standard and energy efficiency of heating in China, the average annual energy consumption of boilers for coal-based UDH for both residential and public buildings is 19.9 kg coal equivalent per unit floor area (CESSTU, 2009). To replace coal-based UDH with natural gas-based UDH, the energy consumption per unit floor area was calculated using the following formula:

$$E_{un} = E_{uc} \times \eta_{uc}/\eta_{un} \tag{1}$$

where E_{un} is the average annual energy consumption per unit floor area of natural gas-based UDH, E_{uc} is the average annual energy consumption per unit floor area of coal-based UDH, η_{uc} is the primary energy ratio of coal-based UDH at 0.75 (Han et al., 2005), and η_{un} is the primary energy ratio of natural gas-based UDH at 0.9 (Han et al., 2005).

To replace coal-based UDH with HPH, the energy consumption per unit floor area was calculated using Eqs. (2) to (4) (Wang et al., 2011):

$$E_{h24} = E_{uc} \times \eta_{uc}/\eta_{hc} \tag{2}$$

where E_{h24} is the average annual energy consumption per unit floor area of 24-h operation of HPH, and η_{hc} is the primary energy ratio of HPH powered by electricity generated from coal (Wang et al., 2011).

Considering the ambient temperature effect, the heating seasonal performance factor (HSPF) was calculated based on the thermodynamic perfection of air conditioners with first-class efficiency in China.

$$\text{HSPF} = 1 + (\text{COP}-1) \times [T_o/(T_i - T_o)]/[T_{od}/(T_{id} - T_{od})] \tag{3}$$

$$\eta_{hc} = \varphi_{ec} \times \text{HSPF} \tag{4}$$

where φ_{ec} is the efficiency of electricity generation from coal, HSPF is the heating seasonal performance factor, COP is the heating coefficient of the performance of heat pumps, T_{id} is the indoor temperature under designated conditions, T_{od} is the outdoor temperature under designated conditions, T_i is the indoor heating temperature, and T_o is the average outdoor temperature during heating seasons in the region feasible for replacing UDH with HPH in China.

Currently, the heating load cannot be adjusted according to indoor temperature and users' demand for UDH in China. On-demand heating can be achieved by the economical operation of HPH. Heating time and load can be controlled according to indoor temperature, and heat pumps can be shut down if users do not need the heating.

For the economical operation of HPH, energy consumption per unit floor area was calculated using Eq. (5) (Wang et al., 2011):

$$E_{he} = E_{h24} \times (1-\varepsilon) \times \delta_p + E_{h24} \times \varepsilon \times \delta_r \tag{5}$$

where E_{he} is the average annual energy consumption per unit floor area of the economical operation of HPH, ε is the ratio of urban residential area to urban building area in the region feasible for replacing UDH with HPH at 0.894 (Wang et al., 2011), δ_p is the ratio of the average annual energy consumption per unit floor area of the economical operation of HPH in public buildings to that of the 24-h operation of HPH at 0.7, and δ_r is the ratio of the average annual energy consumption per unit floor area of the economical operation of HPH in residential buildings to that of the 24-h operation HPH at 0.4.

$$\delta_p = \varepsilon_r + (1-\varepsilon_r) \times \varepsilon_{lt} \tag{6}$$

$$\delta_r = \theta_{r65} \times [(1-\varepsilon_s) + \varepsilon_s \times \theta_b] + (1-\theta_{r65}) \times [(\varepsilon_s \times \theta_b) + (1-\varepsilon_w - \varepsilon_s)] \tag{7}$$

where ε_r is the ratio of regular heating time per day to 24 h per day at 0.5, ε_{lt} is the ratio of energy consumption of low-temperature heating to that of regular heating (every 1 °C decrease in heating temperature results in the reduction of energy consumption ranging from 5% to 10% (NSPRC, 2004)), ε_s is the ratio of sleeping hours per day to 24 h per day at 0.3, ε_w is the ratio of working hours per day to 24 h per day at 0.3, θ_{r65} is the ratio of the urban residential area of people aged 65 and over to the urban residential area in the region feasible for replacing UDH with HPH at 0.097, and θ_b is the ratio of the bedroom area of urban residential buildings to the urban residential area in the region feasible for replacing UDH with HPH at 0.5.

The UDH area is mostly covered by the Northern China power grid, Northwest China power grid, and Central China power grid. In this paper, we analyzed the effect of replacing coal with heat pumps on the three power grids to solve the UDH requirement in China. Power supply for the current heating mode was calculated