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A survey of district heating systems in the heating regions of northern China

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ABSTRACT

To investigate the status quo of heating supply and the impact of energy saving policies in northern China, a survey was conducted on the DHSs (district heating systems) in 15 Chinese cities. The average heating energy consumption was 19.2% lower than in 2008 due to the corresponding policies formulated and promoted by the authorities. Additionally, parameters of DHSs in cold and severe cold zones were collected, which include the energy consumption, operating efficiency, monitoring and control level, and gas emissions. These essential data can serve as a reference for energy efficiency retrofits and further analysis of comprehensive energy consumption of the DHSs in northern China. Finally, suggestions for improving existing policies during "the Twelfth Five-Year Plan" period are put forward to further improve the energy efficiency of DHSs.

1. Introduction

As China's economy is progressing, millions of Chinese people are now living with severe air pollution. Specifically, it led to TSP concentrations that were 184 g/m^3 higher (95% CI: 60, 308) or 55% higher in the North and reductions in life expectancies of 5.52 y (95% CI: 0.8, 10.2) in the North due to elevated rates of cardiorespiratory mortality [1]. For understanding how polluted the air is currently or how polluted it is forecast to become, AQI (air quality index) is put forward by government agencies to communicate to the public. China's AQI level is based on the level of 6 atmospheric pollutants, namely SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3. To the DHS (district heating system), the principal emissions from coal-fired boiler plants are SO_2, NO_2 and particulates. In terms of air pollution emission in Shanxi, it is lower in the non-heating period compared to the heating period, despite the fact that the quantity of coal for heating is only 10.5% of the total coal consumption in the whole year. There are 280 thousand tons of SO_2, 560 thousand tons of particulates, 380 thousand tons of PM_{10} and 110 thousand tons of $PM_{2.5}$ per month in the heating period. In the non-heating period, air pollution emission includes 250 thousand tons of SO_2, 540 thousand tons of particulates, 370 thousand tons of PM_{10} and 100 thousand tons of $PM_{2.5}$ per month [2]. According to [3], 70% of particulate, 85% of SO_2, 67% of NO_y and 80% of CO_2 of domestic pollution emissions come from coal-fired. Besides, due to the heights of emission sources being generally lower than 100 m, as wells as the climate in the heating regions of northern China being drier and colder than that in the non-heating period, air self-purification capacity is worse in the heating period. In the consequence, the heating period (November, December and January) has a higher average AQI than other months, as shown in Fig. 1 [4]. In recent years, China has been on the headlines for her spectacular GDP growth as well as high energy demand growth (particularly coal). Although the increased demand for energy causes the energy price hiking [5], the price of coal for heating in the heating regions of northern China has seen little fluctuation due to government control throughout the time. The main factors of little variation are coal output, the distance between places of origin and utilization, and financial policies. From 2001 to 2011 in northern China, the heating areas increased from 3.3×10^9 m^2 to 10.2×10^9 m^2, and the heating energy consumption rose from 0.84×10^8 tce to 1.66×10^8 tce [6]. It can be seen that the heating areas increased 209.1%, while the heating energy consumption increased 97.6%. This situation illustrates the enormous effects of energy–efficiency policies on the heating supply system development. In recent times, government is dedicated to removing coal-fired boiler plants of low capacity, using nature gas as fuel instead of coal [7], retrofitting building envelope, adopting heating meter [8], and introducing CDM [9]. The Twelfth Five-Year Guideline requires the usage of DHS in the northern heating area to achieve nearly 65%, half of which must be supplied by CHP plants [10], guaranteed by several policies, as shown in Table 1.

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Nomenclatures

Engineering units

kgce	energy consumption, represented by kilogram standard coal

Variables

a	net calorific value of the fuel (kJ/kg)
A	heating area (m^2)
b_{co}	DHS energy consumption (kgce/m^2)
b_m	fuel energy efficiency (kgce/GJ)
b_{zh}	comprehensive energy efficiency of the boiler plant (kgce/GJ)
B_b	fuel consumption in the boiler plant (kgce)
B_{gl}	fuel consumption in the boiler plant (kg)
B_{zh}	total energy consumption in the boiler plant (kgce)
e_{gl}	power consumption in the boiler plant (kWh)
E_{gl}	power consumption in the boiler plant (kgce)
Q_{gl}	total heat supplied (GJ)
η	operating efficiency of the DHS (%)
η_e	power consumption percentage of the total energy consumption in the boiler plants (%)
η_{gl}	thermal efficiency of the boiler (%)
η_p	transmission efficiency of the network (%)

Acronyms

AQI	air quality index
CHP	combined heat and power production
CCHP	combined cooling, heating, and power
CDM	clean development mechanism
DH	district heating
DHS	district heating system
HES	heat exchanging station
MOF	Ministry of Finance
NDRC	National Development and Reform Commission

Replacing the distributed local boilers with new DH + CHP plants has a positive impact on primary energy saving and air pollution reduction [11]. Specifically, CHP systems could save fuel energy when the extraction ratio is larger than 0.15 [12].

Europe has been renovating their heating supply systems since the end of the 20th century. To reduce primary energy consumption, the Energy Efficiency Plan 2011 was introduced [13]. With financial incentives, CHP and garbage incineration that adhere to gas-fired boilers as peak-load heat sources are popular in Europe [14–17]. In Denmark, CHP has accounted for more than 80% of DHSs since 1998 [18]. It is also an important part of the transition to a sustainable energy system in Sweden [19]. A well-designed CHP system can increase energy transformation efficiency to over 80% [20], as well as reduce CO_2 emissions [21]. In terms of the monitoring and control of the heating supply system, it can automatically adjust to weather variation and user-adjusted flow rates [22–24]. As for heating supply retrofitting, building retrofitting has been a focus since the energy crisis in the 1970s, such as enclosure renovation [25–29] and heat metering [30,31]. Holistic approaches that improve the buildings and heating systems together result in the best energy saving [32]. Additionally, heat loss of the heat source and network transmission are the key factors in the optimal design of low-energy DHSs [33–35]. In contrast, studies of energy–efficiency retrofitting for heat sources, heating supply networks and regulation are prevalent in China.

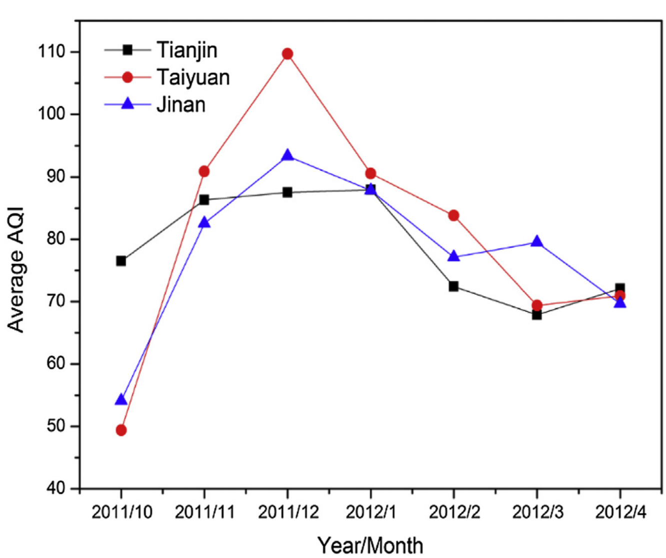

Fig. 1. Average AQI from 10/2011 to 4/2012.

Many surveys have focused on the relationship between user behaviors and building energy consumption [36–43]. Researchers believe that self-conscious energy-saving behavior has a significant effect on the energy efficiency of heating supply systems. Less attention has been paid to surveys of the whole DHS, which consists of the heat source, heating supply network, HES (heat exchanging station), thermal entrance of building and user terminals.

Based on questionnaires and field surveys, this paper determines the status quo of DHSs in the heating area of northern China, analyzes the operation level of heating supply systems, proposes improvements on the current policy and provides the fundamental data for DHS retrofitting.

2. Methods

2.1. Survey methods

Fig. 2 shows the four steps used to obtain the survey results of DHSs in the heating areas of northern China. The following 15 cities were selected, which are located on the map in Fig. 3: eight of them are in severe cold zones, whereas the others are in cold zones, as listed in Table 2. Each system could be on behalf of specific level of heating status quo in China. Therefore, 45 DHSs have been chosen as survey objects.

The questionnaire survey was conducted in the selected cities to evaluate the status quo of DHSs. A field survey, as a supplementary measure, was conducted to encourage high survey participation and completion. The surveys were executed from January to May 2013. Data from the 2011–2012 heating supply period were also collected.

The questionnaire consists of five categories of information: basic information, equipment and operation of boiler plants, heating supply network, HES, and building thermal entrance. Basic information includes the name and ownership of the enterprise, the type of heating supply areas and the charging method. Equipment and operation information consists of the type of the equipment, heat metering, energy consumption and the main controlling