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North–South debate on district heating: Evidence from a household survey

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HIGHLIGHTS

- The debate on whether Southern China apply district heating is present.
- The household data in 2012 is used to compare the energy efficient and cost.
- South resident use more energy and higher cost but less comfort than North.
- Government should not prevent the district heating market.

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ABSTRACT

There has been a long debate on whether South China should supply district heating for the residential sector, a system that is widely used in North China. The major concern is that it may further accelerate China's energy demand. Using a unique urban household level dataset, the *China Residential Energy Consumption Survey* (*CRECS*), we investigate residential energy consumption for heating and examine the energy intensity and energy cost of distributed heating in South China and district heating in North China during the 2012 heating season. Our results show that the total energy consumption for distributed heating system users in southern cities is significantly lower than for users of district heating systems in northern cities. However, when accounting for the heating area and heating season, the distributed heating households in the South consumed 32% more energy and paid 189% higher cost per unit area and per hour, but had lower comfort than district heating users in the North. These findings suggest promoting the district heating market in appropriate areas in South China. This not only can improve residential welfare, but also can indirectly reduce energy consumption and financial burdens.

1. Introduction

With the rapid economic growth and urbanization in China, energy consumption in buildings has become an important issue. A report released by ACEEE (American Council for an Energy-Efficient Economy) shows that, the primary energy consumption of buildings throughout China (excluding biomass energy) in 2008 was nearly 543 million tons of coal equivalent (Mtce), accounting for nearly one-fifth of China's total primary energy consumption (Shui and Li, 2012). Five years later, this number reached 1050–1128 Mtce in 2013, accounting for nearly 28–30% of total energy consumption (Xinhua, 2014). Heating accounts for a large proportion of total building energy consumption. In 2008, the primary energy intensity in terms of energy consumption per square meter of urban residential buildings in China was 148 kWh/m^2 a, 47% of which was consumed for heating (Shui and Li, 2012). [1]

In China, district heating systems are widely used in northern cities, where building energy use accounts for more than 40% of the whole country's total urban building energy consumption (Shui and Li, 2012). The concerns about district heating systems in North China focus on how to improve their energy efficiency and how to measure the heating energy consumption of each household. Residents in southern cities, however, mainly use their own heating equipment (so-called distributed heating) in the winter, such as Heating Ventilation and Air Conditioning units (HVAC), gas-fueled heating equipment, or electric heating equipment.

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[1] Building energy use here refers to the energy used during operation, including energy consumed for space heating, air conditioning, water heating, household appliances, lighting and cooking.

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Fig. 1. North–South heating line in China.

Although the need for heating in South China is beyond doubt because extremely cold weather occurs frequently, whether district heating should be provided is still under debate. In 2012, a proposal that the *District Heating Systems in North China Should be Extended to South China* was put forward to *The Fifth Session of the 11th CPPCC National Committee* (Southern Daily, 2012). However, based on the popular view that energy waste and economic cost would increase with this extension, the proposal was rejected. The main issues are how to calculate and compare the energy efficiency, financial costs and residential welfare of different heating patterns, such as district heating systems, distributed heating or new approaches, for example, small-scale district heating provided by a community. However, there is no clear evidence yet.

In the 1950s, the central government set district heating zones in China according to the “Qin Mountains-Huai River” boundary, named the North–South heating line (Fig. 1). District heating zones include North China, including northeast and northwest regions of China where there are at least 90 days a year with daily average temperature less than or equal to 5 °C. Most urban areas in North China were covered by the district heating system, which helps to maintain 20 °C indoors. In general, the heating period for district heating is consistent in northern provinces, usually from November 15 to March 15 the following year. The heating period in Northeast China, Inner Mongolia and other colder provinces is relative longer, from late October to mid-April the following year.

However, with the continuous increase of household income and relatively abundant supply of energy in recent years, there is a hot debate on whether district heating should be used in some parts of the South. The reason for the debate is that, in some parts of the South, it is at least as cold in winter as in some district heating areas in the North, in some cases even colder[2]. It is unscientific to decide on heating systems based on the North–South heating line, which was a product of the planned economy in an era with energy shortages.

Because of these concerns, some cities in the South have introduced district heating. Wuhan, for example, has become a pioneer in district heating in South China. The *Cool Summer and Warm Winter Project* was started in 2005. Its goal was to provide heating for 160 million residents in 500 km^2 areas (NetEase, 2013). However, The Ministry of Housing and Urban-Rural Development (MHURD hereafter) opposed and later suspended implementation of the project. Even though small-scale local district heating systems were installed and used in some southern cities (like Wuhan, Liupanshui, Xuzhou, Shanghai) (ChongQing News, 2013), they have not been put into large-scale application in all cases because the relevant authorities have not loosened regulations. Moreover, these southern cities administrators were faced with the risk of been abolished city reward or honor (NetEase, 2013).

This issue is of great interest to the general public and to political leaders, and they have made arguments for and against, with cost, fairness and welfare in mind. We will next summarize the main arguments in opposition to and support of district heating in the South (China.com, 2013; NetEase, 2013; People.com, 2014; Xinhua, 2013). To begin, we list four opposition points. (1) A lot of infrastructure investment is required to establish district heating systems in the South. We would need to reconstruct residential buildings on a large scale, because they are currently of low efficiency in keeping warm. The cost would be very high. (2) The shorter heating season and higher humidity in the South cause a great deal of heat loss in heating systems, resulting in inefficient heating and energy waste. (3) The unit energy consumption for district heating systems in the North is about four times the consumption for distributed heating systems in the

[2] We adjust monthly average temperature to the apparent temperature in accordance with local average relative humidity in 7 southern cities (Shanghai, Nanjing, Hefei, Wuhan, Changsha, Chengdu and Guiyang), and compare them with the temperature in Beijing in January, February, March and December 2011. In the winter, the monthly average apparent temperature in all these cities was lower than 10 °C and was lower than 5 °C in most regions. The gap in monthly average apparent temperature between southern cities and Beijing was less than 5 °C. i.e., in January 2011, the average apparent temperature for these 7 southern cities range from −2 °C (Shanghai) to −7.1 °C (Guiyang), much close to the temperature in Beijing (−4.5 °C).

South. Establishing district heating systems in the South will lead to an increase in total energy consumption, worsen energy and environmental problems and even damage human's health in China. A recent scientific evidence shows that the residence in north has lower life expectancies than south result from the free winter heating policy (Chen et al., 2013). (4) The cost of district heating systems in the North is about 4–10 times the cost of distributed heating systems in the South. Establishing district heating systems in the South will lead to an increase in residential heating cost.

The support points are displayed below. (1) The North–South heating line is the product of a specific historical period. It lacks a scientific basis because it did not take into account climate change or extreme weather. (2) Establishment of district heating does not necessarily require the government to provide public heating services. District heating can be achieved by the market. (3) Better heating is a basic need that increases the welfare of residents. No one has the right to deprive southern residents of district heating if they want it. (4) The district heating system in the North heats the entire usable area of the home for 24 hours a day, but distributed heating in the South does not. Thus, there is a huge difference in comfort between northern and southern households. Furthermore, heating subsidies are provided to northern residents while southern residents bear all their own heating costs. These differences go against the principle of fairness.

Because these arguments are political and social as well as economic and technical, it is complicated to evaluate the impact of establishing district heating systems in South. Our results provide micro-level evidence and contribute scientific information to this debate. We show that, when taking into account the difference of heating area and heating season, a southern urban household will consume more energy and expenditure to gain a lower level of comfort than will a northern household.

In order to provide some evidence on energy consumed for different heating patterns in North and South China, we use micro-data from a residential energy consumption survey conducted by Renmin University of China to calculate the energy consumption and cost for heating in northern and southern urban households. We analyze three problems. First, we try to find the difference in energy efficiency between district heating in the North and distributed heating in the South. Second, we estimate the gap in heating cost between district heating in the North and distributed heating in the South. Finally, we predict the change in energy consumption and cost for heating in the South if district heating systems were established there. Our results show that energy consumption in South China is 1.32 times higher than for district heating in North China, while expenditure per hour for unit square heating area of distributed heating is 2.89 times higher in South China than for district heating areas in North China. Thus, if district heating systems were established in southern cities, it not only would improve the welfare of the residents, but also would reduce the energy consumption and cost of heating there.

This paper is organized as follows. In the second section, we introduce the background of heating patterns in China and present some relevant reports and literature. In the third section, we briefly introduce the survey and describe the main features of the heating modes in North and South China in our sample. The research methodology is also discussed in this section. We report the results in the fourth section and simulate energy consumption and cost in the South for different heating scenarios in the fifth section. We make some policy recommendations in the last section.

2. Methods

2.1. Previous studies

Building energy consumption for heating accounts for 45% of the total national urban building energy consumption (Cai et al., 2009). The district heating area in North China is about 6.5 billion m^2, accounting for 70% of the whole country's building area. Intensive studies have contributed to the analysis of energy consumption by district heating in northern cities (Chen et al., 2013; Wei et al., 2010; Zhang, 2004) or in northern rural areas (Tonooka et al., 2006). By contrast, distributed heating is widely used in South China. According to a residential appliance usage survey in the Yangtze River basin areas conducted by Tsinghua University in 2013, the proportion of households who owned HVAC units was 85%, other heating equipment 80%, and district heating supplied by the community less than 1%. Very few households are equipped with a gas boiler or an electric heating device. Based on some small sample surveys, researchers gauged the energy consumption for heating during the winter in southern areas. i.e., Chen et al. (2013) showed that the annual electricity consumption for heating and cooling is estimated at around 47.6 kWh/m^2 per household in Hangzhou.

Many researchers present evidence that district heating in southern cities would consume more energy than the current system of distributed heating. Zhang (2013) estimated that the energy consumption for district heating system is 8–12 kgce/m^2 during a winter, which is 3–5 times more than distributed heating. Xia and Chen (2010) suggested that, in areas with a warm summer and cold winter, a distributed heating system based on heated water and ground radiation should be widely used because of its comfort and efficiency.

There also has been some research on the district heating systems that have been put into operation in the South. District heating on a small scale, i.e., district heating supplied by a community, is very popular. Community district heating is accepted in many southern cities, such as Nanchang, Xuzhou, Shanghai, Wuhan, Hefei, and Changsha. Some communities use heat and power cogeneration to supply heat. However, the selection of a heating system for district heating is determined by the local heat source and end appliance (Ying, 2013).

Nevertheless, few researchers have compared the energy consumption for heating in northern and southern China. Chen et al. (2011) investigate six cities (Urumqi, Xian, Chongqing, Changsha, Kunming, and Hong Kong) in five architectural thermotechnical design zones in China during 2002–2004. The amounts of energy used for space heating in Tangshan, Urumqi and Xian are several times as large as the amounts of all the end uses in the southern cities of Hong Kong, Chongqing, Changsha and Kunming. Our findings are similar but more broadly based. Our research is to determine whether, if the same district heating system used in the North was introduced in the South, it would lead to more energy conservation and cost saving. Our research differs from previous research in the following ways: First, our research covers most provinces in China through household surveys, so that the result is national rather than local. Second, we not only calculate the energy consumption for heating, but also calculate energy intensity and unit heating cost. Most importantly, our calculation accounts for construction characteristics and the length of the heating season, which are two main factors affecting building energy consumption. Third, based on the comparison in energy consumption, energy intensity, and unit heating cost of district heating in the North and distributed heating in the South, we use distributed heating in the South as the basic scenario and district heating in the North as the highest level of heating system improvement. Between them, scenario analysis is used to show gaps in energy conservation and cost saving in detail.

2.2. Survey description

The CRECS survey was administrated by the Department of Energy Economics at Renmin University of China over the winter holiday of 2013. The questionnaire covered six main areas with 324 questions in total: household demographic characteristics, dwelling characteristics, possession of household appliances, space heating and cooling, patterns of private transportation, and household electricity consumption, as well as awareness of relevant energy policy. To have a clear picture of household energy consumption pattern, we collected detailed energy relevant information, such as appliance type, frequency and duration of appliance use, different types of energy costs, and electricity bill information. Households that met the following four criteria were invited to participate in the survey. First, the household had to be able to provide its electricity bills or electricity consumption records for 2012. Second, the household had to have used energy only for consumption purposes, rather than for production purposes. Third, the respondents must have lived in their home for more than six months in 2012. Fourth, only one household from a community could participate in the survey. All in all, a total of 1640 households were initially contacted and invited to take the survey, while 1542 eventually enrolled in the study (a high response rate of 94%). After validity and consistency checks, 1450 total observations were left for the final analysis, with 64% from cities, 16% from towns and 20% from rural areas. To facilitate the comparison, we combine the city and town groups into the urban category.[3]

As shown in Table 1, 39.7% of total surveyed households used district heating systems. The heating sources for these systems were 63% from the city network and 21% from a local boiler. The average heating season was 3.9 months, during which heating was available for the whole day. Because individual heating meters are not widely used, 92% of district heated households paid in accordance with the heated area or the dwelling's construction area. Around 82% of district heat users in our sample receive some subsidies from their employers. In contrast, the 38.6% of households that cannot access the district heating system had to resort to distributed heating. Of these households, 35% used portable electric heaters, 28% used HVAC units, and 28% used heating stoves. This diversification of heating devices led to different fuel choices. Around 67% used electricity and 29% used wood or coal as heating fuel. On average, the households without district heating operated heating devices for 4.3 hours per day and used them for 2.1 months in 2012. They could control the temperature, and 36% of households set the heating temperature as 19.8–23.5 °C. Their heating expenditure was based on fuel cost and heating time. None of them got any subsidies.

Based on this micro-level data, Zheng et al. (2014) aggregated the individual household energy consumption by various fuel types and usage purposes. Averagely, a household consumed 1426 kgce energy in 2012, with a median value of 1230 kgce/year. The energy consumption per family member is 612 kgce/year, with a median value of 477 kgce/year. Among all seven accessible energy sources (district heating, electricity, firewood, gas, LPG, coal, and solar), the district heating supplies 45% of total energy consumption, followed by natural gas (18%) and electricity (15%). All these energy are used for five purposes including cooking, home appliance, water heating, space cooling and space heating. As expected, space heating is the most energy-intensive end use, followed by cooking. These account for 54% and 23% of total energy consumption, respectively.

Table 1
Main features of the household heating.

	District heating	Distributed heating
Sample size (ratio)	575 (39.7%)	560 (38.6%)
Heating type (%)	Municipal heating network: 63%	Electric-heater: 35%
	Local boiler: 21%	HVAC: 28%
		Heating stove: 28%
Fuel mix (%)	–	Electricity: 67%
		Wood/Coal: 29%
Frequency (months/year)	3.9	2.1
Daily usage hour (hours)	24	4.3
Temperature control (°C, ratio)	–	19.8-23.5 °C (36%)
Individual meter (%)	6%	–
Charge type (%)	Heating area (92%)	Fuel cost and heating time
Charged by family (%)	60%	–
Subsidized by others (%)	Employers (82%)	–

Due to the lower population density in rural areas, urban residents are the main subjects of our study. We distinguish the northern region and the southern region according to the North–South heating line (latitude 33°). However, even in the northern region, some families used distributed heating because a district heating system was not available. In the southern region, there were some pilot cities with district heating systems. In this paper, we compare the families with district heating in the northern region to the families with distributed heating in the southern region. In Table 2, we show these two kinds of research subjects: 550 families with district heating systems in the northern cities and 270 families with distributed heating in the southern cities.

We adjust energy consumption and cost for household heating by unit hour and unit area due to the different heating seasons and heating areas in different regions. Two indicators are compared: energy intensity (energy consumption per square meter per hour) and unit heating costs (heating cost per square meter per hour). The method of estimating these indicators is introduced below.

2.3. Estimation of district heating

We use the indirect formula (1) to estimate energy consumption of district heating because the technical characteristics, such as fuel type and heat waste, are not available.

$$\text{Energy}_{\text{district heating}} = \text{Energy}_{\text{base}} \times S \times \beta_{\text{building}} \times E \quad (1)$$

where $\text{Energy}_{\text{district heating}}$ (kgce/year) is the energy consumed for district heating; $\text{Energy}_{\text{base}}$ (kgce/m^2 season) is basic energy consumption; S (m^2) is heating area; $\boldsymbol{\beta}$ is the adjustment coefficient, including the building adjustment coefficient and the energy efficiency coefficient for HVAC; and E (season/year) is heating

Table 2
Definition of research objects.

Sample size (household)		Region	
		North	South
Heating mode	District heating	550	19
	Distributed heating	60	270

Note: the sample size here is slightly differ from Table 1. In Table 1, all respondents on two types of heating system are summarized. Contrarily, Table 2 summarize the sample households who both report their heating pattern and geographic location.

[3] Our sample covers 26 provinces and 91 cities, including 44 northern cities and 47 southern cities. More details of this survey can be referred to in Zheng et al. (2014).

duration. First, we set household basic energy consumption according to the building's age, the relevant national heating requirements (indoor temperature should be higher than 18 °C during the heating season) and energy consumption technical standards in China.[4] A primary characteristic is that the newer the building is, the better it keeps warm. Secondly, district heating is used for the whole household, thus the heating area is the usable housing area. If this information is not available, we choose the average usable housing area for households with district heating, 85 m^2, instead. Thirdly, housing reconstruction affects the amount of heat loss indoors, and thus affects energy consumption for heating. Therefore, we set the building adjustment coefficient as follows. If the edges of doors and windows were insulated, energy loss is reduced by 10%. If external walls were reconstructed for keeping warm, energy loss is reduced by 30%. If ceilings and pipes were treated, this will save 10% of energy. Finally, we transform the household heating period (months) to the standard heating season because there are different heating periods in different regions. We set the average heating period of district heating households, 3.9 months/year, as a standard heating season. Based on survey data, the standard heating season for each household equals its reported heating period (in months) divided by 3.91 (months).

We calculate the energy intensity of district heating according to the heating period and area, as shown in formula (2), where $EneEff_{district\ heating}$ (kgce/hour m^2) is the energy intensity index of district heating. In the denominator, the heating period (months) is based directly on the survey data, and is converted into a value in units of hours per year (T, hour/year). If the variable is missing for a certain observation, we use the sample mean 3.91 months instead.

$$EneEff_{district\ heating} = Energy_{base} \times \beta \times E/T \tag{2}$$

The expenditure for district heating in 2012 was reported by each of the interviewed households; this expenditure is used as the measure of district heating cost. If the data is missing, we use the average expenditure for district heating, 2082 Yuan. For normalization, we also calculate the unit district heating cost per unit heating area and per hour, as shown in formula (3), where $EneCost_{district\ heating}$ (Yuan/hour m^2) is the unit cost of district heating. C (Yuan/year) is the expenditure for district heating.

$$EneCost_{district\ heating} = C/(S \times T) \tag{3}$$

2.4. Estimation of distributed heating

One difference between distributed and district heating is that district heating operates for 24 h and heats the entire usable housing area. In the case of distributed heating, however, the heating areas, as well as heating equipment and fuel type, are different among these families. Therefore, we estimate energy consumption and cost for distributed heating throughout the year 2012 by classifying heating equipment and fuel type. Then we estimate energy intensity and unit cost based on heating duration and heating area. The primary fuels for distributed heating include electricity, gas and firewood. Based on different heating equipment, we estimate energy consumption for each fuel and convert units to kgce.

The main equipment for distributed heating is the HVAC unit. According to *Energy Efficiency Limitation and Energy Efficiency Grade of Room Air Conditioning* (GB12021.3-2010), the actual output power of HVAC equals its output power multiplied by an adjustment coefficient for type of unit (fixed-frequency unit or inverter unit), divided by the energy efficiency ratio (EER). For each variable, the output power is calculated in accordance with the rated power.[5] The adjustment coefficient for fixed-frequency HVAC is 1.0 and for inverter HVAC is 0.7. The default value for missing data is 1.0. The EER reflects the energy efficiency grade of HVAC units. The EER value of grade one, grade two and grade three or lower are 3.6, 3.4, and 3.2, respectively. The default value for a missing value is 3.2. We estimate annual electricity consumption for HVAC heating based on daily heating hours and annual heating days.

Other electricity heating equipment includes electric heaters (e-heaters) and electric-heated boilers. The average power of an e-heater is 1.2 kW, and multiplying this by daily heating hours and annual heating days gives us the annual electricity consumption. An e-heating boiler heats the entire residential area. Its technical parameters are set as follows. Its heat load per area is 0.06 kW/m^2. Thus, the heat load coefficient of an e-heating boiler is 0.6. Its daily working time is 6 hours. Annual electricity consumption can be obtained by multiplying these technical parameters by the usable housing area (m^2), daily heating hours and annual heating days.

When a residence uses natural gas as a fuel for heating boilers, its daily heat load per area is 0.0632 $m^3/(m^2$ day). Annual gas consumption can be obtained by multiplying this heat load coefficient by the usable housing area (m^2), daily heating hours daily and annual heating days,.

Firewood is often used as a fuel for heating boilers and heating stoves that are not electrical. When a residence uses a heating boiler, its daily heat load per area is 0.1 kg/(m^2 day). Annual firewood consumption can be obtained by multiplying this heat load coefficient by the usable housing area (m^2), daily heating hours and annual heating days. When a residence uses a heating stove, 2 kg of firewood is burned per hour. Annual firewood consumption can be obtained by multiplying this coefficient by the heating hours daily and annual heating days.

Table 3 shows different kinds of fuel consumed for heating. We convert their units to kgce by a conversion factor (CF)[6], and the sum is the total energy consumption for distributed heating in southern cities. A general formula is shown, where $Energy_{distributed\ heating}$ (kgce/year) is energy consumed for distributed heating. W (kW, kWh/m^2 or daily heat load per area) is the output power for heating equipment. T (hour/year) is heating hours during the winter. S (m^2) is heating area. $\boldsymbol{\beta}$ is an adjustment coefficient, which includes a building adjustment coefficient and an energy efficiency coefficient for air conditioners.

$$Energy_{distributed\ heating} = \boldsymbol{\Sigma} W \times T \times S \times \boldsymbol{\beta}_{air\ condition} \times CF \tag{4}$$

To compare energy consumption for distributed heating with energy consumption for district heating in northern cities, we also calculate energy intensity per area and per hour based on total

[4] We divide buildings into four categories by different ages, before 1980, 1980–1989, 1990–1999, 2000–2009, and after 2010. The basic delivered site energy consumption of each type of building is set as 31.68 kgce/m^2, 25.30 kgce/m^2, 20.60 kgce/m^2, 18.60 kgce/m^2, and 12.50 kgce/m^2, respectively. If the building information is missing, the basic energy consumption is 25.00 kgce/m^2. The energy conservation program in the construction sector started in 1986. In the first stage, according to the energy conservation standard (heating residential buildings, JGJ 26–86), residential construction in the northern area was required to cut energy consumption by 30% of the 1980–1981 level. In the second stage, according to the energy conservation standard (heating residential buildings, JGJ 26-95), new construction had to cut energy consumption by 50% of the 1980s level. In the third stage, China announced an energy efficiency standard for residential buildings in the hot summer and cold winter zones (JGJ 134-2010) and other standards. The goal in this period was to cut energy by an additional 30%.

[5] Generally speaking, the output power of HVAC in kW=0.735 kW × (rated power/2.5 (kW)).

[6] CF for different kinds of fuel: electricity, 0.1229 kgce/kWh. Natural gas, 1.33 kgce/m^3. Firewood, 0.5 kgce/kg.

Table 3
Energy consumption for distributed heating.

Fuel	Unit	Obs	Mean	Median	S.D.	Min.	Max.
Electricity	kWh/year	396	326.5	206.7	352.7	8.3	2187
Gas	m^3/year	13	613.6	530.9	350.6	99.5	1151.8
Firewood	kg/year	232	1229.8	1125	868.1	15	5535

energy consumption, heating area and heating duration. In southern households, different room areas are multiplied by their respective weights, which represent their usage frequency, and their sum is the total heating area. In our sample, the heating proportion of the living room, bedroom, study room and overall house is 32.17%, 60.18%, 4.53% and 3.12%, respectively. Thus, the total heating area is the sum of the area of the living room, bedroom, study room and overall house, multiplied by their corresponding heating proportion. If the room area is unavailable, we use the mean value of different rooms instead. If the heating equipment is a heating boiler, the heating area is usable housing area. The heating duration (hour/year) in 2012 is the product of daily heating hours and annual heating days. Missing information is replaced by the mean value.

$$\text{EneEff}_{\text{distributed heating}} = \text{Energy}_{\text{distributed heating}}/(S \times T) \quad (5)$$

Because many kinds of heating equipment and types of fuel are used in distributed heating, we need to get the total heating cost by summing up the expenditures on different types of fuel. The price of each kind of fuel (P) is the reported mean value: electricity is 0.53 Yuan/kWh, gas is 2.1 Yuan/m^3, and firewood is 0.31 Yuan/kg. The unit distributed heating cost per heating area and per hour is shown in the formula (6).

$$\text{EneCost}_{\text{distributed heating}} = \sum \text{Energy}_{\text{distributed heating}} \times P/(S \times T) \quad (6)$$

3. Results

3.1. Comparison of total energy consumption

Table 4 lists total energy consumption for district heating in northern cities and distributed heating in southern cities in 2012. There is a huge gap between northern and southern urban households in heating energy consumption. The mean value of energy consumption for district heating is 1647.5 kgce, but is only 64.8 kgce for distributed heating. Total energy consumption for district heating is 25 times larger than for distributed heating.

This is the evidence which is used to argue against district heating in the South. It suggests that, if district heating is established, total energy consumption will increase sharply. However, we need to consider more factors, which have been neglected before. On one hand, different heating services in northern and southern cities affect the difference in energy consumption. On the other hand, the longer heating period and larger heating area in the northern cities contribute to more energy consumption. Therefore, we compare the energy intensity and unit cost in heating.

Table 4
Comparison of total energy consumption between North and South (kgce).

Category	Obs	Mean	Median	S.D.	Min.	Max.
North: district heating	550	1647.5	1423.5	1101.2	316.1	11380.1
South: distributed heating	270	64.8	30.5	142.9	1.0	1456.3

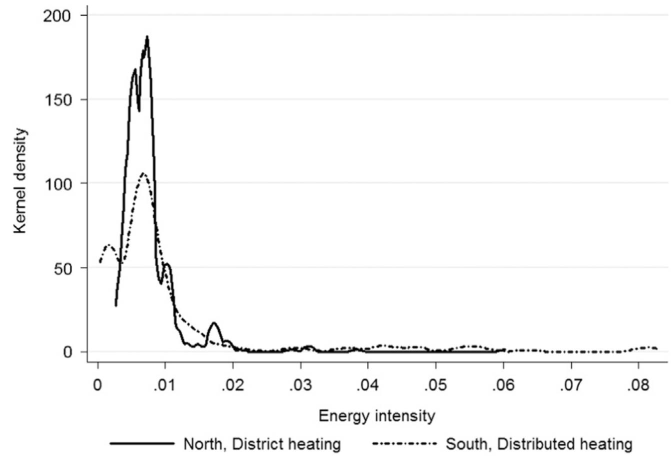

Fig. 2. Kernel density of energy intensity.

3.2. Comparison of energy intensity

Fig. 2 plots the kernel densities of the energy intensity of district heating in the North and distributed heating in the South. From Fig. 2, we can observe that the energy intensity is highly concentrated at 0.008 kgce/hour m^2 and mainly dispersed from 0 kgce/hour m^2 to 0.01 kgce/hour m^2. The mean value of energy intensity for distributed heating (0.0099 kgce/hour m^2) is 1.32 times higher than for district heating. It seems that the present distributed heating system in the South is higher in energy intensity than the district heating system in the North.

We first use the traditional t test to examine whether there is a significant difference in energy intensity between the North and South samples. It assumes that the two samples have the same mean, which fits both unpaired and paired data. This test produces a t value of 3.71, which suggests that the null hypothesis cannot be rejected at the 0.1% significance level. Notice that the sample in Fig. 2 is not normally distributed; therefore, we conduct a non-parametric test, the Kolmogorov–Smirnov test. This test is used to find out whether there is a significant distance between the empirical cumulative probability functions of two samples – in other words, whether the two samples are drawn from the same population distribution. Compared with the t test, Kolmogorov–Smirnov test does not rely on the mean's location only; it can work for non-normal data, and is not sensitive to scaling. It is widely used for two-sample comparisons due to its robustness. The null hypothesis in this case is that there is no difference in the distributions. The test gives a distance value of 0.228 with a p-value of zero, which rejects the null hypothesis that the two samples are drawn from the same distribution. Both tests indicate that the energy intensity for distributed heating is significantly higher than for district heating.

In addition, the degree of comfort is far lower in southern cities than in northern cities. If southern residents want to get the same level of comfort as northern residents, they need to consume more energy. In other words, the gap in energy intensity between northern and southern cities, 1.32 times, may be the floor level. The gap will be increased if we take comfort into account. Therefore, the district heating system used in northern cities is more efficient and energy saving.

3.3. Comparison of heating cost

The arguments above show that southern households consume more energy for heating per area and per hour but get less comfort than do northern households. In addition, we compare the unit heating cost (Yuan/hour m^2) between North and South. Fig. 3 plots

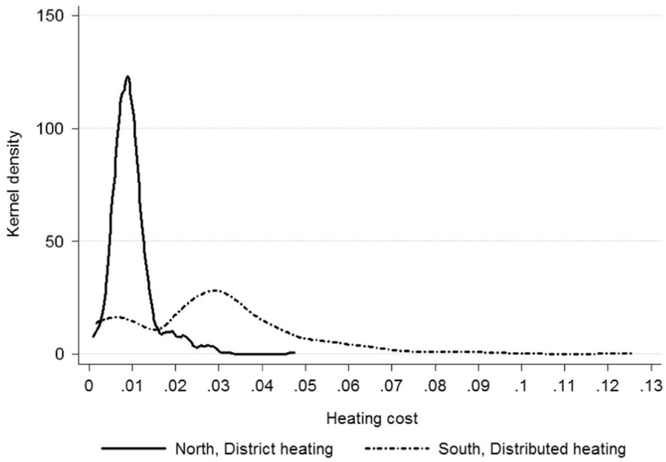

Fig. 3. Kernel density of heating cost.

the kernel densities of the heating cost of district heating in North and distributed heating in South. We can observe that the heating cost of district heating is highly concentrated at 0.01 Yuan/hour m^2 and mainly dispersed from 0 Yuan/hour m^2 to 0.02 Yuan/hour m^2, while the heating cost of distributed heating is much flatter and more dispersed. The kernel density curve for distributed heating moves rightward compared with the curve for district heating. The mean value of heating cost for distributed heating (0.0286 Yuan/hour m^2) is 2.89 times higher than for district heating (0.0099 Yuan/hour m^2). Moreover, a dispersed distribution with a longer tail for distributed heating suggests that the heating cost per area and per hour are more variable in the South than in the North.

We also use the *t* test and Kolmogorov–Smirnov test to examine whether there is a systematic difference in energy expenditure between the North and South. The *t* test produces a statistical value of 21.83, suggesting that the mean difference between the two samples is significantly not equal to zero. The Kolmogorov–Smirnov test reports a distance value of 0.679 and zero *p*-value, indicating that the two samples are not drawn from the same distribution. Both tests suggest that the per unit heating cost for distributed heating is significantly higher than for district heating.

We also take the degree of comfort into account. Obviously, it is far lower in southern cities than in northern cities. The implication is that southern households spend more on heating, but get a lower level of heating service. If they want to achieve the same utility level as enjoyed by households with district heating, they need to spend more. Based on the energy intensity and energy cost per unit m^2 and unit hour, we can further calculate the price for the same heat content. The price of district heating in the North is 1.32 Yuan/kgce, and 2.89 Yuan/kgce in the South. Thus, the price per unit is 2.2 times higher for distributed heating than for district heating.

An important factor impacting heating welfare is heating subsidies. In our sample, northern households reported that they did not need to pay the entire cost of district heating. Some households received considerable heating subsidies. Therefore, the actual expenditure for household heating was lower than what we estimated without taking subsidies into account(0.0099 Yuan/hour m^2). In contrast to the North, most of the southern households had no heating subsidies. In addition, most of the heating equipment for distributed heating consisted of electric appliances. The southern households need to bear an increase in electricity prices because of ladder electricity pricing.[7] So, the actual heating expenditure by southern households was higher than what we estimated before.

4. Discussion

Another concern is whether and to what extent energy consumption and expenditure will change if the southern areas adopt district heating systems, compared with their present distributed heating systems. We use scenario analysis to compare the heating welfare between northern and southern households. The basic logic is that the southern households consume energy $E1$ and spend $C1$ on distributed heating. Under the same conditions, the northern households consume energy $E2$ and spend $C2$ on district heating. Then, if the same district heating system is established in the South, the energy conservation is $\Delta E = (E1 - E2)$. If $\Delta E > 0$, it indicates that district heating will save energy. If $\Delta E < 0$, it indicates that district heating will consume more energy. Similarly, the cost saving is $\Delta C = (C1 – C2)$. To increase the heating welfare in the South to the level in the North, we set up four scenarios in Table 5. In the basic scenario, the characteristics of distributed heating in the South, such as a shorter heating period, are maintained. We then compare this basic scenario with district heating and estimate the energy conservation and cost saving in the South. In scenarios 1–3, we increase the heating area, daily heating hours and annual heating season in the South, and estimate the change in energy consumption and heating cost. The characteristics of distributed heating in scenario 3 are the same as for district heating in the North but without heating subsidies.

The energy consumption and cost saving in different scenarios are shown in Fig. 4. If district heating systems are established in the South, both energy consumption and heating costs will be lower, because district heating, as shown by use in the North, is more efficient and cheaper for consumers on a per-unit basis. Under the basic scenario, adopting district heating will reduce 15.5 kgce of energy and 125 Yuan of expense for each southern household. If a southern household uses district heating to heat the entire usable housing area, energy consumption will be reduced by 68.4 kgce, and heating cost will be reduced by 549 Yuan, relative to the cost of heating the entire usable area using distributed heating. Further, if all usable housing area is heated for 24 h by district heating, each southern household will decrease energy consumption by 382.0 kgce, and decrease heating expenditure by 3067 Yuan, relative to achieving the same level of comfort using distributed heating. Finally, compared with the existing, small-scale district heating systems in the South, each household would reduce energy consumption by 701.3 kgce and expenditure by 5629 Yuan if Northern-style district heating were introduced.

It is worth noting the applicability and generality of the surveyed samples. As the first round national wide survey, it consists detailed information of residential energy consumption pattern. However the sample size is relatively not large. Also it may not fully capture the whole situations and hardly represent the giant country like China. These also motive us to put more substantial efforts in the future.

5. Conclusions and policy implications

This paper investigates residential energy consumption and the cost of distributed heating in southern China and district heating in northern China during the 2012 heating season by studying 820 urban households based on the *China Residential Energy Consumption Survey* (*CRECS*). Our results show that, on average, the heating energy consumption for each northern household is 25

[7] In our sample, the average electricity prices in northern cities and southern cities are 0.51 yuan/kWh and 0.55 yuan/kWh, respectively. In 2012, ladder electricity pricing was introduced, in which consumers face an increasing price if they consume more electricity power.

Table 5
Scenario setting.

Scenario	Heating area	Heating hours daily (hours)	Annual heating season (months)
Basic scenario	partial housing heating	4.3	2.13
Scenario 1	all housing heating	4.3	2.13
Scenario 2	all housing heating	24	2.13
Scenario 3	all housing heating	24	3.91

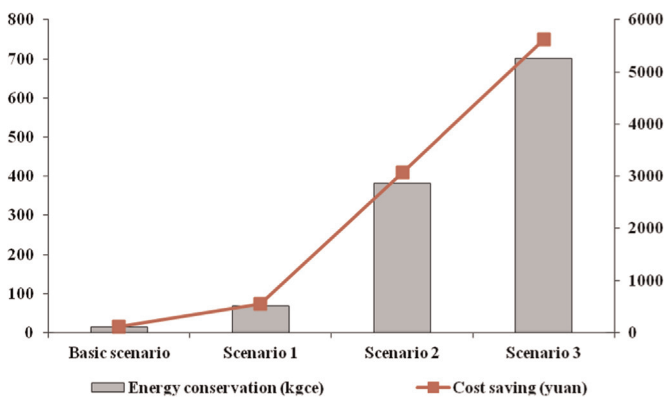

Fig. 4. Scenario analysis.

times greater than for a southern household. However, after considering the difference between southern and northern China in the area heated and the number of hours the heating operates, distributed heating households in southern cities consumed 32% more energy and paid 189% more per unit area and per hour than district heated households in northern cities. Despite consuming more energy per unit, at a greater cost per unit, households in the southern cities received less heating comfort. In addition, the scenario analysis shows that, if district heating is established in the South, it not only can improve residential welfare, but also reduce energy consumption and heating cost, without considering investment and spillover effects on the economy.

It is clear that the present district heating policy neglecting the vast heterogeneity among southern regions. Banning on the local district heating development seems to explicitly control the energy consumption, while it implicitly push the households in southern to access heating services with alternative inefficient and costly way keeping the residential welfare same. This unexpected outcome obviously violet the decision-makers' concern. In contrast, applying district heating system in some southern cities can improve the welfare and would not lead to worse environmental consequence.

Regarding the future policy reform, our suggestion is that a pilot district heating system should be established in some regions of the South where there are good heating resources, appropriate geographical conditions, and high willingness to pay. We suggest promoting a heating market in appropriate areas in southern China. For the residential sector, several government policy instruments can be used to accelerate adoption technologies toward energy conservation and reduced cost, and their effectiveness can also be evaluated. In our proposal, the local government does not need to provide public services to meet the residential demand for heating, but only needs to regulate the industry or provide subsidies.

The result should be interpreted in caution. There will be significant changes in energy conservation and heating cost savings when southern residents achieve a higher level of heating services through district heating systems in our scenario analysis. The change of heating system will also lead to other effects. On one hand, the construction costs of new heating systems, including infrastructure investment, residential reconstruction cost, and heating equipment investment, will be partly transferred to end users. On the other hand, reconstruction of heating systems will promote economic growth through the development of related industries, such as equipment manufacturing and installation and maintenance services. The improvements in infrastructure also would attract investment in the South. The spillover and development effects are likely, but are not quantified in this paper.

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