Supporting Information

Contribution from Urban Heating to China's 2020 Goal of Emission Reduction

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1. Materials and Methods

1.1 CO_2 Emissions

CO_2 emissions of combustion of coal and natural gas are calculated using eq.1 and eq.2, respectively.

CO_2 emissions of solid fuel combustion $Q_{CO_2,solid}$

$$Q_{CO_2,solid} = \frac{44}{12} \times C \ (kg/kg) \qquad \text{(eq.1)}$$

CO_2 emissions of gas fuel combustion $Q_{CO_2,gas}$

$$Q_{CO_2,gas} = (CO + \sum nC_nH_m + CO_2) \times \frac{1}{100} \times \frac{44}{22.4} \ (kg/m^3) \qquad \text{(eq.2)}$$

The percent volume of the constituents of natural gas are: CH_4, 97.1%; C_2H_6, 0.48%; C_3H_8, 0.06%; CO_2, 0.31%; H_2, 0.09%; CO, 0.01%; N_2, 1.95%.[1]

The results for CO_2 emissions of the combustion of unit coal equivalent and natural gas are 3.7 kg/kg and 1.9 kg/m^3, respectively.

1.2 Heat Pump Winter Performance

The heating coefficient of performance (COP-heating) of air conditioners of first class efficiency (Table S2) [2,3] in China is calculated using eq.3, based on the performance parameters listed in Table S3. The average COP-heating of air conditioners of first class efficiency in China is about 3.75 (Table S3).

Considering the ambient temperature effect, the heating seasonal performance factor (HSPF) is calculated using eq.4, and the results are listed in Table S4. The area weighted average HSPF in the region feasible for replacing urban central heating (UCH) with heat pump heating (HPH)(south of 41ºN latitude) in China is about 3.34 (eq.5).

The indoor and outdoor temperature under designated conditions are 20ºC and 7ºC, respectively.[2] The standard of indoor heating temperature during heating seasons in China ranges from 16 to 24ºC.[4] 18ºC is used here to calculate the HSPF in accordance to the requirement of indoor temperature for UCH in China, which is not less than 18ºC.

$$COP\text{-}heating = \frac{H_d}{H_i} \qquad \text{(eq.3)}$$

$$HSPF = \frac{T_{id} - T_{od}}{T_i - T_o} \times COP\text{-}heating_{average} \quad \text{(eq.4)}$$

$$HSPF_{average} = \frac{\sum HSPF \times A}{\sum A} \quad \text{(eq.5)}$$

where, H_d is the rate of heat delivered under designated operating conditions; H_i is the rate of energy input under designated operating conditions; T_{id} is the indoor temperature under designated conditions; T_{od} is the outdoor temperature under designated conditions; T_i is indoor heating temperature; T_o is average outdoor temperature during heating seasons in the region feasible for replacing UCH with HPH (south of 41ºN latitude) in China; $COP\text{-}heating_{\text{average}}$ is average COP-heating of air conditioners of first class efficiency in China; $HSPF_{\text{average}}$ is area weighted average HSPF in the region feasible for replacing UCH with HPH (south of 41ºN latitude) in China; A is area.

1.3 Primary energy ratio

The respective primary energy ratio of natural gas-based and coal-based UCH used for calculations is about 0.90 and 0.75.[5] The primary energy ratio of HPH powered by electricity generated from coal or natural gas is about 1.17 or 2.02, respectively, which is calculated using eq.6 or eq.7. The electricity generation efficiency of coal adopted for calculations is about 0.35.[5] The total thermoelectric efficiency of natural gas in gas-steam combined cycle ranges from 0.85 to 0.95, and 0.85 is used here.[6] The electricity generation efficiency of natural gas in gas-steam combined cycle is 0.50.[6]

$$\eta_{hc} = \varphi_{ec} \times HSPF_{average} \quad \text{(eq.6)}$$

$$\eta_{hn} = \varphi_{en} \times HSPF_{average} + (\varphi_{tn} - \varphi_{en}) \quad \text{(eq.7)}$$

where, η_{hc} is the primary energy ratio of HPH powered by electricity generated from coal; η_{hn} is the primary energy ratio of HPH powered by electricity

generated from natural gas; φ_{ec} is the efficiency of electricity generation from coal; φ_{en} is the efficiency of electricity generation from natural gas in gas-steam combined cycle; φ_{tn} is the total thermoelectric efficiency of natural gas in gas-steam combined cycle.

1.4 Heating energy consumption

The average annual consumption per unit floor area of coal-based UCH is 19.9 kg coal equivalent.[7] The energy consumption of different heating modes in the region feasible for replacing UCH with HPH (south of 41ºN latitude) is calculated using eq.8-eq.13.

For economic operation HPH, the percentage of urban residential area occupied by the people aged 65 and over estimated here is 9.7%. This value is equivalent to the population percentage of people aged 65 and over in 2009.[8] Heating time per day for different locations is set as follows:

(1) Regular heating time of urban public buildings during working hours: 12 hours;

(2) Low-temperature heating time of urban public buildings out of working hours: 12 hours;

(3) Heating time of residences of people aged 65 and over: 24 hours;

(4) Heating time of residences of people under age of 65: 12 hours.

$$\delta_p = \varepsilon_w + (1 - \varepsilon_w) \times \varepsilon_{lt} \quad \text{(eq.8)}$$

$$\delta_r = \theta_{r65} \times [(1 - \varepsilon_s) + \varepsilon_s \times \theta_b] + (1 - \theta_{r65}) \times [(\varepsilon_s \times \theta_b) + (1 - \varepsilon_w - \varepsilon_s)] \quad \text{(eq.9)}$$

$$Q_{uc} = E_{uc} \times A_h \quad \text{(eq.10)}$$

$$Q_{un} = E_{un} \times A_h \quad \text{(eq.11)}$$

$$Q_{h24} = E_{h24} \times A_h \quad \text{(eq.12)}$$

$$Q_{he} = E_{he} \times A_h \quad \text{(eq.13)}$$

where, δ_p is the ratio of the average annual energy consumption per unit floor area of economic operation HPH in public buildings to that of 24-hour operation HPH; δ_r is the ratio of the average annual energy consumption per

unit floor area of economic operation HPH in residential buildings to that of 24-hour operation HPH; ε_w is the ratio of working hours per day to 24 hours per day; ε_{lt} is the ratio of energy consumption of low-temperature heating to that of regular heating; ε_s is the ratio of sleeping hours per day to 24 hours per day; θ_{r65} is the ratio of urban residential area of people aged 65 and over to urban residential area in the region feasible for replacing UCH with HPH; θ_b is the ratio of bedroom area of urban residential buildings to urban residential area in the region feasible for replacing UCH with HPH; E_{uc} is the average annual energy consumption per unit floor area of coal-based UCH; E_{un} is the average annual energy consumption per unit floor area of natural gas-based UCH; E_{h24} is the average annual energy consumption per unit floor area of 24-hour operation HPH; E_{he} is the average annual energy consumption per unit floor area of economic operation HPH; Q_{uc} is the energy consumption of coal-based UCH in the region feasible for replacing UCH with HPH; Q_{un} is the energy consumption of natural gas-based UCH in the region feasible for replacing UCH with HPH; Q_{h24} is the energy consumption of 24-hour operation HPH in the region feasible for replacing UCH with HPH; Q_{he} is the energy consumption of economic operation HPH in the region feasible for replacing UCH with HPH; A_h is the area of the feasible region for replacing UCH with HPH.

1.5 China's total CO_2 emission reduction target in 2020

The CO_2 emissions and gross domestic product (GDP) in China were 5512.7 million tons (Mt) and 18321.74 billion RMB in 2005, respectively.[8,9] According to the amount of the CO_2 emissions of each unit GDP in 2005 and China's current GDP growth rate of 8%, China's CO_2 emissions will reach 17487.2 Mt in 2020, under the condition of constant energy efficiency (eq.14).

China promised to reduce the rate of CO_2 intensity by 40-45% by 2020 from 2005 levels.[10] China's CO_2 emission reduction must exceed 6994.9 Mt to fulfill the promised CO_2 emission reduction target in 2020 (eq.15).

$$M_{y2020} = M_{y2005} \times [1 + \lambda^{(2020-2005)}] \quad \text{(eq.14)}$$

$$R_{y2020,min} = M_{y2020} \times 40\% \quad \text{(eq.15)}$$

where, M_{y2020} is total CO_2 emissions in China in 2020; M_{y2005} is total CO_2

emissions in China in 2005; λ is China's current GDP growth rate; $R_{y2020,min}$ is minimum reduction of CO_2 emissions in China in 2020.

2. Tables

Table S1. Total urban building area and UCH area in UCH region in China, and urban building area, urban residential area and UCH area in the region feasible for replacing UCH with HPH (south of 41ºN latitude) (excluding the region with exhaust heat from cogeneration power plant) in China, based on the data in China statistical yearbook.[8]

Year	In UCH region in China		In the region feasible for replacing UCH with HPH in China (south of 41ºN latitude)		
	Total urban building area (million square meters)	Total UCH area (million square meters)	Urban building area (million square meters)	Urban residential area (million square meters)	UCH area (million square meters)
2020	37825.6	13757.0	35774.5	31978.0	11981.6
2009	11883.1	4679.4	10284.3	7073.8	3547.6
2008	10695.9	4242.4	9182.4	6167.3	3176.0
2007	9627.3	3846.3	8198.6	5376.9	2843.3
2006	8665.4	3487.1	7320.2	4687.8	2545.5
2005	8017.3	3244.1	6724.4	4322.1	2338.9
2004	7345.6	2977.9	6118.4	3921.0	2118.9
2003	7071.6	2777.1	5927.7	3713.2	1976.4
2002	6632.0	2580.9	5561.3	3351.6	1831.3
2001	5497.1	2305.1	4546.5	2715.8	1639.6
2000	3920.0	1664.1	3134.4	1763.3	1114.3
1999	3687.4	1569.1	2944.9	1623.3	1049.2
1998	3530.9	1504.6	2794.6	1808.9	989.2
1997	3258.0	1387.3	2611.9	1396.2	935.0
1996	3151.5	1360.3	2470.0	1308.4	883.1

The data in Table S1 after 2006 is calculated according to the respective average annual growth rate from 1996 to 2006.

Table S2. Class efficiency of air conditioners in China[■3]

Type	Rated cooling capacity (W)	Class efficiency[▲]		
		First Class efficiency	Second Class efficiency	Third Class efficiency
Single package		EER[●] ≥ 3.30 W/W	3.10 W/W ≤ EER<3.30 W/W	2.90 W/W ≤ EER<3.10 W/W
Split type	≤ 4500	EER ≥ 3.60 W/W	3.40 W/W ≤ EER<3.60 W/W	3.20 W/W ≤ EER<3.40 W/W
	4500-7100	EER ≥ 3.50 W/W	3.30 W/W ≤ EER<3.50 W/W	3.10 W/W ≤ EER<3.30 W/W
	7100-14000	EER ≥ 3.40 W/W	3.20 W/W ≤ EER<3.40 W/W	3.00 W/W ≤ EER<3.20 W/W

■ Not suitable to mobile, controllable rotating speed, and multi-connected air conditioning units.

▲ The class efficiency of air conditioners is classified by energy efficiency ratio (EER) in China.

● Energy efficiency ratio (EER) is the ratio of net cooling capacity to the total rate of electric input under designated operating conditions.[2]

Table S3. COP-heating of air conditioners of first class efficiency in the market in China.

Brand	Type	Net cooling capacity (W)	Total rate of electric input (W)	EER (W/W)	Class efficiency	Rate of heat delivered▲ (W)	Rate of energy input● (W)	COP-heating (W/W)
Haier	KFRd-26 GW/02D (HF)-S1	2600	650	4.00	First	2860+ 800	720+800	3.97
	KFRd-35 GW/02D (HF)-S1	3500	920	3.80	First	3850+ 800	1050+ 800	3.67
	KFRd-72 LW/01B (QXF)-S1	7200	2100	3.43	First	8400+ 2500	2350+ 2500	3.57
Midea	KFR-32G W/DY-G C(E1)	3250	890	3.65	First	3750+ 760	990+760	3.79

▲ The value after the symbol "+" in the column of rate of heat delivered is the auxiliary rate of heat delivered with electricity in low temperature environment.

● The value after the symbol "+" in the column of rate of energy input is the auxiliary rate of energy input with electricity in low temperature environment.

Table S4. Average outdoor temperature during heating seasons and HSRF in the region feasible for replacing UCH with HPH (south of 41ºN latitude) (excluding the region with exhaust heat from cogeneration power plant) in China. The indoor heating temperature during heating seasons is 18ºC.

Region feasible for replacing UCH with HPH (south of 41ºN latitude) in China (typical cities)	Monthly average outdoor temperature during heating seasons in 2009 in China[8]					Average outdoor temperature during heating seasons	HSRF
	January	February	March	November	December		
	(ºC)	(ºC)	(ºC)	(ºC)	(ºC)	(ºC)	(W/W)
Beijing●	-3.0	1.0	7.0	2.2	-2.3	1.0	2.86
Tianjin●	-3.5	0.7	6.7	1.6	-2.8	0.5	2.79
Hebei(Shijiazhuang)●	-0.7	3.1	9.6	2.3	-0.5	2.8	3.20
Shanxi(Taiyuan)●	-5.1	1.5	6.7	-0.9	-4.5	-0.5	2.64
Inner Mongolia (HOhht)●	-10.3	-2.8	1.3	-4.0	-10.1	-5.2	2.10
Shandong (Jinan)●	-0.2	5.1	9.0	4.8	0.8	3.9	3.46
Henan (Zhengzhou)●	1.0	5.9	10.1	5.4	2.9	5.1	3.77
Shaanxi (Xi'an)●	0.6	6.4	11.1	4.7	1.8	4.9	3.73
Gansu (Lanzhou)●	-7.7	-0.3	3.9	-2.3	-7.0	-2.7	2.36
Qinghai (Xining)●	-7.8	-0.8	2.0	-2.2	-6.4	-3.0	2.32
Ningxia (Yinchuan)●	-6.2	0.9	5.8	-1.4	-5.6	-1.3	2.53
Xinjiang (Urumqi)●	-9.9	-8.8	2.5	-2.3	-10.0	-5.7	2.06
Shanghai▲	3.8	8.9	10.6	12.1	6.4	8.4	5.06
Jiangsu (Nanjing)▲	2.2	7.3	9.8	8.6	4.5	6.5	4.23
Anhui (Hefei)▲	2.6	7.7	10.5	7.8	4.6	6.6	4.29
Hubei (Wuhan)▲	4.5	9.0	12.1	8.8	5.8	8.0	4.89
Sichuan (Chengdu)▲	5.7	10.8	12.5	10.7	7.9	9.5	5.75
Jiangxi (Nanchang)▲	5.1	10.8	12.1	11.2	7.3	9.3	5.60
Hunan (Changsha)▲	5.1	10.5	12.7	10.6	7.1	9.2	5.54
Chongqing▲	7.7	13.0	14.8	12.9	9.9	11.7	7.69
Guizhou (Guiyang)▲	3.8	10.4	11.3	9.3	5.5	8.1	4.90
Yunnan (Kunming)▲	8.3	13.9	15.8	11.8	10.5	12.1	8.21
Tibet (Lhasa)▲	1.0	3.8	5.8	5.7	0.5	3.4	3.33

● The region feasible for replacing UCH with HPH (south of 41ºN latitude) in northern China (Yellow River basin and its north, 70% of urban building area is covered by UCH[7]).

▲ The region feasible for replacing UCH with HPH (south of 41ºN latitude) in southern China (Yangtze River basin, Hunan, Guizhou and Yunnan etc., less than 5% of urban building area is covered by UCH[7]).

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