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Energy Consumption Analysis and Diagnosis of Heating System

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Abstract: The gas boiler house is responsible for heating 308,000 m2 of residents in the community, and the historical heating energy consumption reached 3,000 tons of standard coal in 2012. The heating energy consumption index in this community is higher than that of heating energy consumption index in other residential communities. The heating system in this community is tested and analyzed comprehensively in this paper. The three aspects of heating system heat source, pipe network transmission and distribution and thermal user are combed and analyzed in this paper, to look for the energy-saving potential of each link.

It is found that the exhaust gas temperature is 175℃ through the test of thermal efficiency of 2 # boiler in XX Community, and the heat loss of exhaust gas is higher. Meanwhile, it is found that the exhaust gas temperature is too high in all boilers through checking the operation record. It is found that the system water recharge is larger and the problems of leaking and aging thermal insulation layer and pipeline appear in the heating network through operation record analysis and on-site inspection. The analysis shows that there is a problem of hydraulic imbalance through the on-site test on the wall temperature of the supply pipe of the hot water supply wells in the residential buildings near, middle and far-ends.

Analyze the problem existing in the heating system in XX Community, and put forward some corresponding energy saving technical proposals, such as flue gas condensing waste heat recovery, hydraulic balance adjustment and pipeline insulation improvement according to on-site survey and analysis; meanwhile, estimate the energy saving effect and the investment payback period.

It is expected to realize the energy saving 728.72 tce and energy saving benefit of 1.4415 million yuan through three measures for energy saving and technical transformation. Estimated investment cost is 3.16 million yuan.

key words: Heating system; Energy-saving potential; Condensing waste heat recovery and hydraulic balance

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1. XX Community Profile

1.1 XX Community Basic Situations

XX Community is located at West Beitucheng Road, Haidian District, Beijing, China, which was completed in 1982. The boiler house, pump house and heat exchange station are set for the heating system in the community, to provide the heating service for the residential building, and the heating area is 308,000 m2 in total. The property management company is responsible for the operation and maintenance of the heating equipment.

1.2 XX Community Heating Energy Consumption Analysis

Refer to Table 1 for the collection of three historical heating season energy consumption of XX Community.

Types of energy	2008-2009 heating season	2009-2010 heating season	2010-2011 heating season
Natural gas (m^3)	2,207,254	2,900,387	2,479,853
Electricity (kWh)	418,100	461,100	490,400
Total energy consumption (tce)	2,731.65	3,578.61	3,071.56

Table 1. XX Community Historical Heating Season Energy Consumption

The heating season consumes 2.4798 million m^3 of natural gas, the power was 490,400 kWh, equivalent to 3,071.56 tons of standard coal, and the energy consumption per unit heating area was 9.97 kgce/m2 from 2010 to 2011 in XX Community through the accounting.

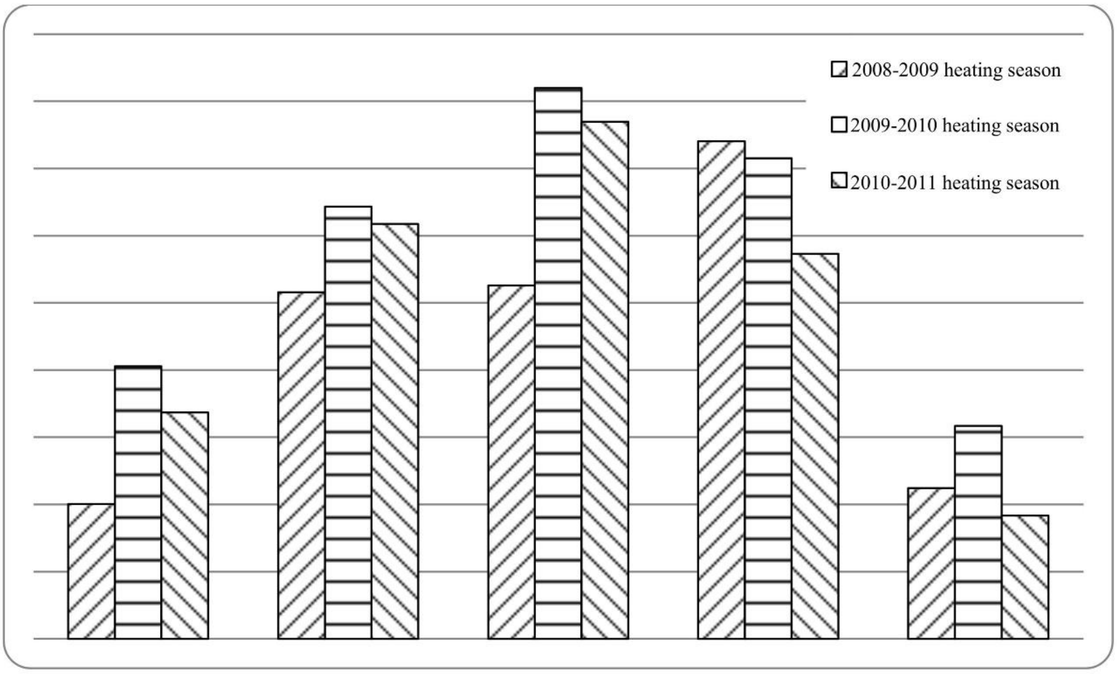

Figure 1. Comparison of Gas Consumption in Heating Season

From the Figure 1, we can see the natural gas consumption in heating season is higher than that of the other two heating seasons from 2009 to 2010. The main reason analysis is that the climate is abnormal in the heating season, and the continuous low temperature increases the monthly consumption of natural gas. The early heating and extended heating are reflected in the figure where the natural gas consumption in November and March was much higher than in the other two months. In addition, the heating energy consumption in 2010 is higher than that of heating energy consumption in 2008. The main reason is the heating area increased by 41,000 m2 in XX Community in 2010.

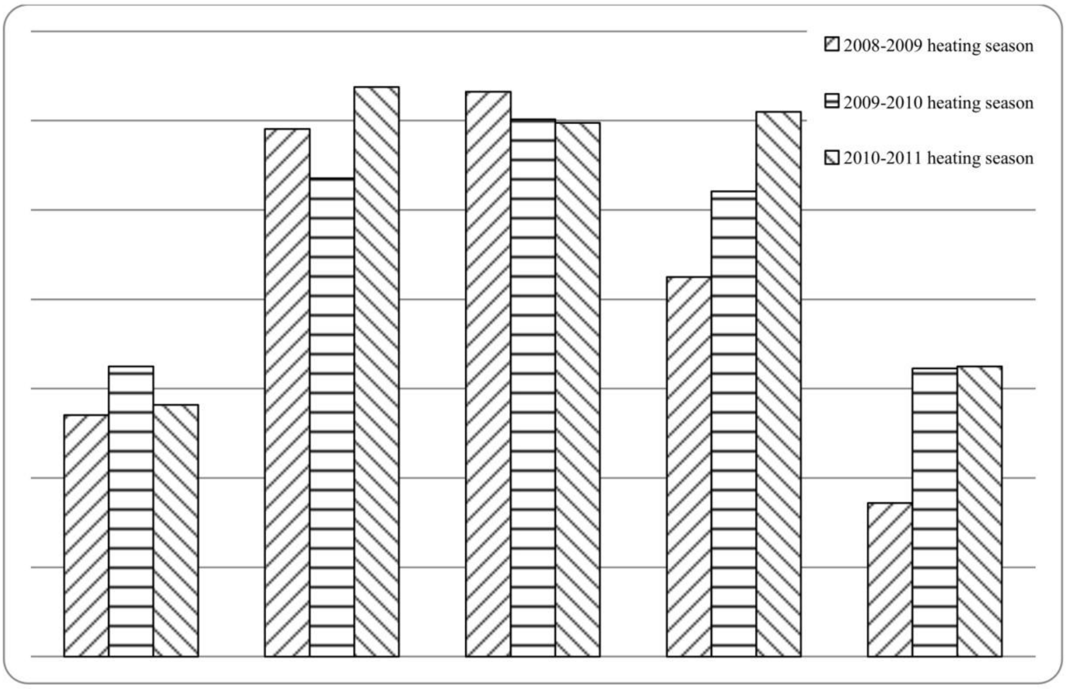

Figure 2. Comparison of Power Consumption in Heating Season

1.2.1 Heat source analysis

8 sets of 2.8 MW gas-fired hot water boilers and auxiliary auxiliaries are set in boiler houses in the community, and refer to Table 2 for the main equipment parameters.

S/N	Equipment name	Equipment model	Main parameters	Manufacturers
1	Gas-fired hot water boiler	LZS2.80-0.7/95/70-Y(Q)-MF7	8 sets, 2.8 MW	Shandong Taishan
2	1 # Southern district low pressure circulating pump	ISG(B)200-315(I)A	374 m^3/h, 28 m, 45 kW	Shandong Shuanglun
3	2 # Southern district low pressure circulating pump	QPG200R-4000	260 m^3/h, 32 m, 37 kW	Wenzhou Tsinghua
4	1 # Northern district low pressure circulating pump	ISG(B)200-315(I)A	374 m^3/h, 28 m, 45 kW	Shandong Shuanglun
5	2# Northern district low pressure circulating pump	QPG200R-4000	260 m^3/h, 32 m, 37 kW	Wenzhou Tsinghua
6	1#high pressure circulating pump	QPG200R-4000	260 m^3/h, 32 m, 37kW	Wenzhou Tsinghua
7	2#high pressure circulating pump	QPG200R-4000	260 m^3/h, 32 m, 37kW	Wenzhou Tsinghua
8	1#boiler circulating pump	QPG200R-260	320 m^3/h, 20 m, 30 kW	Wenzhou Tsinghua
9	2#boiler circulating pump	QPG200R-260	320 m^3/h, 20 m, 30 kW	Wenzhou Tsinghua
10	3#boiler circulating pump	QPG150R-260	200 m^3/h, 20 m, 18.5 kW	Wenzhou Tsinghua
11	4#boiler circulating pump	QPG150R-260	200 m^3/h, 20 m, 18.5 kW	Wenzhou Tsinghua
12	Plate-type heat exchanger	BRX0.6EH	6 sets, 100 m^2	Yungtay Engineering

Table 2. Main Equipment List of XX Boiler House

The community heating mode is the inter supply, and the heating system is shown in Figure 3, 6 block plate heat exchangers are set in the boiler house, and the secondary water and boiler primary water heat exchange each other through the heat exchanger. In the heating season, the firemen take manual start and stop control of the boiler in operation according to outdoor temperature and return water temperature of secondary water supply, and the boiler won't be adjusted after operation. The power consumption of the boiler house was 472,900 kWh in 2013. The transmission coefficient of heating system is calculated 49.21.

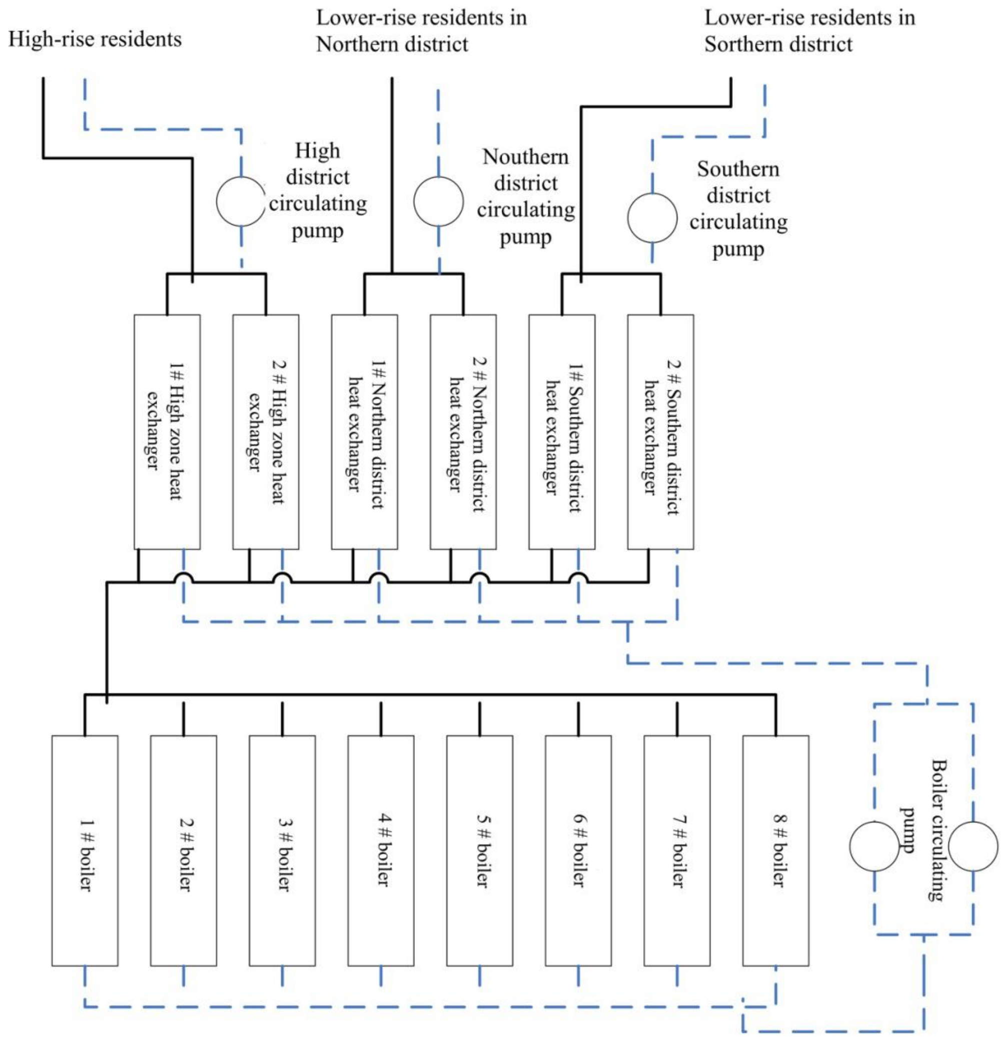

Figure 3. Schematic Diagram of Heating System in XX Community

From the Figure 1, we can see the natural gas consumption in heating season is higher than that of the other two heating seasons from 2009 to 2010. The main reason analysis is that the climate is abnormal in the heating season, and the continuous low temperature increases the monthly consumption of natural gas. The early heating and extended heating are reflected in the figure where the natural gas consumption in November and March was much higher than in the other two months. In addition, the heating energy consumption in 2010 is higher than that of heating energy consumption in 2008. The main reason is the heating area increased by 41,000 m2 in XX Community in 2010.

Project	Unit	Test results	Contrast index
Thermal efficiency η	%	87.59	≥ 90
Exhaust gas temperature tpy	℃	175	< 160
Air coefficient α		1.17	≤ 1.2
CO content:	%	0.001	≤ 0.02
Boiler outlet water temperature	℃	52.3	/
Heat loss of exhaust gas	%	7.32	/
Heat loss due to radiation	%	3.10	/
Heat loss due to mechanical incomplete combustion	%	0.004	/

Table 3. Indicator Comparison of XX Community Boiler Measurement Result

From the above table, we can see that 2# boiler efficiency in the boiler house of XX Community is lower than the control index, and the main cause analysis is the excessive heat loss of exhaust gas. The heat loss of exhaust gas of the boiler is 7.32%, accounting for 70.24% of the sum of the boiler heat loss. The excessive exhaust gas temperature causes a large amount of physical heat to be taken away by the smoke, which increases the natural gas consumption. Thus, the reasonable recovery and utilization of boiler flue gas heat and the improvement of exchange effect of boiler heat will effectively reduce the heat loss of exhaust gas and increase the boiler efficiency. In addition, pay attention to reducing the heat dissipation of the boiler, improve the insulation performance of the furnace body and reduce the heat loss of the boiler.

1.2.2 Analysis and evaluation of pipe network transmission and thermal users

The secondary heat pipe network in XX Community consists of three main loop, including high pressure loop, southern low pressure loop and north community low pressure loop. The perlite is adopted for the pipe insulation originally, and the perlite is changed with polyurethane foam for the insulation in a few pipes during the maintenance process later. At present, the frequency conversion equipment has been installed for the secondary circulating pump, and the one big one and small parallel operation mode is adopted for the primary circulating pump. The heating pipe network in the community is shown in Figure 4.

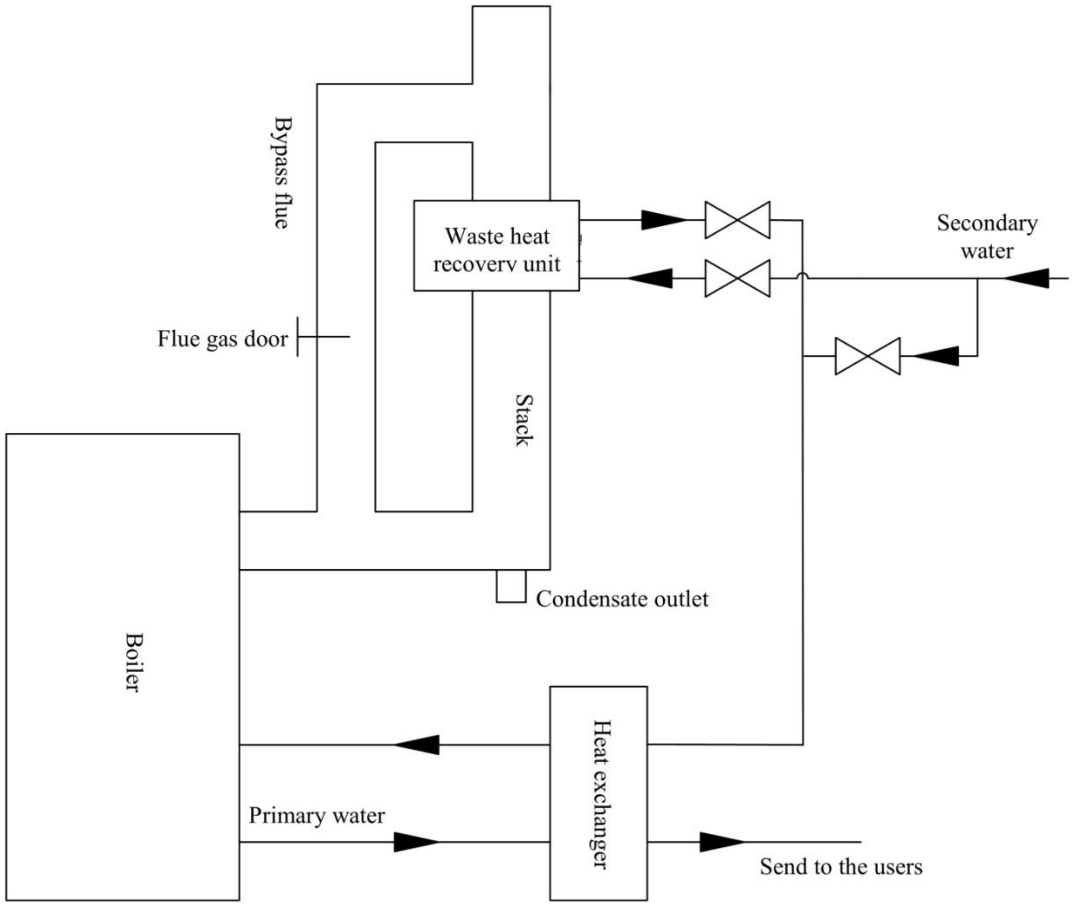

Figure 4. Flue Gas Condensing Waste Heat Recovery and Reconstruction

The community was completed in 1982, and the residence is divided into four regions. There are 12 residential buildings in 1 # garden, and 8 residential buildings in 2 #, 3 # and 4 # gardens. There are about 3,600 residents. Residential buildings are mainly divided into high-rise and multi-storey buildings, and the number of buildings is concentrated on the 6th floor,14th floor and 18th floor. The brick concrete structure is adopted for multi-storey construction, while the steel-concrete frame structure is adopted for the high-rise construction. The typical construc-tion information is shown in Table 4. The insulation is not adopted for the exterior walls of the residents themselves with steel window frames with single layer glass, and the terminal radiator is made of cast iron radiators. The heat metering has not been realized according to the common heating area fee. Meanwhile, the thermal user flow adjustment has not been realized with the collusion form.

	Building No.	Number of stories of building	Construction area/m^2	Heating area/ m^2	Architecture structure form
1 # garden	1 # building	13	21,962	18,469	steel-concrete
	2 # building	6	4,262	4,262	brick-concrete
	3 # building	6	3,162	3,162	brick-concrete
	7 # building	6	3,197	3,197	brick-concrete
	9 # building	6	4,203	4,203	brick-concrete
2 # garden	1 # building	14	17,154	15,384	steel-concrete
	2 # building	6	3,208	3,208	brick-concrete
3 # garden	1 # building	18	9,249	8,528	steel-concrete
	4 # building	14	12,477	12,477	steel-concrete
	5 # building	6	4,148.22	4,148.22	brick-concrete
	6 # building	6	4,262	4,262	brick-concrete
	7 # building	6	4,250	4,250	brick-concrete
4 # garden	1 # building	18	9,429	8,528	steel-concrete
	4 # building	6	4,262	4,262	brick-concrete

Table 4. Typical Construction Information List of XX Community

The boiler operation record is selected as the basis for data analysis of boiler system from November 2010 to March 2011 in this paper, and the Table 5 is obtained through the calculation and arrangement of the boiler operation record.

Circulating water system	Parameter	November 2010	December 2010	January 2011	February 2011	March 2011
Primary test	Average supply water temperature (℃)	42	44	54	53	52
	Average return water temperature (℃)	32	34	46	45	44
	Mean temperature difference (℃)	10	10	8	8	8
Secondary test high-rise loop	Average supply water pressure (MPa)	0.72	0.72	0.72	0.72	0.72
	Average return water pressure (MPa)	0.54	0.54	0.54	0.54	0.54
	Average supply water temperature (℃)	40	41	48	47	46
	Average return water temperature (℃)	38	39	44	43	40
	Mean temperature difference (℃)	2	2	4	4	6
Secondary test low-rise loop	Average supply water pressure (MPa)	0.38	0.38	0.38	0.38	0.38
	Average return water pressure (MPa)	0.24	0.24	0.24	0.24	0.24
	Average supply water temperature (℃)	41	43	48	47	45
	Average return water temperature (℃)	38	40	44	43	39
	Mean temperature difference (℃)	3	3	4	4	6
Average water recharge (t)		47	34	25	9	25

Table 5. Boiler Operation Record and Arrangement List in Heating Season from 2010 to 2011

From the operation record, we can see that in the early stage of boiler house heating in XX Community, the water temperature difference between the high-pressure circulation water supply system and the water supply system is maintained at about 2℃, and about 4 ℃ during the cold period. The water temperature difference between the low pressure cycle and the water supply is maintained from 4 ℃ to 6 ℃ during the heating season. The system temperature is not large between early and late heating stage and cold period, and and there is a big gap compared with the average temperature difference between the supply and return water of the heating system. Thus, the audit team thinks that the "Large flow and small temperature difference" operation mode is adopted as the boiler house heating mode. The average daily water supply of the secondary network in the boiler house of the community is about 25 tons. The leaking phenomena happen occasionally due to the pipe network aging according to the on-site communication and under-standing.

The boiler system was tested on December 16, 2011. The main test object is the temperature of inlet and outlet of plate heat exchanger, and the result is shown in Table 6. The infrared temperature instrument is used to measure the wall temperature of the total supply and return pipe of hot water in some residential buildings. The measurement method is: Choose a straight pipe section, open the insulation layer, perform simple sanding of the pipe surface, and use the thermometer to record the data above 1m of the measuring point within the range. The recorded data are shown in the Table 7.

S/N	Name	Primary test temperature (℃)		Secondary test temperature (℃)	
		Inlet	Outlet	Inlet	Outlet
1	1 # High zone heat exchanger	58	43	41	48
2	2 # High zone heat exchanger	58	41	41	48
3	1 # Northern district heat exchanger	58	46	45	49
4	2 # Northern district heat exchanger	58	46	45	49
5	1 # Southern district heat exchanger	58	45	44	48
6	2 # Southern district heat exchanger	58	45	44	48

Table 6. Boiler House Temperature Test Record

S/N	Position	Building No.	Building type	Supply water temperature/℃	Return water temperature/℃	Temperature difference/℃
1	High loop far-end	Winter Jasmine Garden 1 # building	Small high-rise	41	35	6
2	South loop far-end	Winter Jasmine Garden 2 # building	Multi-storey	44	40	4
3	High loop near-end	Winter Jasmine Garden 8#building	High-rise	44	It cannot be measured	/
4	South loop far-end	Summer Garden 5#building	Multi-storey	44	37	7
5	South loop middle-end	Summer Garden 7#building	Multi-storey	44	38	6
6	North loop far-end	Lang Autumn Garden 6#building	Multi-storey	44	40	4
7	North loop near-end	Lang Autumn Garden 8#building	Multi-storey	45	37	8
8	High loop far-end	Sunny Winter Garden 1#building	High-rise	46	39	7
9	North loop far-end	Sunny Winter Garden 5#building	Multi-storey	42	37	5

Table 7. Temperature Test of the Total Supply and Return Pipe in Some Residential Buildings (outdoor temperature-5℃)

The final analysis of the heat supply network heat maladjustment is caused by uneven flow allocation, that is, the maladjustment is caused by the hydraulic imbalance. The hydraulic imbalance can be reflected from the users' temperature difference between the back and forth. If the system flow distribution is matched with the required heating quantity, the water temperature difference shall be basically the same everywhere. v According to the test result, the supply water temperature difference between the buildings is different with the maximum temperature difference 8 ℃ and the minimum 4℃; according to the calculation result, the hydraulic imbalance is obvious, which will cause 10% of energy waste at least, so we shall pay more attention to it.

From the Table 1-6 and Table 1-7, we can see that the average supply water temperature in all buildings is about 4 ℃ from the total supply water temperature with the maximum value 7℃. On one hand, it is possible that the infrared thermometer itself has measurement errors; on the other hand, it is possible that old heating pipe network, pipeline aging, heating pipe insulation and pipe ditch water shedding phenomenon, and not ideal insulation effect in this community. Thus, it is suggested to strengthen the insulation of main pipe and change the pipe and the insulation layer if necessary.

The indoor temperature of residents in the near and far-end and high and low-rise of each loop was tested on November 21, 2011, and the test result is shown in Table 8 as follows:

S/N	Position	Building No.	Room temperature/℃
1	High loop near-end high-rise	Sunny Winter Garden 3 # 1802	17.7
2	High loop far-end high-rise	Sunny Winter Garden 1 # 1502	16
3	North loop far-end middle-level	Lang Autumn Garden 2 # 301	18.8
4	North loop middle-end high-rise	Lang Autumn Garden 7 # 503	18.1
5	South loop far-end low-rise	Summer Garden 4 # 203	17
6	South loop near-end low-rise	Summer Garden 3 # 201	19
7	High loop near-end low-rise	Winter Jasmine Garden 8 # 806	18.8
8	South loop near-end low-rise	Winter Jasmine Garden 8 # 107	17.4

Table 8. Some Residents House Temperature Test

The heat pipe network temperature for proximal end users about 18℃ and 17 ℃ for the near-end residents, which can meet the heating standard requirements basically. There are no overheating window phenomena for residents while there are individual households with water phenomenon without permission during the investigation period in the community.

2. Energy-Saving Potential Analysis

2.1 Boiler Energy-Saving Potential

According to the on-site operation record check, it is found that in XX Community the exhaust gas temperature of boiler is generally over 160℃ during the severe cold period, and the exhaust gas temperature of some boilers is 180 ℃.

The smoke produced by combustion of natural gas boiler contains a great deal of water vapor, latent heat of vaporization and sensible heat of flue gas, and a large amount of flue gas waste heat is discharged into the atmosphere not utilized, causing the heat waste and increasing the consumption of natural gas in the boiler house. Thus, the reasonable recovery and utilization of boiler gas heat and condensing waste heat and the improvement of exchange effect of boiler heat will effectively reduce the heat loss of exhaust gas and increase the boiler efficiency.

2.2 Energy-saving Potential of Transmission and Distribution

Estimate[2] and arrange the pipe network heat loss in all communities according to pipe network operation time and pipe insulation materials and other basic conditions through the on-site investigation, which is shown in Table 9.

Boiler house name	Exhaust gas temperature in cold period (℃)	Saving rate	Gas saving volume (ten thousand m^3)	Energy-saving amount (tce)
XX Community	160-175	9%	25.25	306.64

Table 10. Energy Saving Meter for Flue Gas Condensing Waste Heat Recovery

4.1.4 Economic Feasibility Analysis

The unit-price of natural gas in XX Community is 2.28 Yuan/m3;

Annual energy saving benefits = 25.25 × 2.28 = 57.57 ten thousand yuan/a;

Investment estimation: a total of 8 gas boilers are set in XX Community and 5 gas boilers are in operation during the cold period, a total of 5 sets of condensing waste heat recovery equipment will be installed, new pipeline and flue, plus installation, commissioning, operation and maintenance costs, etc., the estimated investment is about 600,000 yuan;

Investment payback period = 60 ÷57.57 = 1.04 years, the investment payback period of the project is 13 months.

4.2 Hydraulic Balance Adjustment Project

4.2.1 Project Contents

It is suggested to install the self-operated flow balancing valve on the backwater main pipe of the heat supply network near-end residential building aiming at these communities where the hydraulic imbalance is obvious.

4.2.2 Project Implementation Effects

According to relevant experience, the improvement of hydraulic balance of the network will save 10% of the energy at least. For there is no overheat phenomenon for the near-end users in XX Community, it is possible to save 10% of the circulating pump power at least by improving the hydraulic balance. The power consumption of the boiler house of XX Community was 490,400 kWh in 2010. The power consumption of about 49,000 kWh has been saved, equivalent to 6 tons of standard coal by improving the hydraulic imbalance phenomenon of pipe networks.

4.2.3 Energy Saving Benefit Calculation

The average unit-price of electricity in XX Community is RMB 0.9 Yuan/kWh;

Annual energy saving benefits=4.9×0.9=4.41ten thousand yuan/a;

Investment estimation: the self-operated flow balance valve equipment is increased, with installation, commissioning and operation and maintenance costs, etc., the estimated investment is about 60,000 yuan;

Investment payback period=6÷4.9=1.2 years, the investment payback period of the project is 15 months.

4.3 Heating Pipeline Reconstruction Project

4.3.1 Project Contents

The foamed polyurethane insulation materials are used to completely replace the aging heating pipes in XX Community, to reduce the network pipe heat loss.

4.3.2 Project Implementation Effects

According to the comparison of the energy-saving effect achieved in the heating network reconstruction of Anhua Xili community, check the heat loss before and after the heating network transformation in XX Community at the same time, which is shown in Table 11.

S/N	Community name	Before renovation Pipe network heat loss of %	After renovation Pipe network heat loss of %	Gas saving volume	Amount of saving electricity	Energy saving amount
				Ten thousand m^3	kWh	tce
1	XX Community	17	5	33.67	58848	416.08

Table 11. Comparison of Old Pipeline Network Before and After Transformation

4.3.3 Energy Saving Benefit Calculation

In XX Community, the unit-price of natural gas and electricity is 2.28 yuan/m3 and 0.9 yuan/kWh respectively;

Annual energy saving benefits = 33.67×2.28 + 5.8848 × 0.9 = 82.07 ten thousand yuan/a;

Investment estimation: for the cost of new pipes, insulation materials, equipment, plus replacement, installation, etc., the estimated investment amount is about 5 million yuan. The financial subsidies are 50% of the total investment, and the self-financing of 2.5 million yuan.

Investment payback period =250÷82.07=3.05 years.

5. Conclusion

The heating season consumes 2.4798 million m^3 of natural gas, the power was 490,400 kWh, equivalent to 3,071.56 tons of standard coal, and the energy consumption per unit heating area was 9.97kgce/m2 from 2010 to 2011 in XX Community through the accounting of energy consumption data of heating system. Its energy consumption index is obviously higher than that of the energy consumption index of other heating area. Analyze the heat source, the pipe network transmission and the end of heating system, it is found that the boiler exhaust gas temperature in this community is high, which leads to greater heat loss of exhaust gas; there are leakage and venting and hydraulic imbalance phenomena due to the aging of heating pipes and insulation layer; meanwhile, the enclosure structure of end residential building envelope poor and indoor heating standard at 18℃ cause the high heating energy consumption in XX Community.

Put forward the implementation of boiler condensing waste heat recovery, installation of hydraulic balance valve and energy-saving technical proposal for the old pipe network replacement through the analysis of the energy-saving potential in XX Community. It is expected to realize the energy saving 728.72 tce and energy saving benefit of 1.4415 million yuan through three measures for energy saving and technical transformation. Estimated investment cost is 3.16 million yuan.

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