Analysis on Energy Saving Transformation of Central Heating System in Existing Buildings

Yony Sun\textsuperscript{1}, Hongxi Zhang\textsuperscript{2*}, Huixuan Xu\textsuperscript{3} and Yang Liu\textsuperscript{4}

\textsuperscript{1}Hebei Province Energy Storage Heating Technology Innovation Center
Hebei University of Architecture

\textsuperscript{2}Hebei Province Energy Storage Heating Technology Innovation Center
Hebei University of Architecture

\textsuperscript{3}Graduated Student in Information Department of Energy Engineering of Hebei University of Architecture, Zhangjiakou City, Hebei Province, China

\textsuperscript{4}Graduated Student in Information Department of Energy Engineering of Hebei University of Architecture, Zhangjiakou City, Hebei Province, China

*Email: 42587743@qq.com

Abstract. By comparing the indexes before and after the energy-saving transformation, the heating system in the northern cold region after the transformation of the existing pipe network is studied. Taking a renovation project in severe cold area as an example, the energy-saving renovation of heating system is analyzed. Through data collation and comparison, after the renovation, all energy-saving indexes of heating pipe network meet the requirements of heat users, and good results are achieved. After the renovation, the water consumption and electricity consumption in heating season are saved by 24\% and 21\%, and the cost of heating system is saved by 335,100 yuan compared with that before the renovation. After the transformation, the user satisfaction is increased by 59\%, and the energy-saving effect is remarkable.

1. Introduction
China is a big energy-consuming country, and in recent years, with the continuous development of social economy, the urban infrastructure has been increasing. By the end of 2020, the central heating area of northern cities and towns in China has reached 14.1 billion square meters, and the energy consumption accounts for about 2/3 of the national energy consumption \cite{1}. Therefore, in 2020, General Secretary Xi Jinping listed "peak carbon dioxide emissions, carbon neutrality" as the key task for the first time in the Central Economic Work Conference. At present, due to the unreasonable operation mode of the system, the laying time of the courtyard pipe network is long, and the connection of new buildings to the existing heating pipe network causes the heating pipe network to reach saturation state, which not only affects the heating effect, but also causes a lot of energy waste, which is contrary to the national call for energy conservation and emission reduction, and seriously pollutes the environment \cite{2}. In October 2018, the state revised the Energy Conservation Law of the People's Republic of China \cite{3}, which made it more clear that energy conservation is China's basic national policy, the energy development strategy of putting conservation first, improved relevant laws and regulations, and put forward stricter requirements for energy consumption. According to the development strategy of energy saving and emission reduction issued by the state, in the process of heating pipe network transformation, the most important thing is to take energy saving as the goal,
integrate heating resources continuously during design and construction, optimize the existing pipe network, and accelerate the pace of heating towards high efficiency and energy saving while modernizing the city, so as to improve the energy utilization rate and heating support capacity [4-6].

2. Project Overview

This residential area is located in Shalingzi Town, Zhangjiakou Economic Development Zone, with a construction area of 14,579 ㎡ and an actual construction area of 11,155 ㎡. The building is a civil building, with the existing pipe network directly buried, and the indoor heating form is radiator.

As shown in the figure, before the renovation, the pipe diameter of the existing heating heat pipe network in the residential area was too small, the steel pipes of the pipe network were seriously corroded, the pipeline pressure was low, and there was a phenomenon of pipeline leakage. The original heat insulation of the pipeline was made of glass wool and fiber cloth, and the heat insulation ability was poor, resulting in serious heat loss during transportation and low heating efficiency, which did not meet the national call for environmental protection and energy conservation. Therefore, the original heating system was renovated.

![Figure 1. Severe corrosion of existing pipe network before reconstruction.](image1)

![Figure 2. Thermal insulation damage of existing pipe network before reconstruction is serious.](image2)

In 2015, the residential area was connected to the central heating pipe network system, and household transformation was carried out. The heat exchange station made up water and constant pressure by frequency conversion water pump, and the tap water was softened by automatic water softener. The constant pressure range of heating system is 0.22-0.27MPa, and the initiation pressure of safety valve is 0.37MPa. The equipment parameters in the heat exchange station are shown in Table 1.

| equipment             | parameter                  | unit    | quantity |
|-----------------------|----------------------------|---------|----------|
| Heating unit          | Heating capacity (w)       | set     | one      |
| Plate heat exchanger  | Heat exchange area of single unit (m²) | platform | 2        |
| Circulating water pump| Flow (m/h)                 | platform | 2        |
|                       | Head (m)                   | forty-four |         |
|                       | Power (KW)                 | 37      |          |
| small pump            | Flow (m/h)                 | eight   | platform | 2        |
|                       | Head (m)                   | 48      |          |
|                       | Power (KW)                 | 2.2     |          |
| Fully automatic water softener | Water production (t/h) | eight | set | one |
3. Energy-Saving Transformation of Heating System

3.1. Reasons for Transformation

Zhangjiakou City is located in the north of Hebei Province, and its climate type belongs to temperate continental monsoon climate [7]. According to the division of building climate, it belongs to severe cold area, and the heating season is about 150 days. Through on-the-spot visits and investigations, the insulation layer of the original heating pipe network was damaged, absorbing water seriously, and part of the insulation layer fell off. Under the long-term immersion of rainwater and other liquids, the pipe corrosion was serious, and the heat was lost seriously in the transportation process. And there is a serious water leakage phenomenon, so the make-up water pump makes up a large amount of water, resulting in a lot of waste of hot water, and the water supply increases, but the actual heat gain of heat users is less, resulting in energy waste; Through the visit, residents generally reported that the indoor temperature was less than 18℃ during heating and the comfort was poor. Therefore, the courtyard pipe network in this residential area should be reformed, the pipe insulation layer should be improved, the unsuitable pipe diameter should be replaced, and some unreasonable routes should be changed, so as to improve the heat transmission capacity and water balance rate of the heating pipe network and respond to the national call for energy conservation and emission reduction.

3.2. Renovation Project

Firstly, the insulation layer of the pipe network in the residential area was replaced and improved. The insulation layer was made of Caitong polyurethane, polyethylene was the protective shell, and foam rubber was wrapped in the welded part of the pipe. Secondly, stop valves and vent valves are respectively installed on the water supply and return pipes of the outlet wells of the heating station. A stop valve is installed on the water supply pipe of the unit, and two stop valves, a filter and a drain valve are installed on the return pipe. Finally, some unreasonable routes and inappropriate pipe networks were changed.

4. Transformation Effect

4.1. Energy-Saving Diagnosis of Pipe Network Before and After Transformation

4.1.1. Water Replenishment Rate. Taking a heating season (151 days) as the testing period, according to the "Testing Standard for Energy Efficiency of Residential Buildings" [9], the water replenishment rate of heating system should not be greater than 0.5%.

The formula for calculating the water replenishment rate is shown in formula (1):

$$R_{mu} = \frac{G_{mu}}{G_{wt}} \times 100\%$$  \hspace{1cm} (1)

Where: -water replenishment rate of heating system $R_{mu}$  
$G_{mu}$: Check the total water supply of the system within the duration (T)  
$G_{wt}$: Cumulative value (T) of the designed circulating water volume of the system within the detection duration.

Before transformation

The total water supply of the system in the heating season before renovation is 255.6t, and the cumulative value of the designed circulating water of the system in the heating season is as follows:

$$G_{wt} = 32.01 \times 12 \times 151 = 58002.12t$$

Therefore, the water replenishment rate of the heating system before the renovation is as follows:

$$R_{mu} = \frac{G_{mu}}{G_{wt}} \times 100\% = \frac{255.6}{58002.12} = 0.63\%$$
After transformation

The total water supply of the system in the heating season before renovation is 205.3t, and the cumulative value of the designed circulating water of the system in the heating season is as follows:

\[G_{wt} = 30.76 \times 12 \times 151 = 55737.12t\]

Therefore, the water replenishment rate of the heating system before the renovation is as follows:

\[R_{mu} = \frac{G_{mu}}{G_{wt}} \times 100\% = \frac{205.3}{55737.12} = 0.37\%\]

Through the relevant calculation and analysis of the system water supply, it is found that the water supply rate before the transformation is 0.63%, which does not meet the relevant specifications, and the water supply rate after the transformation is 0.37%, which is less than the specified value and meets the relevant regulations. Through the transformation of the heating pipe network, the tightness of the courtyard pipe network is enhanced, the leakage is reduced, the required water supply is correspondingly reduced, the heating efficiency is improved and the heat loss is reduced, and the goal of energy saving and emission reduction is actively achieved according to the national call.

4.1.2. Transmission Efficiency of Outdoor Pipe Network. Taking a heating season (151 days) as the detection period, according to the "Residential Building Energy Efficiency Testing Standard" [9], the transmission efficiency of outdoor pipe network should not be less than 90%.

The formula for calculating the transmission efficiency of outdoor pipe network is shown in formula (2):

\[\eta = \frac{\sum Q_y}{Q}\]

Where:
- transmission efficiency of outdoor heating pipe network,
- \(\sum Q_y\): sum of heat supply of each user during the testing period, GJ
- Q: heat output of heat exchanger station during testing, GJ

Before transformation

The total heat supply required by residential users in the pre-renovation heating season is 7179.70GJ, and the total heat output of the system during this period is 8777.68 gj.

Therefore, the transmission efficiency of outdoor pipe network before transformation is as follows:

\[\eta = \frac{\sum Q_y}{Q} = \frac{7179.7}{8777.68} \times 100\% = 82\%\]

After transformation

In the post-renovation heating season, the total heat supply required by residential users is 7615.69J, and the total heat output of the system during this period is 8101.80 GJ.

Therefore, the transportation efficiency of outdoor pipe network after transformation is as follows:

\[\eta = \frac{\sum Q_y}{Q} = \frac{7615.69}{8101.80} \times 100\% = 93\%\]

According to the analysis of relevant data, the average indoor temperature increased from 18℃ to 21℃ before and after the transformation, and the heat supplied to users increased, but the total heat output of the system decreased by 7.6%. After the transformation, the temperature of users increased, but the heat transfer of the system decreased, and the transmission efficiency of the pipe network met the relevant regulations and policies of energy conservation, achieving the effects of energy conservation and emission reduction.

4.1.3. Power Consumption and Heat Transmission Ratio. The power consumption and heat transmission ratio of the heating system shall meet the formula (3):

\[EHR_{a,e} \leq \frac{0.0062 (14 + a \cdot L)}{\Delta t}\]

Where:
- the power consumption and heat transmission ratio of the heating system;EHR_{a,e}
- L: The trunk line of outdoor pipe network (counting from the entrance and exit of the heating pipe to the outer wall of the heat source room and ending at the heat entrance of the heat user at the end of
the most unfavorable loop) includes the total length of the water supply and return pipe (m), 168.16×2m;

A: coefficient, the value of which is shown in Table 2.

Table 2. Value range of coefficient A.

| Total length of water supply and return pipe L(m) | A value  |
|-----------------------------------------------|---------|
| L≤500                                         | 0.0115  |
| 500 < L < 1000                                | 0.0092  |
| L≥1000                                        | 0.0069  |

The value range of power consumption and heat transmission ratio of heating system in this residential area should be:

\[
E_{HR,e} \leq \frac{0.0062 (14 + a \cdot L) - 0.0055}{\Delta t} \leq 0.0062 \times (14 + 0.0015 \times 336.32)
\]

The calculation formula of power consumption and heat transfer ratio is shown in formula (4):

\[
E_{HR} = \frac{N}{Q}
\]

Where: Q—heat supply per hour (kW);
N: power consumption per hour (KW);

**Before transformation**

The hourly power consumption of the system is 254.65kw·h, and the hourly heat supply is 35368.05kw.

According to formula 3.1.4, the ratio of power consumption to heat transmission before transformation is as follows:

\[
E_{HR} = \frac{254.65}{35368.05} = 0.0072
\]

**After transformation**

The hourly power consumption of the system is 215.88kw·h, and the hourly heat consumption is 40732.08KW.

According to formula 3.1.4, the power consumption/heat transmission ratio after transformation is as follows:

\[
E_{HR} = \frac{215.88}{40732.08} = 0.0053
\]

According to the above calculation, the power consumption of the system before the transformation of the pipe network is large, but the heat supply is small, and the power consumption and heat transfer ratio is 0.0072, which is beyond the range of values. After the transformation, the power consumption of the system is reduced, but the heat supply is increased, and the power consumption and heat transfer ratio is 0.0053, which meets the specification requirements.

**4.1.4. Hydraulic Imbalance Rate.** According to the relevant standards [10], the hydraulic imbalance rate of the pipe network should not be greater than 15%. In this residential area, the hydraulic balance rate is calculated for each building.

Firstly, the pressure loss \(P\) of each section is calculated according to the flow rate and pipe diameter of the heating pipe network, and then the hydraulic calculation between the parallel loops is carried out according to the obtained pressure loss of each section.

The calculation formula of hydraulic imbalance rate is shown in formula (5):

\[
Hydraulic\ \text{imbalance\ rate} = \frac{\Delta P_1 - \Delta P_2}{\Sigma \Delta P_1}
\]

Where: \(-\)Total pressure loss of the first loop, Pa\(\Sigma \Delta P_1 \)
\(\Sigma \Delta P_2\): Total pressure loss of the second loop, Pa

By calculating and sorting out the hydraulic imbalance rate of the residential area, it is concluded that the hydraulic imbalance rate of the heating pipe network before renovation is about 20%-30%,
which the maximum hydraulic imbalance rate is 31.2% and the minimum is 19.8%, which does not meet the relevant regulations. The hydraulic imbalance rate of the reformed heating pipe network is about 10%-15%, the maximum is about 14.9%, and the minimum is 9.3%, which meets the relevant regulations.

4.2. Indoor Temperature
In order to intuitively understand the effect of this energy-saving renovation, 200 households were visited after the renovation, and the indoor temperature and indoor comfort degree before and after the renovation were investigated, recorded and sorted out.

The statistics of indoor temperature of users before and after the system transformation are shown in table 3.

| Temperature Distribution (°C) | Pre-renovation (Household) | Post-renovation (Household) |
|-------------------------------|----------------------------|-----------------------------|
| 16-18                         | 88                         | 0                           |
| 18-20                         | fifty-two                  | 30                          |
| 20-22                         | 31                         | 84                          |
| 22-24                         | 29                         | 102                         |
| 24-26                         | 0                          | 14                          |

The comparison of indoor temperature before and after the system transformation is shown in figure 3:

Figure 3. Comparison of indoor temperature before and after renovation.

According to the chart analysis, before the energy-saving renovation, the indoor temperature of users was generally low, and the indoor temperature of most families could not reach the specified minimum indoor temperature of 18°C in the heating season. The temperature of heat users only at the front end of the heat pipe network was relatively high at around 20°C, while the minimum indoor temperature of users at the end of the pipe network was as low as 16°C. Because of the serious hydraulic imbalance, the temperature difference between the front end and the end of the existing pipe network was large.

After the energy-saving renovation, the indoor temperature of most families during the heating period was 20-24°C, and the number of users in this temperature range accounted for 90% of the total survey. The difference between the indoor temperature of users at the front end and the end of the
heating pipe network was 2-4℃, and the pipe network basically reached a balance, and only 18% of families surveyed had indoor temperature of 18-20℃. According to further actual investigation, the main reasons for the lower temperature were the external insulation of the enclosure structure and the large infiltration of cold air from doors and windows. The temperature of heat users with better insulation of the enclosure structure at the end of the pipe network will also reach 24-26℃.

To sum up, this transformation has achieved good results.

4.3. Heating Satisfaction

The distribution of users' indoor comfort before and after the system renovation is shown in table 4.

Table 4. Indoor comfort distribution of thermal users before and after system transformation.

| temperature          | Pre-renovation (household) | Post-renovation (household) |
|----------------------|-----------------------------|-----------------------------|
| Extremely uncomfortable | 83                          | 11                          |
| Uncomfortable        | 71                          | 23                          |
| More comfortable     | 30                          | 70                          |
| comfortable          | 16                          | 95                          |

Comparison of indoor comfort before and after the system transformation is shown in figure 4:

Figure 4. Comparison of indoor comfort before and after renovation.

According to the above analysis, before and after the energy-saving transformation, the number of users who think the indoor comfort is extremely poor or uncomfortable has decreased from 83 to 11, a decrease of 85%. The number of users who think the comfort level is poor and uncomfortable has decreased by 48, about 68%. However, the number of users who think they are more comfortable or comfortable indoors has increased by 119, and about 82.5% of the total users think they are more comfortable and comfortable after renovation.

Through the transformation of the heating pipe network, the thermal comfort and satisfaction of users in the heating season are greatly improved while saving energy and reducing emissions, and the process of efficient heating is promoted. The transformation is of great significance.

4.4. Energy Consumption

4.4.1. Power Consumption and its Cost. Compare the electricity consumption per unit area and total cost before and after the renovation with the unit price of 0.8 yuan/kw h. According to the Technical Specification for Energy Saving Transformation of Urban Heating Systems [10], the power
consumption per unit area of heating buildings is 0.8-1.2 kWh/m² in cold areas and 1.0-1.5 kWh/m² in cold areas.

(1) before transformation
The power consumption before renovation is 21195.96 kW h. Power consumption per unit area is:
\[ D = \frac{21195.96}{11155.77} = 1.9 \text{ kWh/m}^2 \]
The electricity cost before the transformation is:
\[ \text{Cost} = 21,195.96 \times 0.8 = 16,900 \text{ yuan} \]

(2) After transformation
The power consumption after transformation is 16733.66 kW·h, and the power consumption per unit area is:
\[ D = \frac{16733.66}{11155.77} = 1.5 \text{ kWh/m}^2 \]
The water cost after renovation is:
\[ \text{Cost} = 16,733.66 \times 0.8 = 13,300 \text{ yuan} \]

To sum up, the heat consumption per unit area before the renovation was 1.9 kWh/m², which did not meet the national standards and requirements for energy conservation and emission reduction. After the renovation, the heat consumption per unit area was 1.5 kWh/m², which met the requirements and saved a total of 0.36 million yuan for electricity. The renovation of the heating pipe network was reasonable.

4.4.2. Water Consumption and its Cost. The unit price is 5 yuan/ton, and the water consumption and its cost before and after the renovation are compared.

(1) before transformation
The water consumption before renovation is 275,700 tons, so the cost before renovation is:
\[ \text{Cost} = 27.57 \times 10,000 \times 5 = 1,378,500 \text{ yuan} \]

(2) After transformation
The water consumption after renovation is 209,400 tons, so the cost after renovation is:
\[ \text{Cost} = 20.94 \times 10,000 \times 5 = 1,047,000 \text{ yuan} \]
By comparison, the water cost was saved by 331,500 yuan before and after the renovation, and the energy saving effect was obvious.

The total cost before and after the renovation is shown in table 5.

| Time                        | Water consumption (ten thousand tons) | Unit price/ton | Total price (ten thousand yuan) | Save water fee (ten thousand yuan) | Electricity consumption (KW·h) | Unit price/kWh | Total price (ten thousand yuan) | Save electricity (ten thousand yuan) | Total price saved (ten thousand yuan) |
|-----------------------------|---------------------------------------|----------------|---------------------------------|-----------------------------------|------------------------------|----------------|---------------------------------|-------------------------------------|-------------------------------------|
| Before transformation       | 27.57                                 | five           | 137.85                          | 21195.96                          | 0.8                          | 1.69                        | 0.36                            | 33.51                               |
| After transformation        | 20.94                                 | five           | 104.7                           | 16733.66                          | 0.8                          | 1.33                        |                                  |                                     |

5. Conclusion
In response to the national call for energy conservation and emission reduction, the heating pipe network has been comprehensively reformed, and achieved good results. After the reform, the hydraulic power of the pipe network has basically reached a balance, reducing the indoor temperature difference between the front end and the end users of the heating pipe network, and the insulation layer of the pipe has been correspondingly improved. By replacing the inappropriate pipe diameter and
the leaking pipe network, the problem of serious water leakage and heat loss of the heating pipe network has been solved, and a large amount of energy waste has been avoided, while the indoor temperature of heat users has been greatly increased. It not only achieves the goal of energy saving and emission reduction, but also meets the heat demand of users. Promote the energy-saving and sustainable development of heating pipe network system.

The transformation of the heating pipe network system has a remarkable effect on energy saving, with the water consumption reduced from 275,700 tons before the transformation to 209,400 tons after the transformation, and the electricity consumption reduced from 21195.96kw·h before the transformation to 16733.66kw·h after the transformation, saving a total of 335,100 yuan before and after the transformation.

Energy-saving transformation of heating system is the main method to realize efficient heating, and it is also an important force to promote "peak carbon dioxide emissions and carbon neutrality". The transformation can not only bring economic benefits and social benefits, but also bring huge environmental benefits, which is of great significance to the sustainable development of cities and countries.

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