Research on benefit and optimum development of residents' heating projects based on different ways

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Abstract: At present, the relevant experts pointed out that the emergence of China's foggy weather is the coal-dominated irrational energy consumption patterns and energy structural contradictions in the long-term accumulation of concentrated exposure. The air pollution caused by coal-fired heating in the northern cities is again attracting attention. As a new type of heating mode, electric heating enters people's view. In order to make the public understand the characteristics of electric heating, this paper firstly analyzes the technical scheme of electric heating, then takes the project of North China as an example to carry on the economic benefit analysis research, and according to the appraisal result gives the government subsidy electricity price proposal, has the important practical reference significance to the electric heating implementation promotion.

1. Introduction
At present, the efficiency of the coal-fired boilers used by residents is usually not high, decentralized coal-fired boiler heating also causes a low utilization of fuel. Therefore, it is of great significance to use electric heating instead of coal-fired boilers to increase the proportion of energy consumption and to change the mode of energy consumption and improve the efficiency of energy utilization.

The implementation of residential electric heating will concentrate coal on large-scale combustion to generate electricity, and then use electric energy to drive heating equipment, the impact on the atmospheric environment is far lower than the direct emission of decentralized coal-fired boiler.

This paper takes a residential district project in Yanbian area as an example, and analyzes the economic angle of different heating modes from the aspects of investment cost, operating cost and annual cost, making a comprehensive quantitative evaluation on the benefits of electric heating.

2. Research trends of Electric heating
Many scholars have probed into the necessity and application technology of electric heating, and [1] have pointed out the necessity of implementing electric heating from the angle of improving energy efficiency and reducing environmental impact. [2] regarded electric heating as one of the important means of "reducing the burden" of environmental pollution. [3] have studied the mainstream form and application of electric heating at present, and pointed out that the electric heating has been widely popularized. [4] proposed a multilayer phase change heat storage System, conducting performance simulation of the thermal storage unit for the system by establishing the mathematical model, it is found that the system has great application value in electric heating at home. [5] had proposed the concept of geothermal energy as the low temperature heat source of ground source heat pump system, and [6-7] have carried out a lot of basic theoretical research on ground source heat pump.
3. Current status of residential electric heating and analysis of electric heating technology

3.1 Current status of residential electric heating
At present, 80% of China's energy consumption is direct combustion of raw coal, resulting in environmental pollution problems, has affected the sustainable development of national economy and the people's physical health. 70% and 90% of China's emissions of soot and sulfur dioxide are produced by coal.

As the rural civil construction area accounted for about 60% of the total area of the country, with the rapid development of the social economy, the original winter traditional heating methods, such as stoves, Kang, firewalls and other consumption of local biomass energy, is switching on a large scale to coal-fired boilers and disperse stoves that consume the energy of commodities. And coal as the main raw material heating mode of a single form, more energy consumption, heavy pollution, poor effect, to the atmospheric environment caused serious losses. And coal as the main raw material heating way, a single form, more energy consumption, heavy pollution, poor effect, resulting in serious damage to the atmosphere environment.

For some independent residential buildings used in gas heating wall-mounted furnace, has become a more commonly used in civil construction heating methods. Gas emissions have air pollution problems; General wall-mounted stoves are placed in small space in the kitchen or balcony, close to the living room, due to the use of conditions and product quality reasons, there are hidden dangers; It is a long-term operation of equipment, its overhaul and maintenance of the tenants themselves are not competent; Low-temperature combustion is also required for long-term uninhabited winters.

3.2 Analysis of electric heating technology
At present, the domestic electric heating technology is mainly divided into resistance and heat pump type, all kinds of electric heating technology as shown in Figure 1. In the choice of application technology of electric heating, we should aim at different types of heating objects, choose their corresponding electric heating technology, give full play to the application advantages of electric heating, realize the maximum benefit of electric heating application. The advantages and disadvantages of different heating methods are shown in Table 1.

![Electric Heating Technology](image)

Table 1 Advantages and disadvantages of different heating methods

| Basic type      | Specific types | Advantages | Disadvantages |
|-----------------|----------------|------------|---------------|
| Resistor type   | Electric Boiler| General     |               |
|                 | Regenerative  | Electric     |               |
|                 | Boiler        |              |               |
| Electric heater | Regenerative  | Electric     |               |
|                 | Electric Heater|              |               |
|                 | Air Source    | Heat Pump    |               |
|                 | Heat Pump     |              |               |
|                 | Water source  | Heat Pump    |               |
|                 | Heat Pump     |              |               |
|                 | Ground source | Heat Pump    |               |
|                 | Heat Pump     |              |               |

Fig1. Electric Heating Technology
4. Economic benefit analysis of electric heating

4.1 Economic index analysis of electric heating

(i) Initial investment costs

1) Land use fee (remember as I1)

The main land of the heating system is the land needed for building the heat source boiler room, and the floor area of the boiler room with different heating modes is shown in Table 2. Buildings for residential heating are civil. The land requisition cost of civil architecture in north China is 3 million yuan/acre (4,500 Yuan/m2).

Table 2. Estimating the floor area of various boiler houses (M2/MW)

| Heat source Form          | Unit heat Load Footprint |
|--------------------------|--------------------------|
| Coal-fired Boiler room   | 150                      |
| Gas Boiler Room          | 85                       |
| Heat Pump Room           | 65                       |
| General Electric Boiler Room | 50                  |
| Water Regenerative Electric Boiler | 60        |
| Solid regenerative Electric Boiler | 30            |

Note: According to the boiler Room design code GB50041-2008
2) Civil construction cost (remember as I2)
Civil engineering cost is construction cost to build boiler room, heat pump system including building material cost, construction labor cost and mechanical equipment use expense. The civil construction cost of a certain area in north China is 2000 Yuan/m² from the following table 3.

Table 3. Cost estimate of civil construction in different regions

| Area       | Civil construction cost (yuan/m²) |
|------------|----------------------------------|
| North      | 2000                             |
| East       | 2100                             |
| South      | 2200                             |
| Central    | 1700                             |
| Northwest  | 1300                             |
| Southwest  | 1600                             |
| Northeast  | 1500                             |

3) Equipment cost (remember as I3)
The equipment fee is the whole set price of boiler and auxiliary machine, the cost of equipment includes the purchase cost of the main body of boiler and heat pump, and the cost of purchasing the auxiliary equipment such as circulating water pump, fan and installation project cost.

4) Indoor and outdoor pipe network fee (remember as I4)
Heating system pipe network mainly includes outdoor and indoor pipe network. The pipe network material should be selected according to the building type and construction area.

5) Total cost of initial investment (remember as I5)
The total cost of initial investment is the sum of the above several expenses, as shown in the formula (1)

\[
\text{Initial investment cost} = I_1 + I_2 + I_3 + I_4 + I_5
\]  

(i) Operating costs
The cost of heating operation mainly includes fuel cost, water and electricity cost, labor cost, operation maintenance cost and so on.

1) Fuel costs (remember as O1)
Fuel costs as the most important part of operating costs, calculated as shown in formula (2)

\[
O_1 = B \times P
\]  

\(B\) - Energy consumption of heating, kg; \(P\) - Fuel price, yuan.

The heating energy consumption is determined by heating consumption, and the calculation formula is as follows.

\[
B = \frac{\sum Q}{Q_{dw} \times \eta_y \times \eta_w}
\]  

\[
\sum Q = Q_n \times \left(\frac{t_p - t_m}{t_w - t_m}\right) \times n \times 24 \times 3600
\]  

\(B\) - Energy consumption of heating, kg; \(\sum Q\) - Total heat consumption of Heating season, KJ; \(Q_{dw}\) - Calorific value of fuel unit, KJ/Unit; \(\eta_y\), \(\eta_w\) - Heat source, Heat efficiency of pipe network; \(Q_n\) - thermal load of heating, KW; \(t_p\) - Indoor calculation temperature in heating period, \(\text{°C}\); \(t_m\) - Usually take 18 \(\text{°C}\); \(t_w\) - Outdoor average temperature during heating period, \(\text{°C}\);
Outdoor calculation temperature of heating period, \( ^{\circ}C \); \( n \)-Days of heating period, days.

\[
\varphi = \frac{t_n - t_{pl}}{t_n - t_w}, \quad \text{Average coefficient of thermal load.}
\]

The low calorific value and fuel price of various common fuels are shown in table 4, and the operating costs of each of the four heating schemes can be calculated separately according to the data in the table.

Table 4. Fuel low calorific value and price for different heating schemes

| Fuel Type  | Calorific value of fuel | Fuel price | Unit calorific value |
|------------|-------------------------|------------|----------------------|
| Coal       | 29.27MJ/kg              | 770yuan/t  | 0.0263yuan/MJ         |
| II bituminous Coal | 17.61MJ/kg     | 468yuan/t  | 0.0266yuan/MJ         |
| Electric   | 3.6MJ/kWh               | 0.5yuan/kWh| 0.1389yuan/MJ         |
| Gas        | 35.58MJ/m³              | 2.67yuan/m³| 0.1265yuan/MJ         |

Note: The fuel calorific value of this table is based on China Coal Classification National Standard (GB5751-86).

2) utilities (remember as O2)

Water charges are the total cost of the amount of water injected into the system of the boiler heating system and the additional water, the calculation formula is as follows.

\[
O_2 = Q \times P
\]  (5)

Q-Quality; P-Price, yuan.

3) labor costs (remember as O3)

The labor cost is to pay the workers’ wages during the heating system operation. After inquiry data, the average wage in north China is 160 yuan/day.

\[
O_3 = N \times \phi \times n
\]  (6)

\( \Phi \)-Average wage, yuan; \( n \)-Days of labouring period, days.

4) Other costs (remember as O4)

Other expenses mainly include the equipment maintenance cost during the operation of heating equipment generally charged based on the construction area or the usage area.

5) Operation Total Cost

The sum of the costs of the operation, as shown in the formula (7)

\[
\text{Operating costs} = O_1 + O_2 + O_3 + O_4
\]  (7)

(iii) Comparison method of cost year value

The cost year value is the cost of the initial investment by the equipment life cycle depreciation to each year, and then the annual operating costs added, we can compare the economic benefits of different life cycle projects by calculating the annual value \( AW \) of project cost, and calculate the formula as follows

\[
AW = C_0 \times \left( \frac{A / P, i, n}{n} \right) + C
\]

\[
\left( \frac{A / P, i, n}{n} \right) = \frac{i \times (1 + i)^n}{(1 + i)^n - 1}
\]  (8)

Among them, \( i \) for the investment rate of return, take 10%; \( n \) for life period, \( C_0 \) for the initial investment cost, \( C \) for the annual operating costs.

4.2 Empirical study on residential electric heating

(i) Architectural overview

Taking the Highland Garden community of Yanbian as an example, the current winter heating mode of Highland Garden District is for the water storage and thermoelectric boiler heating, Building type and
At present, Highland Garden Heating mode is water regenerative type, the heating mode can also be coal, gas and electric heating, selected for electric heating technology mainly are ground-source heat pump and ordinary electric boilers, solid storage and thermoelectric boilers.

(i) Comparison of initial investment costs

Through the calculation above, we can sum up the initial investment cost comparison of different heating modes in the Highland Garden District of Yanbian area, as shown in table 5 below.

| Compare items | Coal-fired Boiler room | Gas Boiler Room | Ground source Heat Pump | General Electric Boiler | Water Regenerative Boiler | Solid regenerative Boiler |
|---------------|------------------------|-----------------|-------------------------|------------------------|---------------------------|--------------------------|
| Land use fee  | 60.02                  | 34.01           | 26.01                   | 20.01                  | 24.01                     | 12                       |
| Civil cost    | 90.02                  | 51.01           | 39.01                   | 30.01                  | 36.01                     | 18                       |
| Equipment cost| 210                    | 290             | 1000                    | 540                    | 620                        | 610                      |
| Pipe network  | 342.9                  | 342.9           | 342.9                   | 342.9                  | 342.9                      | 432.9                    |
| Initial cost  |                        |                 |                         |                        |                            |                          |
| Initial investment costs | 702.94 | 717.92 | 1407.92 | 932.92 | 1022.92 | 982.90 |
| Overall cost of equipment | 15 | 15 | 25 | 25 | 25 | 25 |
| Cost year value | 262.9 | 447.32 | 302.02 | 736.39 | 529.67 | 443.12 |

By comparing the initial investment cost of different heating modes, it can be found that the ground-source heat pump heating system should be significantly higher than other heating modes in the initial investment. Electric boiler heating and coal, gas heating initial investment expenses are similar. Although the initial investment cost of the electric heating method is higher than the that of the coal-fired gas boiler, however, combined with the heating energy consumption and pollutant emission, the comprehensive benefit of the electric heating mode is higher than the ordinary heating mode.

(iii) Economic benefit analysis of operation cost

The total heat load of the building is 4001KW. To calculate the total heat load of the heating season, the heating period is 183 days and the heating time is 24h each day. The average value of the heat load is as follows.

$$\varphi = \frac{t_n - t_0}{t_n - t_w} = 0.635$$

The heating season heat load of the project is calculated according to the formula (4):

$$\sum Q = 4001KW \times 0.635 \times 183 \times 24h = 113.9 \times 10^5 \text{kWh}$$

According to the above calculation, the details of the operation of different heating modes in Highland Garden District are shown in table 6 below.

| Operational efficiency | Fuel | Fuel prices | Energy consumption |
|------------------------|------|-------------|--------------------|
| Coal                   | 0.7  | II bituminous Coal | 468yuan/t | 3259.19 |
| Gas                    | 0.9  | Gas         | 2.67yuan/m3 | 1254.64*10^3m³ |
| Ground source Heat Pump| electric | 0.5250/kWh | 25.36*10^3kWh |
| Electric Boiler        | 0.98 | electric    | 0.5424/kWh | 113.9*10^3kWh |
| Water Regenerative     | Peak | 0.78285/kWh | | |
Table 7. Comparison of operating cost of different heating modes

| Energy consumption | Power consumption (kWh) | Operating costs (yuan) | Operating cost per unit area (元) |
|--------------------|-------------------------|------------------------|----------------------------------|
| Coal boiler room   | 3259.19t               | 35000                  | 1704800                          | 15.47                           |
|                    | bituminous Coal        |                        |                                  |                                 |
| Gas boiler room    | 1254.64×10^3m^3 Gas    | 35000                  | 3529400                          | 32.03                           |
| Ground source heat pump system | 2536000 | 1469100 | 13.33 |
| General Electric Boiler | 11390000  | 6336100 | 57.51 |
| Water Regenerative Electric Boiler | 11390000 | 4169700 | 37.85 |
| Solid regenerative Electric Boiler | 11390000 | 3348300 | 30.39 |

By comparing the annual operating cost of heating mode, it can be found that the operating cost of the ground source heat pump system is the lowest, and the heating system of the ordinary electric boiler is higher than other heating modes, and the annual operating cost of the water storage and the solid heat storage boiler is obviously improved, which is less than the running cost of the gas-fired boiler house, and has good economy.

(4v) Annual Revenue Analysis

The sales revenue of heating enterprises mainly refers to the heating income; the heating price of Yanbian city is about 31 yuan /m^2 by residential heating area, the heating revenue is the same, the annual heating of Yanbian area is 2.8733 million yuan.

Table 8. Income comparison of different heating methods

| Annual Sales revenue (yuan) | Cost year value (yuan) | Annual revenue (万 yuan) |
|-----------------------------|------------------------|-------------------------|
| Coal-fired Boiler room      | 2873300                | 262.9000                | 24.43                           |
| Ground source heat pump system | 2873300 | 302.0200 | -14.69 |
| General Electric Boiler     | 2873300                | 736.3900                | -449.06                         |
| Water Regenerative Electric Boiler | 2873300 | 529.6700 | -242.34 |
| Solid regenerative Electric Boiler | 2873300 | 443.1200 | -155.79 |

4.3 Economic benefit evaluation by Net Present Value

Net present value method refers to the algebra and the present value of the net cash flow of each period in the economic life cycle of the project according to a specified benchmark rate of return.

The formula is as follows:

\[ NPV = P_0 + \sum_{i=1}^{n} \frac{F_i}{(1+i)^t} + A \left[ \frac{(1+i)^n - 1}{i(1+i)^t} \right] \]  

(10)

In the formula:

NPV--Net present value;
P0--Cash flow for the No. 0 year;
Fi--Non-uniform cash flow for T-year;
N--Uniform cash flow from 1th year to nth year
NET residual value is usually calculated by 3%-5% of the original value of the fixed asset. Here we define the net residual value 5% of the fixed asset; Predetermined benchmark rate of return, i₀ = 15%.

The results obtained from Table 9 below are: N_pump > N_Solid > N_Water > N_Electric Boiler. For Highland Garden community, the ground source heat pump has the best heating mode.

Table 9. Specific conditions of different heating modes

|                | coal                | Ground source heat pump system | General Electric Boiler | Water Regenerative Electric Boiler | Solid regenerative Electric Boiler |
|----------------|---------------------|-------------------------------|-------------------------|-----------------------------------|-----------------------------------|
| Initial investment costs | 702.94              | 1407.92                       | 932.92                  | 1022.92                           | 982.90                            |
| Annual income     | 24.43               | 14.69                         | -449.06                 | -242.34                           | -155.79                           |
| Residual value    | 35.147              | 70.396                        | 46.646                  | 51.146                            | 49.145                            |
| Service Period    | 15                  | 25                            | 25                      | 25                                | 25                                |
| NPV              | -555.72             | -1502.49                      | -3832.45                | -2586.88                          | -1987.20                          |

4.4 Government subsidy policy

In order to solve the problem of high initial investment of electric heating users, it can be considered that the government implement electricity heating subsidies to help users, providing users with a part of the funds for the purchase of electric heating equipment and electric heating construction.

Take Highland Garden as an example, from the calculation above can be obtained, both coal-fired heating investment cost and operating cost is low, making the initial investment cost of coal-fired heating and electricity price as the standard price, the government can subsidize from two aspects:

(i) Tariff subsidy

To ensure that the initial investment costs of heating methods, the details of the government's subsidy to the electricity price are shown in Table 13 below.

From the Highland Garden in 2017, the total electricity was 113.9x10^5kwh; For the water regenerative heating method, of which about 71.97% of the power in the valley, about 81.97x10^5kwh, flat section of electricity accounted for 28.03%, about 31.93x10^5kwh. The Government should therefore subsidize the subsidies.

It can be obtained from table 10 below that the General Electric boiler without peak and valley electricity price has the highest price to subsidize, so making the subsidized electricity price is I.

\[ I_{\text{Electric Boiler}} > I_{\text{Water}} > I_{\text{Solid}} > I_{\text{pump}} \]

Table 10. Government fuel price subsidies

|                | Fuel price/yuan/kWh | Operating costs after reform/yuan | Government subsidized fuel prices yuan/kWh |
|----------------|---------------------|----------------------------------|------------------------------------------|
| Coal           | 468yuan/t           |                                  |                                          |
| Ground source Heat Pump | 0.5250              | 1221800                          | 0.097                                    |
| General Electric Boiler (No peak-Valley electricity price is used) | 0.5424              | 1696700                          | 0.390                                    |
| General Electric Boiler (Use peak and valley electricity price) | Peak 0.78285        | 1597400                          | 0.156                                    |
|                 | Flat 0.5324         |                                  |                                          |
|                 | Trough 0.28195      |                                  |                                          |
| Water Regenerative Electric Boiler | Peak 0.78285      | 1540700                          | 0.170                                    |
|                 | Flat 0.5324         |                                  |                                          |
|                 | Trough 0.28195      |                                  |                                          |
| Solid regenerative Electric Boiler | Trough 0.28195    | 1546100                          | 0.148                                    |

(ii) Initial investment and tariff subsidy

Given the initial investment cost of different electric heating methods, the government should give full support to the initial investment cost of different electric heating methods. Namely the investment ground source heat pump 14.0792 million yuan, the General Electric boiler 9.3292 million yuan, the water regenerative electric boiler 10.2292 million yuan, as well as the solid regenerative electric boiler
9.829 million yuan. After the initial investment subsidy, the electricity price subsidy is given to different electric heating modes, as shown in table 11 below.

The following table shows that the government's tariff subsidy policy for different heating modes

\[ I_{\text{Electric Boil}} > I_{\text{Water}} > I_{\text{Solid}} > I_{\text{pump}} \]

In most areas of our country, the peak and valley electricity price has been adopted for heating electric boilers, and through the above calculation we can also get the electric boiler heating with very good economic benefit after using the peak-Valley electricity price policy.

Table 11. Government initial investment and tariff subsidy (unit: million)

| Heating Method                      | Initial Investment Costs | Cost Year Value | Initial Investment Cost of Government Subsidy | Government Subsidy Electricity Price Yuan/kwh |
|-------------------------------------|--------------------------|-----------------|---------------------------------------------|----------------------------------------------|
| Ground source Heat Pump             | 1407.92                  | 302.02          | 1407.92                                     | 0                                            |
| General Electric Boiler (No peak-Valley electricity price is used) | 932.92                  | 736.39          | 932.92                                      | 0.334                                        |
| General Electric Boiler (Use peak and valley electricity price) | 932.92                  | 525.44          | 932.92                                      | 0.089                                        |
| Water Regenerative Electric Boiler  | 1022.92                  | 529.67          | 1022.92                                     | 0.134                                        |
| Solid regenerative Electric Boiler  | 982.90                   | 443.12          | 982.90                                      | 0.101                                        |

5. Conclusions

In order to make the public better understand the advantages of electric heating, accept and adopt this new type of heating, this paper analyzes the technical scheme of electric heating. From the angle of economic benefit, this paper makes a deep comparative study on the heating methods of electric heating, such as coal and gas, and draws the following conclusions:

1) This paper classifies the main electric heating technology in China, it is mainly divided into resistance type and heat pump type, the advantages and disadvantages of various electric heating technology are introduced. At the same time, it should be noted that in the selection of application technology of electric heating, we should choose the suitable electric heating technology for different types of heating objects to realize the maximum benefit of electric heating application.

2) The use of electric heating to replace the need to invest a part of the funds for electric heating reform, in order to solve the problem of high investment costs, to stimulate the user to replace the enthusiasm of electric heating, it can be considered by the government to carry out electric heating replacement of the user electric heating reform subsidy, The government can carry out from two aspects, one of which is to provide subsidy for initial investment, and the other is to subsidize the electricity price on the basis of providing initial investment subsidy.

References

[1] Chu K, Kim D, Sohn Y, et al. Electrical and Thermal Properties of Carbon-Nanotube Composite for Flexible Electric Heating-Unit Applications[J]. IEEE Electron Device Letters, 2013, 34(5): 668-670

[2] Cong Yanhui, Zhang Qibin. Analysis on the experience of electric heating technology application[J]. Innovation and application of science and technology, 2016(29): 140-140.

[3] Lv Weisi, Chen Yuntao. Analysis of application of electric heating technology in China[J]. Innovation and application of science and technology, 2016(29): 151-151.

[4] Sanbao Y E, Diao Y, Zhao Y. Heat Storage-Release Property of Phase-Change Thermal Storage System with New Flat Heat Pipe[J]. Electric Power Construction, 2014, 35(7): 136-140.
[5] Yang W, Sun L, Chen Y. Experimental investigations of the performance of a solar-ground source heat pump system operated in heating modes[J]. Energy & Buildings, 2015, 89: 97-111.

[6] Bi Y, Chen L, Wu C. Heat source performance for solar–ground source heat pump[J]. Journal-Energy Institute, 2016, 78(4): 185-189.

[7] Hein P, Kolditz O, Görke U J, et al. A numerical study on the sustainability and efficiency of borehole heat exchanger coupled ground source heat pump systems[J]. Applied Thermal Engineering, 2016, 100: 421-433.