Discussion on Energy-Efficient Technology for the Reconstruction of Residential Buildings in Cold Areas

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Abstract: Based on the existing residential buildings in cold areas, this paper takes the existing residential buildings in a certain district in Beijing to provide an analysis of the thermal characteristics of envelope and energy consumption in winter with the software PKPM, and provides the technical and economic analysis, which may provide reference for suitable plans for energy efficient reconstruction of buildings in cold areas.

Keywords: residential building energy conservation cold area building envelope reconstruction plan

1. INTRODUCTION

With the rapid development of economic construction and society, the energy consumption used for building construction and operation occupies a big proportion of the total social energy consumption. The building energy consumption occupies 30~40% of the total social energy consumption in western countries; and it occupies about 30% of the total social energy consumption and has the trend to35% in our country.

There is about 40 billion m^2 building areas of the existing residential buildings in cities and countries, and it develops with the speed of 1.6~2 billion m^2 each year [1]. At the same time, the existing residential buildings have big energy consumption, which lead to a continuous increase of building energy consumption. Therefore, building energy conservation has been considered as one of the most important issues of medium and long term energy efficient program. At present, the file of “Medium and long term energy efficient program” prepared by National Development and Reform Commission has put forward that new buildings should be built according to the standard of 50% energy saving in our country and it should be built according to the standard of 65% energy saving in some cities such as Beijing and Tianjin.

Based on the existing residential buildings in cold area, this paper takes the existing residential building in certain district in Beijing to provide an analysis on the thermal characteristics of envelope and energy consumption in winter with the software PKPM, and provides the technical and economic analysis, which may provide reference of the suitable plans for the energy efficient reconstruction of buildings in cold area.

2. ANALYSIS ON HEATING ENERGY CONSUMPTION

2.1 Building Situation

Based on the existing residential building in Beijing, the paper discusses the reconstruction plan of energy saving. The outside air temperature for heating in Beijing is -9℃, and the outside mean temperature is -1.6℃ during the heating period of 125 days. The building has 6 floors with a floor height of 2.8m and a total building area of 6481.7m^2. The building has no basements, and building volume is 18165.76m^3. Building surface area is 5153.86m^2 and the shape coefficient is 0.28. The area ratio of window to wall is 0.33 in south, 0.30 in north, 0.05 in east and 0.03 in west. The heat transfer coefficient of roof is 1.26 W/m^2·K and the area is 1028.5m^2. The heat transfer coefficient of external wall is 1.57 W/m^2·K and the area is 3002.67 m^2. The heat transfer coefficient of external window is 6.4 W/m^2·K and the area is 908.64 m^2.

2.2 Design Heating Load

The design heating load of residential building according to the standard is [2]:

$$Q' = Q_1' + Q_2'$$
$$Q_1' = Q_{1\cdot j}' + Q_{1\cdot x}' = (1+x_g)\sum aKF\left(t_n - t_w'\right)\left(1+x_{ch}+x_f+x_m\right) \quad \text{W} \qquad (1)$$

In formula (1), Q_1' is heat consumption of building envelope, W; Q_2' is heat consumption of wind penetrating, W; $Q_{1\cdot j}'$ and $Q_{1\cdot x}'$ are basic heat consumption of building envelope and additive(correctional) heat consumption of building envelope respectively, W; x_{ch} , x_f , x_m and x_g are correction factor of orientation, wind, external door and floor height respectively, %, the paper considers only x_{ch} ; K is overall heat transfer coefficient of building envelope, W/(m^2·K); F is area of building envelope, m^2; t_n and t_w' are indoor air temperature during winter and outside air temperature during heating period respectively, □; a is correction factor of temperature difference.

The heat consumption of wind penetrating Q_2' is:

$$Q_2' = 0.278V\rho_w c_p\left(t_n - t_w'\right) \quad \text{W} \qquad (2)$$

In formula (2), V is penetrating air capacity through aperture of door and external window, m^3/h, it is calculated with the way of aperture; ρ_w is air density at outside air temperature for heating, kg/m^3; c_p is specific heat at constant pressure of cold air.

The design heating load is 408.6kW, and the index of design heating load is 63.03W/m^2.

2.3 Heat Consumption during Heating Period

2.3.1 Building Heating Consumption

The index of building heat consumption is [2]:

$$q_H = q_{H\cdot T} + q_{INF} - q_{I\cdot H} \quad \text{W/m}^2 \qquad (3)$$

In formula (3), $q_{H\cdot T}$ is heat consumption of building envelope per building area, (W/m^2); q_{INF} is heat consumption of wind penetrating per building area, (W/m^2); $q_{I\cdot H}$ is indoor building heat consumption per building area, it is 3.8 W/m^2 in the residential building.

The heating consumption of building envelope per building area is [2]:

$$q_{H\cdot T} = \left(t_i - t_e\right)\left(\sum_{i=1}^{m} \varepsilon i \cdot Ki \cdot F\,i\right)A_0 \quad \text{W/m}^2 \qquad (4)$$

In formula (4), t_i is indoor mean temperature ,it is 16□ for residential buildings; t_e is outside mean temperature during heating period, □; εi is correction factor for overall heat transfer coefficient of building envelope; Ki is overall heat transfer coefficient of building envelope, W/(m^2•K), A_0 is building area,m^2.

The every year heat consumption of the consumer is [3].

$$Q_{n.a} = 0.0864 Q_n'\left(\frac{t_n - t_e}{t_n - t_w'}\right)Z \quad \text{GJ/a} \qquad (5)$$

In formula (5), Q_n' is design heat duty for heating, kW; Z is heating days, d.

We can see from using the software PKPM to calculate that the total building heat consumption is 199.7kW, and the index of building heat consumption is 27.01W/m^2.

2.3.2 Coal Consumption for Heating

The index of coal consumption for heating is [2]:

$$q_c = 24 \cdot Z \cdot q_H / (H_c \cdot \eta_1 \cdot \eta_2) \quad \text{kg/m}^2 \quad (6)$$

In formula (6), H_c is heat quantity of the normative coal, it is 8.14×10^3W·h/kg; η_1 is heat transfer efficiency of outdoor heating network, it is 0.90 in Beijing; η_2 is rating of boiler efficiency, it is 0.68 in Beijing.

We can see from using the software PKPM to calculate that the index of coal consumption for heating is 16.26 kg/m^2.

"Energy Conservation Design Standard for New Heating Residential Buildings" regulates that the limited value of heat transfer coefficient of external wall in residential buildings in Beijing is1.16W/m^2•K when the shape coefficient of building≤0.3 according to the second index of energy saving, at the same time, the limited value of heat transfer coefficient of external window and roof is 4.00W/m^2•K and 0.82W/m^2•K respectively, the index of building heat consumption is 20.6W/m^2 and the coal consumption for heating is 12.4kg/m^2.So the index of this building can not attain the criterion of energy saving, then it need reconstruct and there is 31.1% potential.

3 ENERGY EFFICIENT MEASURES

There are two approaches to reducing the energy consumption, which are to enhance heat-retaining property of building envelope and efficiency of heating system. And the heat-retaining property of building envelope is the key to building energy conservation. The building envelope mainly includes external wall, door and external window, roof, floor, basement of no heating and so on, and the external wall, external door and window, roof are the key to the energy efficient reconstruction of the existent residential building.

3.1 External Wall

The external wall is the main body of the building envelope, and it is the mainstream to doing heat preservation of external wall. There are three ways to heat preservation, which are outer heat preservation, inner heat preservation and with filling heat preservation. But the outer heat preservation is the best, and the season is:

1) When internal insulation of external wall is involved, the inner surface of building envelope will have a big attenuation to the heat transfer and absorption from outdoor and indoor air, which may lead to much more indoor heat storage and good heat stability [5].
2) It can minish the damnification because of the freezing and thawing since the temperature of the main body of external wall, so it can prolong operating life.
3) The outer heat preservation can cut down about 1/5 heat loss compared with the inner heat preservation.
4) Although the fabrication cost per building area of the outer heat preservation is higher than the inner heat preservation, the outer heat preservation adds about 2% floorage than the inner heat preservation, so the fabrication cost per floorage of the outer heat preservation is comparatively lower [6].
5) It can avoid unnecessary tangle because that the outer heat preservation has small interfere on the tenements and constructs expediently.

3.2 External Window

The external window thermal loss takes a big proportion in the total building thermal loss, so it is an important matter to reduce the external window thermal loss. There are several kinds of energy efficient external windows such as plastic window, double-glass window and so on.

3.3 Roof

Although the thermal loss of roof is little than external wall and external window, the thermal loss of roof per area is very big, so it is important to do heat preservation of roof.

4. RECONSTRUCTION PLAN AND ENERGY EFFICIENT COMPARISON

4.1 Reconstruction Plan of Energy Saving

It discusses the reconstruction of external wall, external window and roof according to the specialty of this building.

1) The external wall is done outer heat preservation with 40mm and $\lambda = 0.042W/m \cdot K$ polystyrene plate, and the heat transfer of coefficient of external wall is 0.63 W/(m^2·K) after doing heat preservation, and the price of 40mm polystyrene plate per floorage is 58 RMB (including material and installation fee), so it needs 17.4 ten thousand RMB; the heat transfer coefficient of external wall is 0.39 W/(m^2·K) after doing heat preservation with 80mm polystyrene plate.
2) To use double-glass plastic steel window whose heat transfer coefficient is 3.26 W/(m^2·K) and the price per floorage is 200 RMB (including material and installation fee), so it needs 18.2 ten thousand RMB.
3) The roof is done heat preservation with 30mm and $\lambda = 0.03W/m \cdot K$ plastic extruded polystyrene plate, and the heat transfer coefficient of roof is 0.62 W/(m^2·K) after doing heat preservation, and the price of 30mm plastic extruded polystyrene plate per floorage is 63 RMB (including material and installation fee), so it needs 6.5 ten thousand RMB; the heat transfer coefficient of roof is 0.36 W/(m^2·K) after doing heat preservation with 60mm plastic extruded polystyrene plate.

4.2 Comparison of Energy Efficient Reconstruction Plans

4.2.1 Effect of Energy Saving

The comparison with various indexes of external wall, external window and roof before and after heat preservation is in tab.1, tab.2 and tab.3, and the comparison with various indexes of the building before and after heat preservation is in tab.4.

We can see from table 4 that there is very big potential of energy saving in this building.

Tab. 1 Comparison of external wall

Title		South external wall	East and external west wall	North external wall	Total external wall
Index of design heating load (W/m^2)	Before heat preservation	4.58	7.20	5.95	17.73
	Heat preservation with 40mm polystyrene plate	1.84	2.89	2.39	7.12
	heat preservation with 80mm polystyrene plate	1.14	1.79	1.48	4.40
Index of heat consumption (W/m^2)	Before heat preservation	2.79	4.25	3.57	10.61
	Heat preservation with 40mm polystyrene plate	1.12	1.70	1.43	4.26
	Heat preservation with 80mm polystyrene plate	0.69	1.06	0.89	2.63
Index of coal consumption (kg/m^2)	Before heat preservation	1.68	2.56	2.15	6.38
	Heat preservation with 40mm polystyrene plate	0.67	1.03	0.86	2.56
	Heat preservation with 80mm polystyrene plate	0.42	0.64	0.53	1.59

Tab.2 Comparison of external window

Title		South external window	East and west external window	North external window	Total external window
Index of design heating load (W/m^2)	Before heat preservation	9.59	1.17	10.21	20.97
	After heat preservation	4.88	0.59	5.20	10.68

Index of heat consumption (W/m^2)	Before heat preservation	2.83	0.53	5.39	8.75
	After heat preservation	1.14	0.21	2.16	3.51
Index of coal consumption (kg/m^2)	Before heat preservation	1.71	0.32	3.25	5.27
	After heat preservation	0.87	0.16	1.65	2.68

Tab.3 Comparison of roof

Title		Roof
Index of design heating load (W/m^2)	Before heat preservation	5.40
	Heat preservation with 30mm plastic extruded polystyrene plate	2.66
	Heat preservation with 60mm plastic extruded polystyrene plate	1.54
Index of heat consumption (W/m^2)	Before heat preservation	3.20
	Heat preservation with 30mm plastic extruded polystyrene plate	1.58
	Heat preservation with 60mm plastic extruded polystyrene plate	0.91
Index of coal consumption (kg/m^2)	Before heat preservation	1.93
	Heat preservation with 30mm plastic extruded polystyrene plate	0.95
	Heat preservation with 60mm plastic extruded polystyrene plate	0.55

Tab.4 Comparison of energy saving

Title	Index of design heating load (W/m^2)	Index of heat consumption(W/m^2)	Index of coal consumption (kg/m^2)
Before heat preservation	63.03	27.01	16.26
Heat preservation of external wall with 40~80mm polystyrene plate	52.42~49.7	20.66~19.04	12.44~11.46
Double-glass plastic steel window	52.74	21.77	13.67
Heat preservation of roof with 30~60mm plastic extruded polystyrene plate	60.29~59.17	25.39~24.72	15.28~14.88
Combination of the above three	39.39~35.55	13.80~11.51	8.87~7.49

4.2.2 Economical Benefit

To do comparison of economical benefit with the way of dynamic pay-back period time, it is[9]:

$$P_t^{'} = \frac{-\lg\left(1-\frac{pi}{A}\right)}{\lg(1+i)} \quad (7)$$

In formula (7), $P_t^{'}$ is dynamic pay-back period time; P is total investment; i is annual interest rate; A is annual net economic benefit.

Comparison of economic benefit is in tab.5 and the price of normative coal is 800 RMB. This paper only does the comparison of economic benefit with heat preservation of external wall with 40mm polystyrene plate, using double-glass plastic steel window, heat preservation of roof with 30mm plastic extruded polystyrene plate and combination of the above three.

4.2.3 Environmental Benefit

Comparison of environmental benefit is in tab.6, and this paper only does the comparison of environmental benefit with heat preservation of external wall with 40mm polystyrene plate, using double-glass plastic steel window, heat preservation of roof with 30mm plastic extruded polystyrene plate and combination of the above three.

5 CONCLUSIONS

Based on the existing residential buildings in cold area, this paper takes the existing residential building in certain district in Beijing to provide an analysis on the energy efficient reconstruction, and does the conclusions is:

Tab.5 Comparison of economical benefit

Title	Saving normative coal(t)	Saving fuel charge during heating period (ten thousand RMB)	Investment (ten thousand RMB)	Pay-back period time(years)
Heat preservation of external wall	24.77	1.98	17.4	12.9
Double-glass plastic steel window	16.76	1.34	18.2	29.0
Heat preservation of roof	6.35	0.51	6.5	24.8
Combination of the above three	47.87	3.83	42.1	18.5

Note: When calculate the economical benefit, the price of contamination is not calculated because there is no price of contamination in China.

Tab.6 Comparison of environmental benefits

Contaminations	CO_2(kg)	SO_2(kg)	Soot(kg)
Emission efficient of contamination per 1GJ heat	0.909	0.095	0.3
Heat preservation of external wall	404.11	42.23	133.37
Double-glass plastic steel window	338.40	35.37	111.68
Heat preservation of roof	103.50	10.82	34.16
Combination of the above three	846.92	88.51	279.51

5.1 The pay-back period time is the best to do heat preservation of external wall, it is 12.9 years, and the effect of energy saving and environmental benefit are the second. The pay-back period time is the worst to use double-glass plastic steel window, it is 29.0 years, and the effect of energy saving and environmental benefit are the third. The pay-back period time is the third to do heat preservation of roof, it is 24.8 years, and the effect of energy saving and environmental benefit is the worst.

5.2 The pay-back period time is the second to do combination of doing heat preservation of external wall, using double-glass plastic steel window and doing heat preservation of roof, it is 18.5 years, and the effect of energy saving and environmental benefit are the best.

5.3 It should choose right reconstruction plan of energy saving according to the idiographic condition to do reconstruction of energy saving in cold area.

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