Analysis of the Double Window in Saving Energy and Economical Efficiency in Nanjing in the Winter

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Abstract: With the rapid progress of the economy, heating in winter is widespread in the eastern area of China. According to the exterior-protected structure of buildings in Nanjing, the hourly and dynamic load of energy consumption during the time of heating in winter is simulated and calculated in the paper. Through calculations, the energy consumption of the different windows, walls and roofs is gained. By analyzing the results of these calculations, the conclusion that using a single frame-double plastic steel window can save energy by 37.68% is reached. As part of the economical efficiency analysis, an investment payback period is analyzed using the methods of static state and dynamic state. The analysis shows that by using single frame-double plastic steel window, the investment payback period is about 7 years.

Key words: save energy; double window; energy consumption; economic efficiency

1. INTRODUCTION

Heating energy consumption of buildings takes up a great proportion of total energy consumption in a lot of countries in winter. So it is significant to reduce energy consumption of buildings. Energy loss of windows, which is mainly the cold-air permeation and heat loss in heat transfer, can reach about the 50% of the total energy loss of exterior-protected structure in buildings. Therefore, it is very important to reduce the energy consumption of windows in the work of energy conservation[1]. The heat-shielding performance of double window is better than single-layer window, and the sealing performance of plastic window is better than steel window. So, double plastic window is widely used in a lot of countries.

With the rapid development of economy, requirement of indoor coziness by people is growing day by day. Heating facilities are used in east part of China. Taking Nanjing for example, the outdoor temperature is often below 5℃ in winter, so heating facilities are used in many public places. Generally speaking, the single-layer steel window is used in traditional building of this region, but the energy consumption is great. In this paper, taking Nanjing for example, the energy saving and economic efficiency of double window is analyzed.

In this paper, on one hand, the percent of energy consumption of single steel window and double window, which takes double plastic window as example, in the total energy consumption of exterior-protected structure including windows, walls and roofs is researched; on the other hand, the economical efficiency of them is analyzed.

2. ANALYSIS OF SAVING ENERGY

2.1 Calculation Model

2.1.1 Calculation of hourly heat gain of glass window

The energy through the window includes: hourly heat transfer of glass window by temperature difference, hourly heat gain of glass window by radiation and hourly heat transfer by infiltration.

2.1.1.1 Hourly heat transfer of glass window by temperature difference

Because the thermal inertia of glass is great, the heat transfer of glass window is calculated as steady-state heat transfer. The heat transfer of glass window at the time of n is:

$$H_1(n)=(t_a-t_r)\times K_0\times F \quad (1)$$

Where: H_1(n)----- the heat transfer of glass window, w; F-----area of window, m^2; t_a----- hourly outdoor temperature, □, which is gained from weather data; t_r----indoor temperature, t_r=18□; according to t_a, the heating period is confirmed from 345th to 365th days and from 1st to 105th days of a year; K_0----coefficient of heat transfer of window, w/(m^2·□), it can be calculated in the following formula:

$$K_0=1/(1/a_1+Rg+1/a_2) \quad (2)$$

Where: Rg----heat resistance of double window,(m^2·□)/ w, it can be calculated with compound heat transfer theory; a_1-----total coefficient of heat transfer of outside surface, w/(m^2·□), which is varied with time[2]; a_2-----total coefficient of heat transfer of inside surface, w/(m^2·□).

2.1.1.2 Hourly heat gain by radiation of glass

To simplify the calculation, the temperature of all radiation surfaces including the sky is supposed to be equal with outdoor temperature, namely, the heat radiation only comes from vertical and scattered solar rays. The heat gain from solar radiation through glass window is related with the orientation of glass window and varies with season and the time of day. The heat gain from solar radiation of glass window at the time of n can be calculated as follows:

$$H_2(n)=(SSG_D\times X_s+SSG_d)\times S_c\times X_f\times F \quad (3)$$

Where: $H_2(n)$----heat gain of glass window by radiation, w; SSG_D----heat gain from vertical solar rays, w/m^2; $SSGd$----heat gain from scattered solar rays, w/m^2; S_c----shading coefficient of non-shading transparent single-layer or double-layer glass window; F----area of window, m^2; X_f---- coefficient of efficient area of glass window; X_s---- area ratio of actual irradiation of sunshine.

2.1.1.3 Hourly heat transfer of infiltration

The energy consumption of wind infiltration is not only related with the structure of window and sealing performance of window frame, but also related with the flux of air infiltration and the indoor and outdoor temperature. In this paper, according to the gradation of sealing performance of window, the flux of air infiltration L of different types of windows through one-meter gap in per hour is gained. The quantity of sensible heat consumed by air infiltration at the time of n is:

$$H_3(n)=0.28\times C_p\times L\times l\times(t_a-t_r)\times\rho_w \quad (4)$$

Where: $H_3(n)$----heat transfer of wind infiltration, w; C_p----specific heat at constant pressure of air, 1.05kJ/(kg.□); L----flux of air through one meter window gap, m^3/(m·h); l---- length of window gap, m; t_r----indoor designing temperature, □; t_a----outdoor temperature, □; ρ_w----outdoor air density, kg/ m^3.

2.1.2 Calculation of unsteady heat transfer of walls and roofs

Reaction Coefficient method is used to calculate the heat transfer of walls and roofs in the paper. The discrete-time interval $\Delta\tau$ is one hour. Isosceles triangular wave is used to discrete disturbance quantity. Heat gain through the siding exterior-protected structure (walls and roofs) at the time of n is[3]:

$$HG(n)=\left[\sum_{j=0}^{n}\mathrm{Y(j)t_z(n-j)-K\times t_r}\right]\times F \quad (5)$$

Where: $Y(j)$---- heat transfer reaction coefficient of isosceles triangle disturbance quantity in walls and roofs, w/(m^2·□); t_z----outdoor air composite temperature, t_z synthetically express the heat action on outside surface of exterior-protected structure by outdoor air temperature, solar radiation, ground reflection, long-wave radiation, atmospheric long-wave radiation and night radiation), □; K---heat transfer coefficient, w/(m^2·□); F----area of walls or roofs, m^2.

2.2 Calculation Example and Results Analysis

2.2.1 Physical model of calculation example

In Nanjing, an air-conditioning heating building in winter, the area is 10,000 m^2, the layer height is 3m, 20 floors altogether. The height×the length×the width is 60m×50m×10m. The length orientation is south-north, and the width orientation is east-west. The area ratio of window and wall is 0.3. Each window has 3 parts, and the area is 1.5m×1.5m, evenly distributed.

The structure of wall surface: it is comprised of three layers: sanded cement layer (20mm), brick (240mm) and sanded lime layer (20mm).

The roof structure: it is comprised of seven layers: mineral granule layer (5mm), three layers of felt with four layers of asphalt (5mm), leveling blanket (20mm), air-entrained insulating layer (100mm), vapor barrier, cement layer (120mm) and sanded lime layer (20mm).

Standard glass with the thickness of 3mm is used. The materials of windows are wood, steel, aluminum and plastic, and are fixed in the center of walls.

2.2.2 Results analysis

1. The net energy consumption of heat transfer of windows in winter is:

$$q_H = q_{HT} - q_t \tag{6}$$

Where: q_{HT} is the energy consumption of heat transfer by temperature difference of windows which is:

$$q_{HT} = Q_{HT} / (A \times D \times 24 \times 3600) \tag{7}$$

Where: Q_{HT}----the accumulating totals of $H_1(n)$ which is the hourly heat quantity from the heat transfer by temperature difference of windows, w; A----the total area of building surface, m^2; D----the days of heating.

In addition, q_t is the heat gain of radiation of windows in winter, and it can be gained as follows:

$$q_t = Q_t / (A \times D \times 24 \times 3600) \tag{8}$$

Where: Q_t----the accumulating totals of $H_2(n)$ which is the hourly heat gain from solar radiation of windows, w; The meaning of A and D is the same as above.

2. The energy consumption of air infiltration q_{INF} of windows can be gained as follows:

$$q_{INF} = Q_{INF} / (A \times D \times 24 \times 3600) \tag{9}$$

Where: Q_{INF}--------the accumulating totals of $H_3(n)$ which is the hourly heat quantity from air infiltration of windows in the entire period of heating, w; The meaning of A and D is the same as above. According to the air tight grading principle of windows, $L \leqslant 5.0$ of general single-layer steel window, it belongs to grade V; the grade of double-layer window can reach to □ ~ □. In the paper, it is assumed that L=4.5m^3/(m·h) of single-layer steel window, L= 1.5m^3/(m·h) of double-layer plastic window.

3. The energy consumption q of walls and roofs is gained by similar formulas:

$$q = Q / (A \times D \times 24 \times 3600) \tag{10}$$

Where: Q----accumulating totals of $HG(n)$; The meaning of A and D is the same as above.

The calculation results are showed as follows:

In the second row of tab.1, the data out of the brackets take the energy loss of night radiation in winter into account, while the data in the brackets don't take the energy loss of night radiation in winter into account. The difference between the two groups of data is that night radiation makes the energy loss in winter increase 50%**.**

The difference between the two groups of data in Tab.2 is the same as that in Tab.1.

2.2.3 Energy saving percent of windows η:

$$\eta = (E_0 - E) / E_0 \times 100\% \tag{11}$$

Where: E_0----total energy consumption of the exterior-protected structure with single-frame and single-layer glass windows; E----total energy consumption of the exterior-protected structure with double plastic windows. Then, the energy saving percent η of double-layer plastic windows against single-frame and single-layer glass windows is 37.68%.

From the analysis above, it can be concluded that double-layer plastic window is better than single-frame and single-layer glass window in energy saving.

3. ECONOMIC ANALYSIS OF ENERGY SAVING

In the economic evaluation of this paper, the energy consumption of windows mainly concludes the energy loss of heat transfer and wind infiltration. Therefore, the calculation results above can be used

Tab. 1 Energy consumption and percent of energy consumption in each parts of exterior-protected structure (single-frame and single-layer glass window)

Exterior-protected Structure		Energy Loss in Winter (w/m^2)	Percent of Energy Consumption (%)
	Wall	20.26(16.85)	36.62
	Roof	1.391(1.065)	2.51
Single-frame and single -layer steel window	Net energy consumption of heat transfer	9.98(6.62)	18.04
	Energy consumption of air infiltration	23.7	42.83
Total energy consumption		55.33	100

Tab. 2 Energy consumption and percent of energy consumption in each parts of exterior-protected structure (double plastic window)

Exterior-protected Structure		Energy Loss in Winter (w/m^2)	Percent of Energy Consumption (%)
	Wall	20.26(16.85)	58.76
	Roof	1.391(1.065)	4.03
Double plastic window	Net energy consumption of heat transfer	4.93(3.21)	14.3
	Energy consumption of air infiltration	7.90	22.91
Total energy consumption		34.48	100

in analysis.

3.1 Evaluation Gist

□. Relevant standards and regulations;

□. Present electrovalence in Nanjing.

3.2 Energy-Saving Proceeds (*B*)

Energy-saving proceeds are the saved electrical cost of every heating period after the energy-saving measures of windows have been taken. The formula is:

$$B = \Delta q \times D \times c / (\xi \times 1000) \text{(yuan/(m}^2\text{·a))} \quad (12)$$

Where: Δq is the energy consumption difference of one square meter of windows before and after the saving energy measures have been taken, w/m^2; *D*----the days of heating, d, *D*=126 in Nanjing; *c*----present electrical cost in Nanjing; because the policy of time-sharing electrovalence has been used in Nanjing now, *c*=(13 × 0.55+11 × 0.35) hour·yuan/degree·day; *ξ*---- coefficient of heating investment, *ξ*=2; *a*---- the year.

3.3 Energy-Saving Investment (I):

Energy-saving investment is the increased cost after the energy-saving measures have been taken. Here, it is the price difference between single-layer steel windows and double-layer plastic windows.

$$I = \Delta W \text{ (yuan/m}^2\text{)} \quad (13)$$

Where: □*W*---the cost difference before and after the energy-saving measures have been taken, yuan/m^2.

3.4 Reclamation Period of Energy-saving Investment (n、n'):

The meaning of reclamation period is that the excessive expense can be compensated from the heating expense that needn't to pay in this period after the energy-saving measures have been taken.

Reclamation period of static method:

$$n = I / B \quad (14)$$

Reclamation period of dynamic method:

$$n' = \lg[B / (B - I \times i)] / \lg(1 + i) \quad (15)$$

Where: *i*---the annual interest rate of energy-saving loan, i=2.4%.

3.5 Sample and Calculation of Relevant Parameters

From the analysis above:

$$\Delta q = 9.98 + 23.7 - 4.93 - 7.90 = 20.85 \text{(w/m}^2\text{)}$$

Where A----the total area of building; the area of windows is 0.3 times of building's area.

So:

$$B = 14.45 \text{(yuan/(m}^2 \cdot \text{a))}$$

Energy-saving investment:

$$I = 100 \text{(yuan/m}^2\text{)}$$

Then:

$$n = 6.92\text{a};\ n' = 7.66\text{a}.$$

Therefore, the investment reclamation period is quite short when the energy-saving window has been used.

4. CONCLUSION

(1) According to Tab.1 and Tab.2, when the windows are all double plastic windows, the net energy consumption of heat transfer of windows takes 18.04% of the total energy consumption of building. The energy loss of air infiltration takes 22.91% of the total energy consumption of building. The total energy consumption of windows is 37.21%. Compared with the single-layer steel window, in total energy consumption of building, the energy consumption of windows decreases greatly.

(2) From the energy-saving analysis, after the energy-saving window has been used, the total energy consumption has decreased by 37.68%, compared with single-layer steel window.

(3) Through the economic analysis, the investment reclamation period of double plastic window is quite short, about seven years.

(4) Double plastic window for saving energy not only saves energy but also has good economical efficiency. Therefore, this kind of window should be completely extended in Nanjing.

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