Study on the Optimal Window and Wall Ratio of Village and Town Housing Based on Energy Consumption

Jian Liu1, Xiang Liu2,*, Xuhong Fan2, Zhaochang Zhang3 and Pengfei Mao4

1Zhumadian Highway Administration, No.10 Guangming Road, Henan 463000, China
2School of Material Science and Engineering, Jiangsu University, No.301 Xuefu Road, Zhenjiang 212013, China
3School of Civil Engineering, Southeast University, No.2 Southeast University Road, Jiangning District, NanJing 211189, China
4Zhenjiang Bureau of housing and urban rural development, No.33 Zhengdong road, Zhenjiang 212001, China

*E-mail address: 1398771804@qq.com

Abstract. Compared with the cities, the villages and towns have greater space, more flexible layout, more abundant resources. We should make full use of the villages and towns' environment and resources to create a comfortable indoor and outdoor environment for villages and towns. In the face of the hot and wet environment of village and town house and the poor outdoor wind environment, this paper focuses on improving the performance of village houses in the aspects of the window-wall ratio. Through theoretical derivation and numerical simulation of different window-wall ratios, we derive formulas for the ratio of energy dissipation to window-wall ratios of buildings, and finally get the optimal window-wall ratio of the house.

1. Introduction

1.1. The importance of improving the comfort performance of houses in villages and towns

1.1.1. One of the important measures to improve the comfort performance of rural houses is to improve the energy-saving property of houses. Housing energy-saving is the response of national society to energy-saving and emission reduction. The task of building energy saving in our country is to make a scientific and feasible energy saving index system on the premise of guaranteeing the use function, building quality and indoor environment to meet the well-off goal. We need take various effective energy saving technology and management measures to reduce the energy consumption of the new building area, and have a planned energy saving for the existing houses in the same time. The purpose is to improve living comfort, save energy and improve environment.

At present, the existing housing in China is nearly 40 billion square meters, of which more than 95% are high energy consumption houses. Energy consumption in building is about 15 times that of building energy consumption, so reducing energy consumption is the key to energy saving.

1.1.2. Energy saving in villages and towns is one of the important measures to reduce energy consumption and improve indoor thermal and humid environment quality. At present, the energy saving level of villages and towns in China is generally low. Through the investigation of the typical
enclosure structure of the demonstration village, as shown in Figure 1. For traditional rural buildings, there are the following defects: 1) poor indoor thermal environment, low air quality; 2) if modern heating and air conditioning equipment, energy consumption is higher. For modern rural architecture, it is basically in the imitation of simple construction of urban buildings. There are the following defects: (1) the construction of a simple structure causes poor thermal performance and has lost the characteristics adapted to the climate of the region; (2) the quality of the indoor thermal environment in the building is very poor in the cold winter and hot summer; (3) With the improvement of economic level, energy consumption of heating and air conditioning will be greatly increased.

![Figure 1. Typical envelope structures of demonstration village](image)

a. Non thermal insulation wall, Large window wall ratio, Non sunshade window
b. condensated single glassy window in winter

2. Estimation and analysis of optimal window wall ratio in village and town house based on energy consumption

In this section, for the rural housing window wall ratio generally larger problems, considering the influence of heating, air conditioning and lighting energy consumption of buildings, we theoretically deduce the energy consumption of indoor artificial lighting throughout the year based on the hourly statistics of outdoor radiation intensity, and combined with heating and air conditioning energy consumption calculation method, propose a formula for estimating annual energy consumption of buildings with variable window to wall ratio. The formula of annual energy consumption estimation is given, which provides quantitative suggestions for determining the optimal window-wall ratio of rural houses. the correctness of the theory is proved by simulation with eQuest software.

The ratio of window to wall is one of the main factors affecting the heat gain and dissipation of indoor solar radiation, and influences indoor natural lighting time at the same time. At present, the research on the influence of window and wall to building energy consumption mainly focuses on heating energy consumption and air conditioning energy consumption, but less research on lighting energy consumption, and the research method mainly adopts software simulation. The research object is office building, such as paper [1-5], but the research on residential building, special in hot summer and cold winter areas of village and town residential research is very little. Zhang Jian’s research on the optimal window wall area ratio of office buildings mainly based on the user's subjective evaluation [1]; Francesco Goia is mainly the software simulation analysis [2] for the optimal window wall ratio of different public buildings in Europe; Rizki A. Mangkuto and other Researchers are analysis the influence factors of the indoor ambient environment under the tropical environment [3].

2.1. Theoretical calculation

2.1.1. Total energy consumption $E_{TOT}(R)$: This paper takes into account the influence of housing window to wall ratio on energy consumption of heating, air conditioning and lighting. The annual total energy consumption $E_{TOT}$ of a house is the sum of heating $E_H$, air conditioning $E_C$ and artificial lighting $E_L$, which is expressed as follows:

$$E_{TOT}(R) = E_H(R) + E_C(R) + E_L(R)$$

(1)
2.1.2. Optimal window wall ratio $R_{opt}$: The ratio of window to wall (WWR for short) refers to the ratio of the area of the window to the elevation of the room. The optimal window wall ratio defined in this paper is to indicate the minimum energy consumption per year for heating, refrigeration and lighting, that is, the total energy consumption $E_{TOT}$ is minimum throughout the year, and the corresponding optimal window wall ratio is expressed as $R_{opt}$:

$$\frac{dE_{TOT}(R_{opt})}{dR} = 0$$  \hspace{1cm} (2)

2.1.3. Heating energy consumption $E_H(R)$: The energy consumption of envelope heating is calculated according to the formula (5.2.4) in the Code for Design of Heating, Ventilation and Air Conditioning of Civil Buildings (GB50736-2012):

$$E_H(R) = \alpha AK(t_n - t_{wn}) \cdot T_H$$  \hspace{1cm} (3)

In the form: $E_H(R)$ is the basic heat consumption (W) for the enclosure structure; $\alpha$ is the temperature difference correction coefficient, according to the standard value; $A$ is the area of the enclosure structure (m$^2$); $K$ is the heat transfer coefficient [W/(m$^2$·K)] for the enclosure structure; $t_n$ is the heating room design temperature (°C), according to the standard value; $t_{wn}$ is heating outdoor design temperature (°C), according to standard value; $T_H$ is the number of warm energy consumption (H).

2.1.4. Air conditioning energy consumption $E_C(R)$: The air conditioning energy consumption $E_C(R)$ of the enclosure is the sum of heat transfer energy consumption $Q_C(R)$ and radiative energy consumption $Q_F(R)$.

$$E_C(R) = Q_C(R) + Q_F(R)$$  \hspace{1cm} (4)

The above formula is founded, according to the formula (7.2.7.1-8) [6] in the code for design of heating, ventilation and air conditioning for civil buildings (GB50736-2012).

2.1.5. Indoor artificial lighting energy consumption $E_L(R)$: In one year, the outdoor illumination changes every moment. When the indoor illumination is less than the specified value, it is necessary to open artificial lighting to compensate, and the specific time and amount of compensation are calculated as follows. We neglect the influence of the number of lamps and lanterns on the indoor cooling load.

$$E_L(R) = T_{L1} \frac{i_{ms,1} + T_{L2} i_{ms,2}}{2} = A_d \frac{D_{LP}}{k_2} \left(5840 - \frac{T_{out1} + T_{out2}}{2}\right)$$  \hspace{1cm} (5)

In the formula, $A_d$ is the building area of the room; $\frac{D_{LP}}{k_2}$ is the corresponding lighting power density; $T_{out1}$, $T_{out2}$ is the cumulative use time of the illuminance for the whole year.

2.2. Comparison and analysis of example calculation and simulation

In this paper, a model of a house is analyzed. The house has one-sided south-facing window, located in Nanjing, belonging to the hot summer and cold winter area. We use a room as an experiment object (opening $W=3.3m$, depth $D=5.4m$, height $H=3.6m$). The total indoor surface area is $A_1=2(WD+WH+DH)=98.28m^2$ and window wall ratio $R=A_{WC}/HW=A_{WC}/11.88$. The external wall heat transfer coefficient $K_{wa}$ is 2.0 W/(m$^2$·K), the heat transfer coefficient of the roof $K_{wc}$ is 0.5W/(m$^2$·K), the heat transfer coefficient of the single layer glass window $K_{wm}$ is 4.8 W/(m$^2$·K) of the single layer glass window, the heat transfer coefficient of the double glazing outer window $K_{wm}$ is 2.8 W/(m$^2$·K).

2.2.1. Energy consumption calculation for heating $E_H(R)$: We bring $\alpha = 1$, $t_n = 18°C$, $T_H = 90d \times 10h / d = 900h$ in the formula (3):

$$E_H(R) = 574.8R_{wn} + 2318.8(kWh \cdot a)$$  \hspace{1cm} (6)
2.2.2. Air conditioning energy consumption calculation \( E_C(R) \): (1) Calculation of heat transfer energy consumption for enclosure structure \( Q_C(R) \):

According to appendix H of GB50736-2012, it is known the data in summer south to one day \(( t_{wq} = 810.6^\circ C, t_{wc} = 740.9^\circ C, t_{wm} = 1030.2^\circ C, t_n = 28^\circ C, T_c = 105 \times 16 = 1680h \) ). We put the data into the following formula:

\[
\begin{align*}
Q_C(R) &= A_w C_{Lwq} + A_{wm} C_{Lwm} + A_{wc} C_{Lwc} \times T_c / 24 \\
C_{Lwq} &= K_{wq} A_w (t_{wq} - t_n) \\
C_{Lwm} &= K_{wm} A_{wm} (t_{wm} - t_n) \\
C_{Lwc} &= K_{wc} A_{wc} (t_{wc} - t_n)
\end{align*}
\]

(7)  
(8)  
(9)  
(10)

\( Q_C(R) = 76.44R + 1438.85(kWh \cdot a) \)  
(11)

(2) Calculation of thermal radiation energy consumption of outer window \( Q_f(R) \):

According to appendix H of GB50736-2012, we can know that \( C_w = 1.0, C_n = 0.6, C_s = 1.0, C_{cIC} = 7.05, D_{jmax} = 216 \). We put the data into the following formula:

\[
\begin{align*}
Q_f(R) &= A_{wc} C_{Lc} T_c \\
C_{Lc} &= C_{cIC} C_s D_{jmax} A_C \\
C_{c} &= C_w C_n C_s \\
C_c &= 0.6
\end{align*}
\]

(12)  
(13)  
(14)  
(15)

\( Q_f(R) = 7.05 \times 0.6 \times 216 \times 11.88 / 1000 \times 1680 / 24 = 759.82(kWh \cdot a) \)  
(16)

(3) Calculation of air conditioning energy consumption of enclosure structure \( E_C(R) \):

We put the above data into the formula(4):

\( E_C(R) = 836.26R + 1438.9(kWh \cdot a) \)  
(17)

2.2.3. Energy consumption calculation of indoor artificial lighting \( E_L(R) \): We take the room’s illumination requirement for 300lx, this case takes a brand LED energy saving lamp, the illuminance is 300lx corresponding to the lighting power density of 15w/m\(^2\), substituting the formula (5) to obtain the annual artificial lighting energy consumption:

\[
E_L(R) = \frac{0.5 \times 15 \times T_{d1} + 15 \times T_{d2} \times 17.82}{1000} = \frac{0.001}{R^3} - \frac{0.137}{R^2} + \frac{50.241}{R} + 465.0
\]

(18)

2.2.4. Total energy consumption for the whole year: The total annual energy consumption of the above calculation:

\[
E_{TOT}(R) = -\frac{0.001}{R^3} - \frac{0.137}{R^2} + \frac{50.241}{R} + 1879.9R + 4222.7
\]

(19)

The optimal window wall ratio is zero which is Proved by the formula (2):

\[
R_{opt} = 0.18
\]

(20)

The relationship between the above energy consumption\( E_{TOT}(R), E_{th}(R), E_C(R), E_L(R) \) and window wall ratio R is drawn as shown in Figure 2.
2.3. Simulation contrast analysis

In this paper, the energy consumption simulation software of eQUEST3-65 is used to simulate the change of energy consumption with window wall ratio. The size of the simulated window and the window wall is shown in Table 1. There are 9 groups. The simulation model is shown in Figure 3, and the simulation results are shown in Figure 4.

Figure 2. Relationship between E (energy consumption) and R (Window and wall ratio)

Figure 3. 3D model of energy saving calculation

Figure 4. Simulation results of energy consumption
Table 1. Comparison between theoretical calculation and energy consumption simulation

| window area $A_{wc}$ (m²) | 1.20 | 1.80 | 2.40 | 3.60 | 4.80 | 6.00 | 7.20 | 8.40 | 9.60 |
|-----------------------------|------|------|------|------|------|------|------|------|------|
| R (Window and wall ratio)   | 0.10 | 0.15 | 0.20 | 0.30 | 0.40 | 0.51 | 0.61 | 0.71 | 0.81 |
| Total energy consumption (kWh·a) | 5115 | 4997 | 4994 | 5188 | 5428 | 5430 | 5753 | 5973 | 6308 |
| Theoretical calculation of total energy consumption (kWh·a) | 4896 | 4833 | 4848 | 4957 | 5106 | 5271 | 5445 | 5623 | 5804 |
| relative error(%) | 4.47 | 3.40 | 3.02 | 4.67 | 6.30 | 3.01 | 5.66 | 6.23 | 8.69 |

According to Figure 2 and Figure 4, the comparison results in Table 1 show that the relative error between the theoretical calculation and the energy consumption simulation is less than 10%, indicating the correctness of the theoretical calculation.

3. Conclusion

Based on the analysis of the optimal window wall ratio of the village and town house and consided of the influence of housing window and wall ratio on the heating, air conditioning and lighting energy consumption, We deduce the energy consumption of light-controlled illumination hourly throughout the year. Combining with the existing energy consumption calculation methods of heating and air-conditioning, we give the calculation formula of the total energy consumption of the whole year. The optimal ratio of window and wall to the lowest total energy consumption is obtained .Based on the analysis of a house in Nanjing, the relationship between the annual total energy consumption and the ratio of window to wall for the single-side window and single-layer glass is given. That is

$$E_{tot}(R) = \frac{0.001}{R^3} - \frac{0.137}{R^2} + \frac{50.241}{R} + 1879.9R + 4222.7$$

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