ENERGY CONSERVATION OF WINDOW SYSTEMS IN RESIDENTIAL BUILDINGS OF HOT SUMMER AND COLD WINTER ZONE IN CHINA

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ABSTRACT

Heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration, it is up to 40 % in hot summer and cold winter zone of china, so it is important to carry out the sustainable window systems design with low energy consumption. The effects of window systems including area ratio of window to wall and categories of glazing on energy consumption of air conditioner (AC) are simulated by using eQUEST software. Results show that west and east windows have more obvious effect on decreasing the AC annual electric consumption, low-e glazing (both single glazing and double glazing) has obvious effect on the energy conservation of heating electric consumption and reflective glazing shows the better effect on the reduction of cooling electric consumption. The limit values of glazing heat-transfer coefficient with different glazing shading coefficients and area ratios of window to wall in hot summer and cold winter zone in china are suggested. All the results can be the reference of revising *Residential Building Energy Conservation Design Standard of Hot Summer and Cold Winter Zone in China (JGJ 134-2001)* and window designing for residential buildings.

KEYWORDS

Energy Conservation, Window systems, area ratio of window to wall, heat-transfer coefficient, shading coefficient

INTRODUCTION

At present, the scale of residential building construction is unprecedented in the histories of china and world. The building area has reached 16.5 billion in town by the end of 2005 and the total residential area of structure has reached 10.8 billion square meters, which accounting for 65.46% (Anonymity). According to the statistic, although the different influence of climate, economic, and the life style, the energy consumption for cooling and heating accounts for 50%-60% of the country's total building energy consumption (Luo et al. 2005), energy efficiency for residential buildings has therefore becomes a hot issue of growing concern. Hot summer and cold winter zone of China is also facing the residential energy consumption problems, where the mean temperature of the hottest month is between 25-30℃ and that of the coldest month is between 2-7℃, the whole year relative humidity in most of the cities of this zone are 75%-80% (Han 2002). Date shows that heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration, it is up to 40 % (Yang and Yu 2002) in hot summer and cold winter zone, so it is important to carry out the sustainable window systems design with low energy consumption. Only a few researches have been conducted to study the effects of residential building window systems on AC electric consumption, and *Residential Building Energy Conservation Design Standard of Hot Summer and Cold Winter Zone in China (JGJ 134-2001)* has only prescribed the heat-transfer coefficient of the glazing, the shading coefficient is not considered. So this paper used the eQUEST software to simulate the influence of window systems including area ratio of window to wall and categories of glazing on energy consumption of AC, the limit values of glazing

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heat-transfer coefficient with different glazing shading coefficients and area ratios of window to wall in hot summer and cold winter zone in china are also studied. Results can be the reference of revising the standard (JGJ 134-2001) and designing residential buildings.

SIMULATION SOFTWARE EQUEST

The simulation software eQUEST is the upgrade program of DOE-2 which is the most widely recognized and respected building energy consumption analysis program in use today. It is suitable to analyze envelop dynamic thermal properties and annual energy consumption of different residential buildings. Fu had calculated the annual cooling and heating electric consumption of one building in Chongqing, a city in hot summer and cold winter zone of china, using DOE-2 and harmonic reaction analysis, respectively. Results are the same in the annual electric consumption of AC by the two methods. The standard of residential building energy saving design in hot summer and cold winter zone had used DOE-2 (Fu and Han 2002).

The simulation engine within eQUEST is derived from the latest official version of DOE-2, but extends and expands DOE-2's capabilities in several important ways. eQUEST calculates hour-by-hour building energy consumption over an entire year using hourly weather data for the location under consideration and provides very accurate simulation of such building feature as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air conditioning systems types and controls. Lawrence Berkeley National Laboratory supplied the TMY2 weather data of Hefei, Nanjing, Shanghai, Hangzhou, Wuhan, Changsha, Nanchang, Chengdu and Chongqing etc of hot summer and cold winter zone.

THE BASECASE MODEL

A residential building of six floors in Changsha is selected as the BASECASE 1 model. The building area is 2616m^2, form coefficient is 0.29, and the height of per floor is 3m, building plane is shown in Fig.1. The whole building except bath rooms and corridors are conditioned. The calculation parameters according to the standard (JGJ 134-2001) are as follows:

1. Exterior wall: 240mm normal brick wall, the U-value is 2.32 W/ (m^2·K)
2. Building roof: 10mm built up roof, 160mm reinforced concrete and 16mm gypsum plaster (from outside to inside), the U-value is 2.74 W/(m^2·K), with an overhead ventilated roof
3. Solar absorptance of exterior wall and roof: 0.6
4. Exterior windows: 3mm clear glazing with aluminum frame, the U-value is 5.85 W/ (m^2·K).
5. The area ratio of window to wall: 50% for the south, west, north and east windows.
6. HVAC systems: room air conditioner with EER of 2.2 for cooling, electric radiator with the EER of 1.0 for heating
7. Air changes per hour: 1.5
8. Indoor temperature set point: 26 ℃ in summer and 18℃ in winter.
9. Air conditioning time: June 1st to September 30th for cooling and December 1st to March 31st for heating;
10. Interior loads: 0.5382W/m^2 for lighting systems, 4.3w/m^2 for others

CONTENTS OF SIMULATION

According to the stand (JGJ 134-2001), the AC energy conservation should achieve 50% in residential building of hot summer and cold winter zone in china by introducing envelope thermal insulation and increasing the EER and COP of the AC based on the same indoor thermal environment. The original building is BASECASE 1, some energy conservation technologies are applied on the BASECASE 1 model as the following, we call it BASECASE 2.

1. 240mm brick wall introduces 23mm extrusion polystyrene insulation, the U-value is 0.92 W/m2·K.
2. Building roof introduces 25mm extrusion polystyrene insulation, the U-value is 0.92 W/m2·K.

3. HVAC systems: Split systems single zone heat pumps with EER of 2.3 for cooling and COP of 1.9 for heating

4. Air changes per hour: 1.0

Reduce the area ratio of window to wall (from 50% to 25%) for the south, west, north and east windows based on BASECASE 2 and study the effects of area ratios of window to wall of different direction on AC cooling, heating and annual electric consumption; change 3mm clear glazing to other kinds of single and double glazing systems based on BASECASE 2 to learn the effect of heat-transfer coefficient and shading coefficient of glazing on the AC cooling, heating and annual electric consumption; at last, aimed at the energy saving of 50% compared with BASECASE 1 which the standard (JGJ 134-2001) has indicated, the limit values of glazing heat-transfer coefficient with different glazing shading coefficients and area ratios of window to wall in hot summer and cold winter zone in china based on BASECASE 2 are suggested.

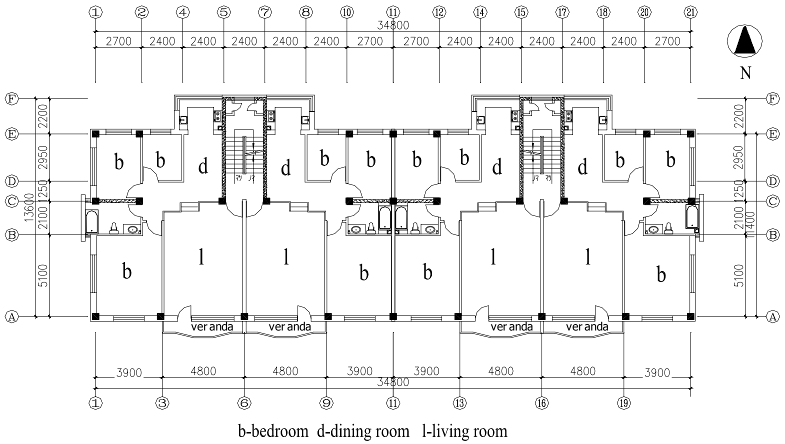

Figure1. Building plane

RESULTS AND DISCUSSIONS

The cooling, heating and annual electric consumption of BASECASE 1 are 523.8MWh, 513.8MWh, and 1037.6MWh, respectively, and those of BASECASE 2 are 408.6MWh, 240.6MWh and 649.2MWh, respectively.

Area ratio of window to wall

Nowadays, building area ratio of window to wall (included window area) becomes larger and larger. Reduce one direction area ratio of window to wall from 50% to 25% under the other three direction of 50% area ratio of window to wall. The curves of AC cooling, heating and annual (both cooling and heating) electric consumption of the whole building with area ratio of window to wall are shown in fig.2-fig.4.

With the decrease of south, north, east and west area ratios of window to wall, the cooling electric consumption is decreased linearly, and the maximum decrease of cooling electric consumption is achieved by reducing the south area ratio of window to wall, the following is reached by reducing north area ratio of window to wall, and the least decrease are produced by reducing west and east area ratios of window to wall (Figure.2).

The heating electric consumption is decreased linearly when the north, east and west area ratios of window to wall decrease. While the effect of south area ratio of window to wall is not the same as others, the heating electric consumption is first decreased and then increased (Figure.3), the lowest heating electric consumption appeared at 35% of area ratio of window to wall, which is decreased by 1.4% compared with BASECASE 2. That's because the reverse effect of heat-transfer from indoor to outdoor and solar radiation heat gain, when reduce the south area ratio from 50% to 35% (or more than 35%), the reduction of heat-transfer from indoor to outdoor is more dominant than the reduction of solar radiation heat gain, so the heating electric consumption is decreased; when the south area ratio is higher than 35%, the case are on the contray.

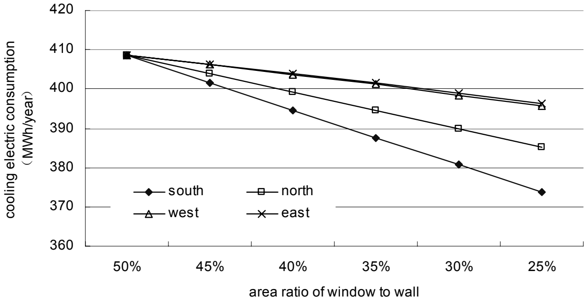

Figure2. The effect of area ratio of window to wall on cooling electric consumption

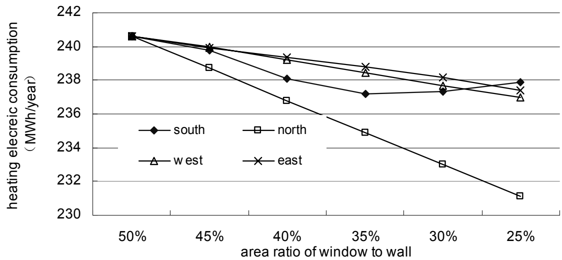

Figure 3. The effect of area ratio of window to wall on heating electric consumption

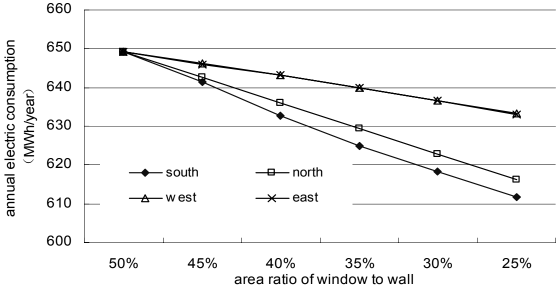

Figure 4. The effect of area ratio of window to wall on annual electric consumption

The annual electric consumption is decreased linearly when the south, north, east and west area ratios of window to wall increase, the decrease of cooling electric consumption by reducing the south area ratio of window to wall is the most (Figure.4). The AC annual electric consumption is decreased by 5.8%, 5.1%, 2.5% and 2.5% respectively by reducing south, north, east and west area ratios of window to wall to be 25%, which include the savings of 8.5%, 5.7%, 3.2% and 3.0% in cooling electric consumption and savings of 1.1% ,4.0%,1.5% and 1.3 in heating electric consumption, respectively. The results are not to say that the south area ratio of window to wall has the greatest effect on the decrease of the AC electric consumption and the east and west area ratio of window to wall influence the AC electric consumption slightly, that's just because the window areas of different directions are different although the area ratio of window to wall is the same. So we introduce the reduction of AC electric consumption when decreasing glazing of unit area for south, north, east and west window to evaluate the essential effect of different direction windows on the AC electric consumption, It means that the reduction of AC electric consumption achieves by decreasing glazing of unit area when the area ratio of window to wall of one direction reduces to a certain degree (such as 40%, 30% and so on) from 50%.

Figure 5 shows the reduction of electric consumption when decreasing unit area glazing of different directions. When decreasing west and east glazing of unit area, the annual electric consumption is decreased by 319.3KWh and 313.7KWh, when decreasing north and south glazing of unit area, the annual electric consumption is only decreased by 262.6KWh and 219.7KWh, so the west and east windows have the more obvious effects on the AC annual electric consumption. For cooling electric consumption, the tendency chart is basically the same as the annual electric consumption: decreasing the west and east glazing of unit area can reduce the cooling electric consumption evidently, and the north glazing has the slightest effect on the reduction of cooling electric consumption. Decreasing the south glazing of unit area, the heating electric consumption is decreased by 30.8KWh, while the reduction is more significant when decreasing the other direction glazing of unit area.

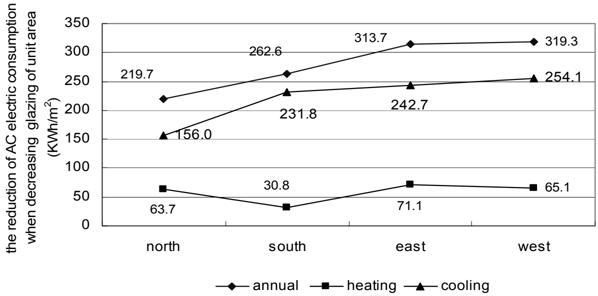

Figure 5. the decrease of electric consumption of per area glazing with area ratio of window to wall

Categories of glazing

The glazing areas accounts for 70-80% of the entire window, glazing property such as heat conduction coefficient and shading coefficient (or solar heat gain coefficient) seriously influence the building energy consumption. The electric consumption of AC in double and single glass window rooms is shown in fig.6, The window is 3mm clear glazing with aluminum in the BASECASE 2, the thicknesses of double glazing and single glazing are 6mm-12mm-6mm and 6mm and the U-values are 2.27W/(m^2·K) and 5.85 W/(m^2·K), respectively. The double low-e electro reflective has the best efficiency in energy conservation of AC, the annual electric consumption of AC is decreased by 28.1%, cooling electric consumption of AC is decreased by 38.3%, and heating electric consumption is decreased by 10.8%. The double glazing windows, as a whole, can decrease the heat-transfer and consume less energy than single ones under the same shading coefficient. The low-e glazing (both single and double) has obvious effect on the energy saving of heating electric consumption and reflective glazing (both single and double) shows the better effect on the reduction of cooling electric consumption.

Fig.7 shows the liner correlation of annual electric consumption with shading coefficient, the annual electric consumption of the double glazing is increased more rapidly than that of the single glazing and the difference of annual electric consumption between single and double glazing becomes weaker with the increase of shading coefficient.

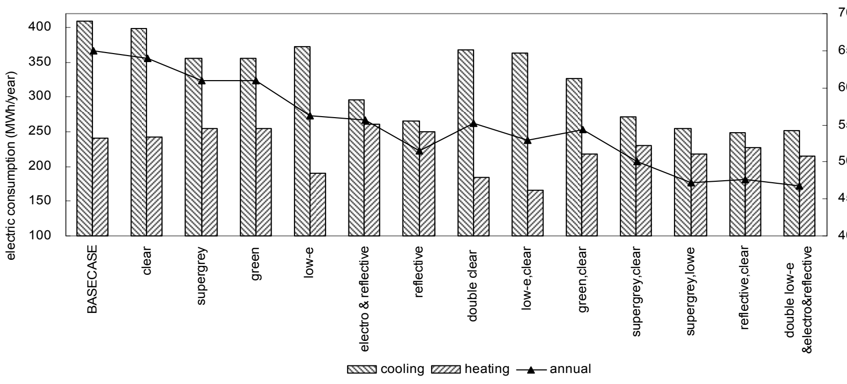

Figure 6. AC electric consumption of different categories glazing

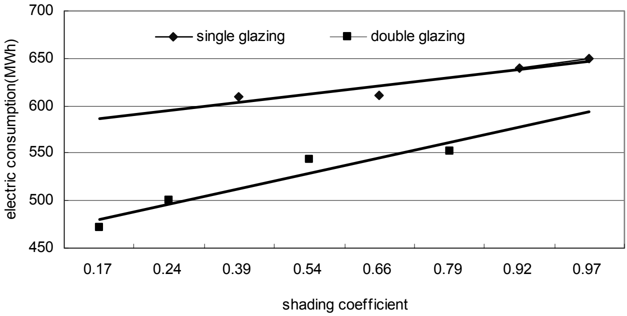

Figure 7. AC electric consumption of glazing shading coefficient

The glazing heat-transfer coefficient with different glazing shading coefficients and area ratios of window to wall

According to the standard (JGJ 134-2001), AC energy conservation should reach 50% in residential building of hot summer and cold winter zone in china by introducing envelope thermal insulation and increasing the EER and COP of the AC based on the same indoor thermal environment, the original building is BASECASE 1, introduce envelope thermal insulation and increase the EER and COP of the AC as BASECASE 2 based on the same indoor thermal environment. Optimize the heat-transfer coefficient with different shading coefficients and area ratios of window to wall in order to maintain the AC energy saving of BSECASE 1 is up to 50%, the glazing coefficient is from 0.3 to 0.9 and the glazing heat-transfer coefficient is from 1.7W/(m^2·K) to 6.4W/(m^2·K), results are shown in table 1.

Table 1 limit values of glazing heat-transfer coefficient with different glazing shading coefficients and area ratios of window to wall

Shading coefficient	North area ratio of window to wall					
	25%	30%	35%	40%	45%	50%
0.9	4.0	2.2	—	—	—	—
0.8	4.7	3.0	1.7	—	—	—
0.7	5.5	3.5	2.5	1.7	—	—
0.6	6.4	4.5	3.0	2.5	1.7	—
0.5	6.4	5.5	4.0	3.0	2.5	2.0
0.4	6.4	6.4	5.0	3.7	3.2	2.5
0.3	6.4	6.4	6.0	5.0	4.0	3.5
Shading coefficient	West/East area ratio of window to wall					
	25%	30%	35%	40%	45%	50%
0.9	3.5	—	—	—	—	—
0.8	4.7	2.2	—	—	—	—
0.7	5.5	3.5	2.0	—	—	—
0.6	6.4	4.0	3.0	2.0	—	—
0.5	6.4	5.5	4.0	3.0	2.2	1.7
0.4	6.4	6.4	5.5	4.0	3.2	2.5
0.3	6.4	6.4	6.4	5.2	4.2	3.7

Shading coefficient	South area ratio of window to wall					
	25%	30%	35%	40%	45%	50%
0.9	4.0	2.5	—	—	—	—
0.8	4.7	3.2	2.0	—	—	—
0.7	6.0	3.5	2.7	2.0	—	—
0.6	6.4	4.7	3.2	2.5	2.0	—
0.5	6.4	6.0	4.5	3.0	2.5	2.0
0.4	6.4	6.4	5.5	4.0	3.2	2.5
0.3	6.4	6.4	6.4	5.2	4.2	3.7

CONCLUSIONS

Window systems including the influence of area ratio of window to wall and categories of glazing on energy consumption of AC in hot summer and cold winter zone of china are simulated. Results show that the west and east windows have the more obvious effects on the AC annual electric consumption, when decreasing west and east glazing of unit area, the annual electric consumption is decreased by 319.3KWh and 313.7KWh; the low-e glazing (both single and double) has obvious effect on the energy saving of heating electric consumption and reflective glazing (both single and double) shows the better effect on the reduction of cooling electric consumption. The double low-e electro reflective has the best efficiency in energy conservation of AC; the annual electric consumption of AC is decreased by 28.1%. Finally, the limit values of glazing heat-transfer coefficient with different shading coefficients and area ratios of window to wall in hot summer and cold winter zone in china are studied. The simulation results indicate that there is a large potential on the window to decrease the energy consumption with properly technologies under the existing window systems of residential building, and the designer can apply the strategy selectively with minimal cost and relatively high efficiency. Results also can be the reference of revising the standard GJ 134-2001) and window designing for new residential buildings.

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