EVALUATION ON ENERGY EFFICIENCY OF WINDOWS IN DIFFERENT CLIMATE ZONES OF CHINA

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ABSTRACT

In this paper several kinds of window shading are introduced and compared. In addition, the potential of energy efficiency of exterior shading and three representative windows in three typical cities of China are analyzed and compared using eQUEST software. The objective of this paper is to analyze the influence of window shading in different climate zones of China through simulation. The result shows that in freezing climate zone it is appropriate to use the low-e windows with small U-value. The window with large SC-value and together with the optimum shading is the best way in hot summer & cold winter climate zone. It is appropriate to use the windows with small SC-value in hot summer & warm winter climate zone. And low-e window has an obvious effect on energy conservation in the three climate zones. This simulation may provide a comparing way for the energy saving design in the future buildings and some suggestions for architects to adopt the optimal type of window shading according to local conditions.

KEYWORDS

Windows, Energy consumption simulation, eQUEST, Shading, Shading coefficient

INTRODUCTION

Windows are the weak parts of buildings for building energy efficiency and have a great influence on the indoor comfort. In cold climates they are responsible for 10–25% of the heat loss from heated ambient (Ismail and Henríquez 2003). In hot climates, the excess of solar radiation penetrating through windows increases space cooling loads. The solar heat gain through fenestration is one of the prime sources contributing to the space cooling load in a building. In summer it is important to minimize the solar heat gain through windows by shading without reducing the natural illumination and in winter it is necessary to increase the fraction of solar radiation entering the room without causing any glare. In some climate areas, which need both cooling in summer and heating in winter, decreasing cooling loads by shading may increase heating loads drastically and vice versa. So it is important to determine the optimal shading system of windows.

Window shading includes several kinds as follows: 1. Exterior shading, such as reveals, overhangs and fins. Francisco Arumí-Noé (1996) described an algorithm to design automatically a fixed overhang to provide passive solar heating during the winter and shading the windows during the summer. Anickan Offiong and A.U.Ukpoho (2003) analyzed the solar gain through windows using the software to show that which is the most effective exterior shading treatment. 2. Interior shading which includes curtains, blinds and drapes. Mills and McCluney (2006) disscussed the advantages of using internal shading elements such as blinds. The type of control of the shading system also seemed to be important. Remotely controlled black Venetian blinds were usually used three times more than manually controlled fabric blinds (Yannick Sutter et al. 2006). 3. Between-glass shading, that is a double-glazed window with shading louver or even motorized highly reflective blinds between the two glazings （Cheng Yihua et al. 2006, A. K. Athienitis and A. Tzempelikos 2002）. 4. Glass system shading (Dong Zhizhong 2003), which means only utilizing the thermodynamic properties of the glass to decrease the solar heat gain without using any shading devices. For example, windows with low SC-value can be used, such as single tint windows, single reflective windows and low-e windows et al.

In this paper, an investigation is conducted to determine the annual energy consumption of a building through eQUEST (2006) simulation in which a shading model for windows is incorporated. This simulation would demonstrate the effect of various shading devices on building energy performance. Three locations in China, Harbin, Shanghai and Guangzhou are selected to simulate, compare and optimize the best shading device for each location.

BUILDING AND WINDOW DESCRIPTIONS

The cities selected are Harbin, Shanghai, and Guangzhou, which locate in the freezing, hot summer & cold winter, and hot summer & warm winter climate zones of China respectively. The hypothetical building is a unit of seven-story dwelling house. The building area is about 1115 m^2 (see Figure 1).

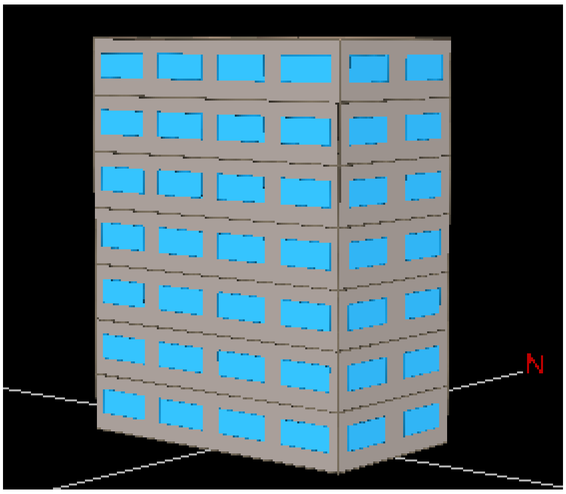

Figure 1 Geometric representation of the building (south-west view)

The weather files of the three cities are downloaded from the DOE-2 web site (Anon.). The building footprint shape is customized by importing a DWG file. The building faces south and each floor is 3 m high. The exterior walls and roofs adopt energy conservation measures respectively, meeting the requirement of the energy conservation code for each climate zone (China architecture science academy 1995, China architecture science academy 2001, China architecture science academy 2003) (see Table 1-4). eQUEST takes a code-number that indicates the relative roughness of the exterior surface finish of an exterior wall or roof. And it specifies the solar radiation absorptance of an exterior surface of an exterior wall or roof. The values decided by the surface finish material are given in the DOE-2's Help Topics. Aluminium and operable windows are modeled in the exterior wall systems. The glass type is single clear 1/8 in (3.175 mm). The window-to-exterior wall ratio (WWR) is 0.25 for north, 0.30 for east and west, and 0.35 for south. The features of the building discussed above are the major considerations.

Table 1 Construction parameters of the roof

Site	U-Value (W/ m^2℃)	Surface Roughness	Solar Absorptance
Harbin	0.293	1	0.6
Shanghai	0.813	1	0.6
Guangzhou	0.99	1	0.6

Other data needed as follows:

(1) Indoor calculate temperature, 18℃ in winter; 26℃ in summer.

(2) Outdoor climate calculate parameters adopt the typical meteorological year.

(3) The primary equipments of this building are electric hermetic reciprocating chiller with air-cooled condenser and hot water boiler fueled by natural gas. The enduse of the HVAC system are chilled water coils and heating coils, furthermore the HVAC system type is 4-pipe fan coils with heat water reheat.

As some information is not mentioned, the eQUEST defaults based on the building type are used here.

SIMULATION

After creating a new building description by eQUEST,

Table 2 Material Layers of the exterior wall in Harbin (ordered from outside to inside)

Material Name	Thickness (mm)	Conductivity [W/(m℃)]	Density (kg/ m^3)	Specific heat [kJ/(kg℃)]	R-Value (m^2℃/W)
cement mortar	20	0.93	1800	0.837	-
brick wall	370	0.756	1700	0.879	-
cement mortar	20	0.93	1800	0.837	-
bitumen vermiculite slab	160	0.087	150	1.34	-
air layer	-	-	-	-	0.16
finish plaster	20	0.81	1800	0.837	-

The surface roughness is 1, and the solar absorptance is 0.6.

Table 3 Material Layers of the exterior wall in Shanghai (ordered from outside to inside)

Material Name	Thickness (mm)	Conductivity [W/(m℃)]	Density (kg/ m^3)	Specific heat [kJ/(kg℃)]	R-Value (m^2℃/W)
brick wall	370	0.756	1700	0.879	-
foamed concrete	100	0.209	600	0.837	-
fiber board	25	0.163	400	2.093	-
finish plaster	20	0.81	1800	0.837	-

The surface roughness is 2, and the solar absorptance is 0.6.

Table 4 Material Layers of the exterior wall in Guangzhou (ordered from outside to inside)

Material Name	Thickness (mm)	Conductivity [W/(m℃)]	Density (kg/ m^3)	Specific heat [kJ/(kg℃)]	R-Value (m^2℃/W)
cement mortar	20	0.93	1800	0.837	-
brick wall	240	0.756	1700	0.879	-
air layer	-	-	-	-	0.16
gypsum plank	50	0.33	1050	1.05	-
finish plaster	20	0.81	1800	0.837	-

The surface roughness is 1, and the solar absorptance is 0.6.

Table 5 The properties of the glass system

Case	Glass Type	Center Glass U-Value	Glass+Frame(NFRC) U-Value	Solar Heat Gain Coefficient SHGC	Shading Coefficient SC	Exterior Shading
Basecase	Single Clear	1.11	1.13	0.86	1.00	No
Case 1	Single Clear	1.11	1.13	0.86	1.00	Overhangs
Case 2	Single Tint Grey	1.11	1.13	0.71	0.83	No
Case 3	Single Reflective	0.86	0.88	0.19	0.23	No
Case 4	Single Low-E Clear (e2=.4)	0.88	0.90	0.78	0.91	No

NFRC stands for the National Fenestration Rating Council in America.

we can launch the parametric run to define and run four alternative simulation cases, in which each new case is a parametric variation of the base case. Then the simulation results can be viewed as either individual or comparative graphs. In addition to the base case, four more cases are considered: cases 1-3 are characterized by changing single clear windows to single tint grey windows, single reflective windows and single low-e windows. The properties of the glass system are determined using eQUEST (see Table 5). Case 4 uses the overhangs which are modeled as opaque surfaces and can block diffuse light from the sky and direct sunlight. The overhang depth (OD) is 500 mm, the horizontal space (OA) is 0, the vertical space (OB) is 100 mm and the overhang angle (OAng) is 90 degree (see Figure 2).

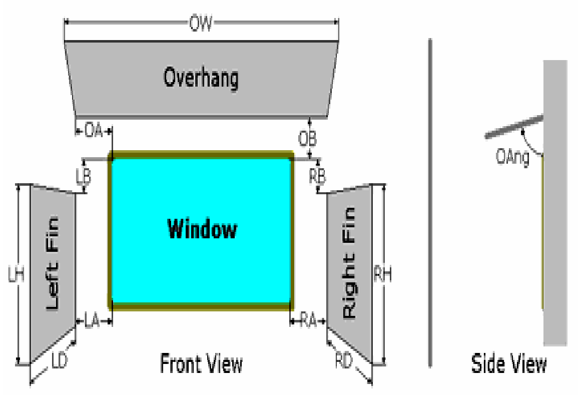

Figure 2 Sketch map of the exterior shading

DISCUSSION AND RESULT ANALYSIS

For each climate zone, energy consumption data provided by the simulation are given in Table 6-8 for the five cases.

Table 6 Annual building summary in Harbin

Annual Energy USE or Demand	Annual Site Energy		HVAC Energy			Peak	
	Electric kwh	Nature Gas kwh	Electric kwh	Nature Gas kwh	Total kwh	Electric kw	Cooling Capacity kw
Basecase	112495	264670	40793	264670	305400	49	120
Case 1	107252	268720	35531	268720	304200	46	98
Case 2	107643	270970	35927	270970	306800	45	102
Case 3	98711	268330	26948	268330	295400	31	56
Case 4	109429	231530	37733	231530	269300	46	109
Incremental SAVINGS	values are relative to previous measure (% savings are relative to the basecase use), negative entries indicate increased use						
Case 1	5244(5%)	-4050(-2%)	5262(13%)	-4050(-2%)	1200(%)	3(5%)	22(18%)
Case 2	4852(4%)	-6300(-2%)	4867(12%)	-6300(-2%)	-1400(-%)	3(7%)	18(15%)
Case 3	13784(12%)	-3660(-1%)	13845(34%)	-3660(-1%)	10000(3%)	18(37%)	64(54%)
Case 4	3066 (3%)	33140(13%)	3060(8%)	33140(13%)	36100(12%)	3(6%)	11(9%)

The shading performance of the glass which blocks the solar radiation is the ratio of the solar radiation energy permeating to indoor through glass to a baseline which is defined as the solar radiation energy permeating to indoor through a piece of single clear glass with the same area as the one before and is 3 mm thick. It is denoted as shading coefficient (SC-value). So decreasing the SC-value of the glass is an efficient way to improve the shading performance of the windows.

From the Table 6-8, it can be seen that single reflective windows has the best effect in shading. For Harbin, Shanghai, and Guangzhou, the decrease of energy consumption of cooling in summer is 34%, 36% and 33% respectively. Comparing Table 5 and Table 6-8, it is clear that the SC-value has a great impact on the energy consumption of cooling in summer. The smaller the SC-value is, the more the windows block the solar radiation into the room and the better the shading effect is. To case 1-3, energy consumption of heating in winter has an increase to some extent, the major reason is that shading device blocks some solar radiation coming into the room and as a result, the indoor heat gain decreases and the energy consumption of heating increases. Single low-e windows reduce the energy consumption of cooling and the energy consumption of heating. The major reason is that single low-e window both reduces the SC-value and the U-value. That is to say, it both reduces the heat gain from solar radiation in summer and heat transfer loss in winter.

To the annual site energy consumption, which includes ambient lights, task lights, misc equipment and HVAC equipment, the incremental savings of the

Table 7 Annual building summary in Shanghai

Annual Energy USE or Demand	Annual Site Energy		HVAC Energy			Peak	
	Electric kwh	Nature Gas kwh	Electric kwh	Nature Gas kwh	Total kwh	Electric kw	Cooling Capacity kw
Basecase	114534	106330	50091	106330	156500	59	137
Case 1	107994	108990	43537	108990	152700	53	120
Case 2	110204	110430	45751	110430	156200	55	127
Case 3	96375	112190	31889	112190	144200	42	88
Case 4	111140	92317	46700	92317	138900	56	127
Incremental SAVINGS	values are relative to previous measure (% savings are relative to the basecase use),negative entries indicate increased use						
Case 1	6541(6%)	-2660(-3%)	6554(13%)	-2660(-3%)	3800(2%)	6(10%)	17(15%)
Case 2	4331(4%)	-4100(-4%)	4340(9%)	-4100(-4%)	300 (%)	4(6%)	10(9%)
Case 3	18159(16%)	-5860(-5%)	18202(36%)	-5860(-5%)	12300(8%)	17(29%)	49(36%)
Case 4	3394(3%)	14013(13%)	3391(7%)	14013(13%)	17600(11%)	3(6%)	10(8%)

Table 8 Annual building summary in Guangzhou

Annual Energy USE or Demand	Annual Site Energy		HVAC Energy			Peak	
	Electric kwh	Nature Gas kwh	Electric kwh	Nature Gas kwh	Total kwh	Electric kw	Cooling Capacity kw
Basecase	127770	27021	67347	27021	94400	53	120
Case 1	118903	27197	58468	27197	85600	46	106
Case 2	121704	28135	61274	28135	89400	49	109
Case 3	105759	29248	45297	29248	74400	38	81
Case 4	123898	23006	63478	23006	86500	49	109
Incremental SAVINGS	values are relative to previous measure (% savings are relative to the basecase use),negative entries indicate increased use						
Case 1	8867(7%)	-176(-%)	8879(13%)	-176(-%)	8800(9%)	7(13%)	14(11%)
Case 2	6066(5%)	-1114(-4%)	6073(9%)	-1114(-4%)	5000(5%)	4(8%)	11(9%)
Case 3	22012(17%)	-2227(-8%)	22050(33%)	-2227(-8%)	20000(21%)	15(29%)	39(32%)
Case 4	3872(3%)	4015(15%)	3870(6%)	4015(15%)	7900(8%)	4(7%)	11(8%)

natural gas consumption is the same as that in HVAC equipment. The incremental savings of the electric consumption is about 50% of that in HVAC equipment. The incremental savings of the electric consumption is about 50% of that in HVAC equipment in Guangzhou. And in Shanghai and Harbin this data is digressive.

To the peak cooling load, the single reflective windows have the best effect in saving energy. The incremental savings of electric power are 29%-37%, and those of cooling capacity are 32%-54%. It can reduce the capacity of the central equipments such as chillers.

Integrated considering of annual energy consumption of the HVAC shows that as follows: For Harbin, the single low-e windows, whose incremental savings is 12%, have the best effect. But overhangs, single tint grey windows and single reflective windows hardly have effect. In the freezing climate zone, the ratio of energy consumption in summer to annual energy consumption is very small, so the SC-value receives little attention and the decreasing of the U-value is the key. For Shanghai, single low-e window is the best mode for that the incremental savings is 11%. The second is the single reflective window whose incremental saving is 8%. In this climate zone, the energy consumption in summer is as important as that in winter so both SC-value and U-value should be considered carefully. For Guangzhou, the single reflective window performs the best and the incremental savings is 21%. The incremental savings of other measures are 5%-9%. In the hot summer & warm winter climate zone, the ratio of energy consumption in winter to annual energy consumption is small, so in this climate zone the SC-value should be decreased as much as possible.

CONCLUSION

Both shading coefficient and heat-transfer coefficient (U-value) of window shading system should be considered to reduce energy consumption through windows. The following conclusions can be drawn: 1. In the three climate zones, low-e windows can reduce the energy consumption of air conditioning and heating evidently. In addition, low-e windows are excellent in light transmission. 2. In freezing climate zone, energy consumption of cooling accounts for a small proportion of annual energy consumption, so it is appropriate to use the low-e windows with small U-value. 3. In hot summer & cold winter climate zone, both the energy consumption of cooling and heating are great. It is obviously that a fixed SC-value in the window system does not benefit to annual building energy conservation. The window with large SC-value and together with the optimum exterior shading and interior shading is the best window system in this climate zone. The curtain, which decorates the room, can be used for interior shading. The movable exterior shading is effective but its best orientation and size should be further investigated. 4. Hot summer & warm winter climate zone where the temperature difference between indoor and outdoor is little, and the heating load is also small, it is appropriate to use the windows with small SC-value such as single reflective windows.

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