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ABSTRACT

In this paper, the standards and energy labeling system of windows was introduced firstly. Then the influence of variation in Thermal Transmittance (U-factor), Shading Coefficient (SC) or Solar Heat Gain Coefficient (SHGC) and Air Leakage (AL) of windows, available in the Chinese market, on the building heating and cooling loads was studied. A 1-story house model was set up to compare different limited values of U-factor, SC and Air Leakage rate of windows in Chinese national standards on the annual heating and cooling energy consumption an energy use of windows in residential buildings calculating code (RESFEN). Window's U-factor ranges 0.6-6.0W/m^2·K; SC ranges 0.1-0.98 and Air Leakage rate ranges 0-12m^3/m^2·h. The analysis of window's U-factor and SHGC changes on the monthly energy loads was realized via a 5-story office building model and a building analysis program (Ecotect). The results show that U-factors of exterior windows have greater impact on the heating energy in heating-dominated regions.

1. INTRODUCTION

1.1 Background

In china, there has been steady increase in the use of energy since the adoption of the Policy of Reforming and Opening in the 1980s (Zhang, 1995; Liu, *et al*. 2008). Total energy use rose from 603 million tones of standard coal equivalent (Mtce) in 1980 to 1320 in 2001, representing an average annual increase of 3.8% during that 22-year period (Wang, 2003). Buildings represent an important and increasing component of China's total energy consumption mix. Officially, residential and commercial energy use account for 19% of China's total consumption without considering many commercial and residential buildings that belong to other sectors of the economy (David G, *et al*. 2007). It was estimated that building stocks accounted for about 24.1% in 1996 of total national energy use in mainland China, rising to about 27.5% in 2001, and is projected to increase to about one-third in 2010 (Lang, 2003; Yao, *et al*. 2005; Liang, *et al*. 2007).

1.2 Standards and Energy Labeling System

In order to improve the building energy efficiency, many building energy standards, labeling and certification systems, financial subsidy and tax credit policies were developed by the Central Government and local authorities. China's first building energy standard, JGJ 26-1995, was one for residential buildings in the Heating Zone in north China that was developed in 1986, and then was revised in 1995. The target of the standard was to reduce building energy consumption compared with pre-existing construction by 30% in the 1986 version, and by 50% in the 1995 version of the standard. The standard with other building energy design standards, JGJ 134-2001 and JGJ 75-2003, will be superseded by a national residential building energy standard in the near future. Now, many residential buildings could achieve the 65% energy reduction goal in many cities such as Beijing and Shanghai.

The national energy efficient design standard for public buildings, GB 50189-2005, was completed and adopted by the former Ministry of Construction (today's Ministry of Housing and Urban-Rural Development of China, MOHURD). This standard also set the target at 50% energy reductions compared with pre-existing public buildings, which could be achieved partly by improving the energy performance of building envelopes such as roofs, walls and windows. It listed the limited value related to the energy performance of windows, Heat Transfer Coefficient and Shading Coefficient for the five different climate regions in China: Severe Cold Region, Cold Region, Hot-Summer Cold-Winter (HSCW) Region, Hot Summer Warm Winter (HSWW) Region and Temperate Region.

The energy-related performance parameters such as U-factor, SC (or SHC), AL and Visible Light Transmittance (VT) of glazing can be measured according to standards or calculated by the computer programmes Therm and Window developed by LBNL. The national standard GB/T 7106 gives the test procedure and performance classification of air leakage through the overall windows and the openable joint perimeters and GB/T 8484-2008 presents the test methods and classification of window's U-factor and condensation index. At present, there are no measure standards for SC or SHGC in China. However, they can be calculated with optical results of glass according to JGJ/T 151-2008. One can find a classification of SC for the aluminum windows in its product standard GB/T 8478-2008.

China has developed the window energy labeling system based on the whole product performance like NFRC (National Fenestration Rating Council) in North America. The window energy labels on window units give ratings for U-factor, Shading Coefficient, Visible Light Transmittance, and Air Leakage to demonstrate the window energy properties and to compare products. Eleven leading laboratories were assigned the first agencies conducting test and simulation task around China. Over 30 manufactories and 100 window units (including 443 frames and glazing types) have received the window energy labels and now MOHURD is endeavoring to expand the label around the whole country. The U-factors of windows acquired China energy efficiency labels range from 1.7 W/(m^2·K) to 3.3 W/(m^2·K) and the distribution of the values is shown in the Figure 1.

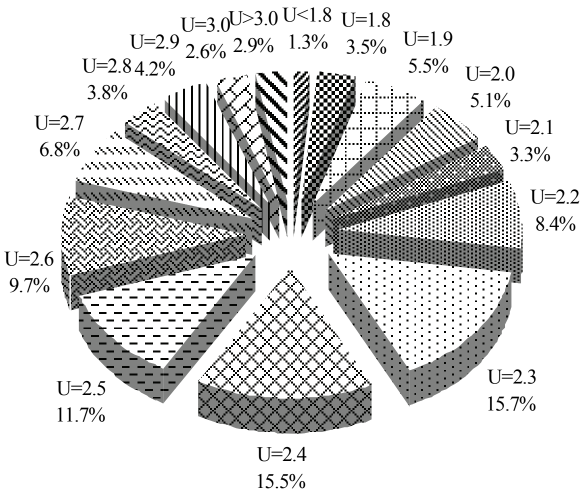


Figure 1: Distribution of U-factors of windows acquired energy efficiency labels (unit: W/(m^2·K))

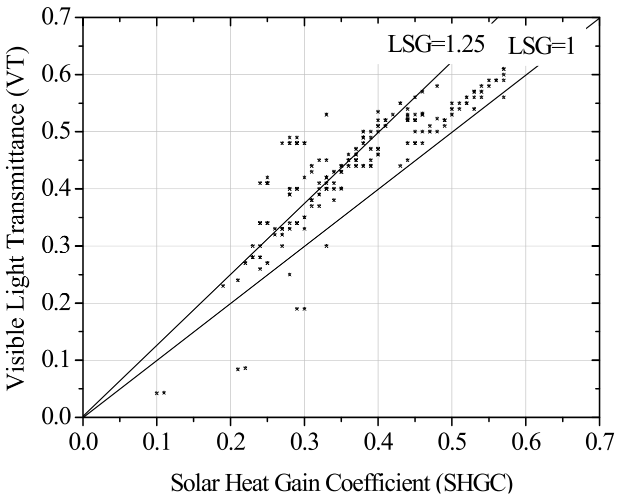


Figure 2: Distribution of SHGC and VT of windows acquired energy efficiency labels

Figure 2 shows the distribution of SHGC (expressed in SC in China windows energy labeling system) and VT of energy efficiency windows. The ratio between the visible transmittance of a glazing and its solar heat gain coefficient is called Light-to-solar-gain ratio (LSG) which means the ability of a glazing to provide light without excessive solar heat gain. A ratio greater than one indicates that the window transmits more light than heat; windows with low LSGs are more often used in passive solar heating applications, whereas windows with high LSGs are used to help prevent heat gain. The Department of Energy's Federal Technology Alert publication of the Federal Energy Management Program (FEMP) views an LSG of 1.25 or greater to be Green Glazing/Spectrally Selective Glazing. The boundary condition adopted by China windows energy labeling system is slightly different from the North American procedure which has been adopted by NFRC and the CEN procedure which has been adopted by European Union. Table 3 summarizes the standardized conditions used in those procedures.

Table 3: Standardized conditions used in the standards

Country or Regions		**North America**	**China**	**Europe**
Standard used		ISO 15099	JGJ/T 151-2008	ISO 10077
U- Factor Calculation	Interior Temperature	21 º C	20 º C	20 º C
	Exterior Temperature	-18 º C	-20 º C	0 º C
	Interior Convection Coefficient	0 $W/m^2 \cdot K$	3.6 $W/m^2 \cdot K$	8 $W/m^2 \cdot K$
	Exterior Convection Coefficient	26 $W/m^2 \cdot K$	16 $W/m^2 \cdot K$	20 $W/m^2 \cdot K$
	Exterior Wind Velocity	5.5 m/s	3 m/s	4 m/s
	Radiant Mean Temperature Exterior	$T_{r,m} = T_{exterior}$	$T_{r,m} = T_{exterior}$	$T_{r,m} = T_{exterior}$
	Radiant Mean Temperature Interior	$T_{r,m} = T_{interior}$	$T_{r,m} = T_{interior}$	$T_{r,m} = T_{interior}$
	Incident Solar Flux	0 W/m^2	0 W/m^2	0 W/m^2
Solar Heat Gain Coefficient Calculation	Interior Temperature	24 º C	25 ºC	25 ºC
	Exterior Temperature	32 ºC	30 ºC	30 ºC
	Interior Convection Coefficient	Calculated	3.6 $w/m^2 \cdot K$	2.5 $w/m^2 \cdot K$
	Exterior Convection Coefficient	15 $W/m^2 \cdot K$	16 $w/m^2 \cdot K$	8 $w/m^2 \cdot K$
	Exterior Wind Velocity	2.8 m/s	3 m/s	1 m/s
	Radiant Mean Temperature Exterior	$T_{r,m} = T_{exterior}$	$T_{r,m} = T_{exterior}$	$T_{r,m} = T_{exterior}$
	Radiant Mean Temperature Interior	$T_{r,m} = T_{interior}$	$T_{r,m} = T_{interior}$	$T_{r,m} = T_{interior}$
	Incident Solar Flux	783 W/m^2	500 W/m^2	500 W/m^2
	Solar Spectrum	NFRC 300	ISO 9050, GB/T 18915	EN 140

1.3 Relationship between Energy-related Parameters of Windows and the Building Energy Use

The energy-related performance parameters such as U-factor, SHGC, VT and Air Leakage of windows have close and complex relationship with the building energy consumption. U-factor measures how well a window assembly prevents heat from escaping. The lower the U-value, the greater a window's resistance to heat flow and the better its insulating value. It has an important relationship with the heating loads of a building in cold winter. SHGC, the fraction of incident solar radiation admitted through a window (both directly transmitted and absorbed) and subsequently released inward, measures how well a window product blocks heat caused by sunlight. SHGC is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits in the house and the less cooling loads in hot summer. VT is an optical property of window's glazing that indicates the amount of visible light transmitted. The higher the VT, the more light transmits and the better view through the windows, the less need for electrical lighting as well. AL measures the volume of air passing through a window. Heat loss and gain occur by infiltration through cracks in the window assembly. The lower the AL, the less air will pass through cracks in the window assembly. All the parameters can affect the building heating, cooling and lighting loads positively or negatively.

In the present study, building energy simulation software RESFEN and Ecotect 2000 has been used for comparing the influence of these parameters change on the heating and cooling loads of a 1-story house and a 5-story office building. The whole house energy consumption has been calculated with different U-factors, SHGCs and Air Leakage rates presented in the GB/T 7106, GB/T 8484 and GB/T 8478, which define the limited values in every classification level. The monthly heating and cooling energy loads of the 5-story office building have been simulated by Ecotect 2000 with different U-factor and SHGC levels.

2. MODELING AND PROGRAMS

2.1 Models

In order to compare the influence of U-factor, SHGC and Air Leakage rate changes on the house energy consumption, one-story house model has been set up firstly with slab-on-grade foundation and super insulated building envelope system. The total floor area of the house is 139m^2 and the total window area is 44m^2. The south and north orientation of the house have 16m^2 windows and the east and west orientation have 6m^2 window respectively. The calculation has adopted the weather data of Beijing.

The limited values from Class 1 to Class 10 of U-factors in GB/T 8484-2008 and overall Air Leakage rates form

Class 1 to Class 8 in GB/T 7106-2008 have been specified for conducting the simulation work. Among the SCs, seven are limited values from Class 1 (0.8≥SC>0.7) to Class 7 (SC≤0.2) presented in GB/T 8478-2008.

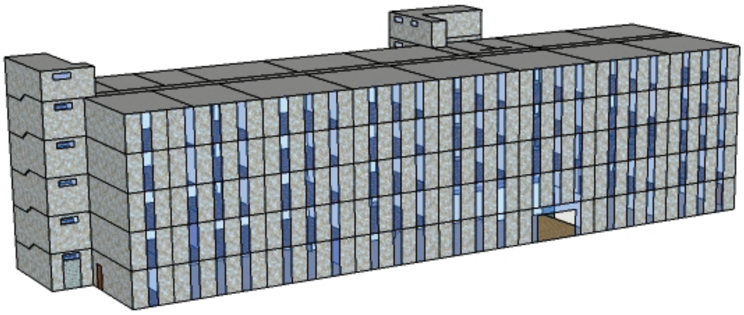


Figure 3: A 5-story office building

Another model is a 5-story office building with about 30% window area in the south orientation wall (see figure 3). The U-values of walls, floors and roofs are about 0.6 $W/m^2{\cdot}K$, 0.88 $W/m^2{\cdot}K$ and 0.50 $W/m^2{\cdot}K$ respectively. All the rooms except the bathrooms and aisles adopt the full air conditioning system for providing heating and/or cooling. The hours of the HVAC system operation is from 8 a.m. to 6 p.m. on weekdays and it keeps off on all the weekends. The lower band of the thermostat range is 18.0 ºC and the upper band is 26 ºC. The values for the exchange of air between zone and outside environment of all the rooms equipped active HVAC systems are set to 0.5 air changes per hour. The occupancy density is about one person per 20 square meters, which belongs to the open office style. Eight windows with different frames and glazings have been used for calculating the whole building heating and cooling loads in the initial design phase (see Table 4).

Table 4: Windows used for calculation

Window	Frame	Glazing	U-factor	SHGC
1	Wood	4mmLow-E+0.1V+3mmClear+12Ar+5mmClear	1.3	0.65
2	Wood-Clad	6mmLow-E+16Ar+6mmClear	1.7	0.65
3	Aluminum with Thermal Break	6mmLow-E+12Ar+6mmClear	2.0	0.65
4	Aluminum with Thermal Break	6mmLow-E+12Ar+6mmClear	2.0	0.50
5	Aluminum with Thermal Break	6mmLow-E+12Ar+6mmClear	2.0	0.25
6	Aluminum with Thermal Break	6mmLow-E+12Ar+6mmClear	2.2	0.30
7	Polyvinyl Chloride (PVC)	6mmClear+12A+6mmClear	2.6	0.50
8	Aluminum with Thermal Break	6mmClear+12A+6mmClear	3.2	0.65

U-factor is in $W/m^2{\cdot}K$.

2.2 Calculation Programs

RESFEN is a computer tool developed by the LBNL which can help consumers and builders pick the most energy-efficient and cost-effective window for a given application, whether it is a new home, an addition, or a window replacement. It calculates heating and cooling energy use and associated costs as well as peak heating and cooling demand for specific window products. Users define a specific "scenario" by specifying house type (single-story or two-story), geographic location, orientation, electricity and gas cost, and building configuration details (such as wall, floor, and HVAC system type). Users also specify size, shading, and thermal properties of the window they wish to investigate. The thermal properties that RESFEN requires are: U-factor, Solar Heat Gain Coefficient, and air leakage rate. RESFEN calculates the energy and cost implications of the window compared to an insulated wall. The relative energy and cost impacts of two different windows can be compared.

Ecotect is a 3D building analysis program that integrates lighting, energy, acoustics and environmental analyses. The software allows the same model to be used for the different analysis, within the same GUI. The most significant feature of Ecotect is its interactive approach to analysis. Adding a new window and immediately we can see its thermal effect, changes in daylight factor, incident solar radiation and overall building cost. Ecotect is also the only application of its kind to include comfort, greenhouse gas emissions and embodied energy analysis alongside capital and running costs for a direct comparison.

3. CALCULATION AND RESULTS

3.1 1-story House

Figure 4 shows the whole house annual heating and cooling energy changes with the U-factor of windows. It can be seen how the variation in the heating and cooling energy consumption caused by U-factor modifications for all windows is different. For instance, the lowest U-factor (0.6 W/m^2·K) has least heating energy consumption than other alternatives when the Air Leakage rate and SHGC keep the same level. The whole house annual heating energy consumption increases sharply from 19.5 GJ to 58.7 GJ when U-factor is raised from 1.1 W/m^2·K (the upper limited value of Class 10 in GB/T 8484-2008) to 5.0 W/m^2·K (the lower limit value of Class 1). The variation of U-factors has less effect on the whole house annual cooling energy consumption. Thus the total annual energy presents a continuous increasing tendency following the increase of U-factor of windows, especially for the heating dominated climate regions.

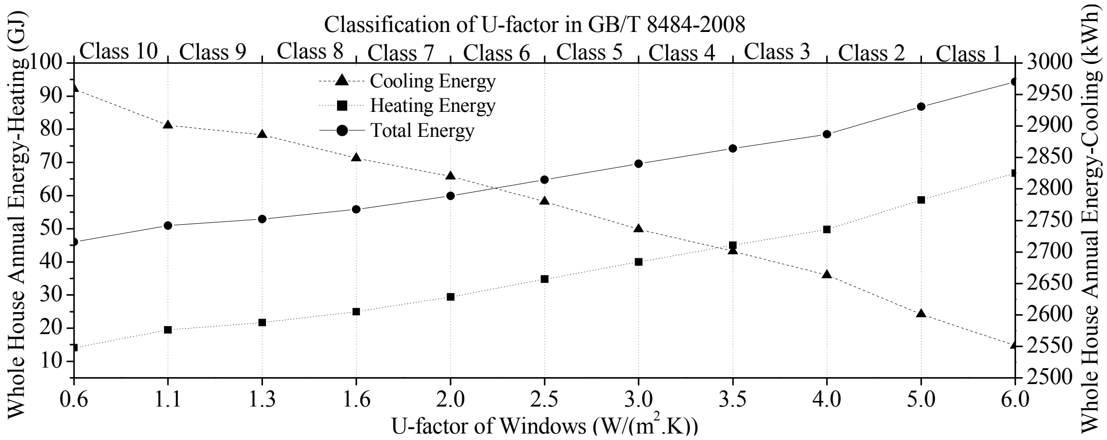


Figure 4: Variation of U-factor on the whole house annual energy

Figure 5 shows the whole house annual heating and cooling energy changes with the SCs (SHGCs) of windows. With a smaller SC value, there are significant differences in cooling energy consumption compared with the higher. For the case that adopts the upper limited value of Class 7 (SC=0.2) indicated in GB/T 8478-2008, the cooling energy consumption is decreased by 180% compared to the highest value shown in the standard's classification table (SC=0.8). Owing to the decrease of the SC, the heat gain by the incident solar radiation admitted through the windows becomes less than higher SCs. In the case of the same other performance parameters, it requires more energy for heating in the heating seasons. So the house annual heating energy keeps increasing following the reduction of SCs. Due to the variation of SC making a strong impact on the house annual cooling energy consumption, the house has a lowest total energy at some certain SC value (about 0.7), neither the minimal SC value nor the maximal SC value.

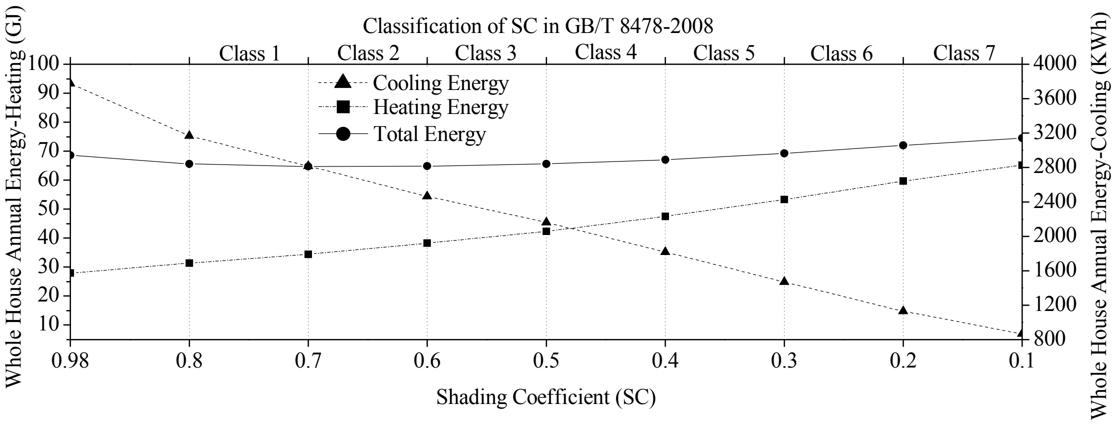


Figure 5: Variation of SC on the whole house annual energy

Figure 6 shows the effect of variation of Air Leakage rate on the whole house annual heating and cooling energy consumption. The worse tightness of windows, the more energy the house consumes. However, compared to the U-factor and SC, it has no such great impact on the house energy use.

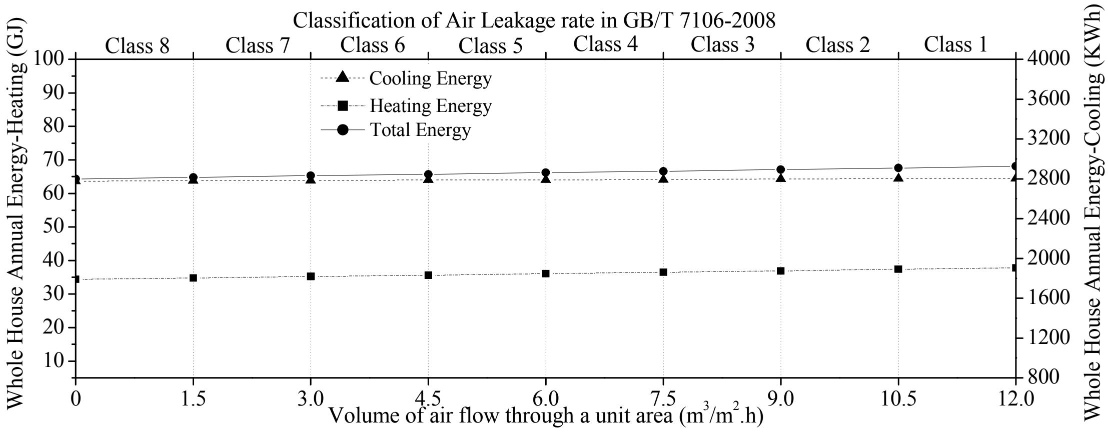


Figure 6: Variation of Air Leakage rate on the whole house annual energy

3.2 5-story Office Building

The heating and cooling loads in April with different 8 windows for the 5-story office building are shown in the Figure 7. In Beijing, the average outdoor temperature in April ranges from -3.8 ºC to 26.5 ºC, which causes both heating and cooling loads for achieving a comfortable indoor environment. Window 1, 2 & 3 have same U-factors and different SHGCs, thus the heating energy consumption of the building rises along with the U-factor increase while the change of cooling loads is slight. Window 5 has lower SHGC than Window 3 & 4 but has same U-factor, which leads the least cooling energy use of the office building with Window 5. However, the building needs more heating load with Window 5 because the less solar radiation enters the indoor through the windows. Besides, the main building energy use is for heating in April in Beijing. Though the Window 5 has lower U-factor and higher SHGC than Window 5, the total energy load of the office building in April is almost the same.

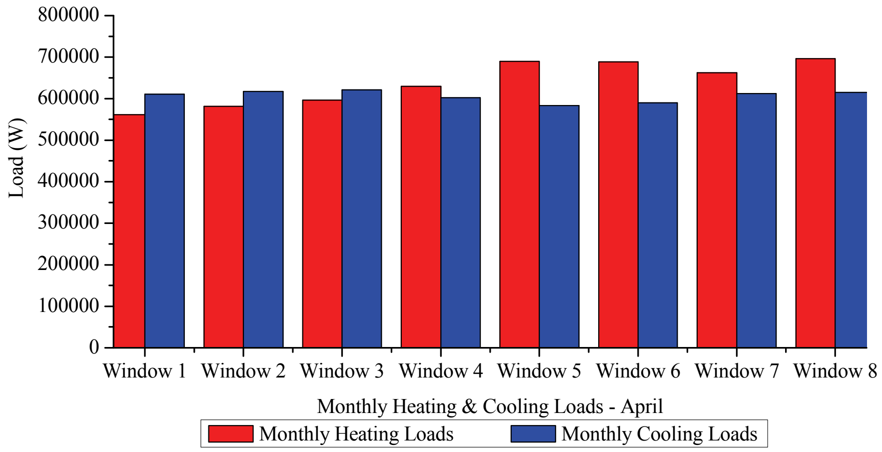
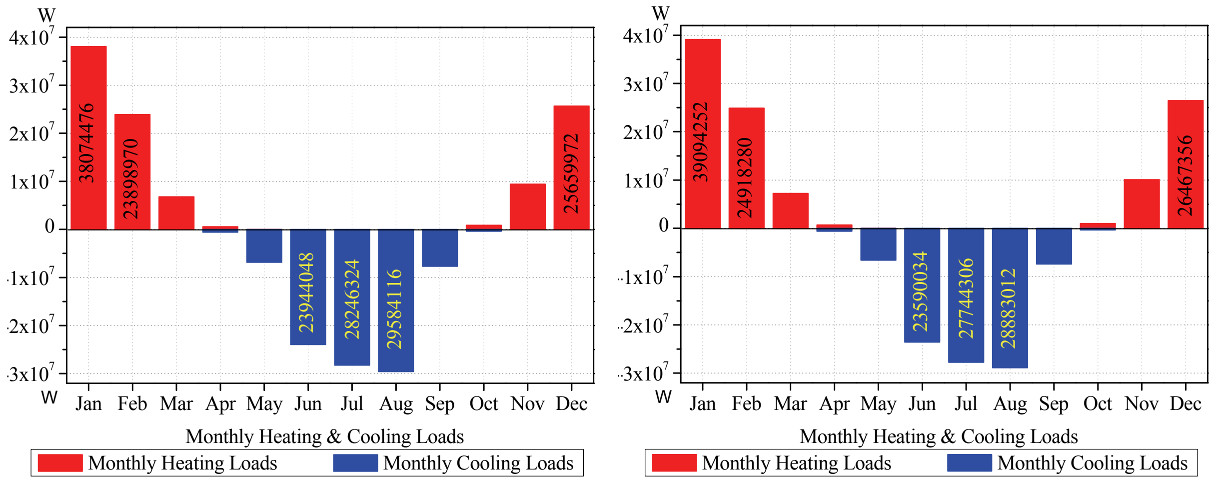


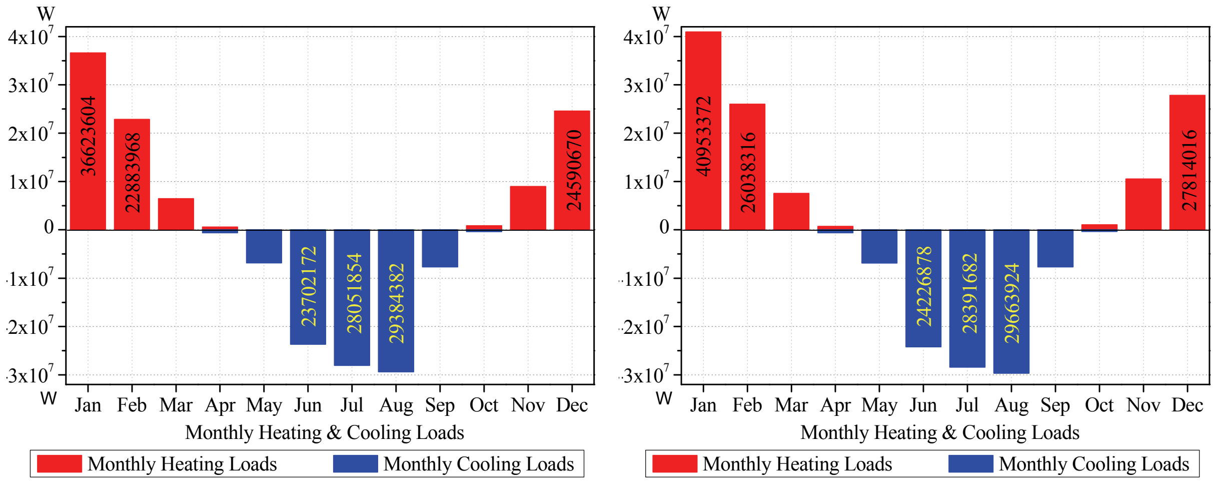
Figure 7: Heating & cooling loads in April with different windows

Figure 8 and Figure 9 further illustrate the influence of different U-factors and SHGCs on the monthly heating and cooling loads. In Figure 8, Window 3 & 5 have same U-factors (U=2.0 W/m^2·K) but Window 5 has a lower SHGC. As a result, 7×10^5 W energy is required for the cooling of the office building additionally. In addition, the extreme low SHGC blocks the solar to come into the indoor so that the load for heating also rises consequently in heating seasons such as January, February and December as show in Figure 8. In Figure 9, Window 1 & 8 has the same SHGC but the U-factor of Window 1 (U=1.3 W/m^2·K) is much less than Window 8 (U=3.2 W/m^2·K). Therefore, the heating energy with Window 8 is much more than that of Window 1 for the office building in heating seasons while the cooling energy requirement is almost the same.



(a) Window 3 (U=2.0, SHGC=0.65) (b) Window 5 (U=2.0, SHGC=0.25)

Figure 8: Monthly heating & cooling loads with different windows



(a) Window 1 (U=1.3, SHGC=0.65) (b) Window 8 (U=3.2, SHGC=0.65)

Figure 9: Monthly heating & cooling loads with different windows

4. CONCLUSION

The work presented in this paper gives an illustration concerning the variation of different energy-related performance parameters of windows on the building heating and cooling energy consumption via the program RESFEN and Ecotect. To compare different limited values of U-factor, SHGC and Air Leakage rate of windows in Chinese national standards, a 1-story house has been built which takes into account the orientation of the windows and the ratio of windows to wall. This makes it possible to compare the variation of energy consumption with different windows parameters. Another 5-story office building has been set up to analyze the variation of U-factors and SHGCs on the building's monthly heating and cooling loads. The results show that U-factors of exterior windows have greater impacts on the heating energy requirements and the annual energy use. But the SHGC also has a certain contribution to building energy savings. The selection of windows should take into account the solar input (SHGC), losses by conduction (U-factor) and by infiltration (Air Leakage rate) as well as the location and environment. In the next step, the energy rating system should be set up for making comparative estimates of the effect on the building annual heating energy requirement with different windows in China's five climate zones.

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