

# Performance of a Solar Spectrum-Selective Absorption Film as a Building Energy-Saving Retrofit in China

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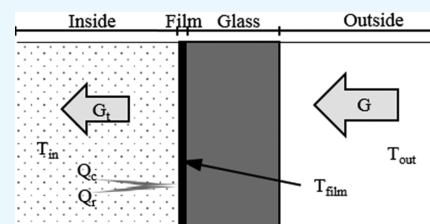
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**ABSTRACT:** The transparent envelope structures in existing buildings have caused so much energy consumption. As one kind of the energy-saving technologies and strategies, the solar spectrum selective absorption film (SSAF) is considered suitable for the retrofit of glazing systems. The energy-saving performance of the SSAF in different types of glazing systems under different climate zones in China was investigated via a field study and simulation experiment. The results indicated that SSAF slowed down the rise of indoor air temperature in the daytime and reduced the total energy entering the room. The effect of the SSAF on the single glazing system was more potent than that on the double glazing system. In the hot summer and cold winter zone, moderate zone, hot summer and warm winter zone, the SSAF could reduce the energy consumption of windows. The highest energy-saving rate reached 35.0% for the single glazing system and 28.3% for the double glazing system. However, the SSAF does not have the energy-saving potential in existing buildings that already have low-E double glazing systems.



## 1. INTRODUCTION

In recent years, building energy consumption, especially the energy consumption of HVAC systems, is continuously increasing due to the improvement of people's requirements for thermal comfort inside buildings. This part of energy consumption occupies a considerable proportion of the total energy consumption in the world.<sup>1,2</sup> The application of transparent envelope structures (including glass windows, glass curtain walls, etc.) may cause as much as 40–50% of the total building energy consumption.<sup>3</sup> Nonetheless, it is unlikely that transparent envelope structures can be reduced or replaced by other more energy-efficient conservation structures in the pursuit of natural lighting quality and the aesthetic of building facades. Instead, transparent envelope materials are increasingly used, especially in commercial and landscape buildings. Therefore, there is substantial potential for reducing buildings' energy loss through transparent envelope structures by using energy-saving measures. A large number of energy-saving technologies and strategies, such as the double glazing system, vacuum glazing system,<sup>4</sup> double low-E glazing system,<sup>5</sup> solar control films,<sup>6</sup> and so forth, were widely studied and applied. The double glazing system is an earlier energy-saving glazing system; however, its energy-saving rate would be limited since it partially decreased the heat transfer efficiency without effecting radiation heat flux transfer. Although the vacuum glazing system and double low-E glazing system have excellent energy-saving properties, the cost of them is a barrier to applying in existing buildings due to the need to replace the whole glazing system (including window framings or keels) to set the vacuum cavity structure for energy-efficient retrofitting.

The solar control film is considered suitable for the retrofitting of the glazing system of existing buildings due to its low cost, excellent thermal insulation performance, easy installation, and minimal disruption to building occupants.<sup>7,8</sup> The solar spectrum selective absorption film (SSAF), a kind of solar control films, is mainly composed of transparent conductive oxides such as antimony tin oxide and indium tin oxide.<sup>9</sup> It can strongly absorb solar near-infrared (NIR) radiation, and some of the absorbed energy may end up to outdoor space ultimately, reducing the transmission of solar radiation through the window.<sup>10,11</sup>

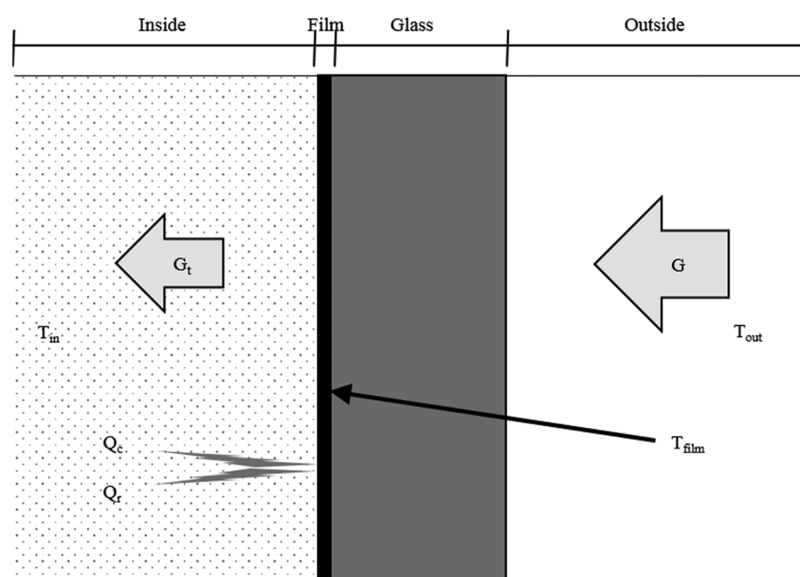
The mechanism of heat transfer into a room through the glazing system coated with the SSAF is illustrated in Figure 1. As it can be seen, the film is the SSAF coated on glass, facing toward the inside of the room. Solar energy ( $G$ ) is assumed to strike perpendicular to the glazing system from outside. A certain percentage of this energy is absorbed by the SSAF and the glass, some is reflected, and the rest is transmitted to the interior ( $G_t$ ). The temperature of the SSAF increases producing dissipation of heat toward the inside and outside of the room. The total energy ( $G_{in-tot}$ ) into a room per unit area consists of the solar energy passing through the glazing system ( $G_t$ ), the convection heat flux toward the interior of the

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**Figure 1.** Heat transfer through the single glazing system coated with the SSF and the temperature at different positions [indoor air temperature ( $T_{in}$ ), outdoor air temperature ( $T_{out}$ ), and SSF temperature ( $T_{film}$ )].

room ( $Q_c$ ), and the radiation heat flux toward the interior of the room ( $Q_r$ )

$$G_{in-tot} = G_t + Q_c + Q_r \quad (1)$$

After simplification, the relationship between  $Q_c$ ,  $Q_r$ , the temperature of the SSF ( $T_f$ ), and the indoor air temperature ( $T_{in}$ ) is as follows

$$Q_c = h(T_f - T_{in}) \quad (2)$$

$$Q_r = \sigma \varepsilon (T_f^4 - T_{in}^4) \quad (3)$$

where,  $h$ ,  $\varepsilon$ , and  $\sigma$  stands for convective coefficient, optical emittance, and Boltzmann constant, respectively.

Compared with other energy-saving technologies and strategies, the energy performance of SSF with a special heat transfer mechanism has also been regarded as positive in many studies. Xu et al.<sup>12</sup> confirmed that the energy-saving effect of NIR-shielding coatings increased by 9.15% compared with low-e coatings under Hong Kong weather conditions. In Canada, where the climate is cold, the glass with selective coating achieved similar energy saving performance to low-E glass. The annual energy savings of the coating were observed in the range of 13–16%, while the windows replaced with low-E glass saved between 11 and 20%.<sup>13</sup> Similar conclusions were obtained by Singh and Garg<sup>14</sup> for Indian climate and Aguilar et al.<sup>15</sup> for Mexican climate, although the energy performances of absorbing films were slightly worse than that of the reflective film in these studies.

But the optical and thermal properties and energy performance of the SSF in different glazing systems under different climate conditions have not been entirely clear, which has aroused widespread concern. Gijón-Rivera et al.<sup>16</sup> presented a simulation of an office room on the top floor of a building with four configurations of glazed areas [clear glass, glass-film (SnS–Cu<sub>x</sub>S solar control coating), double-glass-film, and double clear glass] in Mexico City and Ottawa. In Mexico City, solar control coating showed the worst energy performance when added on both a clear glass and a double glass. But in Ottawa, it showed that the glass film slightly reduced the

amount of energy load (about 2.6% on clear glass and 2.8% on double clear glass) due to the increase of the film temperature. Singh and Garg<sup>14</sup> studied the energy efficiency of double glazing with absorbing film-coated gap in India. The results show that solar-controlled windows consume more energy than base windows in climate conditions where there is no cooling demand. However, solar-controlled windows were successful in predominantly cooling climate conditions. Kim et al.<sup>17</sup> evaluated thermal performance of spectrally selective-coated double glazing in Korea, and the estimation result of annual energy consumption showed that the spectral selective-coated double glazing with low-E layers combination was 21% more energy-efficient than the single-coated low-E double glazing combination and 33% more energy-efficient than clear double glazing. Moretti et al.<sup>18,19</sup> presented a thermal energy analysis, which showed that solar control films strongly reduced the incoming solar radiation (about 60%), decreased the cooling energy demand by about 29%, but increased the heating energy demand by about 15% in Perugia, Italy. Pereira<sup>20</sup> and Teixeira<sup>21</sup> et al. studied the thermal and energy performance of glazing systems with solar control films. The results showed that applying spectrally selective solar control films on glazing systems could reduce energy use and cost by 38% in Lisbon, Portugal.

The previous research has shown that the energy-saving effect of glazing systems with the SSF not only depends on the own parameters of the coated glass itself, but also is related to the climate conditions, the window orientation, the building parameters, and so on. For China, it has vast territory, wide range of latitudes and different terrain, which results in the great variety of climate conditions. According to the different temperature and insolation conditions, it can be divided into five climate zones: severe cold zone, cold zone, hot summer and cold winter zone, moderate zone, and hot summer and warm winter zone. Accordingly, the use of different types of glazing systems is varied in different climate zones. In terms of the structure of glazing systems, there are a large number of existing buildings with single clear glass installed in climate zones where the energy consumption of refrigeration is the main factor. Meanwhile, in climate zones where the energy

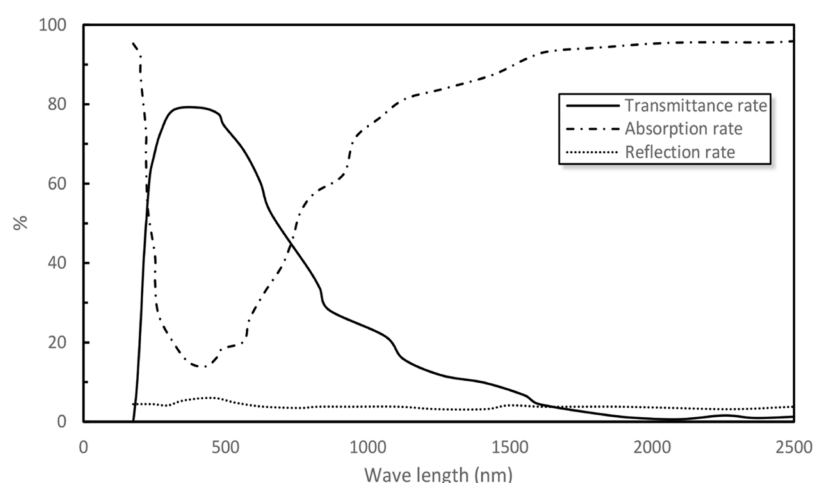


Figure 2. Optical characteristics of SSAF.

consumption of heating is the main factor, a double clear glazing system is the most common in existing buildings. These transparent envelopes would have great potential for energy-saving if they were retrofitted by glazing systems with the SSAF. Several case studies on the climatic conditions of China have also been conducted. Utilizing window films could reduce the building cooling load in the Shanghai,<sup>3</sup> and the increment of the building heating load was slight. In Hong Kong, a solar film on single clear window glass would save 44–57 kW h/m<sup>2</sup> per year for the shopping mall and the hotel guest room,<sup>22</sup> and it could save up to 15.22% of electricity per year in comparison with the normal glass.<sup>12</sup> But the comparative study of the SSAF's performance in different climate zones has not been reported and there is some confusion about the appropriateness of the SSAF for the specific climate in China. In this paper, the optical and thermal properties and energy-saving performance of the SSAF in different types of glazing systems under different climate zones in China will be further studied.

## 2. RESULTS AND DISCUSSION

**2.1. Optical Characteristics of the SSAF.** The transmission, absorption, and reflection characteristics of the SSAF are shown in Figure 2. The SSAF exhibited high transparency in visible light regions (390–780 nm) and good shielding property of the NIR ray regions (800–2500 nm). The solar energy of the NIR ray was almost absorbed by the SSAF, which was eventually dissipated into the room and outdoor by convection, conduction, and longwave radiation. This further verified that SSAF could reduce the solar energy directly entering the room, affecting the heat transfer process of the glazing system.

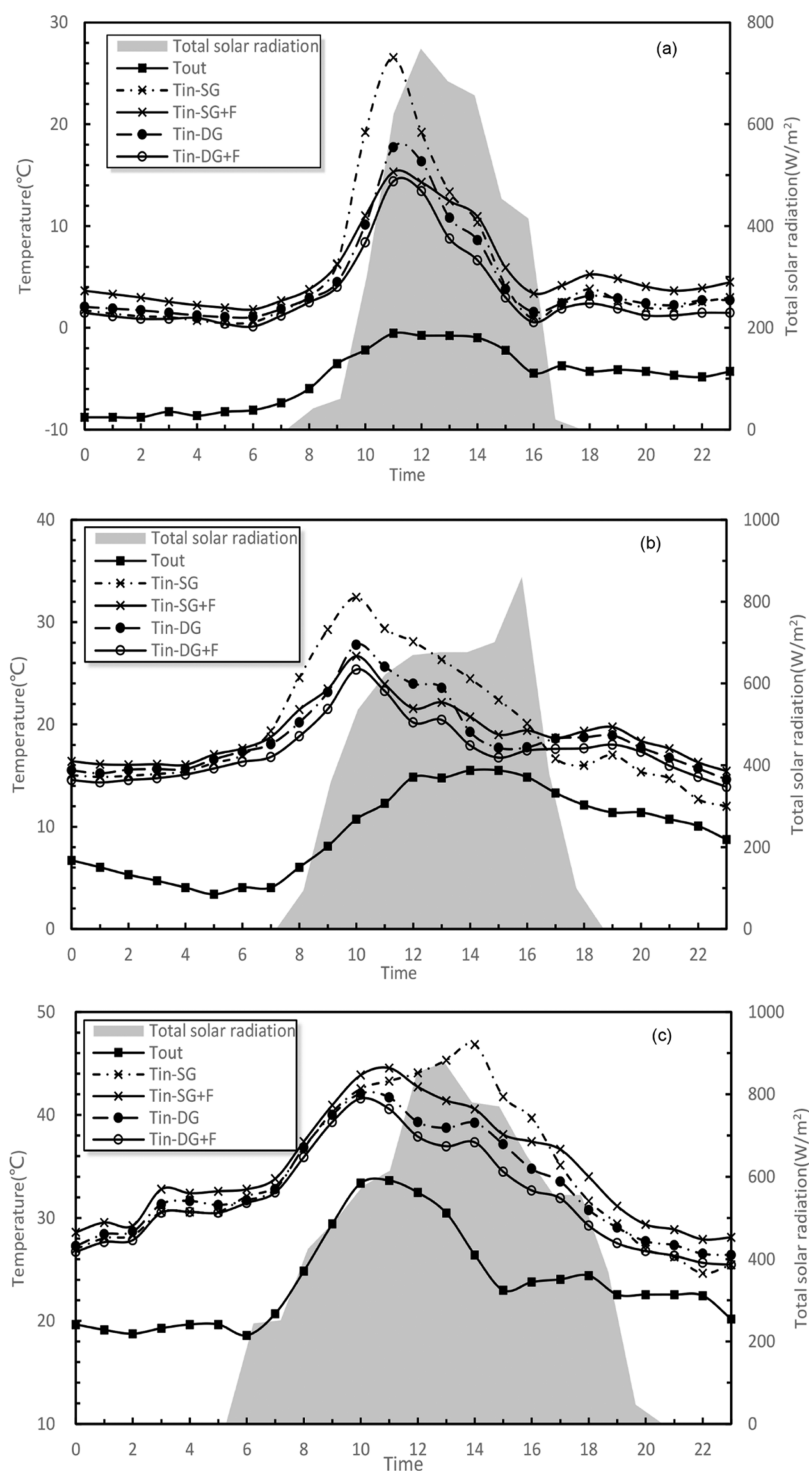
**2.2. Thermal Properties of the SSAF.** Figure 3 shows indoor air temperatures ( $T_{in}$ ) for each glazing system with/without the SSAF in different seasons. For the single glazing system (Case SG) and double glazing system (Case DG), the indoor air temperature ( $T_{in-SG}$ ,  $T_{in-DG}$ ) increased rapidly in the morning and was significantly higher than the outdoor air temperature ( $T_{out}$ ). Apparently, this was attributed to the greenhouse effect, that is, most of the solar radiation energy went directly into the room, while longwave radiation of the interior surfaces was blocked by the window and returned inside. In the daytime (with solar radiation), the maximum air temperature difference between indoor and outdoor of Case SG and Case DG reached 20.4–27.1 and 14.2–18.3 °C,

respectively. Similar temperature trends were found in Case SG and Case DG, although the rise of indoor air temperature was slowed down in Case DG.

For the single glazing systems coated with the SSAF (Case SG + F) and the double glazing system coated with the SSAF (Case DG + F), the indoor air temperatures ( $T_{in-SG+F}$ ,  $T_{in-DG+F}$ ) were reduced. In the daytime, the maximum air temperature difference between indoor and outdoor in Case SG + F and Case DG + F decreased by 2.3–11.2 and 0.5–3.3 °C, respectively, which was much lower than that in Case SG and Case DG (20.4–27.1 and 14.2–18.3 °C). This indicated the SSAF had an important effect to slow down the rise of  $T_{in}$ , especially for the single-glass system. This effect was varied in different seasons. In Case SG + F, the maximum indoor temperature was 15.3 °C (11 am on the winter design day), 26.7 °C (10 am on the spring design day), and 44.6 °C (11 am on the summer design day), respectively. Compared with Case SG, the indoor air temperature decreased by 11.2, 5.8, and 2.3 °C, respectively. In case DG + F, the maximum indoor temperature was 14.4 °C (11 am on the winter design day), 25.4 °C (10 am on the spring design day), and 41.6 °C (10 am on the summer design day), respectively, which were lower than that of Case DG and reduced by 3.3, 2.4, and 0.5 °C, respectively. Although the SSAF can perform the same deceleration in the double glazing system as in the single glazing system, the deceleration rate was obviously weakened in the double glazing system.

In addition, the indoor air temperature difference between glass coated with and without the SSAF almost disappeared at night. This indicated that the SSAF only worked in the presence of solar radiation. At night, there was no significant difference in thermal performance between glazing systems coated with and without the SSAF.

**2.3. Heat Transfer in the Single Glazing System.** The temperature data of the glass system ( $T_{glass}$ ) and indoor and outdoor air for the single glazing system were also synchronously collected, and the results were shown in Figure 4. In Case SG, the maximum temperature of the glass system ( $T_{glass-SG}$ ) was slightly lower (2.6–6.2 °C) than that of indoor ( $T_{in-SG}$ ) in the daytime. After coated with the SSAF (i.e., Case SG + F), the inner surface temperature of the glass system ( $T_{glass-SG+F}$ ) increased significantly and was remarkably higher than the indoor temperature. This phenomenon was ascribed to the NIR ray absorption of the SSAF. The higher



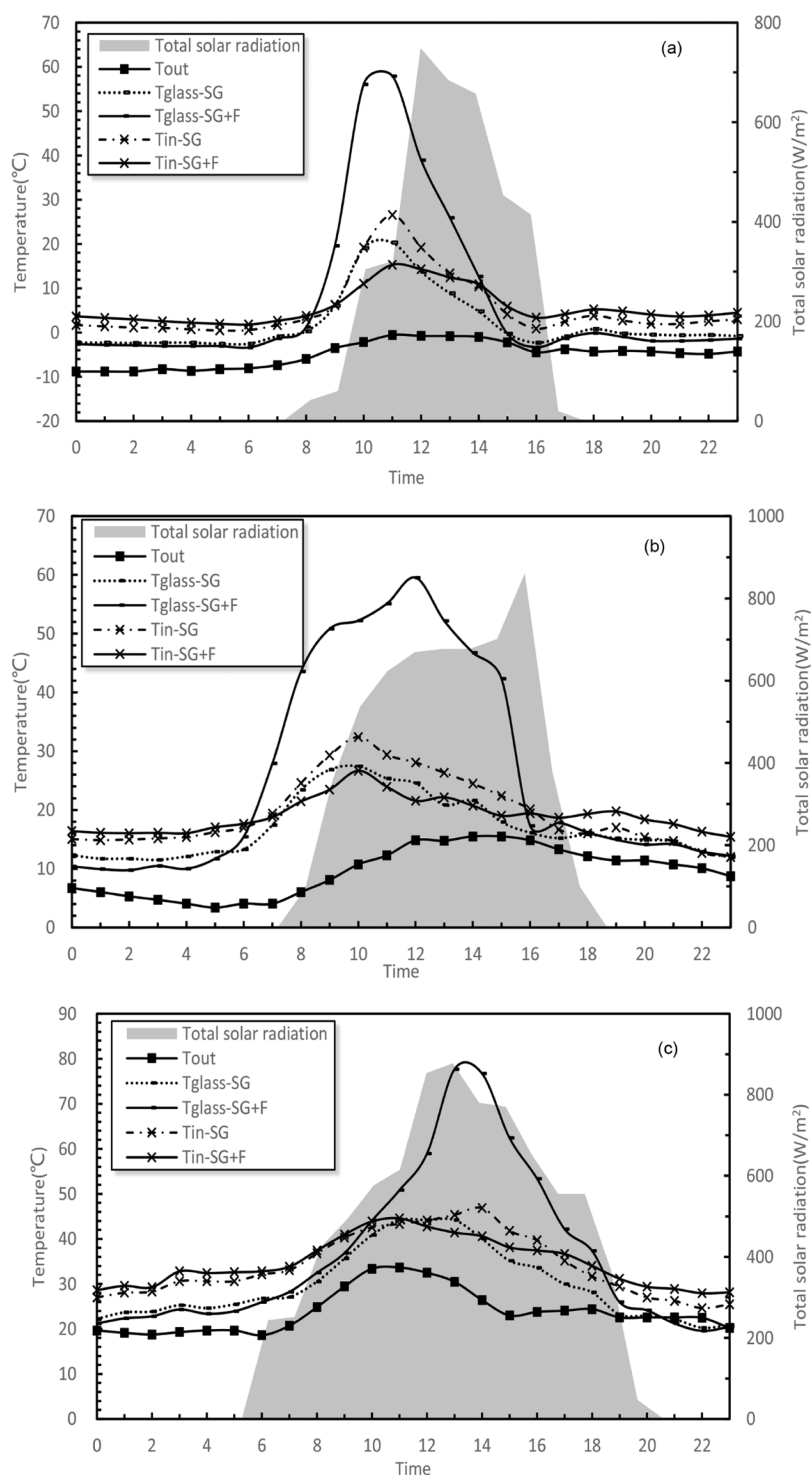
**Figure 3.** Indoor air temperatures for each glazing system, outdoor air temperature, and total solar radiation in different seasons: (a) winter, (b) spring, and (c) summer.

temperature of the glass system indicated that there would be more energy of convection heat flux and radiation heat flux toward the interior of the room; the lower indoor air temperature ( $T_{in}$ ) indicated that there would be less total energy toward the interior of the room passing through the glass. This implied that the reduced value of solar energy passing through the glass was higher than the added value of convection heat flux and radiation heat flux into the room,

which could be considered as the most essential point of the SSAF's optical and thermal performance.

**2.4. Heat Transfer in the Double Glazing System.** The indoor, outdoor, and glass temperature for the double glazing system is shown in Figure 5. By comparing Figures 4 and 5, the influence of the SSAF on the thermal property of the double glazing system was consistent with that of the single glazing system, that is to say, the SSAF would raise the surface temperature of the double glazing system ( $T_{glass-DG+F}$ ). The



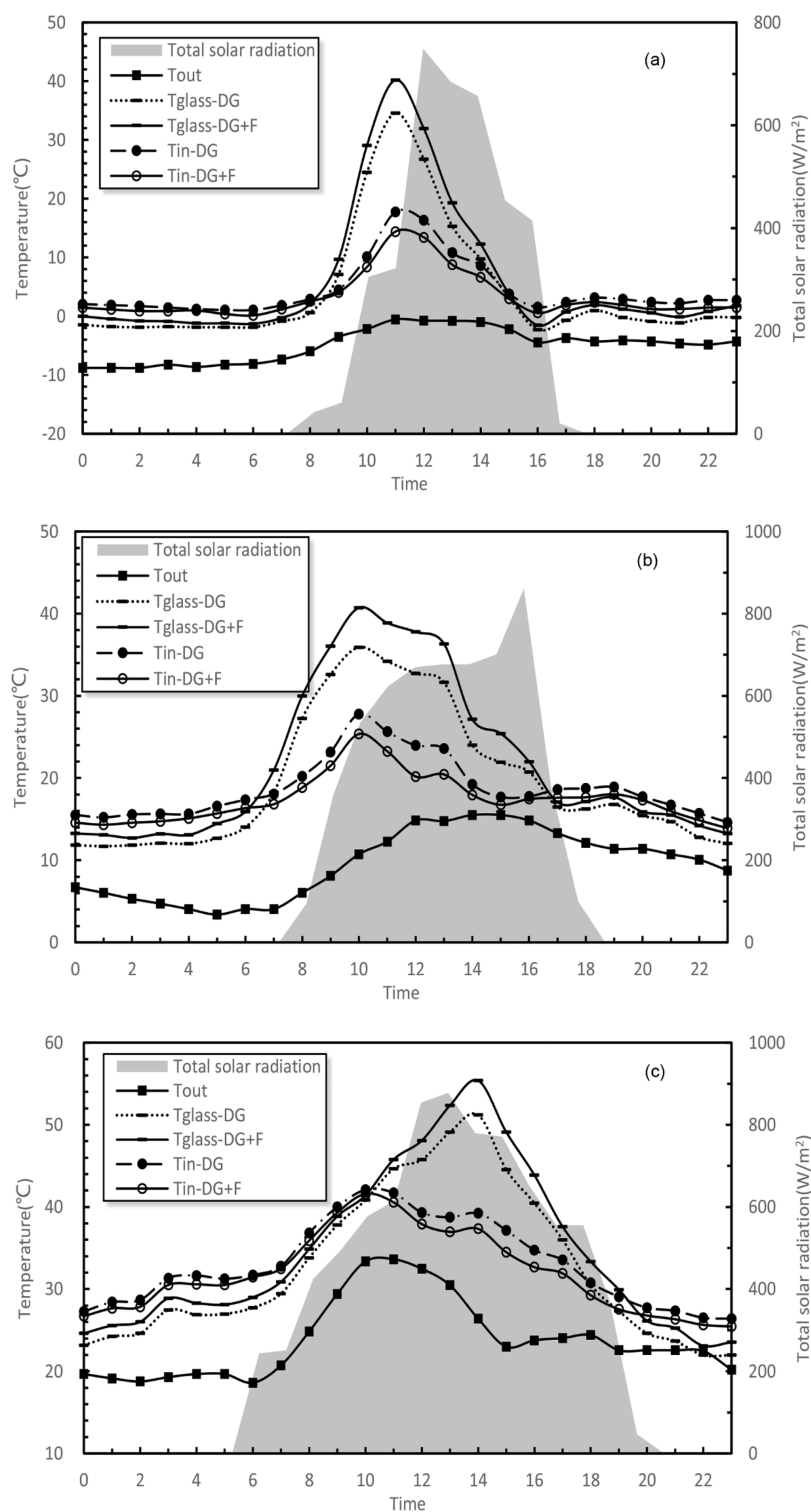


**Figure 4.** Indoor and outdoor air temperature, glazing system temperature for single glazing system, and total solar radiation in different seasons: (a) winter, (b) spring, and (c) summer.

direction of convective heat transfer and radiation heat transfer was toward the interior of the room, and the lower indoor air temperature ( $T_{in-DG+F}$ ) indicated that the SSAF would reduce the total energy into the room. However, it was worth noting that the difference between  $T_{glass-DG}$  and  $T_{glass-DG+F}$  was narrowed by the double glazing system. The maximum  $T_{glass-DG+F}$  was 40.2 °C (11 am on the winter design day), 40.7 °C (10 am on the spring design day), and 55.4 °C (2 pm on the summer design day), and corresponding  $T_{glass-DG}$  was

34.6 °C (11 am on the winter design day), 35.9 °C (10 am on the spring design day), and 51.2 °C (2 pm on the summer design day), respectively. Furthermore, it was illustrated that the influence of the SSAF on the thermal performance of glazing systems and rooms was reduced by double glazing.

Although the above analysis of the heat transfer process was carried out under the weather conditions of Tianjin, the consistent conclusions obtained on design days in different seasons were applicable to different climate zones. These



**Figure 5.** Indoor and outdoor air temperature, glazing system temperature for the double glazing system, and total solar radiation in different seasons: (a) winter, (b) spring, and (c) summer.

conclusions include that the film can slow down the rise of  $T_{in}$  in the daytime, that the rate of the slowdown in the single glazing system is higher than that in the double glazing system, and that SSAF can reduce the total energy entering the room, although the SSAF allows more energy of convection heat flux and radiation heat flux toward the interior of the room.

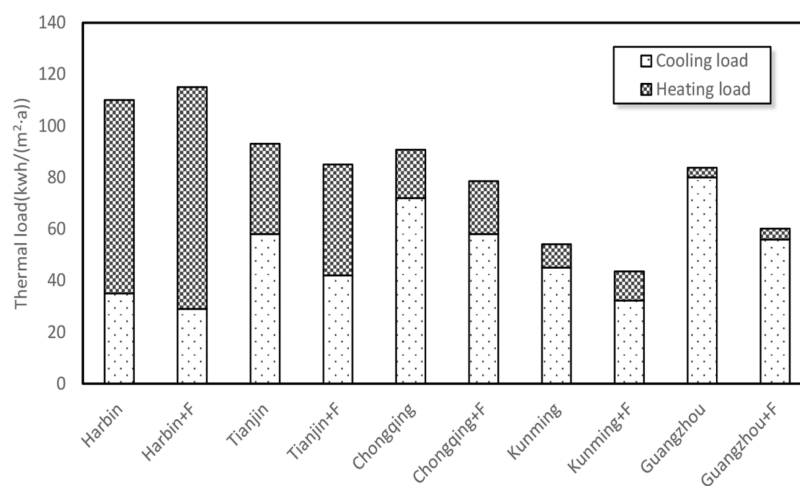
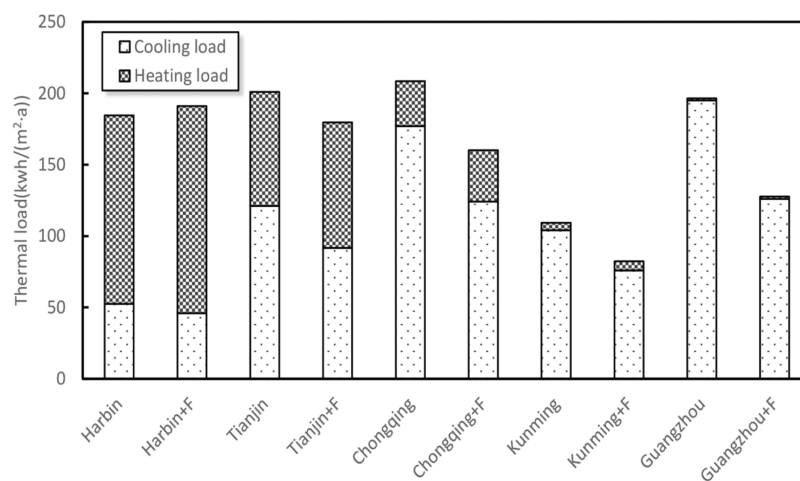
**2.5. Energy Consumption Simulation in Different Zones.** In order to elucidate the energy-saving effect of SSAF

in different zones, the energy consumption simulation was carried out. Before the simulation of building energy consumption, the thermal and optical parameters of the glazing system with/without the SSAF should be fed into EnergyPlus, which are shown in Table 1.

Figure 6 presents the heating and cooling energy demand for single glazing systems coated with and without SSAF in different climate zones. The results showed that the SSAF

**Table 1. Thermal and Optical Parameters of the Glazing System with/without the SSAF**

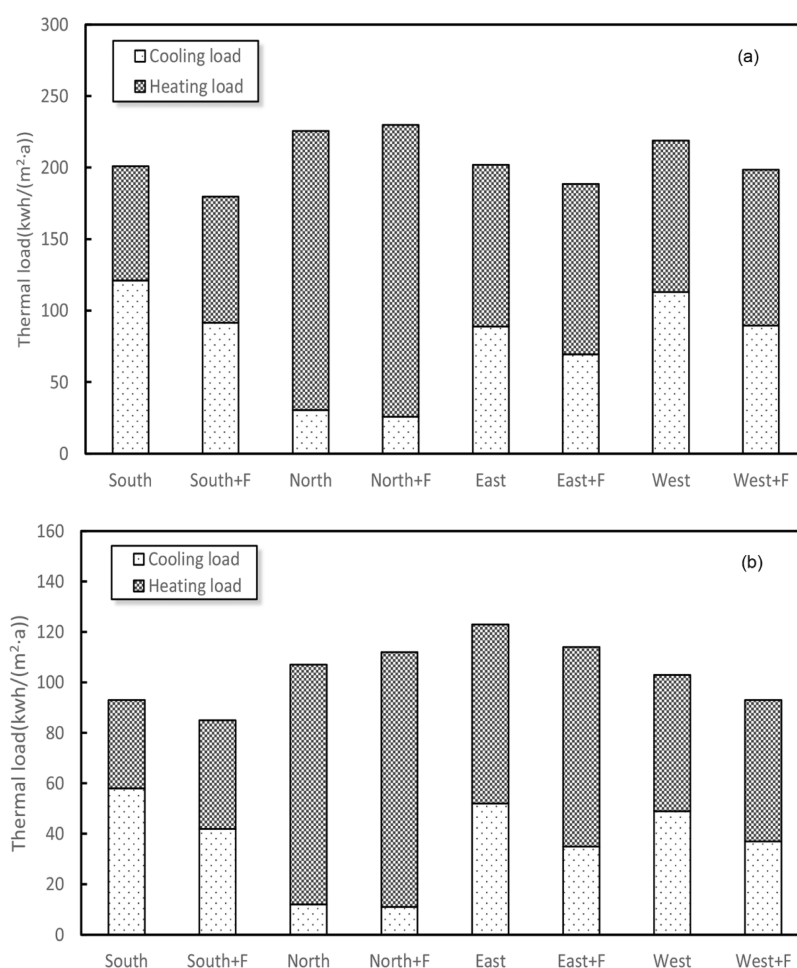
type of glass system	$U$ ( $W/m^2 \cdot K$ )	SC	SHGC	visible transmittance	solar transmittance
clear glass (SG)	5.83	0.95	0.83	0.89	0.78
double glass (DG)	2.67	0.82	0.71	0.79	0.65
clear glass + films (SG + F)	5.82	0.69	0.63	0.52	0.24
double glass + film (DG + F)	2.62	0.64	0.56	0.40	0.16
double low-E glass (DG + low-E)	1.80	0.63	0.54	0.70	0.54
double low-E glass + films (DG + low-E + F)	1.78	0.54	0.47	0.36	0.12

**Figure 6.** Building energy consumption of single glazing systems without SSAF (city) and single glazing systems coated with SSAF (city + F).**Figure 7.** Building energy consumption of double glazing systems without SSAF (city) and double glazing systems coated with SSAF (city + F).

could reduce the energy consumption of windows in Tianjin, Chongqing, Guangzhou, and Kunming. Among them, the energy-saving rate of the SSAF was the highest in Guangzhou, which reached 35.0%. In Tianjin, Chongqing, and Kunming, the rates reached 10.6, 23.3, and 24.7%, respectively. The reduction of total energy consumption in these climatic conditions had direct relevance to the reduction of cooling load. There was hardly any demand of heating load in Guangzhou, which caused an excellent energy-saving effect. In Tianjin, Chongqing, and Kunming, although the heating load increased by 10.0, 14.3, and 20.2%, the reduction trend of total energy consumption did not seem to be influenced by any of them, which was a relatively small part of total energy consumption. In Harbin, the total energy consumption increased by 3.5% after the glazing system was coated with

the SSAF. In particular, the energy consumption of heating increased by 9.8%, and compared with the cooling load, the heating load accounted for a more significant proportion of the total energy consumption. Thus, it can be seen that the energy-saving effect of the SSAF for single glass systems was related to the building climate conditions. In cities where the cooling load was considered as the main part of building energy consumption, the use of the SSAF was energy-saving. The greater the proportion of cooling in the total energy consumption, the better the energy-saving effect. In cold areas, it was not recommended to use the SSAF as an energy-saving measure for single glazing systems.

Figure 7 presents the heating and cooling energy demand for double glazing systems coated with and without SSAF in different climate zones. The results showed that the SSAF



**Figure 8.** Building energy consumption for different orientations (a) in single glazing systems and (b) in double glazing systems.

brought about 8.6, 13.3, 19.4, and 28.3% of the building energy consumption reduction in Tianjin, Chongqing, Kunming, and Guangzhou, respectively. In these applicable cities, the energy-saving rate in the double glazing system was not as good as that in the single glazing system. In Harbin, for a representative city in the severe cold zone, after the double glazing window was coated with the SSAF, the heating energy consumption increased by 14.7%, and the total energy consumption increased by 4.5%. It can be seen that SSAF applies to the same range of climate zones for double glazing systems as for single glazing systems. It demonstrated that the SSAF could not play an energy-saving performance in the severe cold region. Moreover, the simulation studies in Hong Kong suggested that the applying of SSAF would have better energy performance than low-E coatings in hot summer and warm winter zones.<sup>12</sup> Although the research results in Canada showed that the performance of SSAF did not significantly exceed low-e glazing systems<sup>13</sup> under the conditions of both heating and cooling demands, it has been proven to be an effective option to choose SSAF for the retrofitting of the glazing system of existing buildings due to its low cost, easy installation, and minimal disruption to building occupants. Of course, the research in India showed that whether SSAF had better performance than low-E coating was also affected by building location, orientation, window type, and other factors,<sup>14</sup> which required a concrete analysis of specific situations.

To sum up, it can be concluded that the SSAF has a good energy-saving effect in the hot summer and cold winter zone, moderate zone, and hot summer and warm winter zone, where the cooling load plays a major part in total energy consumption. No matter whether the existing glass configuration is single glazing or double glazing, SSAF has the energy-saving potential. The energy-saving rate of the SSAF in the single glass system is higher than that in the double glass system. In the cold zone, if the cooling load is higher than the heating load, the application of SSAF has the possibility of energy-saving. But in the severe cold zone, SSAF is not recommended as an energy-saving measure.

**2.6. Energy Consumption Simulation for Different Orientations.** Taking the Tianjin Zone, for example, the influence of the SSAF for different orientations on building energy consumption was investigated, and the results are shown in Figure 8. Figure 8a showed that the energy-saving effect of the SSAF performed well when applied in the east, south, and west orientations in single glazing systems. Among them, the energy-saving rate in the south orientation was the highest (10.6%), and it could also reach 6.7 and 9.4% in the east and the west orientations, which was acceptable. However, in the case of north orientation, the energy-saving rate was 4.6%. Figure 8b showed that the energy-saving effect of the SSAF in different orientations using the double glazing system was in good agreement with that in the single glass system. In the east, south, and west orientations, the SSAF reduced the building energy consumption by 7.3, 8.6 and 9.7%,



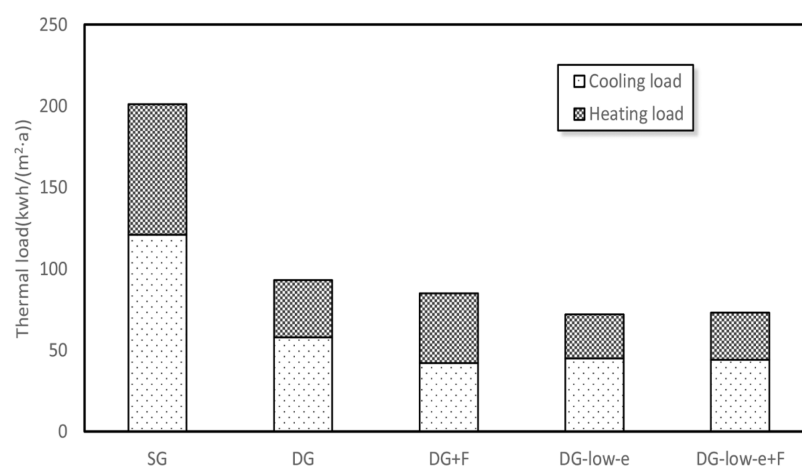


Figure 9. Building energy consumption on the low-E double glazing system.



Figure 10. Field study rooms (room A: SG, room B: SG + F, room C: DG, and room D: DG + F).

respectively. In the case of the north orientation, the SSAF increased the building energy consumption by 4.7%. To sum up, the SSAF can be applied in the east, south, and west orientations, where the SSAF will bring energy-saving effects. But the SSAF was not recommended in the north orientation. Of course, if the city is located in the south of the Tropic of Cancer, that is, windows' shading is demanded in the north orientation, the SSAF can also be considered. But the energy-saving effect needs to be judged according to the actual situation.

**2.7. Energy Consumption Simulation for Low-E Double Glazing System.** The influence of the SSAF on building energy consumption for low-E double glazing system is shown in Figure 9. It could be exhibited that the energy-saving rate of the double glazing system coating the SSAF was 8.6% compared with that of the double-glass system, which was lower than that of the low-E double-glazing system as 22.6%. However, compared with the single-glazed system, the double glazing system coating the SSAF could reduce the building energy consumption from 201 to 85 kW·h/m<sup>2</sup>·a, which was higher than that of the low-E double glazing system (72 kW·h/m<sup>2</sup>·a). The use of the SSAF in low-E double-glazed systems had little effect on building energy consumption (up to 1.4%). Therefore, the SSAF does not have the energy-saving potential in existing buildings that already have low-E double glazing

systems applied. Of course, the SSAF, as a measure to isolate ultraviolet light and prevent glare, will not bring an increase of building energy consumption in the low-E double glazing system.

### 3. CONCLUSIONS

In the room with the south-orientation window,  $T_{in-SG}$  and  $T_{in-DG}$  raised rapidly in the morning and were significantly higher than  $T_{out}$ . The SSAF played an essential role in slowing down the rise of  $T_{in}$ . Compared with the single glazing system, the deceleration rate was obviously weakened in the double glazing system. In Case SG + F and Case DG + F, there would be more energy of convection heat flux and radiation heat flux but less total energy toward the interior of the room, which was generated by the higher  $T_{glass}$  and the lower  $T_{in}$ . The SSAF can reduce the energy consumption of windows in Tianjin, Chongqing, Guangzhou and Kunming. The highest energy-saving rate was 35.0% for the single glazing system and 28.3% for the double glazing system under the Guangzhou condition. The SSAF had a good energy-saving potential in hot summer and cold winter zone, moderate zone, and hot summer and warm winter zone. The energy-saving rate of the SSAF in the single glass system was higher than that in the double glass system. But in severe cold zone, the SSAF was not recommended as an energy-saving measure. Applied in the

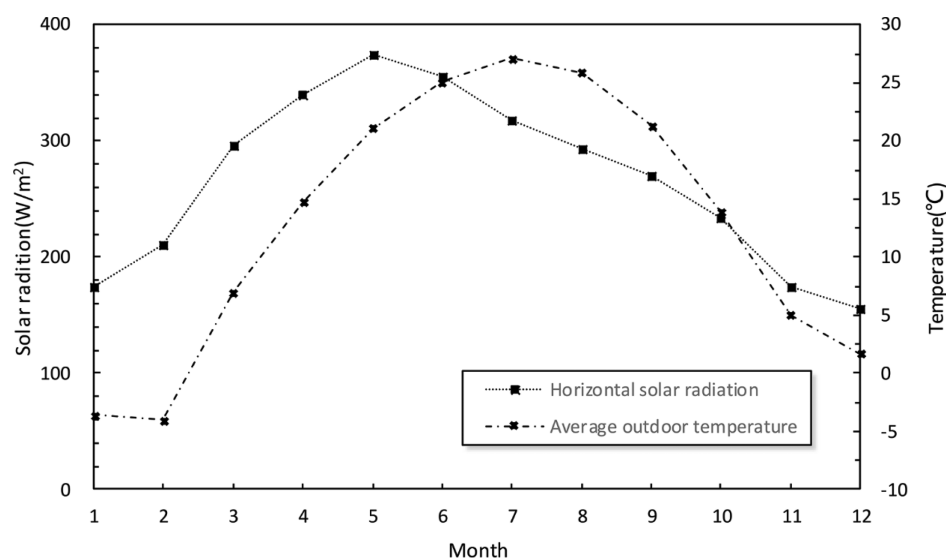


Figure 11. Monthly weather data of Tianjin.

east, south, and west orientations, the SSAF can bring energy-saving effects. Nevertheless, the SSAF did not have the energy-saving potential in existing buildings that have been already applied with low-E double glazing systems.

## 4. EXPERIMENTS AND METHODS

**4.1. Measurement and Analysis of Optical and Thermal Performance Parameters.** The SSAF used in this study was purchased from Chizhou Yingpai Technology Co., Ltd, China. The UV-vis-NIR transmittance and reflectance of the film samples were performed on a Lambda 950 UV/vis/NIR spectrophotometer from PerkinElmer. The UV-vis-NIR spectrophotometer is in the range of 175–3300 nm using an integrating sphere detection system. The absorbance spectra were calculated from the transmittance and reflectance data.

**4.2. Field Study.** In order to evaluate the thermal performance of the glazing system coated with the SSAF, four similar offices (room A, B, C, D in Figure 10) in a four-story office building located in downtown of Tianjin City were used. The four offices are identical in size [17.68 square meters (5.2 m × 3.4 m)]. The only window [a plastic-steel window with double glass units (6 mm + 10 mm A + 6 mm)] is installed on the south facade orientation. Each glass unit has an area of 2.4 m by 1.8 m. Inside the office, the floor is brown and the walls are painted with white interior paint. At the beginning of the measurement, the glass units in two of the offices (room A and room B) were changed to single glazing (6 mm). The single glazing system of room B and the double glazing system of room D were coated with the SSAF. The glazing systems of room A, B, C, and D were single glazing (SG), single glazing coated with the SSAF (SG + F), double glazing (DG), and double glazing coated with the SSAF (DG + F), respectively.

Tianjin is a city with four distinct seasons, which is hot and sunny in summer, cold in winter, and mild in spring and autumn. The typical weather data (monthly average outdoor temperature and horizontal solar radiation) obtained from a self-established weather station near the experimental site was shown in Figure 11. In order to investigate the effect of the SSAF on thermal and energy performance in different seasons, the typical days (named spring design day, summer design day

and winter design day, respectively) between June 2019 and September 2020 were selected in spring, summer, and winter for sample analysis, respectively. The daily average temperature was close to the quarterly average temperature. The climatic characteristics of autumn are similar to those of spring and have not been repeatedly measured and analyzed.

During the measurement process, the following parameters were measured: outdoor temperature, the indoor temperature in each room (the center point of the room and 1 m above the ground), inner surface temperature of the glass in each glazing system (measured by the thermocouples taped on the center point with clear tape), and total solar radiation in the outdoor plane (on the roof). The temperatures were measured by flat metal thermocouples and the total solar radiation was measured by a solar radiation master meter sensor. The program of data acquisition and recording was designed through the temperature detector and radiometer, and the data were collected once an hour. This study only focused on the impact of the coated glass on the thermal performance of buildings, so all the air conditioning systems were turned off during the measurement.

**4.3. Energy Consumption Simulation.** The performance of the building's heating and cooling energy consumption was evaluated by the building energy consumption simulation software (EnergyPlus). Before the simulation, thermal performance calculation software (the Guangdong Jianke MQMC) was used to calculate the thermal and optical parameters (such as *U*-value, shading coefficient, solar heat gain coefficient, visible and solar transmittance, etc.) of the glazing system with/without the SSAF, and then, the results were exported into EnergyPlus for simulation.

For the comparative energy evaluation in different climatic conditions in China, the heating and cooling energy demand assessment was conducted in representative cities in five major climatic zones: Harbin in the severe cold zone, Tianjin in the cold zone, Chongqing in the hot summer and cold winter zone, Kunming in the moderate zone, and Guangzhou in the hot summer and warm winter zone. The models of room A, B, C, and D were used for simulation in different climate zones, which were named as Case SG, Case SG + F, Case DG, and Case DG + F, respectively. The energy consumption results were calculated based on the standard weather document

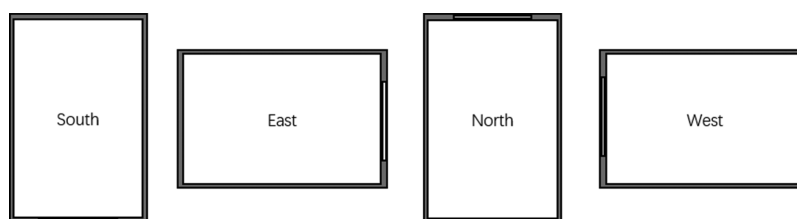


Figure 12. Plan sketch of rooms with different orientations.

(International Weather for Energy Calculation weather file) for the zone. Before the evaluation began, the model was validated according to the measurement data of the Tianjin Spring Design Day to determine whether the model accurately simulated the actual situation. In order to facilitate data comparison, the room air temperature in all energy demand assessments was set to 20 and 26 °C for heating and cooling, respectively, and the building and HVAC systems were operating from 6 am to 6 pm. Other parameters were set by the general setting of the office building. Meanwhile, the influence of different building orientations on thermal and energy performance was also considered. The plan sketch of this case studies different orientations, as shown in Figure 12.

The energy consumption was simulated and analyzed for the building applying the double low-E glazing system with or without solar control window film. It can be used to compare the energy-saving effect of the SSAF and low-E film. The feasibility of the application of the film in the double low-E glazing system was explored.

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