Analysis of Influence of Glazing Systems on Indoor Environment of a Passive Solar Building in Lhasa

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Abstract. Solar energy, which is inexhaustible and clean, has been widely used in passive or positive manners. A well-constructed passive solar house can improve the indoor environment and save energy of mechanical systems. Design of glazing system plays a vital role in passive solar buildings. This paper analyses influence of glazing systems on indoor environments of a passive teaching building in Lhasa, southwest on the Tibetan Plateau, China, for the purpose of optimizing retrofitting its windows. In this project no HVAC system is used, so indoor temperature is the main factor for evaluating the performance of different glazing systems. Four glazing systems were compared by computing uncomfortable hours and net heat addition of windows, using DesignBuilder. Economy is compared as well. Results show that single low-e clear 3mm (e=0.2) glazing leads to the most comfortable indoor environment in this project. Net heat of windows and comfortable rate are suggested to assess the overall performance of glazing systems. Generally speaking, we can't use SHGC or U-Value to determine the best glass system only in the actual situation. Careful simulation is necessary to obtain the comprehensive performance of windows in a passive solar building.

1. INTRODUCTION
The renewable energy has received great attention from the international community. The total amount of development and utilization of renewable energy was 2.86 hundred million tons standard coal, which was about 8.9% of the national total primary energy consumption in China during 2010[1].

Solar energy, which is inexhaustible and clean, has been widely used in passive or positive manners[2]. A well-constructed passive solar house can improve the indoor environment and save energy of mechanical systems[3]. Careful design is needed to ensure low energy use and good thermal comfort. Design of glazing system plays a vital role in passive solar buildings. Persson et al.[4] analyzed the influence of window size on the energy balance of low energy passive houses in the climate conditions of Gothenburg (Sweden). Karlsson and Roos[5] investigated the impact of low thermal emittance values on heating and cooling energy. Their results imply that low emittance glazing can lead to a worse performance especially in heating dominated climates and for south orientations. Poirazis et al.[6] analyzed the effect of glazing features and surface on a large office building. They found that careful design is needed to ensure low energy use and good thermal comfort, especially for highly glazed office buildings.

This paper analyzes influence of glazing systems on indoor environments of a passive teaching building in Lhasa, southwest on the Tibetan Plateau, China, for the purpose of optimizing retrofitting
its windows. Four glazing systems were compared by computing uncomfortable hours and net heat addition of windows, using DesignBuilder. After that, the author selected the optimal glazing system by combining with the economic analysis.

2. INFORMATION OF CLIMATE AND BUILDING

Lhasa has a cool semi-arid climate with frosty winter and mild summer. The annual mean temperature is 7.98°C, with extreme temperatures ranging from -16.5 °C to 30.4 °C. On the other hand, Lhasa has an abundance of solar energy. Monthly percent possible sunshine ranges[7] from 53% in July to 84% in November, and the annual sunlight hour are about 3,000. Lhasa is called the "sunlit city" by Tibetans. The insolation data[8] in Lhasa is shown in Fig.1.

The building studied in this paper is a frame structure five-story teaching building of a senior middle school (in Fig. 2). The building area is 6805 m². The shape coefficient (the ratio of external surface area to inner volume) of this building is 0.295. Occupied time of this building is from 8:00 am to 9:00 pm on work day. The thermal properties of envelope are listed in Table 1. Because it was built several years ago, the U-Values of building envelope fail to meet [9]. Table 2 shows the window to wall ratio.

| Table 1: Thermal properties of existing envelopes |
|-----------------|-----------------|
| Existing envelope | U-Value [W/m²-K] | Description |
| External wall | 1.79 | Thick hollow brick 240mm |
| External window | 5.78 | Single clear glazing 6mm |
| External door | 5.28 | Single glass door |
| Roof | 1.27 | Concrete roof |
| Floor | 1.94 | Reinforced concrete floor |

| Table 2: Window to wall ratio |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Position | Unit | Total | North | East | South | West |
| Gross wall area | [m²] | 3558.27 | 489.42 | 569.31 | 1926.38 | 573.16 |
| Window opening area | [m²] | 940.74 | 32.4 | 117.06 | 713.37 | 77.92 |
| Gross window-wall ratio | [%] | 26.44 | 6.62 | 20.56 | 37.03 | 13.59 |

Retrofitting its windows is under consideration in order to improve the indoor environment, without adding HVAC systems. According to the current design standard for energy efficiency of public buildings, three types of glazing systems, as given in Table 3, will be considered in the retrofit. Thermal properties of Scheme 2 cannot meet prescriptive requirements whereas that of scheme 3 and 4 can meet prescriptive requirements.
Table 3: Thermal properties of glazing systems for retrofitting

| Scheme | Type                              | U-Value [W/m²-k] | SC | SHGC |
|--------|-----------------------------------|------------------|----|------|
| 1      | Single clear 6mm                  | 5.78             | 0.921 | 0.819 |
| 2      | Single low-e clear 3mm (e=0.2)    | 3.84             | 0.864 | 0.768 |
| 3      | Double clear 3mm/13mm air         | 2.72             | 0.859 | 0.764 |
| 4      | Double low-e clear 3mm/13mm air (e=0.1) | 1.79     | 0.673 | 0.598 |

SC: shading coefficient  
SHGC: solar heat gain coefficient

3. METHOD
In this study, DesignBuilder was used to evaluate the best glazing system in Table 3. DesignBuilder is a dynamic building energy simulation program, which can provide performance data to optimize the design and evaluation. It can be applied at any stage in the building design process. The teaching building model is shown in Fig. 2. Hourly simulation will be used to help select the optimal glazing system.

![Figure 2: Building model](image)

In this project no HVAC system is used, so heating and cooling loads are not calculated. The indoor temperature is the main factor for evaluating the performance of different glazing systems. We assumed comfortable indoor temperature is 18°C and indoor temperature below 18°C means uncomfortable. The uncomfortable hours (indoor temperature<18°C) and comfortable hours (indoor temperature>18°C) are obtained based on hourly results. The annual window heat addition and loss are calculated, considering shading and solar reflection from obstructions.

4. SIMULATION RESULTS AND DISCUSSION
Hourly outside and operative temperature of four glazing systems are shown in Fig.3. The outside temperature varies from -15°C to 27°C during the whole winter in Lhasa. Although no HVAC systems are installed, the operative temperature is much higher than the outside temperature because of solar radiation. For example, the operative temperature varies from 9.0°C to 36.6°C in scheme 2; the operative temperature keeps from 9.2°C to 34.1°C in scheme 4.

The indoor environment of the occupied period, from 8 am to 9 pm, is our main interest. Fig.4 indicates the cumulated uncomfortable hours during the occupied period. From 8:00 am to 9:00 am the indoor temperature may be lower than 18 °C, whichever glazing system is employed. The reason is that heat loss exists and there is no solar heat gain in the night. The existing glazing system leads to 83 uncomfortable hours at 8:00 am, whereas uncomfortable hours of schemes 2 to 4 reduce about 48%. After 11:00 am, uncomfortable hours are very small because of the sufficient sunshine.
The rate of two operative temperature bands (i.e. uncomfortable, comfortable temperature) during the occupied period in winter is shown in Fig.5. In the view of comfortable rate, schemes 2 to 4 are all better than the existing system. Scheme 2 is the best because it results in the greatest comfortable rate.

Figure 3: Hourly temperature (Nov. to Mar.)

Figure 4: Cumulated hours under 18 °C (Nov. to Mar.)
Figure 5: Rate of two temperature bands (Nov. to Mar.)

The performance of windows can be explained using net heat. Fig.6 shows heat addition, heat loss and net heat of the four glazing systems. Heat addition depends on SHGC and heat loss depends on U-value. Net heat of windows is the total results of SHGC and U-value. Scheme 2 has the greatest net heat, which corresponds to its greatest comfortable rate.

Figure 6: Window heat (Nov. to Mar.)

As stated above, Scheme 2 does not comply with prescriptive requirements whereas scheme 3 and 4 meet prescriptive requirements. However, hourly simulated results indicate that Scheme 2 exceeds scheme 3 and 4 in terms of comfortable rate. So we cannot determine an optimal glazing system just using either SHGC or U-Value in the real circumstance. Careful simulation is necessary to obtain detail information in order to determine an optimal glazing system. Poirazis et al. have made the same kind of point in [6].

Economy must be considered in real world. Capital costs of window retrofitting are computed in Table 4. Scheme 2 is the most economic. The window opening area of this building is 940.74 m², as given in Table 2.
Table 4: Capital costs of three glazing systems

| scheme | Unit price [RMB/m²] | Total price [RMB] |
|--------|---------------------|-------------------|
| 2      | 80                  | 75259             |
| 3      | 120                 | 112889            |
| 4      | 200                 | 188148            |

In this project, scheme 2 has the greatest net heat and, accordingly, the greatest comfortable rate. Also, it is the most economic. Thus, it can be recommended for retrofitting.

5. CONCLUSION
In this paper, the performance of four glazing systems is studied for retrofitting a teaching building in Lhasa. Hourly indoor temperature, heat addition, heat loss and net heat are computed using DesignBuilder. Based on comparisons, the following main conclusions can be drawn:

In this project, scheme 2 (single low-e clear 3mm, e=0.2) is recommended for retrofitting since it has the greatest net heat and the greatest comfortable rate.

Net heat of windows and comfortable rate are suggested to assess the overall performance of glazing systems.

Generally speaking, we can't use SHGC or U-Value to determine the best glass system only in the actual situation.

Careful simulation is necessary to obtain the comprehensive performance of windows in a passive solar building.

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