A STUDY OF SOLAR CONTROL FILM IN A HOTEL BUILDING

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ABSTRACT

Energy tariff is a major cost in hotel operation. Effective use of energy can reduce operational expenditures and has important environmental benefits. Solar heat gain particularly through fenestration, contributes to a significant proportion of the building envelope cooling load. More solar radiation means more total solar heat gain and hence, more cooling requirements and larger electricity consumption for air-conditioning in hot summer. Daylight makes an interior space look more lively and attractive and people expect good natural lighting in their living spaces. Daylight is always accompanied by solar heat gain. Due to the small angle of incidence, direct sunlight can be excessive for east-facing windows in early morning and west-facing windows in late afternoon. To avoid the problems of glare, excessive brightness and thermal discomfort, occupants may block the windows with internal shading devices, resulting in poor daylighting performance, switching on electric light fittings and completely isolating with the outdoor environment. Recent advances in thin film coatings for window glass products provide a means of substantially reducing heat gain without proportionally reducing daylight transmittance. It indicates that cooling energy can be reduced, while people can enjoy more natural light and maintain visual contact with the outside environment. This study presents the optical and energy performances of a solar control film coating installed in a guest room of a three-star hotel located in Hunan Province, China. The findings indicated that solar film coating can cut down cooling load without substantially reduce the indoor daylight illuminance level. Proper solar film coating designs would minimize the building energy expenditures and maintain the visual and thermal comforts.

KEYWORDS

Solar control film; Energy; Energy efficiency; Daylighting; Hotel

INTRODUCTION

With rapid economic growth and improvement in living standards, there has been a marked increase in energy use for many developed and developing countries (Yoshino 2007). A significant proportion of the energy in terms of electricity is consumed by building stock. Electricity is mainly generated by burning the non-renewable fossil fuel which creates many adverse effects on the environment such as global warming and air pollution causing a long-term impact to the health of human beings (Electrical and Mechanical Services Department 2004). Energy-efficient building designs can reduce the energy consumption and also has important environmental benefits. Heating ventilating and air-conditioning (HVAC) is always the major electricity consuming component in hotels (Deng and Burnett 2002). Solar heat gain, particularly via fenestration, contributes to a significant proportion of the building envelope cooling load during the hot summer. More solar radiation means more total solar heat gain and hence, more cooling requirements and larger air-conditioning plant. Daylight is considered the

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best source of light for good color rendering and closely matches human visual response. The amount of daylight entering a building is through windows that allow light admitting into the indoor environment and provide a connection between the outside world and internal spaces. People expect good natural lighting in their living and working places. Daylight, however, is always accompanied by solar heat gain. Moreover, because of the small angle of incidence, direct sunlight can be excessive for east-facing windows in early morning and west-facing windows in late afternoon causing problems of glare, excessive brightness and thermal discomfort.

Recent advances in thin film coatings for window glass products provide a means of substantially reducing heat gain without proportionally reducing daylight transmittance (Li et al. 2004). It indicates that proper solar film coating applications can minimize cooling requirements for internal spaces but people can enjoy natural light and maintain visual contact with the outside environment. This paper presents the performance of the solar control film in terms of daylight illuminance and cooling energy reductions. Two guest rooms in a three-star hotel located in Hunan Province, China were used for the measurements. Characteristics of the findings are reported and design implications are discussed.

METHODOLOGY

China is a big country with various climates which have been classified into five zones, namely severe cold, cold, warm, hot summer/cold winter, and hot summer/warm winter regions (Lam et al. 2005). Figure 1 shows the distribution. Hunan Province is located in the central of China near the middle part of the Yangtze River as displayed in Figure 2. This region is characterized as hot summer/cold winter climatic zone. The average outdoor air temperatures are 25-30°C in the hottest summer month and 0-10°C during the coldest winter month. There may be quite large temperature variations from day to night times and between summer and winter months. Heating and air-conditioning plants are required in many buildings to improve the indoor built environments.

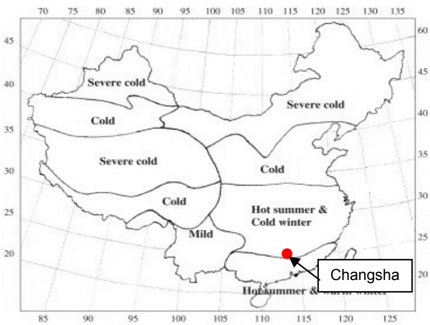

Figure 1. The five climate zones in China

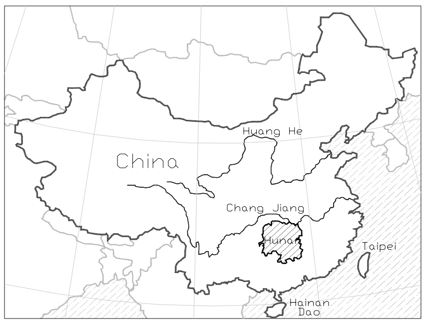

Figure 2. Location of Hunan Province

Field measurements were conducted in July 2006 in a three-star hotel in Xiangtan City, Hunan Province. The hotel is a T-shaped five-storey building located in the central urban area of the city and by the side of a crossroad. These site characteristics enable the hotel to receive direct sunlight without being sheltered by other surrounding buildings. Two standard guest rooms were selected near the east side on the fifth floor with windows facing south. Figure 3 shows that these two selected guest rooms have the same area (28.6m2), orientation and furnishing. The window area is 3.8m² (1.9m width x 2.0m height) with a thickness of 5mm. The two rooms were vacant during the experiment. The potential heat sources such as lighting and television were switched off. The set point temperature for the indoor spaces was 25 ºC. The only difference between these two rooms was that window of Room 1 was coated with a layer of solar-control film, while Room 2 was not. Table 1 shows the physical characteristics of the selected solar control film provided by the manufacturer.

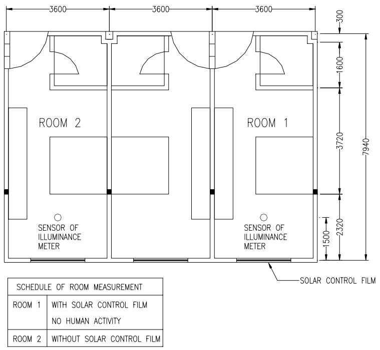

Figure 3. Layout plan for the guest rooms

Table 1 Manufacturer's Specification of solar control film

Index	Value
Sheltering Coefficient	0.66
U-Value	1.06
Visible Light Transmission	51%
Visible Light Reflectivity	15%
Solar Energy Reflectivity	10%
Solar Energy Absorptivity	45%
Solar Energy Transmission	45%
Total Solar Energy Rejection	43%
Ultra-Violet Rejection	99%

The main parameters being monitored in this experiment were the cooling loads and daylight illuminance levels inside the guest rooms, solar radiation, outdoor air temperature and relative humidity. A pyranometer (TBQ-2A, Jinzhou 322) was horizontally installed 300mm from the external wall to measure outdoor solar radiation intensity. Indoor illuminance was logged by using an illuminance meter (LT/G, Beijing QJHB Company Limited). The cooling energy was computed based on the temperature difference and the flow rate of the chilled water. The volume flow rate of the chilled water in the fan coils of the guest rooms was recorded by means of rotermeters (SPX 20mm, U.S. Haifu) and several thermometers (PTWD-2A) were adopted to collect the inlet and outlet temperatures. The indoor and outdoor air temperatures and relative humidity measurements were made using the instruments manufactured by TESTO, Germany. All the instruments were connected to a 24-Channel data logger (EN880-05, Beijing Yinghuada Electronic Co.). The measured data were of 1-minute interval transferred into this data logger for analysis.

RESULTS AND DISCUSSION

The measurement was conducted from 08:00 to 18:00 on the 20th and 21st July 2006 representing hot summer weather conditions.

Table 2 presents the measured outdoor air temperature, relative humidity and solar radiation. As shown in the table, the measured average outdoor air temperature (T_a) was 34.6ºC. The maximum and minimum temperatures were 36.6 ºC and 30.4 ºC respectively. Relative humidity (RH) ranged from 65.1% to 82.1%. In most cases, RH values were relatively high with a mean value of 67.9%. For the solar radiation, its intensity was between 45 W/m^2 and 1100 W/m^2 and the average value was about 440 W/m^2.

Table 2 Outdoor climatic data during experiment

		Day 1	Day 2	Average
	Avg	34.5	34.6	34.6
T_a (ºC)	Max	36.4	36.7	36.6
	Min	29.8	30.9	30.4
	Avg	68.3	67.6	67.9
RH (%)	Max	84.6	79.7	82.1
	Min	64.4	65.8	65.1
Solar	Avg	493.0	404.0	449.0
Radiation	Max	1097.0	1184.0	1140.0
(W/m^2)	Min	47.0	44.0	46.0

Graphical representation is a simple and direct approach to analyze and interpret the measured data. The features can reflect the daily performance of the solar control film in terms of daylight illuminance reduction. Figure 4 shows the daily interior daylight illuminance profiles for the two guest rooms with and without the solar film coating on the window glass measured on 20th July. It can be seen that similar patterns can be found for the two curves indicating the same amount of daylight falling on the facades of the two rooms. The window coatings do reduce the daylight illuminance entering the room space, particularly when large amount of illuminance is recorded. With film coating, the peak value of 950 lux was lowered to 550 lux, representing a 45% reduction. Likewise, the daily daylight illuminance profile for 21st July was determined and is displayed in Figure 5. In general, the features are quite similar to those in Figure 4. The maximum daylight illuminance values were approximately 1200 lux (without solar film coatings) and 700 lux (with solar film coatings) appearing at around 11:00. The experimental results proved that the solar control film can block certain amount of direct sunlight in summer such that the solar heat inside the room can be considerably lowered.

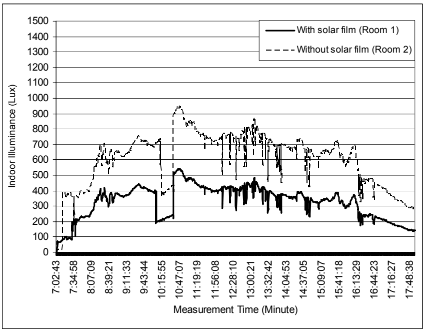

Figure 4. Daylight illuminance profiles on 20 July

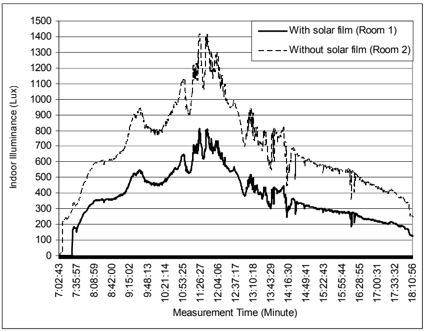

Figure 5. Daylight illuminance profiles on 21 July

To evaluate the energy reduction due to the solar control film, the cooling energy requirements were calculated using the data logged from a set of water flow meters and thermometers. Mathematically, it can be expressed as follows:

$$Q = V \times \rho \times C \times (T_2 - T_1) \quad (1)$$

where Q is the cooling energy (W), V is the volume flow rate of water (m^3/s), ρ is the water density (i.e. 1000 kg/m^3), C is the specific heat capacity of water (i.e. 4200 J kg^{-1} $ºC^{-1}$), and T1, T2 are the water temperatures flowing in and out the air-conditioning system in the room (ºC).

The cooling energy requirements between 08:00 and 16:00 on the 20th and 21st July were calculated and are presented in Figure 6 and 7. With solar film coatings on its windows, Room 1 consumed less cooling energy than that in Room 2. On 20th July, the cooling energy requirements for Room 2 (without using solar control film) were between 2200 and 2400 Wh with an average value of 2300 Wh. With film coating, the cooling energy consumption in Room 1 was significantly reduced to less than 1200Wh. On 21st July, the cooling loads were found quite constant. It can be seen from Figure 7 that the cooling energy consumption varies generally between 2600 and 3000 Wh for Room 2 and it is around 1400 Wh for Room 1, indicating a 45-50% reduction. The findings support that solar control film can reduce the solar heat gain and hence the cooling energy for air-conditioned buildings located in cold winter/hot summer region during the hot summer period.

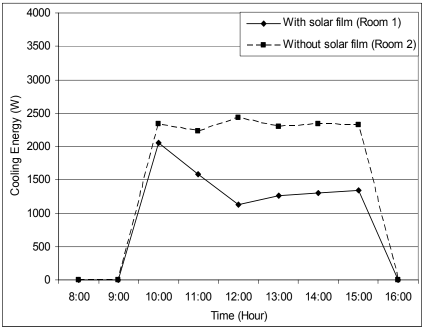

Figure 6. Cooling load consumption on 20 July

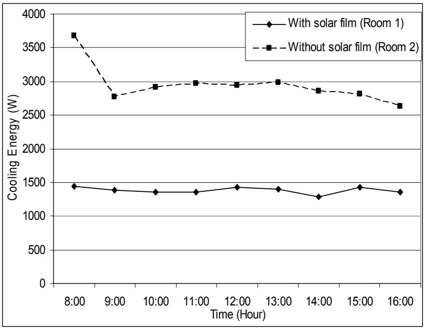

Figure 7. Cooling load consumption on 21 July

It should be pointed out that the artificial lighting energy reduction was not considered in this study. Previous research work revealed that proper lighting controls integrated with daylighting have a strong potential for reducing lighting energy demand (Li and Lam 2001, Li and Lam 2003). As indicated in Figures 4 and 5, over 96% of the measured period, the indoor illuminance level for Room 1 (with solar control film on the windows) was recorded over 100 lux which is the design illuminance for dwellings (CIBSE 1994). Given that electric lighting energy is one of the major electricity-consuming items in hotel buildings (Deng and Burnett 2002), there would be a strong potential for further energy savings if daylight linked lighting controls are used for the guest rooms, offices and restaurants in a hotel.

Apart from building energy conservation, visual and thermal comforts are also the key elements that should be considered for green building designs. A small-size survey was conducted in an open-plan office space using the solar control film in the City University of Hong Kong (Li et al. 2005). The sample size was 8 and the occupants needed to answer 14 questions which were referenced to the ASHRAE standard (ASHRAE 2003). All the occupants were assumed wearing similar clothes (long/short sleeve shirt, long straight trousers, socks and shoes) carrying out the same activity (general office work). The survey was conducted in May representing a hot summer day. The results showed that 5 occupants including those seated near to the window façade felt visual and thermal comforts and only 2 occupants had discomfort feelings. The findings can give an indication of the general feedback regarding the comfort issues for the solar control film.

CONCLUSIONS

Field measurements of solar control film performance in an air-conditioned hotel building located in Hunan Province, China were conducted. The indoor daylight illuminance levels and the cooling

energy requirements of two guest rooms with and without the solar film on the window glass were recorded and compared. Using the film coating, reductions in visible transmittance and cooling energy requirements due to the film coating were quite constant. It was found that the reductions in visible transmittance and cooling energy requirements were around 45% and 45-50%, respectively. Considering the solar control film characteristics, a 46% of cooling energy contributed by solar heat gain through fenestration can be reduced when applying the film coating on guest room window. Using the predicted model of Hong Kong case (Lam and Li 1999), solar heat gain is one of the major cooling load contribution factors. Hence, it can be stated that solar control film can effectively lessen cooling energy consumption due to building envelope cooling load.
A small-size survey regarding the comfort issues using solar film coatings was conducted. The findings revealed that most occupants felt comfortable when the façade windows were coated with a layer of solar control film. Apart from cooling energy reduction, solar film coating can be conducive to daylighting designs. Solar film coating coupled with lighting dimming controls can further cut down the electric lighting energy use and cooling energy. Additional work is required to further validate and refine the overall benefits from the using of solar film coating when more measured data are available.

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