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Effective solar shading devices for residential windows save energy and improve thermal conditions

By Dr. A. Laouadi and A. Galasiu

In office buildings and classrooms it is well-recognized that appropriate solar shading devices can control indoor illumination from daylight, solar heat gains, and glare while maintaining view out through windows, thus saving lighting and thermal energy and maintaining visual comfort. Therefore, lighting designers should have a thorough understanding of the performance of shading devices to enhance the success of their projects. In residential buildings, particularly in cold regions such as in Canada, the effects of shading devices are not well understood. In this article we present research on the thermal effects of shading devices in cold-climate houses, which we hope will provide valuable supplemental information to the lighting designer. In Canada, the energy demand for residential heating and cooling accounts for 62% of the total energy of average homes. Although the overall cooling energy demand is much lower than that for heating, some highly-populated areas experience a peak demand for electricity on summer afternoons. Effective solar shading devices such as exterior movable insulating shutters and interior highly-reflective shades may reduce residential energy demand for heating and cooling and improve thermal conditions near windows.

The National Research Council Canada Institute for Research in Construction (NRC-IRC) conducted studies in the winter and summer of 2008 to determine the thermal effect of exterior insulating rollshutters and highly reflective interior screen shadings. The study took place at the Canadian Centre for Housing Technology* (CCHT) and compared the performance of the facility's Test House fitted with the selected shading devices to the performance of the identical Reference House fitted with typical interior blinds (Figure 1). Both houses were built according to the R-2000 standard (windows are made of low-e and argon-filled insulating glazing units), and were equipped with a standard set of major appliances (stove, dishwasher, washer and dryer) and heating and cooling equipment (furnace, heat recovery ventilator, and air-conditioner), and a simulated occupancy system that replicated the daily water draws, heat and electrical loads of a family of four. Both houses were fully instrumented to measure the hourly indoor thermal conditions, electrical energy and gas use of equipment, temperatures of window and shading surfaces, and thermal conditions (air temperature and velocity, globe temperature and relative humidity) near windows.

TEST ARRANGEMENT

The Reference House was fitted with interior cream, horizontal blinds on most windows and white, vertical blinds on the patio glass door, dining room window, and stairwell window. The slats of the Venetian blinds were slightly curved and made of aluminum, while the vertical blinds were made of fabric. All interior blinds were mounted outside the window frames, leaving an open air space between the blinds and the wall incorporating the window frames.

Exterior rollshutter experiments

The performance of the exterior rollshutters was measured in the winter and summer seasons. All windows of the Test House, except the east-facing windows (which were kept closed and identical to those in the Reference House), were fitted with movable rollshutters (Figure 2). The rollshutters were made of fixed and articulated aluminum slats (beige color) with a sandwiched polyurethane insulation. The slats could be arranged so that they are tightly abutting (for winter use) or arranged with a small gap between the slats to admit some light and provide a view from inside (summer use). They were not designed to allow the slats to be angled, and could only be adjusted up and down in the vertical plane of the window using side railings installed on the brick walls. A rubber gasket installed between the side railings and the walls sealed the air space between the shutters and windows. The bottom of the shutters was not sealed to the window sill; it had a few holes to allow for water drainage.

The rollshutter experiments covered a two-week period in winter (February 1 to 14, 2008) and three-week period in summer (June 27 to July 21, 2008). For the winter experiments, the shading devices in both houses were kept open (shutters fully retracted and slats of interior blinds horizontal) from 9:00 a.m. to 5:00 p.m. to admit daylight and solar heat gains indoors, and closed (shutters drawn down, and slats of interior blinds tightly squeezed) at other times. The winter testing period comprised days with mainly overcast sky conditions (four days had mixed partly cloudy/sunny), with outdoor temperatures ranging from a minimum of -17ºC during the night to a maximum +4ºC during the day. The set point temperature for heating was fixed at 21ºC. For the summer experiments, the shading devices in both houses were kept closed throughout the testing period to explore the maximum effects; it is important to note that most residents would open shading devices for some of this period, and thus the savings reported below would be reduced. The slats of the rollshutters were loosely closed (Figure 3). The slats of the interior blinds were tightly squeezed. The testing period comprised days with various sky conditions (seven clear, three overcast, 11 mixed partly cloudy/overcast), with outdoor temperatures ranging from a minimum of +13ºC during the night to a maximum +33ºC during the day. The set point temperature for cooling was fixed at 24ºC. Indoor relative humidity was free-floating in both houses.

Interior reflective screen shading experiments

The performance of the interior reflective screen shading was measured only in the summer of 2008. All windows of the Test House, except three north-facing windows (which were kept closed and identical to those in the Reference House), were fitted with roller perforated screen shades. The screen shades were mounted outside of the window frames to allow for natural ventilation of the space between the shades and windows. This measure was taken to reduce the potential risk of excessive window glass temperatures and glass breakage, which might be caused by the reflective shades. The screen shades were made of a PVC-coated glass fibre material with an openness factor of 4%, which allowed a view-through to the outside (Figure 4). The shade surface facing the outside was coated with an aluminum-based thin film reflecting about 77% of solar radiation. The screen shades may transmit up to 6% of solar radiation indoors. The summer experiments covered a three-week period (August 26 to September 15, 2008). The shading devices in both houses were kept closed throughout the testing period. The testing period comprised days with various sky conditions (eight overcast, 13 mixed partly cloudy/clear), with outdoor temperatures ranging from a minimum of +9ºC during the night to a maximum +31ºC during the day.

RESULTS

Heating and cooling energy use

The exterior rollshutters reduced the heat loss through windows by about 20% during nighttime when they covered the house windows in the winter. Over the measurement period of twoweeks, the rollshutters reduced the heating enery use of the Test House by 4 ± 2% compared to the Reference House. These energy savings were proportional to the ratio of the window surface areas to the house's total envelope surface area (windows make up 11% of the liveable surface area).

For the summer measurement, the rollshutters reduced the daily energy use of the A/C unit of the Test House by about 45% compared to the Reference House (Figure 5). The maximum difference in the A/C daily energy use was 72%, while the lowest difference was about 23%. When the energy use of the furnace circulation fan was accounted for in the house cooling energy use, the rollshutters reduced the daily cooling energy use of the Test House by ~26±10% compared to the Reference House. The circulation fan used more than 30% of the energy use of the A/C unit. The circulation fan was continuously running with a full nominal speed with the A/C unit, and with a half of the nominal speed with the heat recovery ventilator when space cooling was not required.

The interior reflective screen shades reduced the daily energy use of the A/C unit of the Test House by about 13% compared to the A/C unit of the Reference House. The maximum difference in the A/C daily energy use was about 18%, while the lowest difference was about 10%. The daily cooling energy use (A/C plus circulation fan) of the Test House was on average ~8±2% lower than that of the Reference House.

Peak cooling load

In Ontario (Canada) the on-peak period of electricity demand is between 11 a.m. and 5 p.m. The electricity peaks usually occur during summer heat waves from mid- to late afternoon hours. During this on-peak period, the exterior rollshutters substantially reduced the peak electricity demand regardless of the sky conditions as compared to the interior blinds. A maximum reduction of 80% in the peak electrical demand was recorded around 2 p.m. under clear sky conditions, while for a heavily overcast day the maximum demand reduction was 50% (Figure 6). Calculated across the testing period, the average reduction in the electricity demand during the on-peak period was 52%.

The electricity demand reduction of the interior reflective screen shades was a lot lower than that of the exterior rollshutters. The maximum peak-demand reduction was 45% under clear sky conditions, and the average reduction during the on-peak period was 19%. The electricity demand spike at 8 p.m., shown in Figure 6, was a result of the internal heat gains from appliances and households.

Thermal conditions near windows

In addition to the energy savings and peak electricity demand reduction, the exterior rollshutters reduced the risk of moisture condensation on the interior window surfaces during the winter nighttimes; the temperatures of the internal window surfaces of the Test House with rollshutters were 4^{o}C warmer than those of the Reference House with the internal blinds. The colder window surfaces of the Reference House were, however, shielded by the closed interior blinds. Consequently, both rollshutters and interior blinds resulted in similar thermal conditions for potential occupants near windows. The thermal comfort PPD (predicted percentage dissatisfied) index, calculated for a sedentary person wearing typical winter clothes and seated at 1.2 m from a south facing window, was lower than 10% during night times. PPD indexes below 10% are considered acceptable for thermal environments for residential applications. During summer days, both the exterior rollshutters and interior reflective screen shades resulted in slightly better thermal conditions near windows when compared with the interior blinds. The PPD index in the Test House was mostly below 10% during both day and nighttime, and only reached maximum values of 22% during some evening hours. However, in the Reference House the PPD index was mostly above 10%, especially during nighttimes, reaching a maximum of 34% during the evening hours.

CONCLUSIONS

Exterior insulating rollshutters are one of the most effective shading devices to reduce residential heating and cooling energy use, summer electricity peak demand, and risk of moisture condensation on internal surfaces of windows, and to improve thermal conditions near windows. Where exterior rollshutters cannot be used such as in high-rise buildings, or where there is a risk of ice build-up in winter, interior reflective shades may provide an alternative means to reduce cooling energy use and peak electricity demand compared to absorptive interior shadings.

Figure 1 South façades of the CCHT Houses

Figure 2 Rollshutter at a closed position

Figure 3 View to outdoor through the rollshutter

Figure 4 view to outdoor through the reflective screen

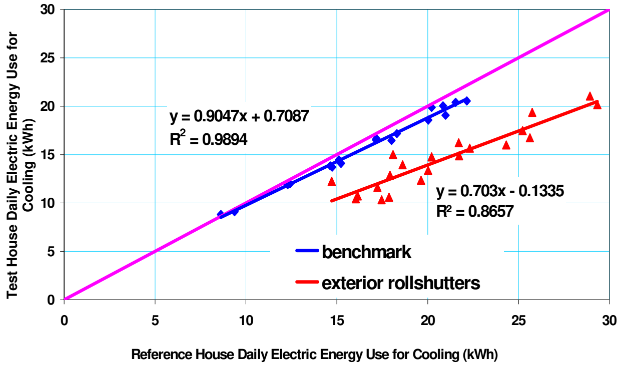

Figure 5 Daily electric energy use for cooling of the CCHT Houses with rollshutters. The benchmark line is when both houses were operated with identical interior blinds.

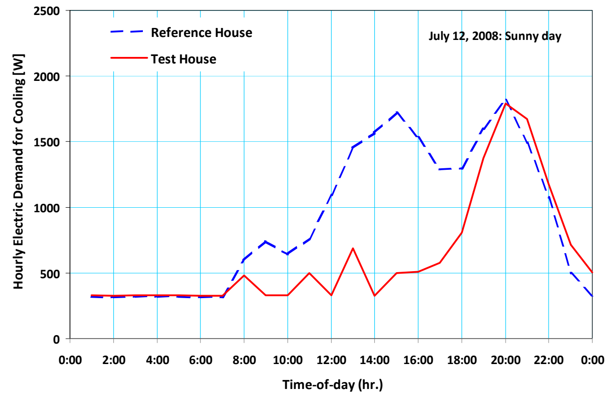

Figure 6 Hourly electric energy demand for cooling of the CCHT houses with rollshutters

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Additional information about the energy performance of the tested shading devices is available at: http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ci/volume-12-n4-13.html
http://www.ccht-cctr.gc.ca/projects/solar_e.html

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