RESEARCH HIGHLIGHT

April 2013 Technical Series 13-100

Selection of Low-e Coated Glass for Older Residential High-Rise Apartment Buildings in Canada

INTRODUCTION

In older multi-unit residential buildings (MURBs), residents often report discomfort in apartments with sunny exposures, arising from solar heat gain through windows. Apartment buildings typically lack features to control solar gain (such as exterior shades, shutters, etc.) and space heating systems often don't have flexibility to adapt to high solar heat gain (overheating) on sunny elevations and at the same time, to heat loss on non-sunlit elevations. Residents may seek relief by opening exterior windows and doors, wasting both solar heat gain as well as space heating energy. Since glazing is part of the problem, can it be part of the solution?

RESEARCH PROGRAM

A research study was carried out in three apartments in an occupied building in Ottawa, Ontario (Figures 1 and 2) owned by Centretown Citizens Ottawa Corporation. Funding for the study was provided by Canada Mortgage and Housing Corporation (CMHC) through its External Research Program (ERP) and by Natural Resources Canada (NRCan). Care should be taken in applying the results from this study to other buildings of different typology, size and location. The assistance of an expert to achieve a balance of performance benefits would be advisable.

Three southeast-facing, one-bedroom apartments in the building were fitted with equipment to monitor indoor air temperature and relative humidity and solar radiation at the exterior of the building and received through window glazings. One Control apartment was left as-is with the existing, uncoated glazing, one was refitted with high solar gain (HSG) low-e glazing and one was refitted with low solar gain (LSG) low-e glazing. Monthly visits were made to

Figure 1 Test building in downtown Ottawa, Ontario.

Figure 2 Test apartments oriented as in the building, facing east of south by 31˚.

download data, review apartment space heating and cooling operation and survey the residents of the test units on their perceptions of thermal comfort from September 2010 through September 2011. At the end of the monitoring period, data and observations in the HSG and LSG apartments were compared to the control apartment to determine what effects, if any, of HSG and LSG low-e glazing had on resident thermal comfort.

Glazing

Glazing systems were identical in each apartment. In each living room there was a sliding patio door with two parallel pairs of single-glazed sashes and a window with a fixed, double-pane insulating glass unit above a horizontal sliding window with two parallel pairs of single-glazed sliding sashes. In each bedroom there was a window with an awning sash above a fixed window, both glazed with double-pane insulating glass units. Characteristics of Control, HSG and LSG low-e glazings used in this study are given in Table 1.

Equipment and Monitoring

Test equipment was obtained from Structure Monitoring Technologies Research Ltd. (SMT) in Winnipeg, Manitoba. Each apartment was outfitted with data loggers to measure indoor air temperature and relative humidity (Figure 3). Solar radiation passing through the Control, HSG and LSG low-e glazings was measured with pyranometers installed behind the fixed glazed portion of the bedroom windows (Figure 4). Outdoor solar radiation was measured with an identical pyranometer outside the HSG apartment (Figure 5). Indoor and outdoor pyranometers were wired to data loggers

Figure 3 Data logger measuring indoor air temperature and relative humidity, typical installation (red circle).

Figure 4 Pyranometer installed behind the fixed glazed portion of the HSG apartment bedroom window, facing outward (red circle).

Table 1 Performance Data for Existing (Control) and Replacement Glazing.

Apartment	Glazing Products	U-factor W/m5.5K BTU/hr/ft^2/^{0}F	Solar Heat Gain Coefficient
Control	Living/dining and bedroom windows, double glazed, sealed insulating glass units	2.73 (0.49)	0.76
	Living/dining sliding door and window, double-run, single-glazed sashes	2.80 (0.49)	0.76
HSG Low-e	Living/dining and bedroom windows, double-glazed, sealed insulating glass units	1.91 (0.33)	0.72
	Living/dining sliding door and window, double-run, single-glazed sashes	2.04 (0.33)	0.72
LSG Low-e	Living/dining and bedroom windows, double-glazed, sealed insulating glass units	1.69 (0.30)	0.40
	Living/dining sliding door and window, double-run, single-glazed sashes	1.99 (0.33)	0.59

inside the apartments. Data was downloaded during the monthly visits to the apartments.

Assessment

Indoor Air Temperature and Relative Humidity

The effect of HSG and LSG low-e glazing on indoor conditions was examined by comparing indoor air temperature and relative humidity measurements with resident reports of thermal comfort. This was done in four time blocks coinciding approximately with the common calendar definition of fall, winter, spring and summer seasons, with start dates of September 23, 2010, December 10, 2010, March 10, 2011 and June 9, 2011, ending September 23, 2011. To provide an objective context, measured indoor conditions and resident perceptions of comfort and discomfort were compared against 'comfort zones' in the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55, *Thermal Environmental Conditions for Human Occupancy*

Figure 5 Pyranometer installed outside the HSG apartment bedroom window.

and Health Canada *Exposure Guidelines for Residential Indoor Air Quality* for indoor relative humidity exposure, as shown in Figure 6.

The building space heating system consisted of hot water baseboard radiators in each room in the apartments with thermostatic valves to vary output controlled by the residents. In accordance with Provincial Legislation and Municipal by-law, the heating system was engaged in early September and thus was supplying heat to the apartments at the start of the fall monitoring period.

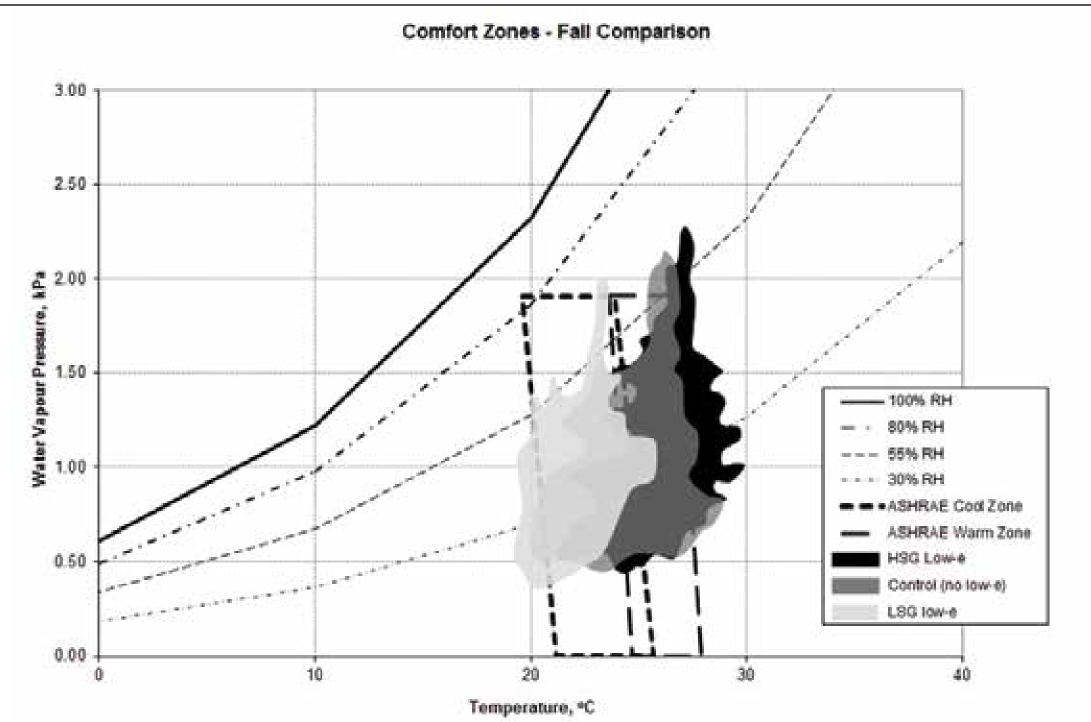

Figure 6 Example of measured indoor air temperature and relative humidity for all three test apartments for the Fall 2010 period.

Figure 6 shows recorded indoor air temperature and relative humidity in the fall period. The resident of the LSG apartment reported comfortable indoor conditions with radiator thermostats set to minimum until late fall due to colder weather. The resident of the Control apartment reported indoor conditions that were often too warm early in the fall, but more comfortable later, while indoor conditions in the HSG apartment were reported as too warm in the early fall and then too cool in the late fall.

When it was too warm indoors, the resident of the Control apartment set baseboard radiator thermostats to minimum and opened windows and/or the balcony sliding door to reduce indoor air temperature. At the same time, the resident of the HSG apartment also opened windows and/or the balcony sliding door but in addition, set radiator thermostats to maximum. That resident advised of a preference for warmer than usual indoor conditions. The observed operation of the apartments and reported impressions of thermal comfort are consistent with the distribution of indoor temperature and relative humidity data points in the ASHRAE Standard 55 comfort zones, with data points for the LSG apartment (grey) mostly in the cool zone (considered appropriate given a general trend of decreasing outdoor air temperature), data points for the Control apartment (dark grey) extending from the warm zone to the cool zone (consistent with a change from uncomfortably warm to comfortable conditions, while outdoor temperatures were cooling down) and data points for the HSG apartment (black) mostly in the warm zone (consistent with a struggle to maintain warmer than usual indoor conditions).

During the the winter period, the resident of the Control apartment reported acceptable thermal comfort until March when it became warm and "stuffy" indoors (warm and humid). Radiator thermostats were set higher during the coldest part of the winter and set lower as spring approached. The resident of the HSG apartment continued to report conditions that were too cool and used supplementary heat sources (plug-in electric heaters) to maintain comfort. Radiator thermostats were set at maximum. The resident of the LSG apartment continued to report comfortable conditions, better than those experienced in the previous winter, before refit of glazing, although radiator thermostats were set at maximum. Air temperature and relative humidity in the Control and LSG apartments generally coincided with the ASHRAE Standard 55 cool weather zone. HSG apartment conditions straddled cool and summer zones, again reflecting the preference for warmer indoor temperatures.

During the spring period, the residents of the Control and LSG apartments were comfortable until hot, humid weather in June. The resident of the HSG apartment reported conditions changed from cool to comfortable. Thermostats were set to minimum in the Control apartment, set at maximum in the HSG apartment, and progressively reduced from maximum to minimum in the LSG apartment. In all apartments, doors and/or windows were often found open during warm weather. The building space heating system was shut down about half way through this period. Indoor air temperature and relative humidity was scattered across both ASHRAE Standard 55 comfort zones, reflecting the change from cold winter weather to hot summer weather during this period.

During the summer period, the residents of the Control and LSG apartments reported uncomfortably warm indoor conditions. Windows and doors were opened and fans were used for cooling. Not surprisingly, the resident of the HSG apartment reported generally comfortable conditions. All residents advised there was no appreciable change compared to the previous summer, before the study began. Air temperature and relative humidity was frequently beyond the ASHRAE Standard 55 warm comfort zone, reflecting the considerable discomfort reported by the Control and HSG residents.

Solar Radiation

How does LSG and HSG low-e contribute to resident comfort or discomfort? Measured outdoor and indoor solar radiation on clear, sunny days in the fall, winter, spring and summer were examined and compared against the indoor air temperature and relative humidity analysis. Figures 7, 8 and 9 show outdoor solar radiation (top lines) and two measurements of solar radiation received indoors through the Control, HSG and LSG low-e glazings: hourly maximum (relevant solid lines) and total daily solar radiation (areas below the solid lines). Hourly maximum solar radiation changes little from winter to spring but falls by about half from spring to summer.

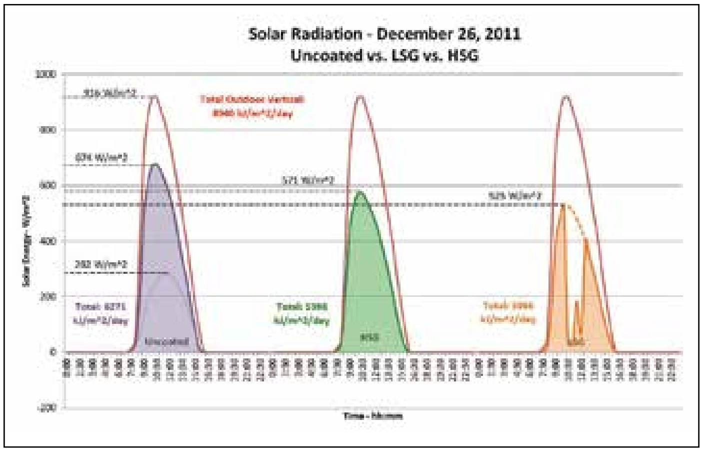

Figure 7 Outdoor solar radiation (top thick lines) and indoor received radiation in the three test apartments on December 26, 2011.

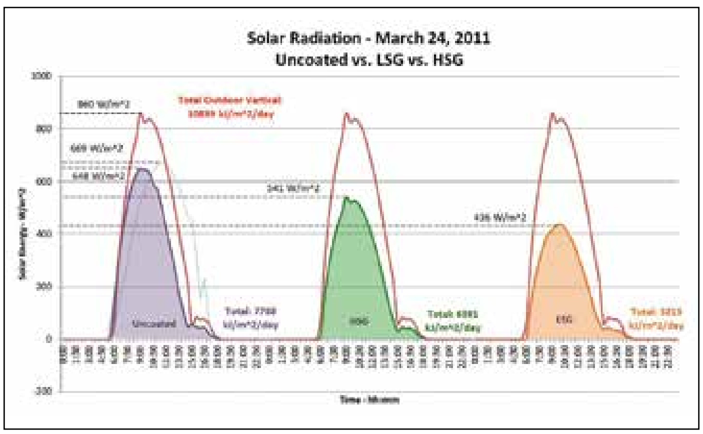

Figure 8 Outdoor solar radiation (top thick lines) and indoor received solar radiation in the three test apartments on March 24, 2011.

However, measured total daily solar radiation increases from winter to spring before decreasing to about half of the winter value in the summer.

The measured variations in solar radiation received in the test apartments show some consistency with the results of indoor air temperature and relative humidity and resident reports of comfort and discomfort. In the fall and spring when the residents of the Control and HSG apartment reported uncomfortably warm conditions and the resident of the LSG apartment reported comfortable conditions, solar radiation was higher in the Control and HSG apartments than in the LSG apartment. In the late fall, winter and

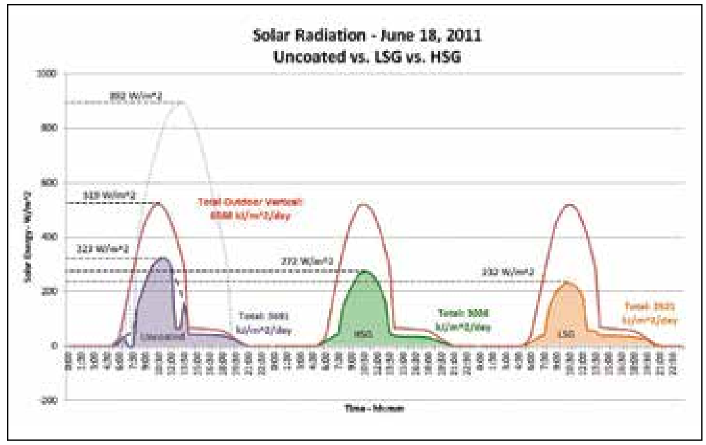

Figure 9 Outdoor solar radiation (top thick lines) and indoor received solar radiation in the three test apartments on June 18, 2011.

spring, space heating usage was higher in the HSG and LSG apartments despite solar radiation being high with little variation. This suggests that too much solar energy can contribute to discomfort, but that some solar energy is beneficial for reducing building space heating requirements. In the summer, all residents reported discomfort in the summer when solar radiation is much lower. This suggests that at certain times of the year, solar heat gain contributes much less to resident comfort or discomfort.

Seasonal variations in solar radiation received in the test apartments can be traced to differences in solar radiation transmission, reflection and absorption characteristics of the window glass, HSG and LSG low-e coatings. The combined effect of these characteristics is known as the Solar Heat Gain Coefficient (SHGC) which ranges from 1, when all solar energy striking a window is transmitted (ie. the sun's rays are perpendicular to the glass surface, with an angle of incidence[1] of 0°), to 0 when no direct solar energy is transmitted (that is, the sun's rays are parallel to the glass surface, with an angle of incidence of 90°). The relationship between angle of incidence and SHGC is not linear, with little decrease in SHGC from 0° to about 50° then a rapid decrease to zero at 90° angle of incidence (Figure 10).

Angle of incidence and SHGC varies during the day as the altitude (vertical angle above the horizon) and solar azimuth (horizontal angle measured from south) of the sun changes with the apparent motion across the sky from sunrise to

[1] Angle between sun's rays irradiated on a surface and the line perpendicular to this surface at the point of incidence.

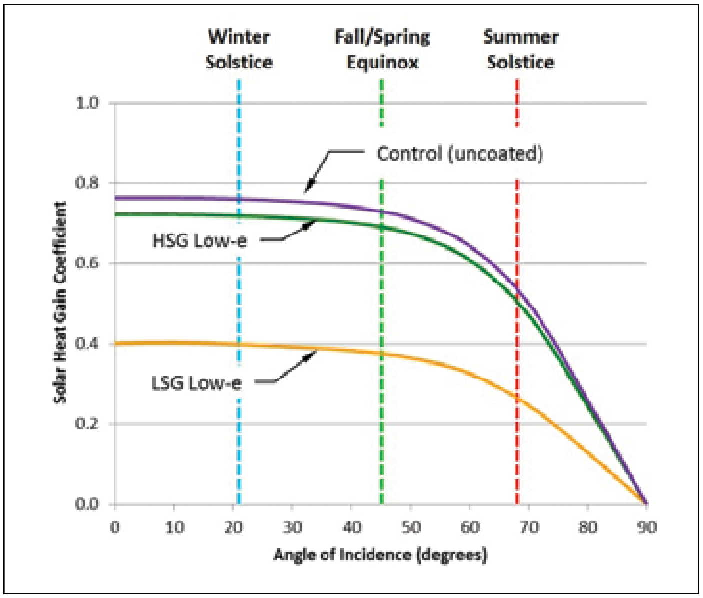

Figure 10 Solar Heat Gain Coefficient for glazing in the Control, HSG and LSG apartments.

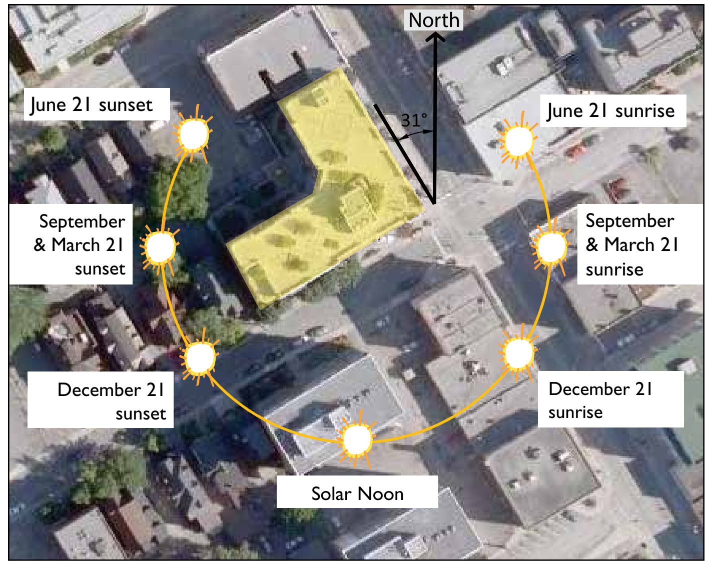

Figure 11 Aerial photo of test building (coloured yellow) with sunrise and sunset positioning at solstices and equinoxes.

sunset. At sunrise, for a south-facing window, a combination of low altitude but high azimuth results in a large angle of incidence and therefore, a low SHGC and thus, low solar gain. At solar noon, altitude is higher but azimuth is lower, resulting in a lower angle of incidence and therefore, higher SHGC and higher solar heat gain. This gives rise to the distinctive bell-shaped curves of maximum hourly solar radiation shown in Figures 7, 8 and 9.

In a northern location such as Ottawa, the maximum altitude of the sun increases from winter to summer. This is illustrated by the dashed lines in Figure 10 which represent the maximum angle of incidence at solar noon in the winter, spring, summer and fall. In addition, from winter to summer the sun rises earlier and sets later, increasing the duration of exposure. From winter to spring, increased duration offsets the decrease in SHGC so that total daily solar radiation increases slightly. However, from spring to summer, the increase in duration is not sufficient to offset the decrease in SHGC so that total daily solar radiation decreases by about half in the summer, as shown in Figures 7, 8 and 9.

Solar radiation gain is also affected by building shape and orientation. The study building faces about 31° east of south (Figure 11). Consequently, all year, maximum solar radiation increases rapidly in the morning to a maximum before noon. In addition, in the summer the sun rises slightly behind the plane of the exterior wall of the test apartments and in the spring, summer and fall it sets well behind plane of the exterior walls so that in the early morning and late afternoon and evening there are periods of low, indirect solar radiation. These periods of indirect radiation add to the total heat load in the apartment but are little affected by HSG or LSG low-e coatings.

CONCLUSIONS AND IMPLICATIONS

Decreased solar radiation received through HSG and LSG low-e glazing corresponds to observed and reported increased usage of space heating (higher thermostat settings and for longer time) indicating that solar radiation can contribute to heating of the space. However, higher levels of solar radiation can cause discomfort, such as experienced in the Control and HSG apartments in the fall and spring. Factors contributing to reduction of SHGC include transmission, reflection and absorption characteristics of glass, HSG and LSG low-e coatings applied to glazing and duration of sun exposure modified by building shape and orientation.

In apartments with sunny exposures, in order to improve resident thermal comfort in the spring and fall, the use of LSG low-e glazing can be beneficial. However, it is advisable to consider including heat-loss reducing features such as triple glazing, argon gas fill and warm-edge spacers in sealed, insulating glass units to offset increased space heating usage. In this study, such features would have improved the thermal performance of the glazing and thus might have addressed discomfort experienced by the resident of the HSG apartment. In buildings where entire windows and doors are to be replaced, thermally-efficient frame materials and fewer intermediate frame members would further help reduce heat loss. When designing new buildings, the extent of glazing could be reduced which would also help reduce solar gain in the fall and spring and thus, solar radiation related thermal discomfort.

Solar radiation received in the apartments is lowest in the summer, generally less than half of winter values. Nevertheless, residents reported discomfort in the summer, especially in the Control and LSG apartments. Direct solar radiation likely contributes to discomfort, but in the context of MURBs, little benefit appears to have been provided by LSG low-e glazing to improve summer thermal comfort. Other measures may be more effective such as dynamic[2] glass in the outboard pane to further reduce SHGC and/or outdoor shading devices. The efficacy of such approaches have been studied and reported by others, although usually in the context of houses, instead of MURBs.

2 Glass that can be made lighter or darker depending on the intensity of light and may be automatically or manually controlled.

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