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Thermal performance impacts of center-of-glass deflections in installed insulating glazing units

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ABSTRACT

This study examines the thermal performance impact of center-of-glass (COG) deflections in double- and triple-pane insulating glass units (IGUs) installed at several locations throughout the U.S. Deflection was measured during summer and winter temperatures; the results show that outdoor temperature variations can be represented a linear change in COG gap width in double- and triple-pane IGUs within the temperature ranges measured. However, the summer-winter temperature-induced deflection is similar in magnitude to the observed spread in COG deflection of similar units at the same temperature, which suggests that factors other than temperature are of equal importance in determining the in situ deflection of windows. The effect of deflection on thermal performance depends on the IGU's designed gap. Units constructed with smaller-than-optimal gaps often exhibit significant *U*-factor change due to temperature-induced reduction in gap width. This effect is particularly problematic in high-performance triple glazing where small gap dimension changes can have a large impact on performance.

1. Introduction

Highly insulating windows have the potential to provide net energy gain to buildings in cold climates, which could save two quads of heating energy use in the U.S. [1]. Whether those savings can be achieved in practice depends on actually achieving the designed insulating performance in installed units under normal operating conditions.

Variations between the designed and actual insulating performance of windows can be attributed to many factors. The effects of material properties, such as spacer and frame conductivities, on insulating performance are considered by Gustavsen et al. [2]. However, the largest and therefore usually the most thermally significant area of typical insulating glass units (IGUs) is the center-of-glass (COG). This study examines the thermal performance impact of COG deflections in installed double-and triple-pane units at several locations in the US.

COG deflection, i.e., the difference in gas space width at the COG compared to the edge-of-glass (EOG), as illustrated in Fig. 1, can result from several factors; initial manufacturing conditions that establish a bias toward either concave or convex deflection depending on the relative elevation or atmospheric pressure at the manufacturing facility compared to at that installation location; gas fill temperature offset experienced during fabrication compared to average gas temperature during typical use; dissimilar diffusion rates of gases into or out of gas-filled IGUs over time; and transient natural environmental conditions including temperature, pressure, and wind load, which might induce temporary, reversible deflection.

An industry standard addresses the initial COG deflection of a unit while it is still in the manufacturing facility where it was produced [3], but there are currently no requirements or guidelines on acceptable deflection of installed IGUs. Insulating performance of windows in the U.S. is simulated and validated using the procedures outlined in National Fenestration Council (NFRC) technical documents 100 and 102, respectively. For highly insulating windows, in this paper defined as windows with thermal performance better than $U = 1.7$ watts per square meter per Kelvin (W/m^2 K), an acceptable validation test per NFRC 100 can vary by up to 0.17 W/m^2 K from the simulations. On the most insulating products currently certified (0.51 W/m^2 K), this translates to a 33% allowable variation. Therefore, validation testing of highly insulating windows might not recognize potential cold temperature thermal degradation.

Previous key investigations of glass deflection have focused on deflection of double-pane IGUs as part of structural–mechanical research, including linear [4] and non-linear [5] plate models. To date, the most notable research extending the analysis of glass plate curvature or deflection to the impacts on IGU thermal performance

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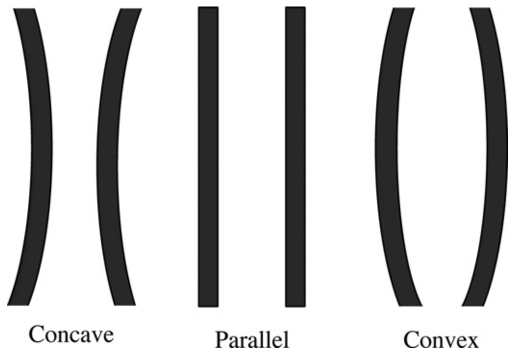

Fig. 1. Types of deflection in a double-pane IGU.

is by Bernier [6], who calculated gas space thickness reductions of up to 7.3% for American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) type winter conditions (−18 °C). He correlated this reduction to a 5.8% drop in *U*-factor for a triple-pane IGU.

Along with reduced insulating performance, COG deflection can concentrate solar energy reflected off the glass surface. These solar reflections have reportedly caused permanent distortion on vinyl siding and damage to other objects in the reflection path [7]. Understanding the extent of deflection in installed units under normal conditions is essential for understanding reflected radiation as well.

2. Procedure

For field measurements, we selected windows installed in several locations throughout the country based on outreach to sites with window types relevant to the testing effort – i.e., both minimum-code-compliant products and higher-performance units – and where the testing would have minimal impact on residents. As a result of reliance on these criteria, the tested windows do not represent statistically average U.S. windows. All windows tested were verified as NFRC-certified units and were no more than three years old at the time of testing.

The team measured IGUs at cold outdoor temperatures at each of the four sites (A–D) in winter (January–March 2011) and warm outdoor temperatures in June 2011 for all sites except A, which was not available in summer. Table 1 briefly describes the four sites, their associated window groups, and the measurements taken.

Table 1
Test site details and associated window groups tested.

Site A	Windows	Group A-1: 93 single sliders, 2-pane, 90% Argon gas fill; typical size: 845 mm × 1290 mm Group A-2: 92 fixed, 2-pane, 90% Argon gas fill; typical size: 830 mm × 380 mm Vinyl window frames
	Building type	Hotel, conditioned but unoccupied for winter shutdown
	Measurements	Winter only because no equivalent warm-weather shutdown available
Site B	Windows	Group B-1: 70 casements, 2-pane, 90% Argon gas fill; typical size: 1495 mm × 760 mm Group B-2: 32 fixed, 2-pane, 90% Argon gas fill; typical size: 760 mm × 355 mm Group B-3: 30 casements, 3-pane, 90% krypton gas fill; typical size: 760 mm × 1495 mm Group B-4: 30 casements, 3-pane, 90% Argon gas fill; typical size: 760 mm × 1495 mm Vinyl and aluminum-clad wood window frames
	Building type	Single family homes, conditioned but unoccupied
	Measurements	Winter and summer
Site C	Windows	Group C-1: 48 double hung, 2-pane, 90% Argon gas fill; typical size: 775 mm × 1320 mm Group C-2: 82 double hung, 3-pane, 90% krypton gas fill; typical size: 775 mm × 1320 mm Vinyl window frames
	Building type	Duplexes, conditioned but unoccupied
	Measurements	Winter and summer
Site D	Windows	Group D-1: 424 double hung, 2-pane, 90% Argon gas fill; Typical size: 850 mm × 1770 mm Vinyl window frames
	Building type	Single family homes, conditioned but unoccupied
	Measurements	Winter and summer

There are multiple methods for measuring glass deflection. Handheld laser-pointer-based tools, such as the EDTM model MG1500 and Sparklike Spyglass used for this study, are quick, convenient, and accurate. These devices measure distance using a laser pointer held at a fixed angle, which projects a series of bright reflections that are either read by the operator directly against a measurement scale (EDTM) or collected by an array detector, analyzed, and reported by the device (Sparklike). We used this equipment to measure glass thickness, gap width, and to detect low-emissivity coatings. The width of the tools prevents measurements at the true EOG. Therefore, with the EDTM MG1500 detector, measurements were taken 32.7 or 90 millimeters (mm) from the EOG, depending on orientation; with the Spyglass detector, measurements were taken at 40 mm from the EOG. Fig. 2 illustrates how the laser reflection measurement devices work.

We began by surface mapping IGU gaps on the interior glass surface of a limited number of double-pane units from Site A to explore the shape of the entire surface of a deflected IGU. For this purpose, we used the EDTM MG1500 to record the gas gap width for each point on a 50.8 mm-interval-grid over the entire glass surface.

We measured temperature at the COG and EOG of each test unit. Temperature measurements were taken either using thermocouples taped directly to the glass surface or using a non-contact infrared (IR) thermometer device adjusted for a glass surface emissivity of 0.86. The two measurement methods produced similar results and were therefore used interchangeably as needed. The contact thermocouples needed to stabilize before recording temperature, so they were slower than the IR spot measurement device. Therefore, non-contact IR spot measurements were preferred when a large number of field measurements of surface temperature had to be made at one time.

Indoor room air temperature measurements were made using a handheld thermocouple with readings recorded manually or using a small portable temperature data-logger (Onset Hobo U12-011) that recorded automated time stamped recordings. In either case, the temperatures were taken approximately 1.2 m above the floor, out of direct sun, and in the center of the room where the test IGU was located. Outdoor temperatures were recorded with a portable data-logger that was placed at a single location per test site, out of direct sun and near one of the homes where test units were located.

Additional data recorded for each IGU were: gas fill percentage, internal/external grid locations, spacer type, presence of a screen, sun exposure, proximity to air distribution grilles, and glass treatment (tempered or annealed). These data were not the focus of the study, and the analysis did not attempt to determine the effect of these factors on performance. They were used only to filter out dissimilar units when grouping the units for analysis.