BEST Center Funded Research Summary

Evaluation of Field Methods for Assessment of Architectural Window Degradation

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Motivation

The US DOE estimates that 25-30% of residential heating and cooling energy use is due to heat loss through windows. Insulating glass units (IGUs), a core component of modern building envelopes, are critical for minimizing these losses. However, IGU performance may decline as the window ages, increasing energy demand and operational costs. This project seeks to evaluate measurement methods of characterizing IGUs to determine which method is most accurate and accessible for in-field use. The goal is to develop a robust in-field measurement technique that can be used to understand the relationship between IGU degradation and thermal performance.

Understanding IGU Degradation

IGUs consist of multiple panes of glass separated by spacers, with the interior space often filled with an insulating gas like argon or krypton. Low-emissivity (low-e) coatings are applied to reduce solar heat gain. Over time, these components degrade due to environmental stressors such as high temperatures, humidity, and wind loads. The two biggest failures in a window are sealant failure and low-e coating degradation. Sealant failure occurs when the edges of IGUs, sealed to retain the insulating gas and prevent moisture ingress, are weakened. This leads to fill gas leakage, condensation within the panes, and potential degradation of chemically unstable low-e coatings. Low-e coating degradation reduces the ability of the coating to effectively block solar radiation. These failures compromise IGU thermal performance, reflected in increased U-values (thermal transmittance) and energy use.

Simulations and field studies reveal that IGU degradation can significantly increase energy consumption in both residential and commercial buildings. For example, a typical office building might experience a 65 MWh rise in heating demand over 20 years due to seal failure and gas loss. A single-family home could see an additional 1.3 MWh annual energy consumption. This highlights the importance of maintaining IGU integrity to ensure long-term building efficiency.

Figure 1. *IGU on CU Boulder campus being evaluated for performance reduction due to degradation.*

About the BEST Center

The Building Energy Smart Technologies (BEST) Center is a partnership between the University of Colorado Boulder and City College of New York operating using the NSF's industry-university cooperative research center model. The center fosters interdisciplinary collaborations between the building industry and university research to advance energy systems through university-industry partnerships to engineer the intelligent and efficient cities of tomorrow.

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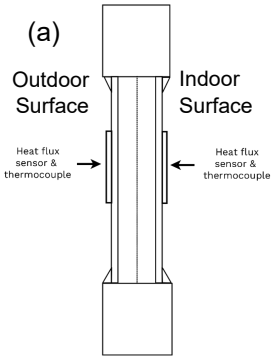
Measuring IGU Performance

Laboratory methods for assessing IGU performance simulate aging through controlled exposure to temperature cycles, humidity, and UV light, but these tests fail to account for real-world conditions. Emerging *in situ* techniques, like field deployed heat flux meters and infrared thermography, offer a more realistic evaluation of IGU performance under operational conditions but lack validation or fail to decouple low-e coating degradation and fill gas leakage. This study aimed to develop a hybrid methodology combining interior infrared thermography with the heat flux method to estimate center-of-glass U-values.

Shown in Figure 2 is a lab-based validation of the sensitivity of the proposed hybrid field testing method. Using four samples with a known U-values (low-e argon fill, low-e air fill, clear argon fill, clear air fill), testing was conducted for 10 hours with three different temperature differentials (ΔT=10, 20, 30 °C). Errors in U-values using the hybrid field method, compared to the known U-value, were lowest when measured with a ΔT of 10 °C, ranging from -2.8 to 1.7%. Measurement error had increasing negative bias as ΔT increased, with errors ranging from -10.3% to -4.1% at a ΔT of 30 °C.

Figure 2. *U-value field testing method validation using NLR IGU test chamber.*



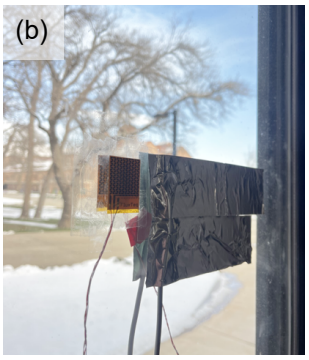


Figure 3a is a schematic of the hybrid field test measurement, and Figure 3b shows the sensors deployed on an IGU. Heat flux sensors and surface temperature probes were mounted at the center of the IGU while indoor and outdoor temperatures, surface temperatures, humidity, and heat flux were continuously recorded for at least 72 hours. Interior infrared thermography was performed during nighttime hours. The methodology combines ASTM E1933A, ISO 6781, ISO 9869-1, ISO 6946, and ISO 15099 into a unified field-testing procedure for evaluating installed window performance.

Figure 3. *Heat flux field testing method (a) schematic and (b) deployed to measure an IGU on CU Boulder campus*

Field Test Results and Modeling

Measurements using the hybrid field testing method on a window on CU Boulder campus, shown in Figures 1, 3b, and 4, demonstrate the method is capable of measuring IGU emissivity (0.83) and U-value (1.53 W/m^2-K) comparable to the manufacturer's reported values (1.59 W/m^2-K). Uncertainty analysis of the hybrid method demonstrated U-value uncertainty of ±0.27-0.3 W/m^2-K. Window indoor-outdoor temperature differential and wind speed significantly influenced measured U-values.

The modeling tool WINDOW 7.8 (LBNL) was used to create a thermal model of the tested IGU to predict center-of-glass U-value, with measured environmental boundary conditions incorporated into simulations. A simplified ISO 15099 calculation procedure was developed in parallel. The simplified approach predicted center-of-glass U-values within 6% of the WINDOW 7.8 simulation.

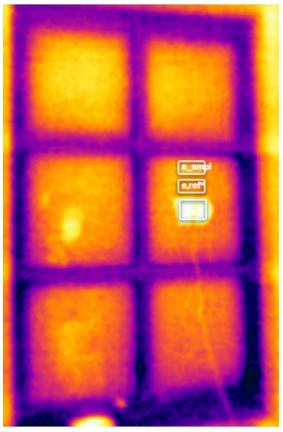


Figure 4. *Infrared thermography of the IGU evaluated on CU Boulder Campus.*

Research Products

1. Madison Likins-White, Robert C. Tenent, Zhiqiang (John) Zhai (2023). Degradation of Insulating Glass Units: Thermal Performance, Measurements and Energy Impacts. Buildings, 12(2): 551. https://doi.org/10.3390/buildings13020551.
2. Abdullah J. Alkhamees (2023). Establishment of an in-site methodology for window evaluation: Center of glass U-value. M.S. Thesis, University of Colorado Boulder.

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