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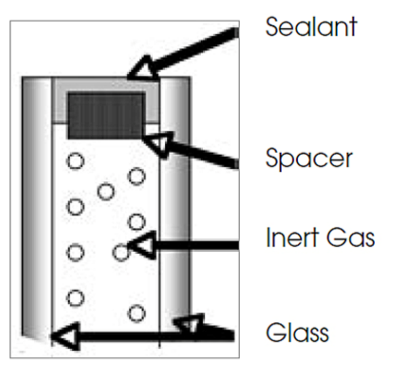
A Unique Thermal Problem Found in Certain Double-Glazed Windows

Typical insulating glass (IG) units are constructed using two sheets of window glass separated by spacers.



Thermography has been used with great success for a number of years to inspect building fenestration, both during design and production as well as after installation.[1] Typically double-glazed windows exhibit a well-understood pattern of increased heat loss around the perimeter, due mainly to thermal bridging or "edge-effect" losses.

In this paper we present the findings of an investigation about a very different—and unusual—thermal pattern discovered on windows in the home of one of the authors. The pattern was first illuminated by condensation in the central portion of the window. This thermal pattern was verified with a radiometric thermal imaging camera as well as thermal contact probes.

After additional investigation we found the cause of this anomalous pattern is related to the loss of some of the insulating argon gas installed in the window during manufacturing. We also discovered the problem was not uncommon for certain types of windows. As these windows age, the problems usually become more pronounced and, in some cases, a total failure of the window by implosion results. We hope that publication of this information will prove useful to others who may have been mystified after seeing similar patterns.

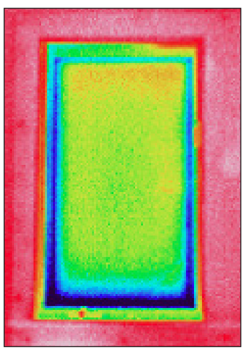
Construction of Insulating Glass Units

Typical insulating glass (IG) units are constructed using two sheets of window glass separated by spacers. The unit is sealed and filled with dry air or an inert gas. A desiccant is often installed in the spacer to minimize internal condensation of moisture. The exact design and placement of the spacers, sealants, and desiccants, as well as the specific type of insulating gas and fill technique used, may vary with the type, brand, and design needs of the window. Early IG units were rather crude by comparison to today's high-performance fenestration although many continue to perform even after fifty years. Premature failures of sealants, in particular, were not uncommon, resulting in poor window performance and condensation forming between the panes of glass.

During the 1970's consumers began to demand windows that would be guaranteed to retain their seals for longer periods, typically 20 years. They also wanted windows with better thermal performance in order to reduce energy use, increase comfort levels, and improve condensation resistance.

Numerous design changes were explored to achieve these goals. These involved optimizing the width of the space between the panes of glass, using various inert gases to fill the unit, the technique used to install the gas, the spacer material and design, the desiccant used, and the use of selective coatings and films.

The relative thermal performance of three windows: single-glazed (top), double-glazed with nitrogen gas (right) and double glazed with argon-fill (left), is readily apparent in this thermogram taken from inside during the heating season.



A typical insulated glass unit showing edge-effect losses and a more pronounced pattern at the bottom due to internal convection.

Significant performance gains came from improving fill-gas mixtures, as well as installation techniques. Nitrogen-filled windows soon gave way to argon-filled windows because of the decreased thermal conductivity and reduced convection between panes of this heavier gas. With increased performance, however, came new problems. It was not unusual to find an argon-filled IG unit devoid of gas after a year or two; in fact studies of early units showed nine out of ten had lost their argon! Some may have been inadequately filled during manufacturing, but most probably failed due to poor construction or inadequately designed or failed sealants. The sealants and construction techniques used in many of the first of these windows simply were not adequate to contain the gas.

In nearly all cases IG units share a similar thermal pattern as shown in the thermal image at the right. During the heating season on very cold days, the typical pattern of condensation that forms on the inside surface of the window is concentrated around the edges of the window. It is also not unusual to also see a wider area along the bottom edge due to several factors, including cooler temperatures in the lower portions of the room, reduced convective warming of the lower window due to the sill, and cooling due to inner window convection. Not surprisingly a thermogram of a typical IG unit inevitably shows a similar pattern.

A Condensed Mystery or a Mysterious Condensation Pattern?

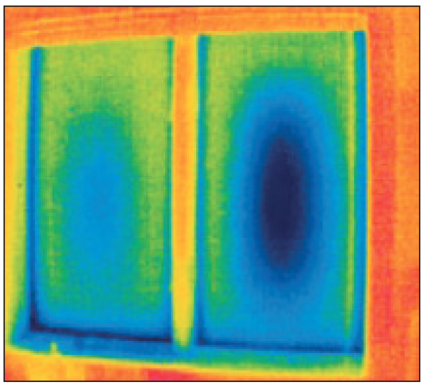
Thus it was quite disquieting when one of the authors came across a condensation pattern on the inside surface of a window in his house that was exactly the opposite of a "normal" pattern. The pattern was first evident on several windows late in October as we began to enter the heating season in earnest. As outdoor temperatures decreased in November and December the inside glass surface more often reached the dew point. Because humidity levels are often still quite high in early winter, the patterns became more noticeable more often. The windows were all ten years old, double-glazed, argon-filled IG units manufactured by a well-known, reputable vendor.

The first window to display the pattern was on the south side of the house. Within two years of noticing the first failure, sixty percent of the remaining windows, independent of their orientation, displayed the atypical condensation pattern. Interestingly, only the casement units showed the pattern, not the fixed units, even when installed nearby. Thermal images verified the obvious: the inside glass surface was, in fact, cooler in the center of the unit!

Additionally, we noticed that the window glass was bowed slightly into the space between the panes. This was obvious visually but was also confirmed with a straightedge. A call to the manufacturer brought action. The units were replaced under warranty at no small expense to the manufacturer or inconvenience to the author! Additional research indicated that the problem was by no means limited to the author's home. While we do not have access to industry statistics, it appears the problem is not uncommon in windows manufactured in the late 1980's and early 1990's.

What is the Cause?

Windows exhibiting this anomalous pattern are argon- filled units, and generally not large ones. Over time the argon gas escapes from the window, but it is not easily re-



Condensation formed first on the right window which was exhibiting a more advanced stage of argon gas loss than the left window. The thermograph shows that in fact both windows have the same argon loss.

Imploded widow with gaping oval hole in the inner glass.

placed by air, leaving the internal space at a negative pressure. The panes of glass are thus pushed together resulting in increased heat transfer and, when conditions are right, condensation in the center of the window.

The causes for the argon loss are interesting. Some is certainly lost due to inadequate design or construction, especially of the spacer in the corners. Sealants too have long been recognized as a weak point. Argon molecules are smaller than most of the gases which compose air, it can travel through many sealants which were previously used to contain other gases. Some sealants obviously allow argon to pass through them, but not allow air to replace the displaced argon.

The difference in partial pressure between the gases inside the window and the air also causes the argon to be lost. Air is approximately one percent argon; with the inside of the window at ninety percent or greater, gas will flow out to equalize partial gas pressures. Researchers estimate that argon may escape three times faster than it is being replaced.

Desiccants are also probably a mechanism for loss. Many IG units adsorb not only water vapor but also other molecules, including argon. Over time some of the gas is adsorbed onto the desiccant, again resulting in a negative pressure inside the unit. Adsorption also increases during cold weather.

It also appears that conditions at time of manufacturing may have an important influence. Both ambient air and sealant temperatures, as well as the elevation of the filling facility, have a significant impact on the initial pressure inside the cavity; this, in turn, can make the window more sensitive to changes at its installed location.

All of the above factors probably work together with the result being that over time the unit loses argon and pressure. When conditions are right, especially during colder weather, thermal stresses may become so great that the window unit may actually implode. Reports indicate that smaller units, with a short dimension of 10”–20”, are particularly vulnerable where pressure induced deflection exceeds the material failure point.[2]

The Plot Thickens

Interestingly, several of the windows in the home of the brother of one of the authors recently imploded. Two small windows (12” x 24”) shattered leaving a gaping oval hole in the inner glass. Both units were seven years old; many of the other IG units in the house have exhibited the anomalous condensation patterns, but no more have imploded. It is probable that the larger size windows allow enough deflection such that they do not fail as often.

How is the Problem Being Addressed?

Window manufacturers have been working on several fronts to minimize the problem of argon depletion. Changes have been made to the way units are filled to assure they are actually full at the time of manufacturing. Sealants have also been improved, and in some cases, two types of sealants are used rather than a single one; designs also now incorporate longer sealant pathways so that the gas must go further if it is to escape. Spacers and sealants are more carefully installed, especially at the corners where signifi-

Thermography can locate degraded windows long before their failure and before any condensation patterns become regularly obvious.

cant breaks have occurred in previous designs. Desiccants are now being used that do not adsorb argon as readily; additionally larger quantities of desiccant are being used. Some manufacturers are even beginning to pay attention to the air temperature/pressure conditions at the time of manufacturing.

Will all this be enough to prevent failures in the future? There is little doubt the measures will help reduce failures. It is probable, however, that some failures will continue to occur. For that reason, it may be useful to find and perfect a means of injecting make-up argon into depleted windows to maintain their thermal efficiency and prevent failure. It is clear from our experiences that thermography can locate degraded windows long before their failure and before any condensation patterns become regularly obvious.

Conclusion

When we are observant of our immediate environment and take the time to "Think Thermally®", thermal relationships are often very understandable. Thermal imaging can be used to better understand these relationships and validate them, such as those on and around windows. When the normal patterns we have grown to expect are contradicted, as was the case with our anomalous condensation pattern, explanations must be sought.

After all, the physical world does not lie! Our job, then, is to discover the cause of the pattern. Researchers may shed additional light upon our mystery, but at this time it appears the cause is a combination of factors conspiring to bring the invisible thermal pattern into the visual realm. Although the "magic" of a thermal imaging system allows us to see the anomalous patterns before they are otherwise obvious, the argon depletion from the insulated glass unit is the probable culprit. We expect manufacturers will continue to develop strategies to minimize the problem of depletion in argon-filled windows and hope that thermography can play a role in that work.

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