Foggy Glass Disease.

Looking Through Hazy Windows.

Is your window foggy? If so, welcome to the growing club of unhappy owners of the hazy glazing.

This article is intended to instruct readers how to check their glass, shed some light on reasons why the glass became foggy, and give some practical solutions.

We assume that at this point you have already had your glass cleaned and have removed a deposit of foreign material (e.g. paint overspray) from the list of possible suspects. Furthermore, we would ask you to rub glass surfaces in order to verify whether they are smooth. Glass deteriorates in presence of water and alkali, developing a rough surface, which gives it a slightly hazy appearance. Also, some types of scratches and surface blemishes form dispersed patterns obstructing vision. Polishing an ordinary, annealed, uncoated glass with mild abrasives and acidic treatments may restore the appearance. Unless you know the difference, it's best to consult a professional before undertaking such task because many glass defects are irreparable, and repair attempts may render them unsafe and diminish your rights.

The deficiency is primarily seen in insulated glass units (IGU) and laminated glass, and typically stems from two different phenomena: de-hermetization of insulated glass and a chemical changes in the laminates. These two are the most common, but there are cases that fall outside this general division. We would not attempt to exhaust the subject. Our goal is to provide an explanation that would be practical enough for the early decision making, as opposed to producing a scientific paper.

How to tell which one you have: insulated glass units (IGU) or laminated glass or both? If the haziness periodically disappears or changes location within a unit, you are most likely dealing with an excess moisture condensing within the IGU's cavity. However, if the haziness stays in one place or grows, particularly around edges, you are most likely a victim of a delamination or decomposition of the laminated glass interlayer.

Figure 1: The widespread "Florida Glass Disease." Delamination of the PVB interlayer in an improperly designed framing.

Replacement of the glass without the diagnosis and treatment of the underlying cause is almost always futile - the fogging would reappear in a matter of months.

We need you to verify the age of your glass; modern architectural glass is expensive but has a relatively short lifespan ranging from 5 to 25 years. There are chances that your glass simply failed due to its age. On the other hand, a replacement of a prematurely failed glass without curing the underlying problem would virtually guarantee a quickly ensuing repetitive failure. Owners sometimes replace foggy glass panes only to discover that the costly replacement was futile. This is particularly typical in Florida, where almost all new glazing is laminated due to the hurricane protection requirements, and the frequent contributing reason of the failure is a poor design and construction of framing holding the glass.

Insulated Glass Fogging

Longevity of modern glass is often a significant overlooked factor in the overall cost of owning IGUs and in life-cycle analysis. Fogging should be expected as a normal result of gradual deterioration. IGUs typically carry a warranty for 10 to 20 years, and this is often their actual lifespan. They are built as a hermetically sealed assembly, but in many cases the fogging occurs much earlier, and is sometimes found to be caused by a fabrication or design error. Unlike the laminated glass delamination, this subject is fairly well covered by American standards, including the dedicated ASTM E2189 "*Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units."*

The mechanism is fairly simple. Haziness indicates presence of excessive volume of moisture in the cavity between glass layers. Moisture can enter the cavity in several ways, depending on the construction of the spacer and its seals. It's initially absorbed by the desiccant, and then the excess periodically condenses or freezes on cool surfaces. The failure is sometimes traced to the primary seal of glazing spacers. In a modern IGU, the longevity of the primary seal, typically made of a butyl sealant, depends on many factors, including exposure to shear stresses. And so, generally speaking, a well-made, conservatively framed, small-size, transparent window in a permanently shaded location would generally last longer than e.g., a large glass pane, dead loaded by its inner ply, installed as a spandrel and exposed to large temperature and pressure variations, which are all conditions known to increase shear stresses of primary seals.

Figure 2: When all dams break loose, IGU may serve as an aquarium. The Metropolitan Museum of Art in New York City.

Owners often find limited warranties to be useless for two chief reasons: 1) the marginal ratio (sometimes less than 5%) of the reimbursed cost of material to the total replacement cost and a waiver of consequential damages, 2) Broad exclusions that indemnify glass providers.

Let's quote some typical exclusions that apply to insulated glass: "*This warranty does not apply to or cover : (a) Units in excess of (50) square feet; (b) use of or application to an IGU, it's installation or subsequent maintenance, materials that are not compatible with the IGU organic seals , coated or laminated glass surfaces; (c) failure caused by broken glass or other damage to an IGU; (d) IGU that have been retrofitted with a solar, blast resistant, or security contact film adhered to any glass surface by others than the fabricator; (e) an IGU installed in a continuous or cyclical high moisture environment, including without limitation swimming pool enclosures and greenhouses without the use of fabricator's approved humidity control devices; (f) any IGU installed in facilities which may incur high vibration; (g) an IGU installed in sloped glazing; (h) an IGU solely utilizing Lexan®, polycarbonate, acrylic or other plastic materials as a component lite or ; (k) IGU containing unsealed capillary tubes; (l) any IGU not paid for in full; (m) an IGU that has not been stored, installed and maintained in accordance with GANA Guidelines, specific instructions and other documented standard industry practices, not limited to the following instructions, which the installer and purchaser agrees to follow:*" (followed by the list of additional instructions).

The presence of excess moisture in the IGU cavity is often found to be a purely aesthetic consideration, but should be investigated further in a structurally sealed glazing which often structurally depends on the integrity of the spacer assembly.

Figure 3: Frosting observed in failed insulated glass units on a facade. The Cleveland Museum of Art in Cleveland, OH.

If occupants find the hazy (and periodically frosted in cold and mixed climates) appearance objectionable, a questions "can it be repaired" is often asked. A foggy IGU can theoretically be repaired, but a careful

analysis of the overall repair cost versus longevity of a repair would often lead to the conclusion that the replacement may be the only viable option.

Figure 4: A typical glass mismatch caused by the lack of correct specification in a replacement glass procurement process. Miami.

Replacement of failed glass units may lead to the non-uniform appearance of a glazed facade. Due to the often widespread and systemic character of the failure, the blanket replacement is typically recommended. Matching of the glass appearance is challenging on aged facades and is recommended chiefly in case of a glass breakage, when the remaining glass has a high remaining technical life expectancy, or in a severe maintenance budget shortage situation.

Figure 5: A laminated glass is intended to stay in frame when broken, replacing a wired glass previously used in such applications.

Laminated Glass Fogging: "Foggy Glass Disease."

While a vast majority of construction and design professionals is generally familiar with the concept of the insulated glass, due to its 70+ years of presence in the marketplace and its application mandatory by most modern building codes, we found they are sometimes unfamiliar with the concept of the laminated glass. In order to avoid losing them, we feel the need for the elementary explanation before jumping into the detailed discussion.

A laminated glass is formed by bonding entire surfaces of two or more plies of glass together in order to achieve redundancy and composite action, with the physical characteristics of the laminate interlayer complementing those of an inorganic glass. Such an interlayer is tear resistant, preventing a glass pane from vacating its framing in case of its breakage, it isolates layers of glass preventing transfer of stresses and breakage onto an adjacent glass ply, it damps some sound frequencies, and screens UV rays. The laminated glass is often recognized as a replacement of wired and tempered glass in many safety and security applications. In the last two decades, it became widely used in hurricane-resistant glazing, raising the basic awareness in coastal regions. How to tell whether your glass is laminated? At the absence of obvious clues, such as glass stamp, fabrication label, trapped air bubbles, or access to the edge, the identification is best left to professionals. Also, a glass stamp may not identify the laminated glass, listing the safety standards, such as 16 CFR 1201 and ANSI Z97.1, shared with a toughened glass.

Opening Protection in Wind Mitigation Reports. However, Florida insurers require verification and re-verification of protective character of openings, in apparent expectation that the laminated, hurricane-proof glazing would be subsequently replaced with lesser one. Without examining the premises of such a strange expectation, the issue is how to examine whether the certain piece of fenestration is rated or not. Such a rating is seldom marked anywhere on the fenestration, besides any labels that might indicated it often were either removed by owners or peeled away during cleaning and maintenance over time. Some incompetent insurance inspectors skip this step and simply flag perfectly good hurricane-proof fenestration as not compliant, without even telling the owners. However, the basic examination is best done with one’s knuckle: the habit of knocking on the glass marks an experienced inspector. It’s as simple as subjective method, which explains why inspectors are not trained to do so. Thick glass is easy to distinguish from a thin glass this way, which would separate a rated from unrated fenestration in the great majority of cases. Further determination: whether a thick glass was actually laminated would be best left to professionals, if economies of preparing such reports made it possible. Therefore, a working assumption that the cost of any thicker glass would defeat any benefit of such substitution should suffice to write off the rest of cases. The real danger rests with a wrongful substitution with a heat treated glass, which concern however has less to do with wind mitigation, and more with public safety.

Longevity of a modern laminated glass is a significant and frequently overlooked life cycle analysis factor. A laminated glass typically carries a 5+ year warranty, and it indicates its expected lifespan in locations characterized by high heat and humidity. Coincidentally, those localities (e.g., Windborne-Debris Region and High Velocity Hurricane Zone) where the laminated glass is a prerequisite for protection of openings against windborne missile impact, are often characterized by high heat and humidity because they are either spread along coastlines or located in the hot and humid climate or both. Longevity of the laminated glass may be indirectly improved in the design stage by specifying the European standard EN ISO 12543 "*Glass in building- Laminated glass and laminated safety glass - Part 4: Test methods for durability*" which describes heat and moisture test procedures.

Figure 6: A laminated glass is intended to stay in frame when broken, and prevent simultaneous breakage of plies of glass. Glass laminate becomes foggy when stretched, indicating the areas stressed after breakage of both plies. New York City.

The appearance of laminated glass is typically specified using Table #1 of ASTM C1172 "Standard Specification for Laminated Architectural Flat Glass." Like in case of other glass types, it's important to understand the glass quality criteria stem from production limitations as opposed to users' visual expectations. Fogging within the 15mm from an autoclaved glass edge and 25mm from cut edges is normally expected in a brand-new glass, but this distance is covered by a glass bite in a typical four-edge clamped framing configuration, and therefore often hidden from view.

Fogging and bubbling are typically found to be signs of failure of the laminate interlayer, often made of polyvinyl butyral (PVB). The failure occurs most often by chemical reaction caused by a direct physical contact of the glass interlayers' edge with substances such as water and solvents, including byproducts released during a curing process of almost all sealants. PVB moisture content of about 0.5% by weight is enough to cause loss of adhesion to glass.

Therefore, a laminated glass edge should be treated cautiously in design and engineering of architectural glazing. A number of conditions are well known to contribute to the failure, including: butt-sealed laminated glass edges, edges exposed to elements (e.g. in exterior glass guards), edges permanently submerged in water (e.g. in depressed balustrade cradles), or only periodically exposed to standing water (e.g. in many sloped glazing applications). These conditions are commonly seen in manufacturers' catalogs and architectural drawings.

It's worth mentioning that all the above-mentioned items can be successfully re-engineered to keep the desired architectural appearance without sacrificing the glass performance; however, in our practice we found that architects of record are seldom interested in those solutions because they typically delegate the glazing design and engineering to contractors.

Glazing providers in turn indemnify themselves by limited warranties containing broad exclusions. The warranty is void *"if the Laminated Glass is compromised by contact with incompatible glazing lubricants, glazing soaps, incompatible glazing gaskets, glazing sealants, incompatible cleaning fluids, moisture or building runoff, gluing or attachment applied films, direct contact with paints, adhesives, solvents or*

insulation, or exposure to solvent or chemical fumes. Installation in a system that does not include a weep system or some means of water repulsion, or used in a butt joint or structural glazing system, or with edgework (polishing or mitering), or subjected to stress and strain as a result of localized application of heat, which causes uneven edge stress due to temperature differences in the glass." A careful reader would probably find that the above exclusion list have exhausted almost all typical applications of laminated glass, making the average limited warranty an instrument depriving an owner from essential rights.

Also, fabrication defects (such as e.g. use of salty water for glass cleaning prior to lamination) are sometimes responsible for the delamination, which would be mainly discernible by its location off edges. Fabricators are generally known to reimburse manufacturing and fabrication defects in spite of the protective language of their warranties. However, as mentioned above, a reimbursed cost of material is a small fraction of the total cost of replacement.

To make things worse, product manufacturers sometimes screw up and leave their customers stranded. There was a well-known case of a once-reputable manufacturer of the laminate interlayer, who changed the formula without notice, leading their product vulnerable to UV light spectrum. It happened in Florida, where ultraviolet exposure is oppressive, and not surprisingly, led to multiple and widespread failures. The manufacturer was so unwilling to reimburse the losses, that the case dragged long through federal court, leaving an impressive public trail of evidence for us all to learn. If you are interested, search for Reichhold case in Florida.

If occupants find the hazy and bubbly appearance objectionable, a questions "can it be repaired" is often asked. Unfortunately, such a glass cannot be repaired; it can only be replaced and it should be replaced before a hurricane season because a delaminated glass was found to be structurally compromised.

The cost of replacement varies depending on many factors, with the most typical range $1-10k per pane of glass. Among factors increasing the cost are a custom glass makeup, size, access, and union labor. While a replacement of an ordinary laminated glass in a slider may cost less than $500, a replacement of a custom-made glass pane in a high-rise curtain wall lacking a permanent facade access may exceed $300k, consumed mainly by general conditions, such as crane setup and operation, street closures, etc. (Please kindly note these costs were current when this text was originally written in year 2010, and may require adjustments with time).

As mentioned above, the replacement is very often futile without curing the underlying problem which typically lies within the surrounding glazing assembly. The most typical example is a recurring glass replacement undertaken in glazed doors and windows in which the edge of the glass is positioned in contact with a seal or water in an insufficiently wept framing. Such a replacement should be preceded by diagnosis of the underlying problem by a glass expert, and a subsequent re-design of the glass edge conditions in order to avoid the same problem reoccurring in the nearest future.

Important consideration is the building code compliance. Commentaries to The Florida Building Code "Existing" clarify the replacement of a glass pane is considered a repair and not an alteration; therefore, a replacement glass does not need to meet the current building code. Otherwise, it would most often require a replacement of framing as well, due to the new requirements mandating a heavier glass.

Figure 7: Laminated glass is characterized by poorer dimensional tolerances than other types of glass. However, this fact is seldom accounted for a glazing design when a standard framing is used, resulting in glass edge contamination.

How To Find Help.

If you have a foggy glass, don't replace it without getting diagnosis from someone knowledgeable, otherwise you may easily end up wasting your money.

Architectural glass is one of these subjects everybody seems to talk about, but we found approximately half of this talk is informed and factual. The trick is to know which half.

If you intend to rely on your architect, contractor, or engineer, we strongly recommend verifying their knowledge by posing questions to which you already know the answer, for example from this article. We sometimes found design professionals presenting foggy understanding of elementary characteristics of different types of glass.

We are often approached by apparently confused building envelope consultants asking about the glass fogging; therefore, we have a reason to believe that even the average enclosure consultants may not be privy with glass performance issues.

How can you find someone to help? We found that it's not enough to know someone who in turn knows an expert, like in the case of clients of the building enclosure consultants mentioned above who eventually got their answers via a middlemen, because the remediation projects in questions were almost finished by that time, and it was too late to correct them economically.

Getting a glass expert is challenging for two reasons: they are hard to find, and their services may be considered expensive, and therefore only justified by economies of large projects. There are so few forensic architectural glazing experts in the country that it seems they know each other by the first name, and such a tight club is therefore challenging to discover by laymen. Hint: some of them sat on the ASTM committee called: "E06.51 Performance of Windows, Doors, Skylights and Curtain Walls."

Recommended Further Reading:

- Richard A. Behr, Joseph E. Minor, Paul A. Kremer. "*Effects of Accelerated Weathering on Architectural Laminated Glass in A Windstorm Environment."*
- Patrick Loughran *"Falling Glass"*
- ASTM C1036 *" Standard Specification For Flat Glass."*
- ASTM C1172 "*Standard Specification for Laminated Architectural Flat Glass*"
- ASTM E2188 "*Standard Test Method for Insulating Glass Unit Performance"*
- ASTM E2189 "*Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units"*
- ASTM C2190 " *Standard Specification for Insulating Glass Unit Performance and Evaluation."*
- EN ISO 12543 "*Glass in building- Laminated glass and laminated safety glass - Part 4: Test methods for durability*."
- GANA "Laminated Glazing Reference Manual."
- Monsanto Technical Bulletin No. 1512 *"Architectural Saflex Interlayer. A Study of Sealant Compatibility with Saflex PVB Interlayer in Laminated Architectural Glass"*
- *and other glass-related items in the "suggested reading" section of our webpage.*

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