DRAFT: FENESTRATIONS – VINYL WINDOWS

By

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Windows are one of the most complex and expensive facets of the building envelope as they can account for approximately 10% of a building's air infiltration according to the U.S. Department of Energy, and can cost up to several thousand dollars per unit. The number, size, material choice and orientation of windows can make or break the energy efficiency of the entire building. With so much on the line, it is important for windows to be weather and water tight. There are slightly less than 100 different American Society for Testing and Materials (ASTM) tests and 40 American Architectural Manufacturer's Association (AAMA) standards, in addition to various other NFRC, ANSI, ASCE, CPSC, NFPA, UL and GANA Standards pertaining solely to windows. One of the most specified glazing products in multi and single family construction is the vinyl window.

Figure 1A – Vinyl Windows

HISTORY

In the l800s, European researchers were experimenting with a gas known as vinyl chloride and accidentally created a rigid material, which was thought as useless since no commercial uses could be found for it at the time. In the 1920's BF Goodrich began expanding on the earlier research and came up with Poly-vinyl Chloride (PVC) or vinyl, but struggled to market the new material. It wasn't until the 1930's that vinyl began to develop a commercial usage. The "History of Vinyl Windows" states vinyl was initially used in shock absorbers and later used to create the first American synthetic tires. Slowly the use began expanding to insulators, coatings and in the 1950's the PVC pipe was made from rigid vinyl. In the 1990's vinyl sales grew by 125%, and today it is the most popular choice for window frames.

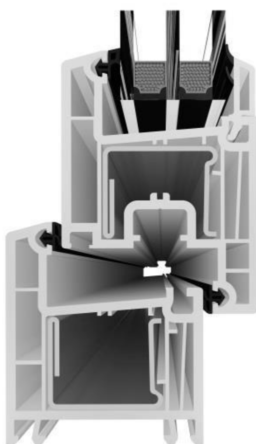

Figure 1B – Vinyl Windows

Figure 1C – Vinyl Windows

PROS OF VINYL WINDOWS

Vinyl windows (Figure 1A) have grown in popularity over the past twenty years and now over 18 billion pounds of vinyl account for 67% of all conventional residential windows in the United States because they are a good thermal insulator, fire resistant, and are low maintenance, as they do not require any painting or finishing. In fact the Federal Trade Commission issued a publication endorsing vinyl-frame windows precisely because they "insulate well and don't need painting." Modern vinyl window frames are extruded creating linear air chambers which provide additional resistance to heat transfer. The thermal insulting properties of vinyl windows can also be further boosted by filling in the non-draining hollow cavities, or insulating air pockets, with additional insulation in addition to using high performance glazing such as double or triple insulated glazed sash, or panes of glass, as shown in Figure 1B. These insulated glazing units (IGU) serve as an additional insulator from both heat and sound transmission.

Because vinyl windows are a good insulator and thus have low conductivity, they resist condensation better than other aluminum. When moisture settles on a cold surface such as the glass pane (a humid and warm environment paired with cold surfaces), condensation can form. But because the interior surface of the vinyl windows tends to remain close to room temperature and has a high condensation resistance factor (CRF), condensation does not form in most conditions. Prolonged condensation in or on many materials can lead to mold and mildew, negatively affecting the air quality and health of the building occupants.

Part of the reason for vinyl window's growing success is that they are energy efficient during both the manufacturing and use phases lifecycle. They have a low embodied energy, meaning it takes little energy to convert the raw material to the end product. For reference, aluminum windows use about 3 times more energy to manufacture. According to a lifecycle study report by Franklin Associates, if the United States were to completely switch over to manufacturing only vinyl windows, the U.S. could save almost 2 trillion BTUs (British Thermal Unit) of energy every year, which could meet the annual needs of 20,000 single family homes. Vinyl windows are also thermoplastic, so when the windows have reached the end of their lifespan they can be reprocessed for recycling with minimal loss of its original properties. Scraps, trims and other off-spec materials can be melted and remolded to create new window frames.

In addition to being energy efficient, when manufactured and installed correctly, vinyl windows are also very low maintenance. They have a lifespan of 20 to 30 years without requiring any painting or finishing. Air quality is improved because there are no harmful fumes from using paints, strippers, and stains. They are also resistant to rot, rust, corrosion, blistering, flaking and insect infestations. Because they can be finished with UV inhibitors, vinyl windows will not crack, split, pit, or chalk. Vinyl windows can also be heat welded, which means they will be water tight for the life of the window. They are also inexpensive and quick to install because they are usually pre-fabricated.

CONS OF VINYL WINDOWS

However, despite all their benefits, vinyl windows also have several drawbacks. Despite the fact that vinyl windows use very little energy to manufacture, they are still harmful to the environment. They use over 40% of the chlorine gas produced in the United States, as about 57% of the weight of PVC is made up of chlorine. For reference, only 5% of the nation's chlorine gas is used to disinfect water, which includes sewage treatment. In addition, several harmful by-products are created during the manufacturing of vinyl such as ethylene dichloride (EDC), vinyl chloride monomer (VCM) and dioxin, which is one of the most potent carcinogens known to science today as noted by the Center for Health Environment and Justice, and Environmental Health Strategy Center, 2004. And even though vinyl can be recycled, the percentage of vinyl windows that are recycled is actually relatively low as very few facilities know how to process vinyl. Since vinyl is inexpensive to produce, the incentive to recycle old vinyl is quite low, so most vinyl windows are thrown away once they reach the end of their lifecycle. Vinyl is also relatively newer product and the need to recycle has not been there. Because vinyl is so durable it doesn't biodegrade and if incinerated, releases toxic chemicals into the air.

Vinyl is a relatively flexible material making it weak in bending strength. vinyl windows in a larger size are generally not available since the frame lacks the stiffness and rigidity to support a large piece of glass. They are more effective for smaller windows, but sometimes longer span vinyl frames are reinforced with steel to reduce bending and bowing of the frame, which can result in reduced thermal performance. Flexibility and excessive bending make it more difficult for sealants and glazing gaskets to uniformly and effectively attach resulting in air leaks and water infiltration, as shown in Figure 2A. Vinyl window mullions are not as strong as aluminum therefore, larger mullions are required to span the same sized window as compared to aluminum or steel. To overcome the lack of larger vinyl windows, often several windows, usually 2 to 3, are mulled, or joined together, to form a larger window.

Figure 2A – Common Window Failures

Figure 2B– Common Window Failures

Image Source: C. Window Expert

Mulling windows has its inherent risks and issues as well, as mulled joints are a very common area for water intrusion. Because fixed mullions are not flexible unlike the vinyl frames, they do not move with the vinyl window frame and they can crack due to temperature changes resulting in a vertical mulled failure. Mullions and capping trim attachments need to be continuously sealed to the exterior of the window to be effective. Sealant also needs to be applied between the mullions to effectively prevent leaks. Also, we have noticed several examples when screws are driven into the window from the interior during the mulling process, which is another big source of leaks. One of the advantages of vinyl windows is having a continuous welded frame and welded fin; however, mulled windows do not have continuous welded fins often resulting in leaks at the joints between fins. Even if individual windows are tested and deemed successful, if the mulled window is not tested as an assembled unit, it can be susceptible to failure at the mulled joints from the lack of windows' welded fins. Many manufactures and builders fail to test windows in the actual mulled configuration, resulting in water and air intrusion issues down the line.

Figure 3A – Vertical Mullion Failure

Caulking also sometimes has a difficult time adhering to the PVC due its waviness and flexibility, making it difficult for sealants to adhere properly or uniformly (Figure 2B). As a precaution when working with PVC, adhesion tests must be performed prior to applying sealants to ensure they will adhere and effectively prevent water intrusion. Also as vinyl and PVC have a low melting point, windows tend to bend and sometimes set in the bent position because vinyl has a greater coefficient of thermal expansion, meaning it shrinks and grows more with temperature changes, than the glass window, sealants can often shear because thermal movement of PVC is up to 7 times that of a glass window. The glazing seals, often a kind of foam tape, used in vinyl windows can fail due to internal glazing, an independent window system on the interior side of the window also known as secondary glazing, making the seals vulnerable to long term exposure to UV and water. It is also difficult to obtain high quality vinyl windows due to different manufacturing techniques, imported materials not being subject to as stringent standards as domestically manufactured products, and many mass produced windows being made with lower quality and lower grade materials. To ensure vinyl windows will last make sure they are certified by AAMA. In general, high quality vinyl window frames will be pure white, as opposed to a light blue, and will have many chambers to provide a strong structure that will resist heat deformation. Premature failures can mostly be attributed to cheaper materials, poor manufacturing techniques or poor design. For example, older windows often lack fused or welded corners which make them more prone to water leaks. Another common area of failure is the screw-spline joinery, which holds the window frame corner joint together, because they are usually not conducive to effective sealing and sealant adhesion.

However, it is not only the vinyl frame that is subject to failure, the insulated glass seal commonly used with vinyl windows can also fail. In between the panes of glass a desiccant, a material used to promote a dry environment (usually an inert gas), is used and then closed off with a sealant. However, sometimes moisture moves pass the sealant and when too much moisture moves into the sealed off space, the desiccant loses its ability to absorb any more moisture allowing condensation and fogging to appear between the panes of glass as shown in Figures 3A and 3B.. This type of condensation is different from condensation that appears on the interior window pane which is a result of temperature and humidity differences. Usually premature failure is caused by poor design which allows the unit to sit in a high moisture environment or poor workmanship during fabrication. This can usually be prevented by passing several ASTM tests recommended by the Sealed Insulated Glass Manufacturers Association (SIGMA).

CASE STUDY

A case study displaying some of these vinyl window failures was an apartment project built in 2007 and 2008. The apartment buildings were 4 to 5 stories of wood frame construction built over a post tensioned concrete podium which housed a garage and retail shops. The apartment building consisted of “fin” style vinyl casement windows with steel reinforced mullions. The project also had sliding windows and doors with Juliette balcony railings, which do not protrude out of the building, at courtyard entrances.

In order to obtain a thorough analysis of the window failures the apartment building was suffering from, our company performed various air and water infiltration tests such as the ASTM E1105.01, “Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference,” and ASTM E783.02, “Standard Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.” Our company also reviewed shop drawings and previous reports in addition to conducting visual observations.

The windows immediately failed the two water and air ASTM tests leakage occurred at failed glazing seals. The interior-glazed windows had compressed acrylic closed-cell foam glazing tape with glazing stops at the interior which did not have uniform contact with the glass, allowing water to completely bypass the seal. In all windows where glazing was tested, the glass to glazing seals failed. Upon further examination and removal of the glass window panes, the glazing tape was found to be discolored and stained likely from standing dirt and water. The failure of these windows was caused by inadequate attention to design factors on the part of the manufacturer and contractor.

When glazing is installed from the interior as opposed to exterior or double glazing, it exposes the foam gaskets and forces the glazing tape to be the primary line of defense against leaks, a very short term solution. This is problematic because the glazing tape, especially when it is of lower quality, is very susceptible to damage from UV and heat and can quickly fail. But not only did the failure of the glazing tape allow water intrusion, it also caused air-leakage failure. This was confirmed with the ASTM E283 test, in which all seven windows that were tested failed to prevent air leakage. When glazing fails, the intruding water flows into the sill tracks of the window panes. Sometimes it will flow into the upper lites which contains a drained horizontal mullion, but it becomes problematic when it enters the lower sill track because it is not designed to manage water.

During testing water rushed into the lower frame via the horizontal track which then percolated into the dry sill track and then overflowed onto the wood stool. A fixed “dry” sill track does not provide drainage, leaving no method of managing the water that enters the frame. The water leakage led to rusting of the structural steel reinforcing and buildup of standing water in the lower sill track resulting in growth of mold, mildew, rust, and damaged wood stools. This water intrusion was due to improperly sealed horizontal to vertical coped mullion jamb extrusion joints which allowed water to flow through the sealant-dependent joint in the horizontal mullion into the lower sill track.

Figure 4A – Coped Mullion Joint Failure

Since the window failure was due to improperly sealed joints in the factory, the manufacturer was asked to repair the leaking windows under warranty prior to our testing. Attempts made by the manufacturer were a short term fix and have since failed. The frame was sealed with a silicone sealant from the exterior, and on the frame's interior a hole was drilled to equalize and relieve pressure and expanding foam was blindly injected. During the inspection of the windows, the temporary solution had failed resulting in more damage to interior finishes.

After the glazing failure was isolated, additional tests were performed to find other potential failures and additional water leaks were found at glass-to-glazing bead junctures. Once the glass-to-glazing failure was isolated, our company performed the ASTM E1105 to solely test the glazing to frame connections and the frame conditions. Three windows were tested at 3.5 psf, which was only $^{2}/_{3rds}$ of the manufacturer's stated performance standards. All three windows that were tested without isolating the glazing failed to pass, constituting a 100% failure rate.

There were also leaking fastener holes at the coped juncture in addition to improperly constructed weep holes in the drainage pathway allowing water to leak into the interior of the building. The weep holes found in the windows were only 5 mm in diameter as opposed to the 8 mm or $^{5}/_{16}$ inches recommended by the Glazing Association of North America. The smaller weep hole prevents proper drainage because there is too much surface tension. Out of the 13 windows tested, all 13 failed to protect against water intrusion. To correct the problem, our company recommended a dual seal for the glazing gaskets using both foam or butyl tape in addition to a wet silicone sealant.

The second case study involves a similar multi-family project in Northern California. The larger window openings of this project consisted of smaller window units which were mulled together. Mulled windows consist of smaller windows that are individually tested for air, water and structural rating. These smaller windows are than joined together to form a large composite window which as an assembled unit has often never been tested for air, water and structural considerations.

Many of the mulled windows that were leaking and we tested suffered from various failures including glazing seal failure as discussed in the Case Study 1 above and failures at mulled frame joints. Since the original window frames had "nailing fins", when they were mulled or joined together, the fins were cut and joints were sealed with foam tape. Some of the manufacturers grind off to remove the fins on the sides of the windows that come in contact with each other. The windows are tightly joined/mulled together and shipped as a single unit. During shipping and handling, thermal movement and racking movement resulted in cracking at the welded corners of the window and caused leaks.

The two case studies exemplify the problems encountered with vinyl windows; however, properly designed and fabricated vinyl windows can work and be a long lasting solution. Vinyl is a great insulator and thermal breaks are not required to meet energy code requirements. Properly designed and fabricated vinyl windows have great potential for sustainability and longevity. This presentation and paper is intended to be a learning experience from what to specify in vinyl windows and how to avoid failures.