Vinyl Siding Distortion

Instances of vinyl siding distortion have been reported along with questions related to how it occurs. This bulletin provides information related to a study and analysis conducted by Cardinal Glass Industries along with general recommendations on how to avoid vinyl siding distortion.

Vinyl siding distortion can occur when radiated or reflected solar energy from various sources combine with ambient temperature and direct sunlight exposure to cause visible distortion of vinyl siding. According to a recent LBNL report, the heat deflection temperature of vinyl siding ranges from 142 °F - 192 °F with an average distortion temperature of 166 °F[1].

While the occurrence of vinyl siding distortion cannot be reliably predicted, awareness of its contributing factors may help to avoid it. The following variables should be considered when determining whether vinyl siding distortion may occur or has already occurred:

- Color and solar absorption of the vinyl siding;
- Heat distortion temperature of the vinyl siding;
- Cumulative time and temperature effects on vinyl siding;
- Molecular strains in the vinyl siding that were frozen in during the manufacturing process;
- Installation strains on the vinyl siding that exacerbate any manufacturing related strains;
- Ambient outdoor temperatures to which the vinyl siding is exposed;
- Exposure of the vinyl siding to wind, which affects the cooling of the siding;
- Architectural designs that block wind and trap heat (e.g, overhangs, alcoves, inside corners);
- Proximity of the siding to other heat sources, such as air conditioning compressors, motors, and barbeque grills;
- Reflections from building materials, including adjacent vinyl siding, windows, doors, shingles, nearby walls, asphalt, concrete, swimming pools, etc.;
- Orientation of any reflective building product relative to the sun and the affected vinyl siding;
- Distance of the involved reflective building product to the vinyl siding;
- Excessive deflection of any involved glass product when manufactured. This may be exacerbated by changes in barometric pressure and temperature in the field.

The following sections describe how these variables may contribute to vinyl siding distortion, and offer considerations and recommendations for minimizing the risk of its occurrence. Because of the numerous variables involved, however, there is no single solution.

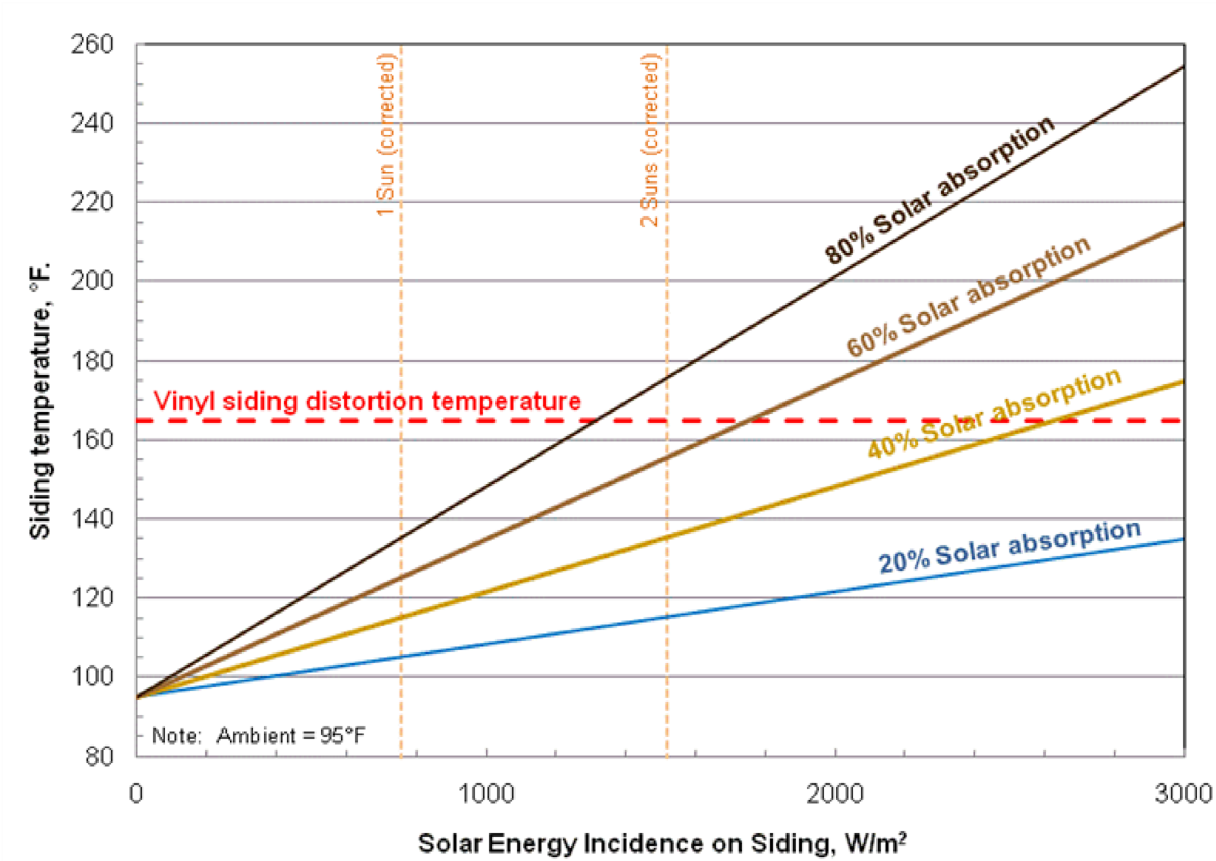
<u>Vinyl Siding Considerations</u>
Vinyl siding is often selected as an exterior cladding material because of its low maintenance and low cost qualities. However, there are several considerations that need to be taken into account when using vinyl siding products because vinyl siding can soften and visibly distort at approximately 165 °F[2]

Role of Color / Absorptance
Vinyl siding is available in a variety of colors with related solar absorptance levels. In general, the darker the color, the more absorptive the siding. The absorptance values can range from 20% to 80%. The more solar absorptive the vinyl siding, the faster its temperature will increase when exposed to thermal energy or solar irradiance.

There is a direct correlation between vinyl siding solar absorptance and the heating of the vinyl siding above the ambient air temperature. Figure 1 shows surface temperature versus solar irradiance for four vinyl siding products at various solar absorptances. (Clear, non-windy day, with an ambient air temperature of 95 °F)

[1] Lawrence Berkeley National Laboratory Research Report “Research Needs: Glass Solar Reflectance and Vinyl Siding”; R. Hart, *et. al*; July 2011

[2] VSI Report, Solar Reflection and Heat Distortion dated 7/13/2011



Sky Condition Correlation

½ Sun	1 Sun	1-1/2 Suns	2 Suns
Partly cloudy	Clear sunny day	Clear sunny day + ½ sun material reflection	Clear sunny day + 1 sun material reflection

Figure 1. Temperature vs. Solar Irradiance

With no sun on the siding, the vinyl siding temperature is the same as the ambient air temperature. At 20% and 40% solar absorptance, vinyl siding is able to withstand greater exposure to solar irradiance before distorting, than darker vinyl siding at 60% and 80% solar absorptance.

The maximum direct solar irradiance normal to the sun for a given location, on a clear day, with the sun highest in sky, is approximately 1000 W/m^2. This level of solar irradiance is often referred to as "one sun". However, the orientation of the sun relative to the siding will lessen the intensity of the solar irradiance due to the sun's angle of incidence. The solar irradiance experienced by the siding will vary with location, time of day and weather conditions, but a typical "corrected one sun" value for the irradiance on a vertical wall, is approximately 750 W/m^2.

Role of Built-In Manufacturing Stresses

During the manufacturing process, vinyl siding is extruded, reheated, shaped, and cooled at least two times. This process quenches the polymer before the molecular structure reaches its lowest energy state, in essence "freezing in" strains of the vinyl siding. These strains are captured in the manufactured product, making it more susceptible to stress relaxation, which results in visible physical deformation of the siding when exposed to external stressors.

All plastics relax at their glass transition temperature. Vinyl siding tends to shrink above this temperature. Consequently, when vinyl siding is heated to its glass transition temperature after installation, the frozen-in strains relax, creating buckling and wrinkles as shown in Figure 2. The figure also demonstrates how white vinyl products (with a lower absorptance) perform better when exposed to the same solar energy. Notably, the white vinyl corner shown in Figure 2 has not distorted, while the adjacent darker siding has visibly distorted.

Figure 2. Vinyl Siding Distortion

Role of Installation Strains

Vinyl siding is designed with slots through which fasteners are inserted to attach the siding to a structure. These slots are longer than the width of the fastener, allowing for some movement of the vinyl siding as the siding expands and contracts with environmental temperature changes. If the vinyl siding is attached too tightly, the movement of the vinyl siding can be impaired, placing further stress on the siding. In addition, proper end clearance of the siding lineals is necessary to prevent buckling during thermal expansion.

Role of Time and Temperature

Modulus refers to a material's rigidity or stiffness. All plastics are subject to a time-temperature superposition principle that can be used to predict the behavior of the plastic over time. Like other plastics, the modulus of vinyl siding is time and temperature dependent. Figure 3 shows the appearance of PVC vinyl siding specimens (0.038 inch thick) after being heated for one hour in an oven at four different temperatures (160 °F, 165 °F, 170 °F and 180 °F). After one hour of exposure to 165 °F of heat, vinyl siding visibly distorts.

Not heated (A) 160 °F (B) 165 °F (C) 170 °F (D) 180 °F

Figure 3. Vinyl Siding Heated for One Hour

The time-temperature superposition principle can also be used to predict when the same amount of relaxation and distortion will occur at other times and temperatures. The dashed line in Figure 4 shows that one hour of exposure at 165 °F (B) is equivalent to a ten second exposure at 180 °F (X) and a one day exposure at 155 °F (Y).

The modulus of vinyl siding (material stiffness and rigidity) is time dependent. The time-temperature superposition principle is used for all plastic materials and Figure 4 above shows the modulus of vinyl siding vs. temperature with respect to time. Plastic materials relax more as the modulus is lower. The vinyl siding product tested relaxed and distorted visibly when subjected to 165 °F for 1 hour as indicated by point "B" in Figure 4.

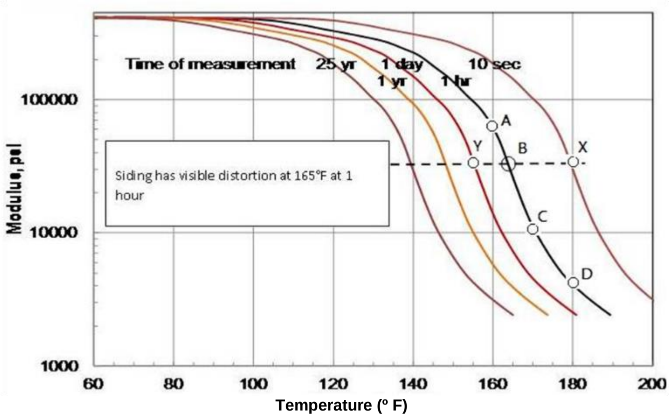


Figure 4. Vinyl Siding Modulus vs. Temperature with Respect to Time

The information from Figure 4 is further summarized in Figure 5 to demonstrate how the interplay between exposure time and exposure temperature impacts the appearance of the vinyl siding. The exposure over time is cumulative. While the sun's energy may strike a particular section of vinyl siding only for a short time each day, when repeated on a daily basis, the molecular bonds of the siding are further degraded each day. Therefore, exposure for one hour at 165 °F is equivalent to ten minutes of exposure, repeated for six consecutive days, at 165 °F.

	Degree of vinyl siding distortion	160 °F	165 °F	170 °F	180 °F
Condition A	Very Slight	1 hour	30 min.	2 min.	< 1 min.
Condition B	Slightly Noticeable	6 hours	1 hour	10 min.	< 1 min.
Condition C	Definitely Noticeable	4 months	6 hours	1 hour	1 min.
Condition D	Significant Distortion	4 years	4 months	5 days	1 hour

Figure 5. Distortion Table

Vinyl Siding Industry Standards

Current testing requirements for the vinyl siding industry are per ASTM D3679, *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*. This standard specification has a maximum test level of 120 °F. This is significantly below the temperature that vinyl siding can experience when exposed to direct sunlight. See Figure 1.

In ASTM D 4803, *Standard Test Method for Predicting Heat Buildup in PVC Building Products*, it is recognized that the sun can cause PVC building products to distort. Under section 5.1 Significance and Use, it states:

> "Heat buildup in PVC exterior building products due to absorption of the energy from the sun may lead to distortion problems. Heat buildup is affected by the color, emittance, absorptance, and reflectance of a product."

Storage of Vinyl Siding

The Vinyl Siding Institute recommends to not store the cartons with vinyl siding in any location where temperatures may exceed 130 °F (e.g., on blacktop pavement during unusually hot weather or under dark tarps or plastic wraps without air circulation)[3].

Uneven heating of vinyl siding panels

The effect of uneven heating on vinyl siding is covered in the LBNL report[4] on the subject, where it states:

> "Temperature rise in nearly all materials, including vinyl siding, results in thermal expansion. Vinyl's coefficient of thermal expansion is relatively high compared to that of other typical siding products, e.g., approximately 10 times that of wood parallel-to-grain (Matweb 2010, USDA 2010). However, properly processed and installed vinyl siding is designed to account for this expansion (ASTM 2006). Permanent

[3] Vinyl Siding Institute – "Vinyl Siding Installation Manual", dated Oct 2004

[4] Lawrence Berkeley National Laboratory Research Report "Research Needs: Glass Solar Reflectance and Vinyl Siding"; R. Hart, *et. al*; July 2011

distortion may be introduced into properly processed and installed vinyl siding at high temperatures, particularly when unevenly heated across the surface. Improperly processed or installed vinyl siding may be susceptible to a surface distortion known as oil-canning at relatively low temperatures when the temperature rise is uniform or uneven across the surface."

Comparison to Other Building Materials

Other cladding materials can withstand exposure to higher temperatures than vinyl PVC siding. Figure 6 compares distortion temperatures of various exterior cladding products.

This data demonstrates that vinyl PVC siding can withstand temperatures of only 165 °F, while all other cladding materials can withstand significantly higher temperatures. In applications where vinyl siding distortion may occur, other materials should be considered as alternatives

Material	*Maximum Temperature to Softening or Distortion*	*Reference*
Vinyl PVC	165 °F (softening)	http://www.vinylsiding.org/aboutsiding/cleanmain/solarandheat/NAHB_Reflected_Sunlight_from_Low-e_argon_clarified_doc.pdf
Vinyl CPVC	220 °F (softening)	http://www.youtube.com/watch?v=W-WME_kXSy0
Polypropylene	316 °F (softening)	http://www.tcforensic.com.au/docs/article10.html#1.1
Fiberglass	350 °F (recommended maximum operating temperature)	http://fiberglasssiding.com/fiberglass-siding-benefits
Plywood	250 °F (slow charring)	http://www.lodgelumber.com/docs/msds/plywood.pdf
Lumber	250 °F (slow charring)	http://www.tcforensic.com.au/docs/article10.html#1.1
Wood shingle	250 °F (slow charring)	http://www.tcforensic.com.au/docs/article10.html#1.1
Hardboard	607 °F (ignition)	http://www.fs.fed.us/psw/programs/uesd/uep/products/powerpoint/psw_cufr678ecoSmart_Fire_Congress_All.swf
Aluminum siding	1220 °F (melting point; with softening seen around 700 °F)	http://www.tcforensic.com.au/docs/article10.html#1.1
Fiber Cement	2500 °F (this material is non-combustible and non-ignitable)	http://www.jameshardie.com/homeowner/fire_technical.shtml
Stucco	2700 °F (sintering temperature of Portland cement)	http://www.cement.org/stucco/faq_fire_rating.asp
Brick	2700 °F (melting point of a single brick; masonry wall collapse may occur at lower temperatures)	http://www.tcforensic.com.au/docs/article10.html#1.1

Figure 6. Temperature Influence on Exterior Cladding Materials

Window / Energy Considerations

The United States Department of Energy (DOE), the Environmental Protection Agency (EPA), and state building code committees have developed energy performance criteria for windows that must be satisfied. In addition, the federal government has given tax incentives for installing windows that improve energy efficiency. The energy efficiency criteria developed are intended to reduce heat loss in the winter (U-Factor) and reduce solar heat gain in the summer (Solar Heat Gain Coefficient, SHGC). To achieve these objectives and mandates, the window and glass industries have designed and manufactured energy efficient windows with high performance glass that have played a significant role in decreasing the energy consumption of homes in the United States.

Today, energy efficient windows and doors typically contain insulating glass (IG) units comprised of two lites of glass, separated by a spacer bar. Argon or another inert gas is contained in the sealed airspace between the two lites of glass. Frequently, one lite of glass is coated with a low emissivity ("Low-E") coating that serves two functions:

1. Reflect out the sun's short wave infrared energy in summer;
2. Reflect and keep in the home's long wave infrared energy in winter.

Flexing and Deflection of Insulating Glass Units

Insulating glass is designed to be a dynamic unit that flexes in response to changes in environmental conditions, such as temperature and barometric pressure. This flexing minimizes stresses on the unit's seal and glass, reducing the chance of seal failure and glass breakage, thus preserving the longevity and durability of the product. Consequently, some deflection in an insulating glass unit can be expected to account for changes in the environment.

IG units are typically constructed with two or more panes of glass separated by a spacer and containing a sealed gas volume. The seal is designed to have very low moisture and gas transmission so that the inside of the unit is essentially a closed system. When the gas temperature decreases, the gas volume also decreases to maintain pressure equilibrium with outside air. The glass will deflect inward, becoming slightly concave. Glass deflections resulting from environmental conditions such as temperature and barometric pressure are normal and do not indicate a defective unit.

Figure 7 shows the dynamic flexing of insulating glass lites that may be seen in an insulating glass unit due to temperature and pressure changes in the environment. Most insulating glass units do not flex as much as indicated in the illustration. It is shown for illustrative purposes only.

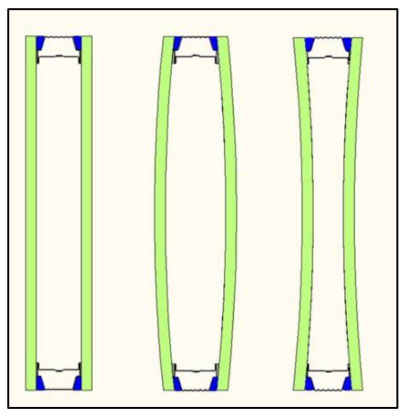


Figure 7. Dynamic Flexing

Many window manufacturers comply with the requirements of the National Fenestration Rating Council (NFRC). To certify their compliance, these manufacturers must verify at the point of manufacture that the insulating glass gap width reduction does not exceed the allowable reduction widths. These gap reduction requirements <u>do not apply after the units are installed in the field</u>, as there may be temperature and pressure changes yielding different results[5]. Adherence to these

[5] NFRC, "Certification and Inspection Agency (IA) Operations Manual", 2011

NFRC in-plant gap width requirements limits the onsite glass deflection to that which occurs in response to environmental changes.

Some IG sealants are applied hot or require a heating process. This results in an elevated airspace temperature. If the airspace is not vented during the cool down process, a reduced airspace can occur at ambient conditions. Careful attention should be paid by the IG manufacturer to assure that the NFRC gap reduction limits are met.

It has been suggested that capillary tubes can be used as a solution to reduce glass deflection. This is not a recommended solution for several reasons:

1) The tube may not eliminate all the glass deflection. It may not correct the deflection in IG units that are fabricated with a contracted airspace, as the IG edge sealants may have taken a permanent set.
2) It is imperative that the tube be installed properly to ensure pressure equalization actually occurs.
3) A capillary tube does not address the other factors, as outlined above: solar absorptance of the siding, installation strains in the siding, strains built-in to the siding at manufacturing, proximity to other heat sources, etc.
4) Moisture is transported through the tube and into the IG unit with pressure changes caused by daily and seasonal temperature changes ("breathing" of the IG unit). This can allow significant amounts of moisture into the airspace and drastically reduce the longevity of the IG unit. This is especially true in climates with high humidity conditions.
5) Capillary tubes are recommended to only be used in high altitude installations where the airspace pressure is equilibrated to the ambient barometric pressure outside the unit. Typically these high altitude installations also have low humidity conditions reducing the longevity concerns.
6) When a capillary tube is used, thermal performance of the window may be impacted.

Screens

Screens have also been suggested as a solution. Adding screens to the outside of windows can help by blocking more than 40% of the reflected energy. Screens can block most of the incident solar direct beam radiation from reaching the glass. This is especially useful for the "inside corner condition" described below. While this would be a significant help, it does not address the other contributing factors noted above.

In addition, not all windows are designed to accommodate exterior screens. Fixed windows, casements, and the upper sash of a single hung window are examples where adding an exterior screen would compromise window aesthetics and the view through the window.

Building Design Considerations

Most instances of vinyl siding distortion involving windows fall into one of two categories: opposite wall condition or inside corner condition.

Opposite Wall Condition

Figures 8 and 9 illustrate how the sun's energy can be reflected off a window or door onto vinyl siding installed on an opposing wall of a neighboring structure ("opposite wall condition"). In this scenario, the solar energy is reflecting off the glass of the insulating glass unit.

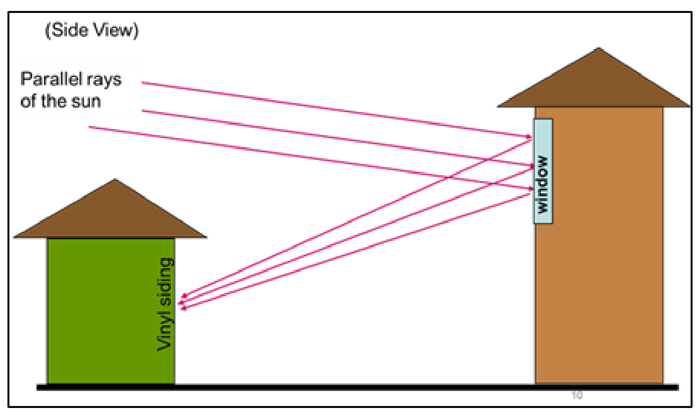


Figure 8. Opposite Wall


Figure 9. Opposite Wall Distortion

When solar energy is reflected off of an insulating glass unit with no or minimal deflection, the resulting reflection stays in relatively parallel lines and does not concentrate. As the amount of deflection increases, the reflected energy becomes more concentrated, resulting in higher temperatures where the light rays converge. As noted previously, some glass deflection is expected due to environmental changes.

Inside Corner Condition

Figures 10 and 11 illustrate how a vinyl siding clad inside corner can be exposed to solar energy. In this situation, the vinyl siding receives direct exposure to the sun's energy. In addition, sun may reflect off an adjacent glass product at a grazing angle onto the vinyl siding. This results in a near doubling of the solar exposure on the vinyl siding.

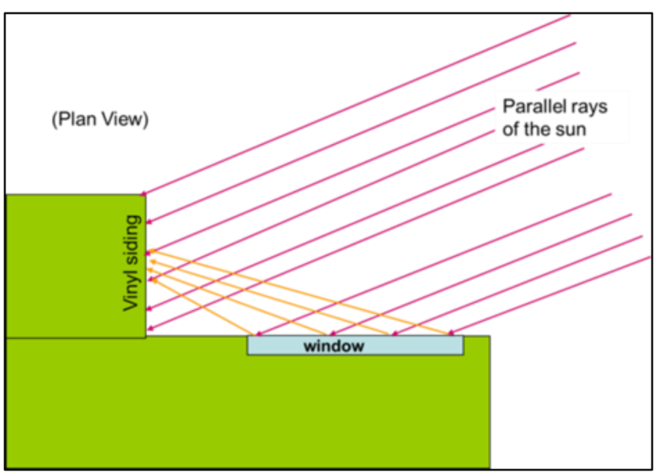


Figure 10. Inside Corner


Figure 11. Inside Corner Distortion

The inside corner condition occurs when the sun's rays reflect off a glass product at a very small grazing angle. In this scenario, the solar energy is generally reflecting off the first surface (i.e. outer surface of the exterior lite of glass) of an insulating glass unit. The reflection associated with Figure 11 came from the upper sash of a clear, uncoated dual pane window that did not have a screen on it. Small grazing angle reflections will usually result in the same amount of reflected energy from windows containing a Low-E coating as from windows with clear uncoated glass.

At a grazing angle (<10°), the reflectance off clear glass is essentially the same as the reflectance off Low-E coated glass. Figure 12 shows how the solar incidence angle between the sun and glass pane impacts the resulting reflectance. As the incidence angle approaches 0° (grazing angle), the reflectance for clear glass and Low-E glass approaches 100%.

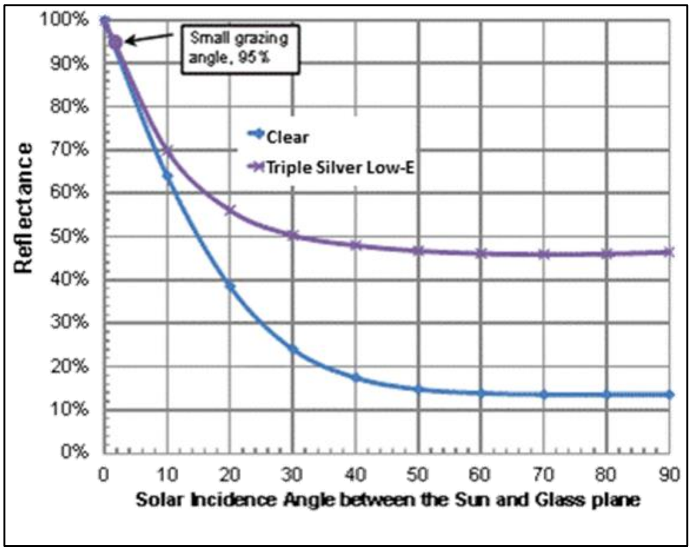


Figure 12. Reflectance at Grazing Angle

Figure 13

Case Study

An inside corner condition with vinyl siding distortion was observed during the study of a residential development in North Carolina. Vinyl siding with 65% absorptance was installed throughout the development. The windows in the development contained insulating glass units with two lites of clear glass. Distortion was observed on an inside corner where the vinyl siding was subjected to direct solar energy and energy reflected at a grazing angle off the glass of the upper sash of a single hung window.

Figures 13 and 14 depict the inside corner condition and distortion observed. Note the dark shingles adjacent to the distorted area. The shingles likely contributed to increasing the overall temperature of the vinyl siding through infrared radiation and warm air convection from the hot shingles.

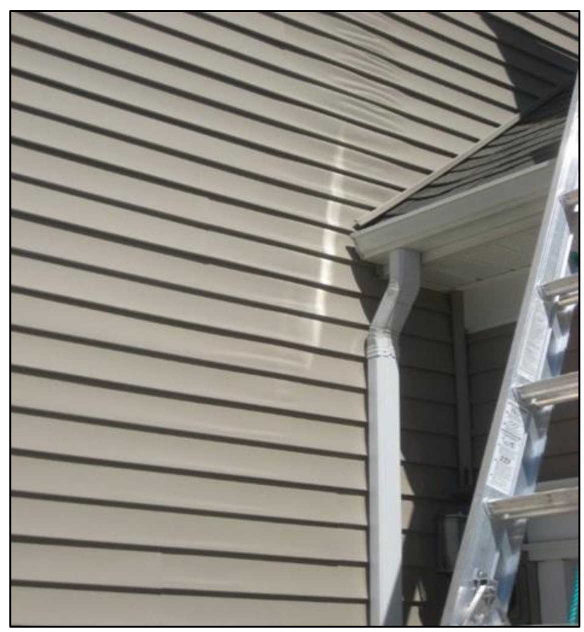


Figure 14

Figure 13

During an inspection at the development, the following conditions were observed:

- Outdoor air temperature: 75 °F
- Siding absorptance: 65%
- Thickness of siding: 0.038”
- Color of Siding: Tan
- Angle of siding: 7° from vertical
- Window type: Single hung, no screen
- Glass dimensions: 27” W x 30.5” H
- IG unit construction: 2.2mm clear glass/ 11mm airspace / 2.2 mm clear glass
- Airspace gap reduction: 0.132” (~1/8”)
- Glass deflection: 0.066” (~1/16”)
- Distance from center of glass (upper sash) to siding distortion: 87” to top of distortion, 116” to bottom
- Other radiating/reflective surfaces: Roof
- Color of the roof: Black
- Solar irradiance on siding without reflectance: 759 W/m² (corrected for 7° slope from vertical wall)
- Solar irradiance on siding with reflectance: >1,766 W/m² (corrected for 7° slope from vertical wall)
- Siding temperature direct sun w/o reflections: 125 °F
- Siding temperature direct sun w/ reflections: 166 °F

Note that these conditions show that the siding temperature can get hot enough to produce visible vinyl siding distortion. The temperature readings are shown in Figures 15.

Without Reflection With Reflection

Figure 15. Siding Temperatures

Figure 16 shows the siding temperature versus solar irradiance for a siding with 65% absorptance. Note that there are two plots; one for the field data from the North Carolina project, and one based on projected temperatures from an analysis similar to Figure 1. The higher temperatures in the field data plot can be attributed to the influence of additional heat generated on the siding by the dark shingled roof, reflection of solar energy off of adjacent siding, and the trapping of heat due to the geometry of the inside corner condition. The other plot does not include these other heat sources in the projected temperatures.

In this case, the data shows that at an inside corner condition, with grazing angle reflections from clear glass and adjacent siding, along with additional heat generated from other building materials were conditions present when vinyl siding distortion occurred.

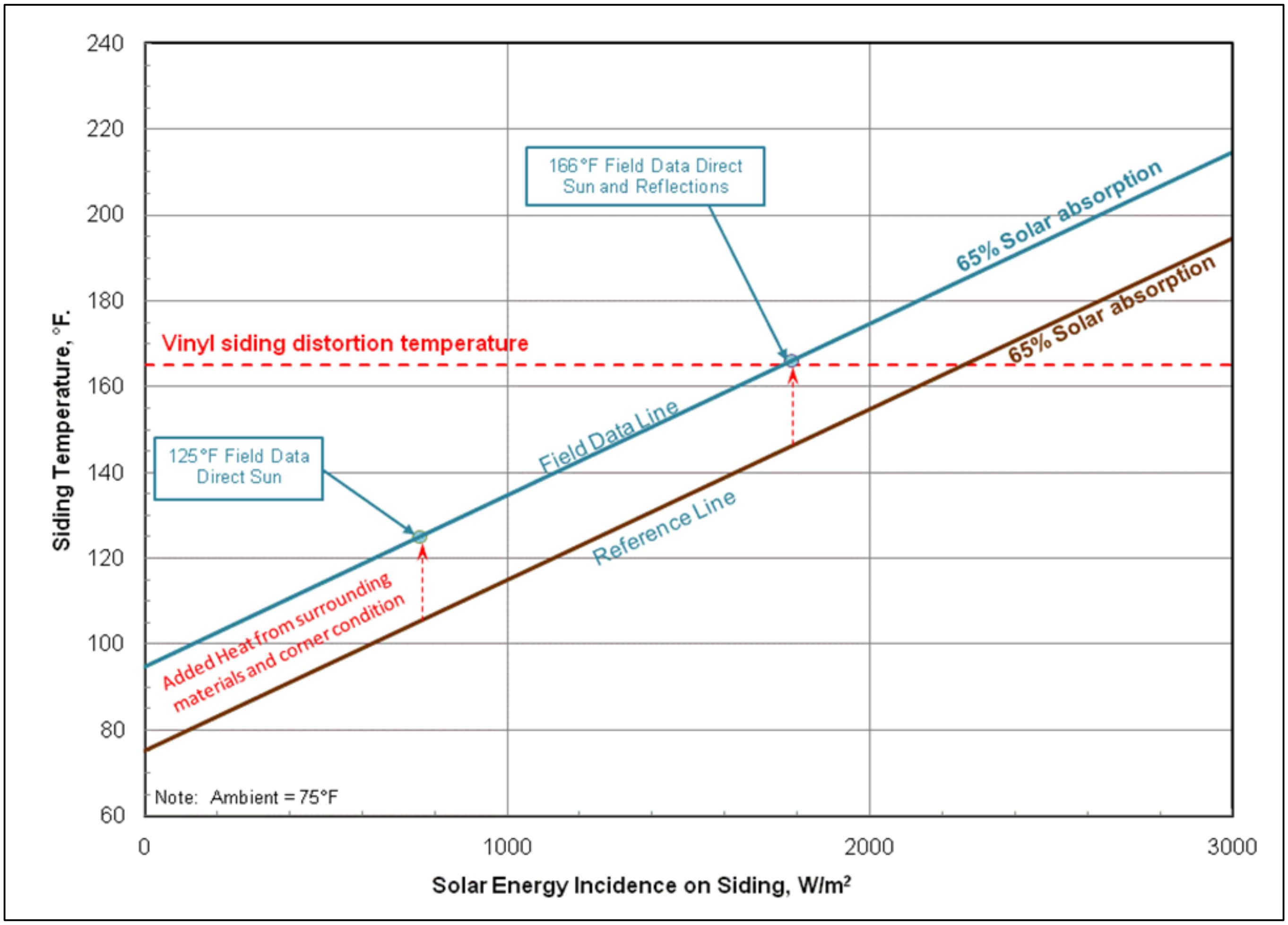


Figure 16. Field Measurements of Siding Temperatures vs. Irradiance

Summary and Recommendations

It is a documented fact that vinyl siding distortion can occur at temperatures as low as 165 °F. There are numerous factors that contribute to reaching this temperature, resulting in vinyl siding distortion.

These include:

- Color and solar absorptance of the vinyl siding;
- Presence of solar absorptance reducing pigments ;
- Frozen-in manufacturing strains in the vinyl siding;
- Installation strains in the vinyl siding;
- Additional heat sources (reflections from swimming pools, windows, pavement, asphalt shingles, adjacent walls, and barbeque grills);
- Architectural designs such as inside corner conditions that nearly double the solar irradiance on the vinyl siding;
- The angle of the sun;
- Distance between the reflective building product and the vinyl siding;
- Excessive deflection of any involved glass product when manufactured. This may be exacerbated by changes in barometric pressure and temperature in the field;
- Architectural designs that trap heat and minimize convective wind cooling;

- Cumulative time and temperature effects on vinyl siding.

Because vinyl siding distortion results from the convergence of these numerous contributing factors, no single solution is effective for all situations. Replacing the siding alone or replacing the window alone may not correct the issue, since distortion can reoccur in the same location if the other contributing factors are not addressed.

The following are considerations for controlling the factors identified and mitigating the risk of vinyl siding distortion.

Siding-Related Practices

There are several steps that can be taken by siding manufacturers to reduce the risk of vinyl siding distortion:

- Use pigments that have high solar reflectivity characteristics independent of their visible color;
- Control the manufacturing process to minimize vinyl siding's frozen-in strains.

Building Design Considerations/Practices

Attention to building design and material selection by the builder/homeowner can also minimize risk with the following considerations:

- Review the building design for the potential of solar irradiance and heat build-up and select building materials that will perform in the conditions present for the particular building design and site;
- Consider how the building will be oriented on the site, and how that orientation will impact the solar irradiance experienced by the siding and other building materials as well as the distance between neighboring homes;
- Identify high risk areas (alcoves, overhangs and inside corners) and determine whether reflection from adjacent windows or other building products could contribute to added heat on the vinyl siding;
- Incorporate strategic placement of trees, bushes, or other landscaping elements;
- Use sunshades (awnings) and or screens on windows to reduce solar reflections;
- Take into account the siding's exposure to solar irradiance and select siding; with the appropriate heat distortion temperature for the anticipated environment;
- Consider installing vinyl siding with solar absorptance levels of 40% or less in applications where there is close proximity to other structures or other reflective surfaces. This should reduce the potential for vinyl siding distortion from other material reflections and other heat sources;
- Follow the recommendations of the vinyl siding manufacturers regarding storage, handling, and installation of vinyl siding.

Window-Related Practices

Steps can also be taken relative to window manufacture and selection to minimize the occurrence of vinyl siding distortion.

For builders/homeowners:

- Select windows that are NFRC certified and labeled;
- Identify windows that will receive direct sun exposure plus reflection from nearby surfaces. Consider alternatives for these windows, such as the addition of an external screen, to block solar energy.

For window manufacturers:

- Follow the NFRC guidelines for allowable gap reduction at the point of window manufacture;
- Use of capillary tubes to equalize the airspace pressure should only be used as a last resort in appropriate geographic locations on a job by job basis after all other remedies have been exhausted. When a capillary tube is used, thermal performance of the window may be impacted.

Furthermore, capillary tubes compromise the longevity of the IG unit.

While these mitigation techniques are good principles in general, the number of and analysis of those factors potentially contributing to vinyl siding distortion is complex. Addressing a specific incident of vinyl siding distortion should be done on a case by case basis, taking into consideration the details of the particular job site

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