Recent Advances in Acoustical Glazing

Jerry G. Lilly, JGL Acoustics, Inc., Issaquah, Washington

A comprehensive review of the properties of acoustical windows and glass is provided for currently available products. Recommendations are given for the specification and application of these products to typical buildings. Complete test data from recognized laboratories are included as well.

To some it might come as a surprise that on a molecular level glass is a liquid, and that glass is actually denser than concrete. Glass is indeed an incredible material from a structural and an architectural point of view. It can be molded into amazing shapes and colors as an artistic medium. It can be used to stop water intrusion, wind and weather, and even bullets (in certain instances). Now it can even be transformed from transparent to opaque at the flip of a switch. The focus of this article is on the acoustical properties of glass, specifically the ability of glass to prevent sound transmission from one side of a window to the other.

The effectiveness of glass as a sound barrier has been known for many years. For example, increasing the thickness of glass will reduce sound transmission through the glass. Because glass is a very dense material, the added weight of thicker glass creates economic and structural concerns that make using thick sheets of solid glass an unattractive choice for most applications. As it turns out, glass is not a good thermal insulator, so in exterior applications the most common glazing choice is dual-pane or "insulated glazing." Insulated glazing is typically fabricated from two sheets of glass that are separated by a continuous metal spacer placed around the perimeter, then sealed air-tight for all eternity. The sealing process is especially important for exterior applications, because the window may fog up from moisture condensation in the air space if the seal is lost or broken. In the "old days" the typical air gap for an insulated window was about 1/4 in. The optimum air space from a thermal insulation point of view is about 5/8 in. Research has shown that air recirculation between the two panes of glass begins to reduce the thermal insulation value when the air space is much larger than 5/8 in. According to many window manufacturers, maintaining a good seal between the two panes of glass becomes increasingly difficult as the air space gets larger. As a result, spacer bars greater than 1/2 in. are uncommon, and spacer bars greater than 3/4 in. are generally not available with a warranty from the manufacturer. More detailed information relating to the acoustical performance of insulated glazing will be provided later.

Another technique for improving the acoustical performance of glass is to laminate two layers of glass together with a clear, plastic material. The plastic inner layer bonds to both pieces of glass creating what appears to the naked eye as a single pane of glass. Automobiles have laminated glass primarily for safety reasons, to minimize the possibility of glass fragments injuring passengers during a collision. As it turns out, the plastic inner layer (or laminate) provides a significant amount of internal structural damping to the glass. This damping effect has a major impact on the sound transmission properties of glass at high frequencies, especially near its critical frequency. The critical frequency is the acoustic frequency at which the wavelength of bending waves in the glass surface equals the wavelength of sound in air. At frequencies in the vicinity of the critical frequency, sound waves will pass through the glass much more readily than at other frequencies. This effect (reduced sound isolation in the region of the critical frequency) is called the coincidence effect. The critical frequency for glass depends only on the thickness of the glass. Thicker glass will have a lower critical frequency than thinner glass. For example, 1/8 in. thick glass has a critical frequency of 4800 Hz, while 1/4 in. thick glass has a critical frequency of 2400 Hz, and 1/2 in. thick glass has a critical frequency of 1200 Hz. Laboratory tests have shown that the reduction of sound as it passes through laminated glass in the coincidence frequency region is much greater than with regular (non-laminated) glass. That is to say, laminated glass provides better sound control than regular glass (of the same total thickness), but the improvement occurs only in the frequency range of the coincidence effect.

Types of Laminates

The most common laminate material for acoustical glazing is polyvinyl butyral (PVB). The PVB inner layer is generally available in three different thicknesses: 0.015 in., 0.030 in. and 0.060 in. Although one might think that a thicker inner layer would provide superior acoustical performance, laboratory tests have shown very little difference between the 0.030 in. and the 0.060 in. thick materials. As a result, the 0.030 in. thick inner layer is the most commonly used material for acoustical laminated glass.

In recent years a new inner layer material has arrived in the marketplace. This new laminate bears the acronym SAF, which stands for S-Lec® Acoustic Film (SAF).[1] It is manufactured in Japan by the Sekisui Corporation, laminated in the U.S. by Northwestern Industries and marketed under the name Enhanced Sound Control Laminate (ESCL). The new laminate has superior damping characteristics to laminated glass with PVB and to other new mono layer film laminates, as shown in Figure 1. These data are based on vibration tests using ISO/PRF PAS 16940, which is the mechanical impedance method (MIM) of measuring the loss factor. ESCL also has superior acoustical properties as compared with PVB when used in acoustical glass.

Sound Transmission

Sound transmission through glass is measured in an acoustical laboratory with two reverberation chambers. The rooms are arranged side by side with an opening between in which to place the test specimen, a glazing sample in this case. The reverberation chambers are specially designed to prevent sound transmission from one room to the other, except via the opening where the test specimen is placed. The test is performed by measuring the sound pressure levels in both rooms (simultaneously) with an electronic noise generator injecting high level broadband noise into the source room. The outcome of the test is the sound transmission loss (expressed in decibels), which is directly proportional to the difference in the measured sound pressure levels in the two test chambers. The sound transmission loss (TL) values are simultaneously measured in frequency bands ranging from approximately 100 Hz to 4000 Hz. These values are then used to calculate single number ratings for the glazing assembly.

Currently, there are two single number rating systems that are widely used: STC and OITC. The STC (Sound Transmission Class) rating has been in use for decades. It was originally designed to assess sound privacy for interior walls, but its use has expanded to cover virtually all types of partitions and partition elements. The OITC (Outdoor Indoor Transmission Class) rating system is relatively new, and it was designed to assess exterior partitions and partition elements exposed to traffic noise. The OITC rating has a different frequency range and weighting than the STC rating, with more emphasis on low frequency sounds. Unlike the STC rating, the OITC value actually represents something specific. The OITC rating represents the approximate A-weighted sound level difference between the exterior noise and the resulting interior noise in the 80 Hz to 4000 Hz frequency region. The accuracy of this approximation depends upon the actual spectrum of the exterior noise and the surface area of the partition exposed to the traffic noise. The STC rating is a single number rating assigned to

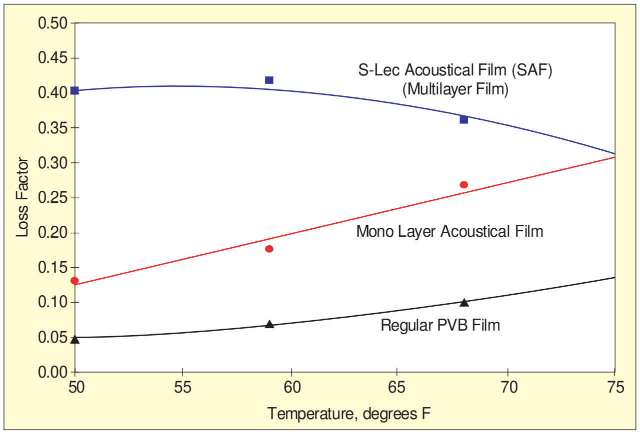

Figure 1. Laminated glass internal damping (2000 to 4000 Hz).

16 different transmission loss values between 125 Hz and 4000 Hz. The STC weighting curve is designed to correlate with human speech sounds. In general, higher STC and OITC values represent improved sound isolation. However, because STC and OITC are single number ratings based on different TL values, there may be cases when comparing two different products where a higher STC or OITC value does not necessarily provide a lower sound pressure level in the receiving space.

Single Glazing

Figure 2 presents the measured sound transmission loss of three different types of glass, all 1/4 in. thick. These data were collected in Japan at the Kobayashi Institute of Physical Research in accordance with JIS A-1416, which is similar to ASTM E90. The size of each test specimen was 1.25 m × 1.5 m, which is approximately equal to 20.2 ft^2. The curve marked by solid black circles represents the non-laminated or 'float' glass. The curve marked by blue triangles represents two pieces of 1/8 in. glass laminated with 0.030 in. thick PVB, forming a single sheet of 1/4 in. PVB laminated glass. The curve marked by solid red squares represents two pieces of 1/8 in. glass laminated with 0.030 in. thick SAF, forming a single sheet of 1/4 in. ESCL glass. There are two very obvious and important characteristics about this figure. First, note that the acoustical performance (TL) at low frequencies (800 Hz and below) is essentially identical for all three samples. In this frequency region the acoustical performance is controlled by the surface weight of the glass, which is the same for all three samples. Clearly, laminating the glass does not help improve the sound transmission loss in this frequency region. The other important characteristic is the pronounced improvement of the ESCL glass, compared to both the PVB laminated and non-laminated glazing. It is important to note that these data were collected at an ambient temperature of 68° F, which is at the extreme low end of the range of air temperature allowed for testing glazing elements using ASTM E 90-02. (The ASTM E 90-02 allowable temperature range is 68° F to 75.2° F, or 22.0 ±2° C.) As it turns out, a lower temperature decreases the damping capacity of some laminates, includuing PVB (see Figure 1). This is the most likely reason that the STC ratings from these tests are slightly lower than ratings measured with PVB laminate in U.S. laboratories.

Figure 3 presents the measured sound transmission loss for the same three glass samples at an ambient temperature of 43° F. It is clear that the acoustical performance has deteriorated in the coincidence region with all three samples. Note that the PVB laminate glazing has deteriorated to the point where it is no better than the non-laminated glazing. Both samples achieved an STC rating of 31. However, the acoustical performance of the ESCL glazing at 43° F is approximately equal to the acoustical performance of the PVB laminate glazing at 68° F. The STC rating of the ESCL glazing at 43° F is 33, which is actually 1 point higher than the PVB laminate at 68° F.

The acoustical performance of exterior glazing is especially

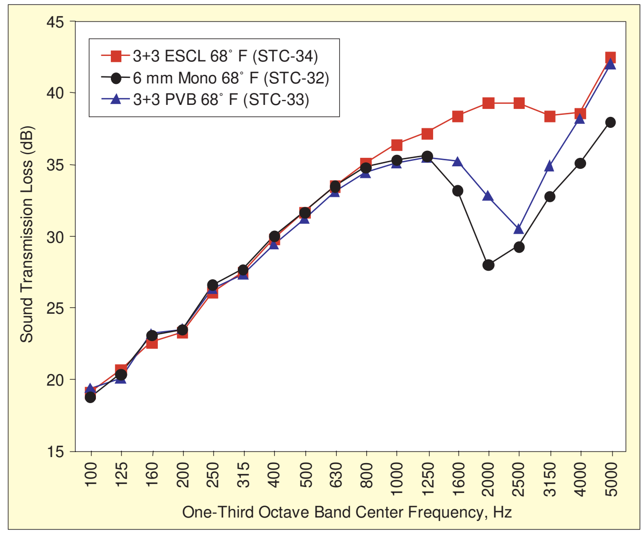

Figure 2. Sound transmission loss of laminated glass (6 mm laminated glass, 68° F).

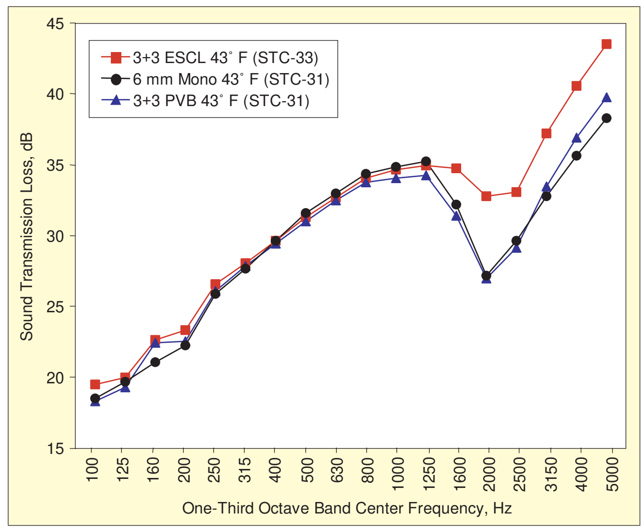

Figure 3. Sound transmission loss of laminated glass (6 mm laminated glass, 43° F).

important in areas with cold climates. Unfortunately, we do not have laboratory sound test data for glass at other temperatures between 43° F and 68° F. However, studies have shown that the temperature of the outer layer of 1-in. thick insulated glass will be less than 43° F when the outdoor air temperature is less than freezing (32° F) and the interior air temperature is 70° F. Likewise, the temperature of the inside layer of glass will be only 58° F when the exterior layer of glass is 43° F.

Figure 4 presents a graph showing the surface temperature of both the inner and outer layers of 1 in. insulating glass as a function of outdoor air temperature, assuming no wind and no solar radiation through the window. These data were obtained from the computer program Window 5.2, which was developed by Lawrence Berkeley National Laboratories. Note that even the indoor glass temperature can drop below 50° F when the outdoor air temperature goes below zero.

Double Glazing

Not surprisingly, it is possible to achieve improved acoustical performance (higher STC and OITC ratings) by using laminated glass in insulated windows. From an acoustical point of view, increasing the depth of the air space will almost always result in improved acoustical performance. I say 'almost' because a dual-pane window will not have better performance than a single pane window of equal weight in the region of the mass-air-mass resonance frequency of the insulated glazing. For most insulated glazing, the mass-air-mass resonance occurs

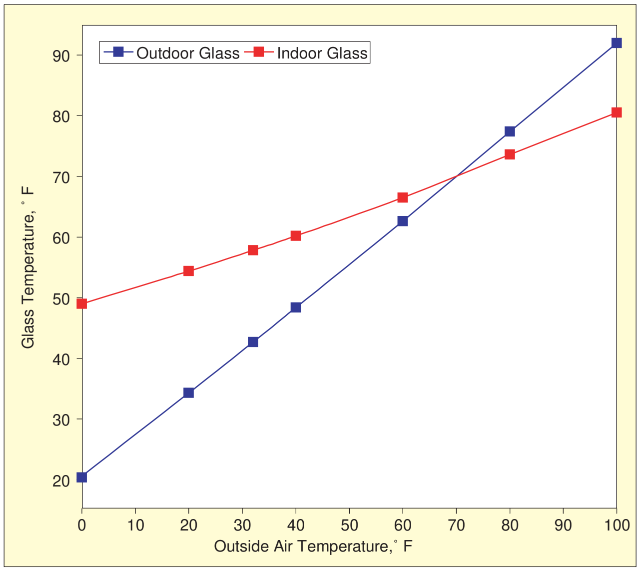

Figure 4. Glass temperature vs. outdoor temperature (1 in. insulating glass, 70° F inside).

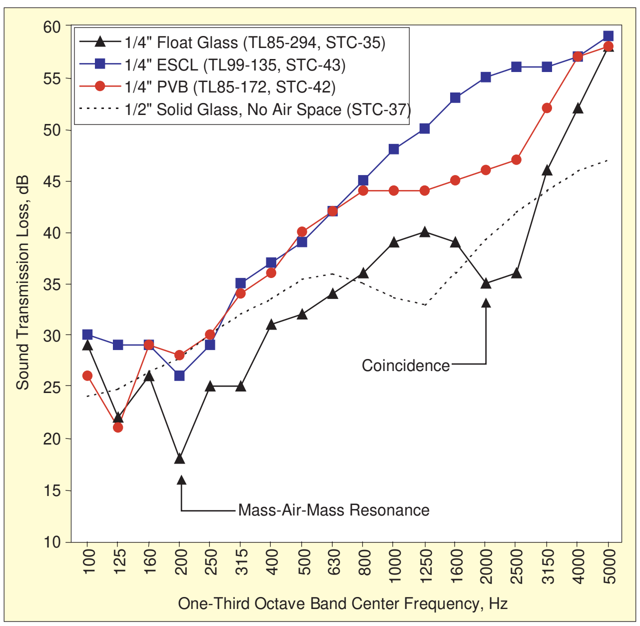

Figure 5. Sound transmission loss for insulated glass (1 in. overall thickness).

somewhere in the 125 Hz to 250 Hz frequency region, which is at the lower end of the acoustic spectrum that is used to calculate the STC rating.

Figure 5 presents laboratory test data for three different types of 1 in. thick insulated glazing, each with the same amount of glass and the same 1/2 in. air space. In all three tests presented in this figure the two sides of the sealed air space are identical. The measured STC ratings range from 35 to 43. These data were all collected at Riverbank Acoustical Laboratories in Geneva, IL. Details of the two tests conducted in 1985 were not available to me, but in the test conducted with ESCL glazing, the test sample was 21 ft^2 and the temperature in the laboratory was 73° F. There are several important characteristics exposed by this data. First, note the extremely poor acoustical performance of the non-laminated insulated glass at the mass-air-mass resonance, which in this case is in the 200 Hz frequency band. The measured TL in this band is only 18 dB, compared to 23 dB with 1/4 in. thick single-pane, non-laminated glass! So, switching from single-pane 1/4 in. thick regular glass to 1 in. dual-pane glazing with 1/4 in. thick regular glass will give you an increase of 5 points in the STC rating, but the TL at 200 Hz will decrease by 5 dB because of the mass-air-mass

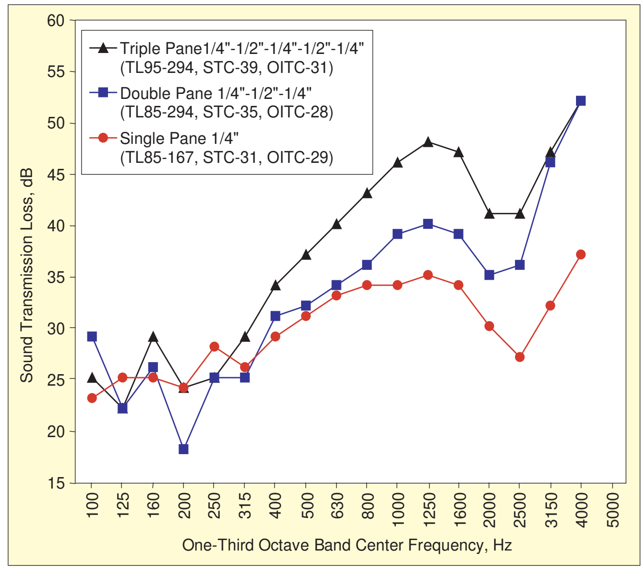

Figure 6. Sound transmission loss for 1/4 in. glass (single, double and triple pane).

resonance.

Notice also that the dip in the TL curve in the coincidence region is virtually gone for both types of double laminated insulated glass, but it is still a prominent feature of the non-laminated insulating glass. As you can see, the improvement in the coincidence region is about 11 dB with PVB laminate glazing and nearly 20 dB with ESCL glazing. It is interesting to note that in comparing the results of PVB vs. ESCL, there is only a one point difference in the STC rating even though the difference in the transmission loss (TL) in the coincidence region is nearly 9 dB.

Also notice the black dashed line in Figure 5. This curve represents the transmission loss of 1/2 in. thick, single-pane glass. Even though it has the same total amount of glass as the non-laminated insulated glazing, its low frequency TL performance is much better because of the elimination of the mass-air-mass resonance (note the absence of a low frequency dip) and the added stiffness provided by the extra thick glass. The two laminated insulated glazing curves show a low frequency dip due to the mass-air-mass resonance, but the depth of the dip is much reduced, presumably due to the added damping of the inner layer. Note the dip in the 1/2 in. thick glass curve in the 1250 Hz band, which contains the critical frequency for 1/2 in. thick glass.

Triple Glazing

In extreme cases triple-glazing may be necessary to achieve the required acoustical performance. In general, triple glazing is not a cost-effective approach unless the overall thickness of the window is increased significantly. For example, creating a sealed triple-pane window with two 1/2 in. air cavities will significantly improve the high frequency sound transmission loss, but there is very little improvement at low frequencies. Figure 6 presents measured transmission loss values for single, double and triple pane windows using 1/4 in. thick regular (non-laminated) glass and 1/2 in. sealed air cavities. As you can see, there is little improvement below 250 Hz when switching from single to triple glazing. Clearly, triple glazing is much better than single or double glazing at high frequencies, but keep in mind that the overall window thickness is much different.

Some window manufacturers are now offering triple-glazed windows with two panes forming a sealed unit (primarily for weather protection), and a third pane (unsealed) separated from the insulated portion by several inches of air space on the inside (primarily for acoustical benefit). Not surprisingly, the acoustical performance of these windows can even exceed the performance of the 1 in. thick, double-laminated insulating windows. Figure 7 presents the measured sound transmission

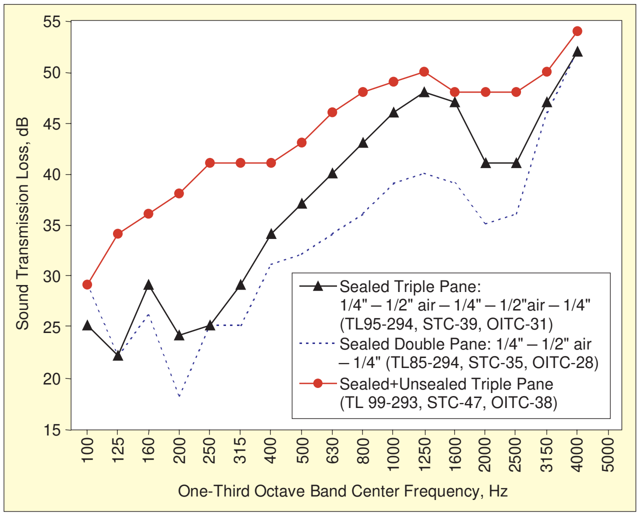

Figure 7. Transmission loss for triple glazed windows (compared with standard 1 in. insulating glass).

loss of one of these commercially available windows, compared with a more conventional triple pane window (three layers of 1/4 in. glass separated by two 1/2 in. air cavities in a fully sealed unit). The sealed triple pane window has an overall thickness of 1.75 in. Also shown in the same graph is the TL of a standard 1 in. insulating window, which is shown by the blue dashed line without symbols. This particular combination sealed + unsealed window consists of a 3/4 in. thick insulated window (two layers of 7/32 in. thick laminated glass separated by a nominal 1/4 in. sealed air cavity) plus a 7/32 in. thick PVB laminated glass inner layer with a 2.5 in. deep air cavity (unsealed). The overall thickness of this window (excluding the frame) is approximately 3.5 in. This is approximately double the overall thickness of the sealed triple pane window (excluding the frame).

Conclusion

In summary, there are many options available for acoustical glazing. Glass is a major portion of the exterior shell of most buildings, so it is very important to make the right choice – especially if the building is exposed to significant exterior noise and the interior spaces are noise sensitive. The use of double-pane insulating glass is not adequate for many projects. Even single- or double-laminated insulating glass may not be adequate, especially at low outside temperatures, where regular PVB laminated glass deteriorates to the performance of non-laminated glass.

Fortunately, there is now a new and improved laminate material (SAF) available in the U.S. that offers improved acoustical performance in the temperature region of most importance for exterior glazing applications. The product has undergone extensive testing in Japan and domestically at Riverbank Acoustical Laboratories (see Table 1), and is now available to a wide range of window manufacturers. As far as I know, the ESCL glazing has not been tested in triple pane constructions, but there is no reason to believe that it would not outperform standard PVB in any configuration. The primary advantage of the new laminate is improved sound transmission loss in the coincidence frequency region. This is particularly evident at low temperatures where it has been shown that standard PVB laminates deteriorate to the acoustical performance of non-laminated glass.

Table 1. Summary of Acoustical Laboratory Tests (single & double pane)

Glazing Construction	Laminate	Test No.	Temp	STC	OITC
6 mm monolithic	None	95593	68	32	28
3+3 mm lam (0.76 mm)	PVB	95598	68	33	28
3+3 mm lam (0.76 mm)	SAF	95597	68	35	29
6 mm monolithic	None	95593	43	31	27
3+3 mm lam (0.76 mm)	PVB	95623	43	31	27
3+3 mm lam (0.76 mm)	SAF	95624	43	33	28
12 mm monolithic	None	E2833	68	37	32
6+6 mm lam (0.76 mm)	PVB	99703	68	38	33
6+6 mm lam (0.76 mm)	SAF	99704	68	39	34
12 mm monolithic	None	E2833	43	37	32
6+6 mm lam (0.76 mm)	PVB	98721	43	37	33
6+6 mm lam (0.76 mm)	SAF	98720	43	39	33
7/32" lam (0.030")	PVB	RAL TL99-82	71	33	30
7/32" lam (0.015")	SAF	RAL TL99-81	72	34	30
1/4" monolithic	None	RAL TL85-169	N/A	31	29
1/4" lam (0.015")	SAF	RAL TL99-210	74	36	32
1/4" lam (0.030")	SAF	RAL TL99-209	74	37	33
3/8" lam (0.030")	PVB	RAL TL85-225	N/A	36	33
3/8" lam (0.030")	SAF	RAL TL99-138	74	39	35
1/2" lam (0.030")	PVB	RAL TL85-198	N/A	36	33
1/2" lam (0.030")	SAF	RAL TL99-137	74	39	36
3/4" lam (0.030")	SAF	RAL TL99-211	74	43	39
1/4", 1/2" air, 1/4"	None	RAL TL85-294	N/A	35	28
1/4", 1/2" air, 1/4" L	PVB	RAL TL85-235	N/A	39	31
1/4", 15/32" air, 1/4" L	SAF	RAL TL99-136	73	41	34
1/4" L, 1/2" air, 1/4" L	PVB	RAL TL85-172	N/A	42	33
1/4" L, 15/32" air, 1/4" L	SAF	RAL TL99-135	73	43	35
3/8" L, 3/8" air, 1/4" L	SAF	RAL TL99-208	73	42	35
1/4" L, 7/8" air, 1/4" L	SAF	RAL TL99-207	73	45	36

Note: Unless otherwise noted, the thickness of the laminate is 0.76 mm or 0.030 in.

Reference

1. Yoshioka, Terry, "Future Possibility of High Performance PVB Interlayer," Glass Processing Days 2003, Conference Proceedings. pp. 525 – 527.

The author can be contacted at: jerrylilly@aol.com.