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Passenger Window Solar Glazing Test Summary

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THE PROBLEM DESCRIPTION

In many warm, southern climates and regions with extreme summer periods, the radiant and conductive effects of solar energy can significantly impact the level of comfort experienced by passengers and operators alike. This challenge exists despite the significant resources expended by engineering and maintenance organizations to design and maintain bus HVAC systems to control the interior environment at a prescribed set point. The extent to which a maintenance organization succeeds at maintaining a comfortable bus environment can have a significant impact on the overall passenger experience and therefore plays an ongoing, key role in the support of improved ridership.

While an appropriately-sized and maintained HVAC system will handily maintain the targeted internal set point for air temperature, passengers and operators can still feel hot and uncomfortable as the solar energy of the sun relentlessly enters the bus through the glazing of the passenger windows. This phenomenon may be explained as the difference between the surrounding air temperature (ie. the air temperature controlled by the HVAC system) and the "effective" temperature (ie. the temperature that the operator or passenger may experience as a result of the solar heat radiating through the passenger window glazing and from the internal bus surfaces). On warm, sunny days, there can be significant variation in this "effective" temperature throughout the bus attributable to several factors including the location of the passengers in the bus, the position of the sun, the duration the bus has been in service and the number of passengers in the bus. This "effective" temperature is further influenced by the extent to which the passenger window glazing inhibits the transmission of solar energy through

conduction (interior window surface temperatures) and radiation (heat transmitted through the glass and radiated into the bus interior).

There are many alternatives for passenger window glazing that provide varying levels of Solar Energy Transmittance ("%SET"¹, measured as a percent value between 0% and 100%) ranging from some simple solutions like a darker tinted, low "%LT" (% Visible Light Transmittance) glazing that inherently possesses low %SET characteristics at the expense of significantly reduced visibility, to more complex, and expensive solutions where special glass coating, lamination or solar film technologies are deployed to reduce %SET while maintaining high levels of visibility. However the practical implications of using these products are not well understood nor is it clear whether or not the more expensive alternatives provide sufficiently high value to warrant the higher costs by providing quantifiable longer-term benefits.

So there is a constant balancing act that the fleet operator must perform when specifying bus passenger glazing where consideration must be given to passenger comfort, initial cost, operating costs and the desire to keep a high level of visibility (high %LT) against a desire to keep the level of solar transmittance low. It is intended that this article provide some insight into the practical effects of high performance solar glazing (herein referred to as **solar management glazing, SMG**, and defined as glazing with a %SET in the 25%-35% range) to aid the fleet operator in making a better-informed decision.

¹ %SET is commonly referred to as TSER, or Total Solar Energy Rejected, which also includes a portion of the solar energy which is reflected from the glazing.

PULL DOWN TESTING

In August of 2012 AROW Global engaged in a cooperative exercise with the City of Phoenix, Thermo King and 3M to conduct pull down testing (ie. test to observe timing required to reduce internal bus temperature to a prescribed set point) in an environment where the solar effects are particularly pronounced (ie. the city of Phoenix in late August). The passenger windows of four similar (same 40' platform and model year) buses were outfitted with four different glazing configurations:

- 6mm, laminated glass, grey 44%LT and 51%SET (a very common glass type in mass transit)
- 6mm, tempered glass with 3M Crystalline 50 Solar Control Film, grey 50%LT and 27%SET
- 6mm, laminated glass, blue/green 75%LT and 31%SET
- 6mm, laminated XIR solar management glass, grey 49%LT, 27%SET

These test buses were outfitted with several temperature probes and data recorders on the interior and exterior as well as strategically placed QUESTemp[®] Heat Stress Monitors² designed to measure thermal comfort indices using wet bulb globe temperature sensing technology. The hypothesis purported at the outset was that the buses equipped with the solar management glass (ie. when compared to more conventional glazing) reduce the net influence of solar energy transmittance on the bus interior and result in a quicker pull down, a lessened load on the engine, and will result in a more comfortable passenger space as measured by a more consistent internal temperature distribution, lower interior surface temperatures near the windows and fewer hot-spots in the seating area.

Upon commencement of the test, each bus was soaked in the late morning sun until a natural upper limit was reached (approximately 120°F) and several periodic temperatures were recorded along with the net time to reach the upper limit. The engine of each bus was then started and the HVAC system engaged



Without the use of Solar Management Glazing the heat from the sun penetrates the bus having a negative effect on passenger comfort.

and similar measurements (periodic temperature readings and elapsed time) were recorded as the temperature pull down occurred until the lower 75°F set point was achieved. This test was repeated twice for each bus, once in the late morning and then again in the afternoon. In addition, an operational simulation was undertaken, where the bus was left with the engine and HVAC system operating while door cycling occurred – open for one minute, closed for four minutes over a one hour period.

² QUESTemp[®] Series Heat Stress Monitors are commercially available devices used to measure and analyze heat stress related exposure levels.

PASSENGER COMFORT

After a thorough analysis of the data collected, it was quickly observed that in order to draw comprehensive and quantifiable conclusions, a much higher sample rate would be required. This is due, in large part, to the fact that ambient conditions vary from day to day and season-to-season and it is therefore difficult to ensure each glass type is evaluated under identical conditions. Nevertheless, this experiment leads us to suggest that there is significant evidence of the following key conclusions (and subsequent operational benefits) concerning solar management glass, SMG:

- **A reduction of up to 11% in the “heat up” rate of the bus is plausible.** *The SMG will reduce the warming effects of the sun so that a longer period of time is required for peak temperature to be achieved.*
- **A reduction of the interior surface (glass, frames, stanchions) temperature between 6°F and 9°F is achievable.** *This results in lower levels of radiant heat which affects the effective temperature/comfort of passengers in close proximity to surfaces. The risk of a passenger making contact with warmer than expected surfaces (measured as high as 140°F during our testing) is subsequently reduced. The surface temperatures of passengers and their belongings will also be reduced.*
- **The overall operator and passenger comfort is improved with SMG.** *This improved comfort is achieved by a narrowing of the gap between the effective passenger temperature and the surrounding air. This effective interior bus temperature can be reduced by between 7°F and 8°F in areas of the bus with higher solar exposure.*



With the use of Solar Management Glazing the overall operator and passenger comfort is improved as the net influence of solar energy transmittance is reduced.

OPERATIONAL IMPLICATIONS

In addition to the prospective effects SMG will have on passenger comfort, we considered the quantifiable implications of utilizing SMG (compared to a baseline, common glazing) by comparing theoretical heat load standard calculations to better quantify the potential operational effects of SMG on the net heat load for a bus. When considering the net difference between the lowest-rated glazing (51%SET) and the highest-rated SMG glazing (27%SET) from the sample group, the corresponding heat loads can be seen in the table below.

It may be observed through a review of this table that a net heat load reduction of approximately 4,544 BTU/Hr (7%) is possible by utilizing a solar management

glazing. Using standard, reference vehicle operating conditions and ambient conditions of (75°F low & 95°F high) this reduced heat would theoretically result in an approximate reduction of fuel costs of about \$164 (@ \$3.50/gallon) or \$1,963 over the 12 year life span of the bus. There may be additional, related operational benefits from the reduced duty cycle on the HVAC system and other vehicle subsystems, however a more comprehensive and controlled sample set would be necessary to fully validate and quantify operational advantages.

HEAT LOAD	DESCRIPTION	GRAY LAMINATED, 44% LT, 51% SET	GRAY XIR LAMINATED, 49% LT, 27% SET
Passenger Heat Load	Rate of heat transfer produced from the passengers within the bus	30,240 BTU/Hr	30,240 BTU/Hr
Solar Heat Load	Rate of heat transfer from Solar Energy entering the bus through the windows	13,758 BTU/Hr	9,214 BTU/Hr
U-Factor Heat Load	Rate of heat transfer entering the bus through the bus structure	18,400 BTU/Hr	18,400 BTU/Hr
Fresh Air Heat Load	Rate of heat transfer introduced into the bus from the outside via the HVAC system	3,726 BTU/Hr	3,726 BTU/Hr
Total Heat Load	Total rate of heat transfer from all sources	66,124 BTU/Hr	61,580 BTU/Hr

CONCLUDING REMARKS AND RECOMMENDATIONS

It is clear that the utilization of solar management glazing (glass with a %SET of between 25% and 35%) can have an impact on improving passenger comfort in environment where there is a significant difference between the outside/ambient temperature and the temperature inside a bus compartment. Advantages relating to passenger comfort, include a lengthening of the time required to warm the bus interior, a reduction in the temperature of interior surfaces and a narrowing of the gap between the temperature experienced by the passenger and that for which the bus HVAC system is tuned so that the solar effects do not make the passenger feel substantially warmer than the interior set point air temperature.

In consideration of the more quantifiable effects of using SMG, a theoretical analysis indicates that a modest improvement of fuel efficiency is possible by a reduction in the HVAC duty cycle, although the net savings appear quite small and subject to a significant margin of error and as such a more comprehensive analysis and larger sample size would be required in order to draw more detailed conclusions.

There are many alternatives for passenger window glazing that provide SMG characteristics (ie. %SET between 25% and 35%) including:

- Darker tinted glazing that inherently possesses low solar transmittance at the expense of significantly reduced visibility (ie. darker tint, typically less than 20%LT)
- Laminated or tempered glass with specialized coating, lamination or solar film materials that reduce the solar transmittance without significantly impacting visibility (ie. include higher %LT)
- Selecting a specialty architectural (PPG Azuria or Guardian SMGII for example) glazing that inherently offers a good balance between low solar transmittance and high light transmittance.

It is ultimately up to the fleet operator to decide the

extent to which he or she will invest in SMG for any particular bus fleet. There are definite advantages to SMG in terms of passenger comfort, although this benefit may prove difficult to quantify as it is only one aspect of many that ultimately influence overall ridership. Furthermore, the capital outlay and replacement costs for SMG alternatives must be evaluated on a case-by-case basis as each fleet is subject to a unique set of conditions and environmental variables.

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