***Enclosure 1*: Temperature Load Measurements and Specification**

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1.1.1 Initial Situation

The initial situation is specified in the Öko-Institute revised final report of 28 July 2010 page 151 ff taking reference to recommendations from Sept 2009. Sections in " " are taken from this report.

" ACEA et al. (2009) put forward that most Lead free solders are known to be unsuitable for soldering electrical connectors to printed automotive glass products. The main reason for this is that Lead is very good at equalising the thermal expansion differences between the metallic connectors used for these products and the base glass used for the product. These physical differences between the two components are very difficult to overcome. Use of Lead free solders that do not have the desired properties results. …"

Because in the past there were no thermal problems with Lead based solders for soldering contacts on glass, the temperature load was not scrutinized in depth and mainly indirectly specified (repair of painting, temperature load on interior components etc.). Examples for such specifications were provided during the 2007 stakeholder consultation and additional present specifications can be made available on request.

" …After several meetings, phone conferences and discussions, the stakeholders agreed upon a test program and started conducting tests in March 2009. The results have become available in April and May 2009. …".

Due to missing data on real temperature load on glass connectors during the last stakeholder procedure in 2009 a final decision was not possible. First tests have been conducted at 90 °C and under use of alloys 25Sn 62Pb 10Bi 3Ag and 30Sn 65In 0.5Cu 4.5 Ag (Booth 2009b, OI report).

Tests at higher temperatures that were proposed by some companies and being part of their specifications, were not conducted because the supplier of the tested Indium based solder insisted not to apply tests above 90 °C.

" … Taking into consideration the lack of results from the Joint Stakeholder Working Group, the available data from testing of other Indium containing solders, the unknown suitability of the Antaya proposal and the timeline required by the Vehicle Manufacturers to implement any validated Lead free solder, ACEA et al. (2009) conclude that the present timing in exemption 8b (31 December 2010) is not achievable. ACEA et al. (2009) therefore propose to postpone the phase out date to 31 December 2014 with a review of technical progress starting in March 2011, after the first OEM field tests have been completed and results assessed. …"

It has to be noted that the test conditions of the last test program were never agreed as being a specification for the release of volume production. It had been a compromise to enable feasibility studies to assess the suitability of potential substitutes for the Lead containing solder. As well it could not cover real vehicle tests, which are always necessary in addition to positive component test results.

1.1.2 Current Situation

Temperature load tests conducted between 2009 and 2011 on different vehicles showed that 90 °C as maximum test temperature is not representative and a higher temperature load has to be applied.

Measured temperature load varied between around 80 °C and up to around 130 °C. These reflect experience of temperature load test results made in summer tests.

Five degrees more or less alone make a big difference in the suitability of a relevant substitute.

These up-to-date test results reflect that – depending on the car design, screen inclination, thickness and color of the glass - there is a broad range in temperature load on the soldered glass connector terminals (for example, if all other parameters are kept constant then a change in glass colour alone, would affect this temperature with about a 20°C range, from light green glass to dark tinted glass, as shown by computer simulations and test result).

Despite continuous R&D activities in this field in the last years there is still no solution known, which is currently proven suitable for volume production. Some recently finished research projects for substitutes have shown some new potential, but have to be developed further and have to prove their ability for industrialization. Indium based solders may be suitable in some cases depending on car designs but are not a general solution and have significant technical disadvantages beside the temperature limits.

1.2. Solder Topics

1.2.1 General Requirements

The means of electrical connection is a critical item in terms of product performance and the manufacturing process e.g.

- The product must remain fully functional throughout the 15yr life of the vehicle.
- The soldered joints must not interfere with the performance of the glazing, which must satisfy the stringent safety requirements of ECE R43.
- The method of and type of attachment must be compatible with both the glass manufacturing process and vehicle assembly procedure.
- A sufficient safety margin is needed, since the absolute maximum temperature of extreme real life conditions is not exactly foreseeable (e.g. additional load by reflection from other objects).

1.2.2 Solder Specific Aspects

1.2.2.1 Homologous Temperature T_{hom}

Homologous temperature is well known in metallurgy [1], [2]. The principle is that maximum operating temperature should be expressed as a fraction of the metal's melting point (in K). Seen from the perspective of operational strength, consideration of possible fatigue failure applies to the design of metal materials if the homologous temperature T_{hom} ($T_{hom} = T_{use}/T_{melting}$) is above 0,4.

Most metals are used in the range of 0.3 – 0.5 but solders can be up to 0.87. To add a little more leniency we can use a ratio of 0.9.

With increasing values for T_{hom} the creep rate (resp. creep velocity) of the material under mechanical load is increasing whereas the mechanical strength of the material is decreasing. Whereas the current Lead based solder has T_{hom} values of 0.7 to 0.84 in the range of 50 to 110 °C the Indium based solder has T_{hom} values between 0.83 and 0.98 in the range of 50 to 110 °C [3] [4] . A publication of IZM from 2004 recommends values not higher than 0.8 to 0.85 for the design of long term reliable solder connections[5]. Unknown new solder types should not be above 0.8. Well known solders could be up to 0.9. At our position 0.9 is the limit, which should not be exceeded.

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[1] http://www.ami.ac.uk/courses/topics/0164_homt/index.html: 16.8.2011

[2] Solder Joint Technology by King-Ning Tu; ISBN 978-0-387-38890-8; pages 215, 228, 305

[3] Calculated with In Sn 118° C (source IZM) and 183°C for Lead based solder (source IZM)

[4] http://www.izm.fraunhofer.de/Images/FGLoeten_2005_pb_frei_LV_HT_Pape_tcm357-119079.pdf; 16.8.2011

[5] Nowottnick, Pape et alt.: Zuverlässigkeit bleifreier Weichlötverbindungen; ZVE –Technologieforum Lötverbindungen für Hochtemperaturprodukte p 6ff 30.Nov.2004; Fraunhofer IZM Berlin ; http://www.izm.fraunhofer.de/ Images/ZVE_Oberpf2004_Zuverl_Pb_frei_WLV_Nowottnick_tcm357-119052.pdf ; 19.8.2011

Let's consider the following situation applying a ratio of 0.9, which is higher than the IZM recommendation and higher than proposed maximum values in more conservative literature.

With the measurements presented in section 3 below showing that temperatures inside vehicles could reach 120˚C, the minimum melting point of a solder based on the homologous temperature should be 163.7˚C.

Working Temperature = 120˚C (393K)

Homologous temperature ratio = 0.9

Desired solder melting point = 393 ÷ 0.9 = 436 K (163.7˚C)

At 110˚C and a ratio of 0.9 the solder melting point should be 152˚C and at 100˚C it should be 141˚C.

For this application (soldering connectors to silver prints on Automotive Glass Products) we need at least a solder with a melting point of around 160˚C minimum.

Typical solder melting properties	Pb Solder	160˚C to 224˚C*
	Antaya Pb free solder	109˚C to 127˚C*!

* Data from Final Recommendations report from Fraunhofer Institut for Reliability and Öko-Institut e.V. dated 16th September 2009

In other words: Applying the above mentioned recommended homologous ratio of 0.8 for new solder types to the proposed Indium containing solder, with the solidus of 109°C the homologous T calculates to 33°C, and with the liquidus of 127°C the homologous T calculates to 47°C.

The T measurement of solder joints in hot regions during one summer in 2009 e.g. results in 1,140.2 hours above 50°C for backlights and 1,574 hours for a windscreen (VW temperature measurement) without defroster operation. We have to consider that the temperatures of defrosting connection points during operation will exceed 50°C even in winter time in the north of Europe.

Therefore we can assume that the use of this Indium based solder for standard windscreen or backlight application contradicts any scientific and technical base.

Because there is a dynamic mechanical load on the connector by operating a vehicle and because of the characterized situation of the high T_{hom} we have to consider that the mechanical behavior of new solder substitutes has to be scrutinized specifically for each car model to ensure the long term reliability. Simple static temperature or mechanical load tests are applicable for preselecting of potential substitutes. The high values for T_{hom} we have to accomodate here require validation of feasibility of any substitutes in each new developed vehicle model to prevent mechanical failure over lifetime. Life time predictions for Lead free solders are still a subject of research [6]. This is why car model specific validation during car development is still required.

The discussion of the corrosion aspects and instability of Indium solders can be found in <u>enclosure 3:</u> Non low melting point related obstacles.

1.2.3 Unsatisfactory Technical Performance in Customer Specified Tests

All vehicle manufacturers develop test specifications that give the best assessment of the ability of the product to meet the long term functionality requirements of normal service expectations. These specifications cover the full fleet of any vehicle manufacturer and are global.
To support the industry activities the vehicle manufacturers agreed on a revised draft test specification (based on the specification of the German vehicle manufactures) to evaluate the suitability of Pb free solders for use on automotive glass products. This specification (see annex I) is an agreed compromise to identify potential substitutes, accepting that some company specific demands (e.g. like pull off forces for robust handling at production) are higher.

The results from testing are shown in table 1.2.3.1 below and it can be seen that the Indium containing solders have not passed the draft OEM test specification.

Test Description	Specification	Indium solder 1	Indium solder 2	Indium solder 3	Indium solder 4	Indium solder 5
Temperature cycling test according to DIN EN ISO 16750-4-H section 5.3.1.2	-40C to +105C, Humidity not controlled (dry), Electrical current loading with 14V (+/- 0.2) starting at end of low temperature phase - 60 cycles (20 days)	Fail	Fail	Pass	Fail	Fail
Heat soak test according to DIN EN ISO 16750-4-K section 5.1.2.2	Glass at 105°C Electrical current loading with 14V (+/- 0.2) throughout the test. 6N mechanical load to soldering joints during heat storage. 96 hours	Fail	Fail	Fail	Fail	Fail
High temperature storage test	Temperature: 120°C; No mechanical load and no electrical load during the test. 24 hours	Pass	Fail	Fail	Fail	Pass
Long term test without mechanical load	Glass at 105°C, Electrical current loading with 14V (+/- 0.2) throughout the test, no mechanical load on connector. 500 hours	Fail	Fail	Fail	Fail	Fail
Heat shock test (water splash) according to DIN EN ISO 16750-4-H. Splash water following section 5.4.2	Heat glass to 105°C and keep at this temperature for 1 hour Remove from oven and within 20 seconds pour 3 litres of water at 23 +/- 5°C onto the outside face (not on the connectors).	Pass	Pass	Not tested	Not tested	Not tested
High Humidity test: constant climate following DIN EN ISO 6270-2-CH	Storage at: 80°C, 96 - 100%RH, After 10 hours, 14V applied for 15 minutes (chamber 85°C) then switched off, applied again after 24 hours and repeated until the end of the test. No mechanical load on connectors, no voltage applied. 500 hours.	Fail	Fail	Pass	Fail	Fail
Glass washing liquid test	Immersion in washing liquid consisting of 69,5 Vol% water 20 Vol% ethanol 10 Vol% isopropanol 0.09 Weight% sodium lauryl sulphate 0.5 weight % ethylene glycol	Pass	Pass	Not tested	Not tested	Not tested
Salt Spray Test according to DIN EN ISO 9227 (ISO 50021)	5% salt solution, 35°C. No voltage applied, no mechanical load applied. 96 hours	Pass	Pass	Not tested	Not tested	Not tested

<u>Table 1.2.3.1:</u> test results Indium solders applying current test criteria

The weak point is the low melting temperature of the Indium based solders. All tests with thermal load fail.

1.3. Temperature Measurements in Vehicles

Outdoor car tests in southern regions of Europe were planned for summer 2010. Due to unforeseeable bad weather conditions in European summer 2010 the majority of the temperature load under solar radiation tests were conducted in laboratory climate chambers under defined company specific test conditions and applying good laboratory practice as well as corresponding standards like DIN, EN or ISO standards. The recorded solar radiation load varied between 850 and 1,050 W/m^2. An additional test result with a load of 1,250 W/m^2 was not considered here. Solar loads as high as 1,250W/m^2 have been measured in front of reflective surroundings like glass façades of buildings.

- Knowing that Indium containing solders have low melting points it was decided to measure temperatures inside vehicles to evaluate if this was a concern.

- Thermocouples were attached to connectors on backlights in vehicles. The vehicles were positioned in solar test chambers and exposed to varying levels of solar intensity.

- In the table below (table 1.3.1) the first data column (˚C, Defrost, 0 min) shows the temperature measured by the thermocouple when the vehicle had been under the set conditions for a pre-determined time. The other columns show the temperature measured when the heating circuit had been switched on for the time indicated.

	°C Defrost 0 min	°C Defrost 10 min	°C Defrost 15 min	°C Defrost 20 min	°C Defrost 50 min		Remarks
Japan 4 Sedan Lab Test;	104	116,5	117,5				normal glass; no dark glass
Japan 4 Hatch Lab Test	93	100	100,3				normal glass; no dark glass
Japan 1 Lab Test	98						1000 W/m^2 2h load ; 35 °C ambient temp.
EU 7 sports car Lab Test	100			118			4 mm green glass 1050 W/m^2; inclination 15°
EU 5 wagon Lab Test	126,3				132		dark tinted glass; 1000 W/m^2
EU 6 test car		102					normal glass 1049 W/m^2
EU 9 Lab Test	95		118				1000 W/m2; 42 °C
EU 6 Lab Test	98 - 102						max value ; 1050 W/m^2; defrost not tested
Japan 2 Sports Coupé car	104 -109						1000 W/m^2; 42 °C ambient air 4 mm light green glass; different points measured front & rear; Heater off
EU 2; roadster	80		91				around 950 W/m^2; outdoor; normal ESG green 3,15 mm

Table 1.3.1: survey on the test results

- The base temperature (ie: heating circuit not switched on) shown in the first column of the data shows that there is some variation depending on vehicle type, glass type and radiation intensity. The data pinpoints that in the worst case that temperatures can reach around 120˚C with dark tinted glass and without the heating circuit switched on.

These recorded temperatures are above the solidus point of Indium containing solders (NB: Solidus point = the temperature above which the solder is no longer solid). With defrost on temperatures up to around 130 °C were measured. Defrost off/on is considered in test because condensation is possible under specific climate conditions.

The recorded values were reflected in the actual specification which was adopted accordingly. In the meantime it is also valid as “VDA spec” and accepted as ACEA draft specification for testing screens.

Unfortunately, few records with dark tinted glass are available, while some computer simulations (see annex IIof enclosure 1) have shown the influence of glass colour and glass thickness on the temperature load. For example, if all other parameters are kept constant (thickness, inclination, heating flux…), then a change in glass colour alone would affect this temperature with about a 20°C range, from light green glass to dark tinted glass, as highlighted by computer simulation. That’s why we might have expected glass temperatures 10 to 20°C more than recorded if all glasses would have been dark tinted. This is in line with temperatures measured as listed in table 1.3.1.

Because intensively tinted glass can reduce heat up of the interior significantly and consequently reduce power consumption of the air conditioning system the use of more dark tinted glass is in consideration and very probably for future models.

The worst case should have been a dark tinted glass, 5 mm thickness, with low inclination position (15° on horizontal), 1100 W/m² heating flux 2h load, 45°C ambient air. Glass terminals temperature for this worst case vehicle was not recorded, but up to 20 K more in temperature for measured values of standard glazing might be possible.

Some examples for car test reports are given below:

1.3.1 Car Tests Examples

A: Coupé / Sports car type

test	location	result
Mesurement of temperature of inner surface of a windshield installed in a car. Heater not operated. Ambient temperature : 42°C Incident solar energy : 1000W/m² Glass type:light green : 4mm	Laboratory / climate chamber	FR WDW : 109°C RR WDW UPPER : 104°C MID : 104°C LOWER : 104°C

Coupé (EU 7)

Our part Product Development have conducted solar load simulation tests in our whole vehicle climatic chamber to determine temperature loads that could be experienced by vehicles operating in territories where 40 & 50 degree ambient conditions are encountered. The vehicle used for the test was a sports car, backlight, 4mm, green, toughened, ~ 15 degrees from horizontal.
The test conditions simulate thermal soak of stationary, closed fully built & trimmed vehicle parked with the rear facing mid day sun at ambient of 40 degrees, 1050 W/m^2 & 50 degrees. The temperatures were measured by thermocouples embedded in the solder joints during soldering of the metal electrical connectors to the glass.

Temperatures recorded were as follows:

Solar Load intensity	Vehicle Code EU 7	Glass type 4 mm green	Glass type 4 mm green
1050 W/m^2		Connector	Busbar
	Power Off	97,2	100,1
	Power On	107,6	118,1

It was not possible to repeat the test with privacy (black) glass, this is not a standard option for this vehicle, manufacture of a prototype was not possible.

In our opinion the results indicate that the current Indium solder has no possibility of working in the territories and extremes of climate experienced in both Europe & North America, Australia, North Africa that our vehicles are designed to operate in.

B: station wagon

End of life vehicles directive 2000/53/EC/Annex II (20101264)
Temperature Test on heated Backlight
Test Condition

- Vehicle: Wagon with dark tinted rear window (TL= 20%)
- IR-Radiation: ~ 1000 W/m^2 (~ 50°C ambient temp)
- 2 Thermocouples Type J (Fe-Const)

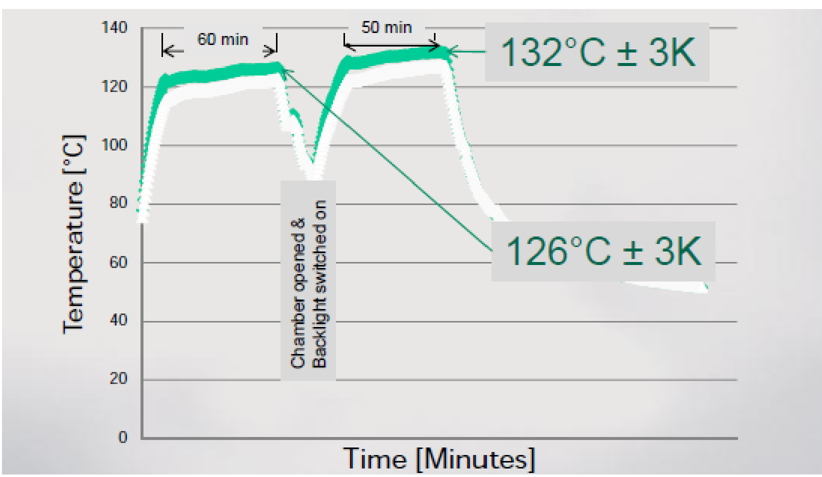
  1 couple at the bus bar

  1 couple at the soldering joint
- Test Time

  60 Minutes non operated

  50 Minutes with heated Backlight

The following graph shows the recorded temperature over time:



With defrost off 126 °C and with defrost on 132 °C have been measured.

This confirms that dark tinted glass results in higher temperature load at bus bar and solder joint.

1.4. Solar Load Measurements in Europe

Solar load is an indication of the intensity of the sun. Maximum recorded solar radiation values for Europe are around 1050 W/m² and may reach 1100 W/m² or slightly higher depending on solar activity [6]. E.g. at one day in the summer of 2010 1150 W/m² were recorded in Italy (see figure 1.4.1 below).

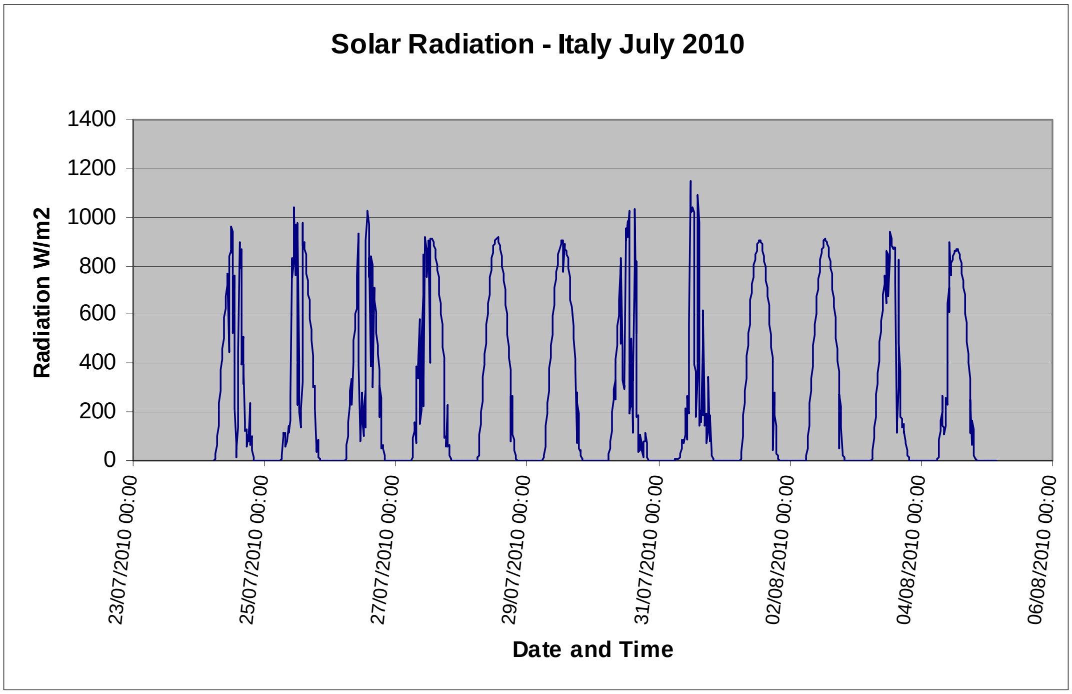


Figure 1.4.1: Recorded Solar radiation Italy 2010

Furthermore the SoDa [7]project investigated and collected the temperatures and the radiation for Europe over a number of years.

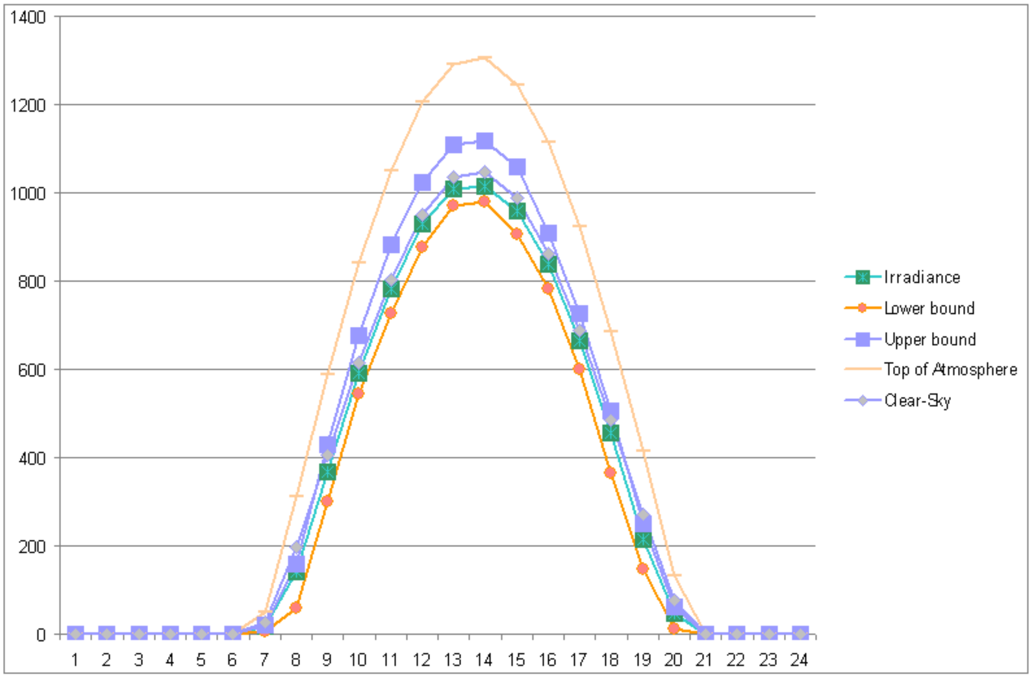
The data in figure 1.4.2 show the radiation values for a common summer day on Teneriffe (there exist even hotter days with more radiation).

There is a 68% chance that the actual value is comprised between lower and upper bounds.

The real measured radiation amounts to 1017 W/m^2. With the same input and without secondary radiation contributors it could be even **1117 W/m^2** or 987 W/m^2. There is a 32 % chance that the real value is not between these extremes'.

[6] http://re.jrc.ec.europa.eu/pvgis/apps/radmonth.php?lang=de&map=europe; http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php
e.g. solar irradiance values for Cadiz /Spain in July between 11:37 and 12:22 are 1070 W/m²

[7] (http://www.soda-is.com/doc/enviroinfo2002.pdf)



<u>Figure 1.4.2:</u> Recorded Solar Tenerife 2005 SoDA project

Site latitude (positive means North) 28.45; Site longitude (positive means East) -16.23; Elevation (m) 0
Date beginning 19.07.2005; Date end 19.07.2005
Time reference (decimal hour) TU Summarization (period of integration) Hour (h)
Date - Instant The date or instant given for each value corresponds to the end of the summarization

Irradiance (W/m^2) Irradiance averaged over the period (-999 if no data)
Lower bound (W/m^2) Uncertainty in irradiance. Lower bound
Upper bound (W/m^2) Uncertainty in irradiance. Upper bound.
There is a 68% chance that the actual value is comprised between lower and upper bounds
Code 0: no data; 1: sun below horizon; 2: satellite assessment; 5: interpolation in time

Top of Atmosphere (W/m^2) Irradiance averaged over the period at the top of the atmosphere (extraterrestrial)
Clear-Sky (W/m^2) Typical irradiance averaged over the period if the sky were clear
Irradiation (Wh/m^2) Irradiation over the period (-999 if no data)

Without secondary effects like scattering or other contributors like reflecting houses, white sand, etc. the real radiation values should not exceed the values on the top of the atmosphere (between 1,325 W/m^2 and 1,420 W/m^2 depending on sun activity and distance).

For this reason we can say the value of 1,000+/- 100 W/m^2 for artificial radiation is the correct fitting for simulation of south European conditions without the consideration of peaks.

Conclusion:

Above 100 °C the tested In-based solder loses its usability which is critical for many cars.

The solar loads of 1,000+/- 100 W/m^2 for artificial radiation used in above mentioned vehicle tests (see section 1.3) are realistic for Europe and the high temperatures that have been measured mean that Indium containing solders are unsuitable.

1.5 Further Information

1.5.1 Relation of Climate Chamber Tests to Real Conditions

The accordance of chamber test conditions to real solar radiation temperature and outdoor weathering tests is given. Otherwise such tests would not make sense. Such tests are not applied for testing screens only. By far they are widely used to test ageing behavior of exterior and interior cars components and systems. The climate chamber tests have the advantage to realize exact defined test conditions, whereas outdoor tests may be influenced e.g. by wind, clouds and dust etc. and are therefore not exactly reproducible.

The test conditions in the chambers reflect the normal and maximum radiation load in Europe and deliver results comparable to weathering experiments in free air.

So called solar simulation units reproduce the spectra of the sun. Special filters are used to reduce or to eliminate peaks of the lamps which do not belong to sun spectra.

Artificial global radiation is similar to global radiation which is used for test purposes. Ambient temperature can be adjusted by cooling.

Solar simulation is therefore an international standard and defined in the DIN 75220 "Aging of automotive components in solar simulation units which is used for test purposes" (even other standards exist for other application like solar or others). The amount of 1,000+/- 100 W/m^2 is less than the value for maxima which occur under real conditions.

http://atlas-mts.com/download/what_light_is_right.pdf shows the global radiation and the artificial radiation of the lamps used for the simulation.

1.5.2 Temperature Inside Solder Joint

Temperature measurements mainly were made by attached thermocouples at the contacts. In addition the temperature inside the solder joint was determined via some measurements in a laboratory of a supplier. The effect of positioning connectors underneath a soldered T-piece (between solder and silver print) and on top of the soldered T-piece was investigated.

In replacing a solar test chamber an IR lamp was positioned over the glass and the distance from the lamp to the glass was varied. The outside surface of the glass was facing the lamp to simulate real conditions (glass protecting T-piece from direct radiation). The temperature measurements are shown in the graph below. In the core the temperature is 2 to 4 degree °C higher, which is not surprising.

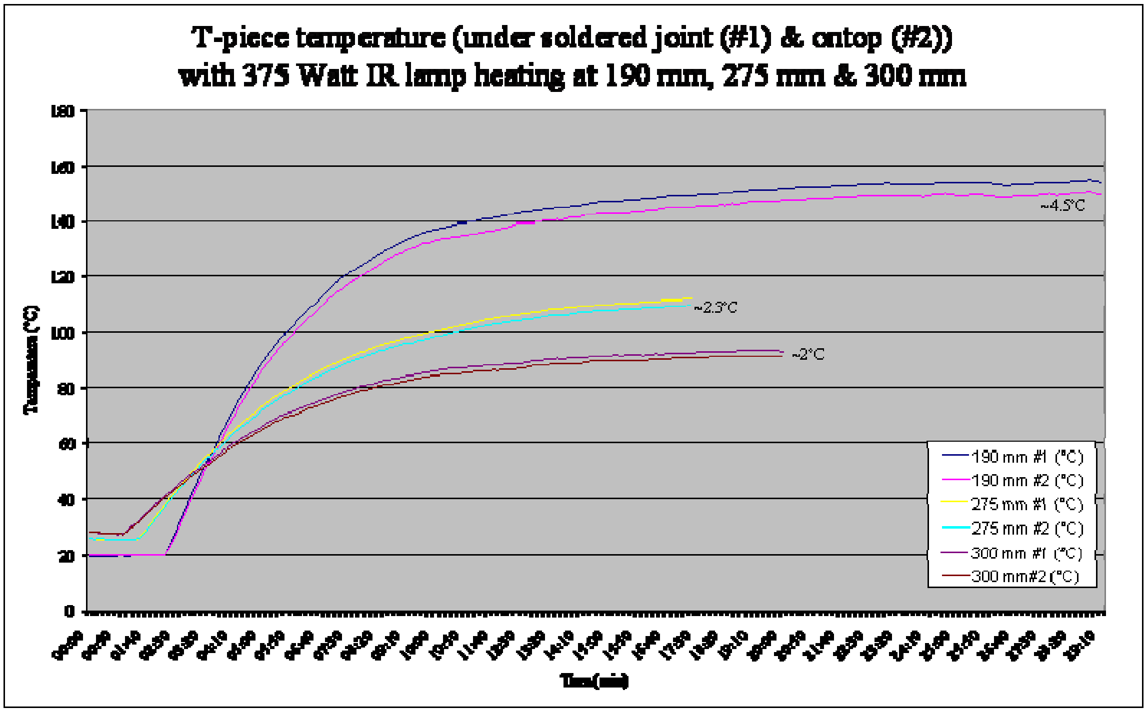


Figure 1.5.2.1: Temperatures inside and outside solder joint

" We can see that in all three tests there was a slight difference and the thermocouple underneath the connector was always slightly hotter than the thermocouple on top of the connector. The difference between the two temperatures varied depending on how close the lamp was to the glass. So when the lamp was closer the difference was greater – this would equate to a greater difference at higher solar intensities. Although this test is not conclusive enough to be able to say that we have to adjust the temperature data it does indicate that if thermocouples are positioned underneath the connector then the temperatures would be higher. Typically the difference is between 2 – 4˚C in these tests. At higher intensities the difference would be greater."

1.6 Influence of Vehicle Design

- The temperature measurements in table1.3.1 show that higher temperatures are reached when the glass is installed at a low angle relative to horizontal.

- Vehicle design trends show an increasing number of vehicles with low installation angle glazings to support reduction in CO_2 emissions through improved aerodynamic design (see fig. 1.6.1).

Figure 1.6.1: examples for current car design

- In the future there will be an increasing number of vehicles that will experience internal cabin temperatures that are higher than the melting point of Indium containing solders.

- The future use of more tinted glass can help to reduce the heating of car interior by solar radiation and by this contribute to a reduced energy consumption of air conditioning systems. But whereas the cabin interior temperature is decreasing the glass temperature is rising (see section 1.3). So it can be assumed that temperature at solder joints will increase by some degrees.

Based on the experimental test data presented above and the trends in vehicle design it can be concluded that Indium solders are not suitable to replace Lead solders for all glazing applications.

1.7 Overall Conclusions

The maximum test temperature of 90°C used in the last test program was too low.

Based on the current temperature load test results, which were made also on new cars coming to road in future, it was clear that the test specification needed to be revised. This test specification is not a legal binding test specification for all cars because some specification demands of some OEM were and are higher (e.g. one major OEM postulates 135 °C in his spec) and require harsher test conditions. But it was agreed after longer discussions among the OEM´s and the suppliers to apply this revised specification as standard for scrutinizing potential substitutes.

The revised specification was adopted by some OEM specific standards in the meantime for the qualification of screens. It is fulfilled by solder joints made with Lead containing solder without any problems.

As described in section 1.2.3 and table 1.2.3.1 all tests with Indium based solders achieved insufficient results.

The revised tests specification was made available to the involved Indium based solder supplier. In a subsequent audio conference this solder and equipment supplier stated that the revised specification would be no problem for him and some other of his developed solders would be able to meet these requirements. This company was asked to provide data for these solders or samples but up to now nothing has been provided. Because of missing data and samples no tests could be conducted in the meantime.

There is still no proven alternative in this application to Lead free solder that can be used reliably and meets all the long term durability requirements for electrical connectors on automotive glass products.

In 2011 recently investigated new Lead and Indium-free potential substitutes still have to undergo component and vehicle tests to scrutinize their suitability.

To meet current entry 8i expiry date for vehicles type approved after 1/1/2013 is impossible for technical reasons.

Annex I : Revised draft test specification for assessing potential substitutes:

Section I component specific tests

1. **Temperature cycling test**

According to DIN EN ISO 16750-4-H section 5.3.1.2

Before test: Temperature of climate chamber -40°C to 105°C
Humidity not controlled (dry)
Min. 60 cycles
Electrical current loading with 14V (+/- 0.2) starting at end of low temperature phase
Temperature-time following current loading eg. acc. VW 80101

After test: Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

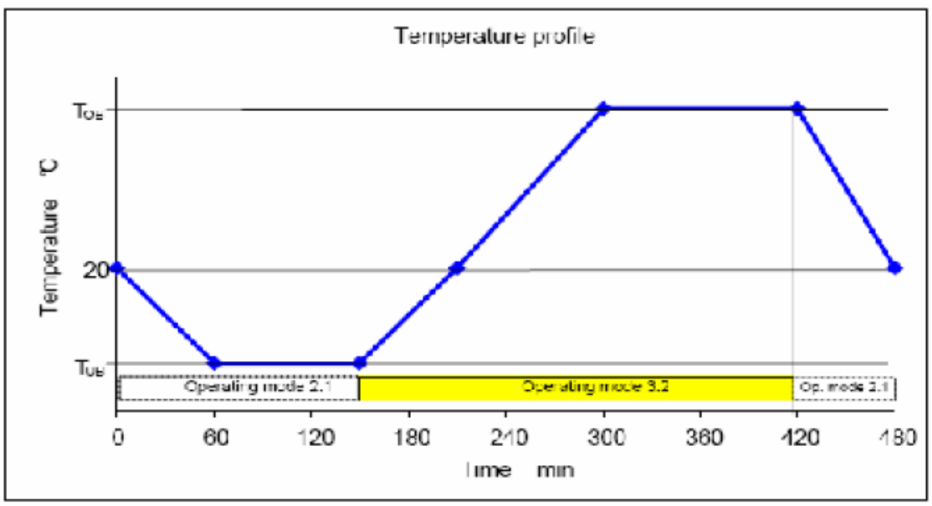


Figure 19 – Temperature profile

Table 21 - Temperatures and durations of a temperature cycle

Time (min)	Temperatures (°C)
0	20
60	T_{uB}
150	T_{uB}
210	20
300	T_{oB}
420	T_{oB}
480	20

T_{uB} : - 40°C
T_{oB} : +105°C

2. **Heat soak test** according DIN EN ISO 16750-4-K, section 5.1.2.2

Before test:

Temperature of climate chamber 105°C
Test time at 105°C inside chamber: 96 hours

Electrical current loading with 14V (+/- 0.2) throughout the test for heater connectors, only

Mechanical load to soldering joints during heat storage:
position of screen horizontally, inside down
Mechanical load: vertical down, directed as acceleration of gravity

Pull forces: 2N for antenna connectors, theft warning system
6N for heater connectors (14V)

After test: Electrical testing (see below, section III)
Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)
Electrical testing (tbd)

3. High temperature storage test

Considers recent investigated max. data for thick dark tinted glass and requirements for adhesives testing (Polyurethane for glass bonding).

Duration: 24 h
Temperature: 120°C
After test: Electrical testing (see below, section III)
Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

4. Long term test with electrical load
(purpose of test: Dissolution of silver print and solder)

Temperature of climate chamber: 105°C
Test time at 105°C inside chamber: 500 hours
Electrical current loading with 14V (± 0.2) throughout the test

After test:
Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

5. Heat shock test following DIN EN ISO 16750-4-H

Splash water test following section 5.4.2
Temperature of climate chamber: 105°C, 1 hour
Temperature of splash water: 23°C ± 5°C or lower (from refrigerator)
Number of cycles: 10, checks after 5, 10
Dry samples after every cycle.
Can be done on lab samples (difficult with backlights).

After test: Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

6. High Humidity test: constant climate

Storage at: 80°C reflects bus bar temperature under load, >96 %RH (condensing), reflects the experience to discern "good" and "bad" solders
Duration: 500 hours
electrical load: 14 V 15 min. every 24h, first cycle after 10 hours

After test: Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

If Silver separates from the glass, pull-tests and electrical tests cannot be performed. In this case, the solder contact is assessed as good.

7. Resistance to screen washer fluids:

Test fluid: Immersion in or continuous wetting with glass washing liquid consisting of:
69,5 Vol% water
20 Vol% ethanol
10 Vol% Isopropoanol
0.09% weight sodium lauryl sulphate
0.5 Vol% ethylene glycol

Duration of immersion or wetting: 24 hours at 23C
pre-conditioning: 24 hours at 23C

After test: Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

8. Salt spray test according to DIN EN ISO 9227

Salt spray test (neutral): duration 96 hours
After test: Pull test (perpendicular) 10N for antenna, theft warning system
50N for heater connectors (14V)

Remark: revision of pull off forces before after / ageing in discussion / harmonization.

Section II OEM Company specific vehicle tests

Target: test behavior of screen and connectors in cars

1. Lab tests
   Company specific hydropulse test equipment applying dynamic mechanical load to car body at low and high temperatures

2. On the road tests
   Screens are tested in regular development car test program

   a. Summer tests program

   b. Winter tests program

Annex II: Results of study computation of glass temperature for a car exposed to intense heat flux (sunlight); May 2010.

In the following study of an automotive glass producer the influence of glass colour on temperature was analyzed. The cited text of the study begins with "… and ends after 4 pages with … ".

" …Context of the study

The ELV directive 2000/53/EC will ban the use of Pb & other heavy metals in vehicles in a few years. Lead used in solder alloys for soldering electrical connectors to glass is thus a concern for OEMs and glass makers.

The Antaya company propose to the market an Indium based solder (Lead-free), which could be an alternative to Lead-solder, but its low melting point (solidus temperature at 109°C for 65% Indium alloy) may be a serious concern for OEMs, notably regarding to the extreme operating conditions for vehicles.

…

Objective of the simulation

Based on the simple experience that, when you leave a car exposed to intense sun light, the glass temperature on a "privacy" glazing (very dark glass with low light transmission) is significantly higher than on any other glazing of the car (that temperature difference can be easily confirmed by touch with the hand), it appeared to make sense to perform a simulation study to quantify this temperature difference due to the glass tint (as well as to quantify the influence of the glass thickness), in order to emphasize that it should be more than a few degrees. In extreme operating conditions, an important difference of temperature on such privacy glazings can affect seriously the resistance of the connectors soldered to glass.

…

Method

As it is really difficult to simulate the real temperature reached on glass in a vehicle parked under intensive sun light in very hot areas (desert areas), the physical phenomenon being numerous and complex to model, as well as the whole geometry of the vehicle, a very simple model was used for the following computations with the objective not to give reliable absolute values for any glass type, but simply to give relative figures (comparatively to standard glass), with the idea to quantify by comparison the influence of the nature of glass on the temperature result.

Nevertheless, realistic values to characterize environmental conditions and physical phenomenon have been used, as well as realistic physical properties of real glazings (not far from nominal values).

Results

Results from simulation show an influence of glass nature which is much more than a few degrees:

dark grey "privacy" glass should be about 15-20°C hotter than standard tinted glass for same glass thickness, and the darkest "privacy" glass should even be about 25°C hotter than standard glass.

The influence of the glass thickness, for a same raw color (the perceived tint is different due to thickness) is not insignificant : about +3°C for a 4 mm glass compared to a 3 mm or for a 5 mm glass compared to a 4 mm.

Detailed information about the study is given in the following pages.

Recommendation

To know the worst conditions, it make sense for OEMs to redo some new measurement campaigns this summer in severe operating conditions, using very dark "privacy" glass (growing demand is very probable) for backlite, instead of standard tinted. This type of dark glazing is favorable to lower the temperature inside the car but not favorable for solder resistance since the glass temperature is higher due to higher absorption.

…

…

Simulations conditions & hypothesis

- External t° : 45°C ambient
- Internal t° : 80°C ambient (imposed, not computed)
- Heat flux (incident solar energy) : 1100 W/m²
- Exchange coefficients :
    - external h = 11 W/m².K
    - internal h = 9 W/m².K
- Glass t° is assumed to be uniform through the whole thickness

Simulated glasses

The glazings listed here under have been used as examples for computations. Not all existing or possible combinations of color and thickness are given here. Only a single computation has been made for the case of laminated glass sunroof.

Glazing type	Tint type (given for the reference thickness)	Tint : Commercial name or code	Glass maker	glass thickness (nominal value)	energy trans-mission (*)
tempered monolithic	light green	TSA (FGNO)	AGC	3.15 mm	59%
tempered monolithic	light green	TSA (FGNO)	AGC	3.85 mm	54%
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	3.15 mm	50%
tempered monolithic	light green	TSA (FGNO)	AGC	4.85 mm	48%
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	3.85 mm	45%
tempered monolithic	deep green	Solarplus 66 (S66-FGN4)	AGC	3.85 mm	40%
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	4.85 mm	39%
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	3.15 mm	24%
tempered monolithic	dark glass (privacy)	Venus green 35 (VG35)	St Gobain	3.85 mm	19%
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	3.85 mm	18%
tempered monolithic	dark glass (privacy)	Galaxsee 418	Pilkington	3.85 mm	17%
laminated sunroof	dark glass	TSA3+ + Venus10	St Gobain	6.00 mm	13%
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	4.85 mm	12%
tempered monolithic	dark glass (privacy)	Venus grey 10 (VG10)	St Gobain	3.85 mm	9%

(*) = indicative values (a 2% absolute error vs. nominal value may be possible)

In the list, ranking of glazings is done according to darkness (decreasing light/energy transmission), whatever the thickness. Same tints are highlighted, considering raw color (true color). Notice that the perceived tint of a S71 3.15 mm is nearly the same as for TSA 3.85 mm, as well as a S66 3.15 mm is nearly the same as a S71 3.85 mm.

Remark:

Even if 3 mm is the most standard thickness for backlites, the share of 5 mm is not insignificant (> 10%) and is used for mobile glazing (opening B/L) or to improve acoustic comfort in luxury cars. On the other hand, even if normal green is the most standard tint, market share of privacy glass is also not insignificant (about 15%) and could be growing in the future, as privacy glass help to decrease the temperature inside the vehicle due to its higher absorption property, what could be interesting for OEMs in order to reduce A/C power further to some regulation."

Results of simulated glasses

As far as n.n. glasses are concerned, these are the temperature results from simulation:

Glazing type	Tint type (given for the reference thickness)	Tint : Commercial name or code	Glass maker	glass thickness (nominal value)	energy trans-mission	energy absorp-tion	energy reflexion	glass thickness used in simulation	glass temperature °C (*)
tempered monolithic	light green	TSA (FGNO)	AGC	3.15 mm	59%	35%	6%	3 mm	**80,1**
				3.85 mm	54%	40%	6%	4 mm	**82,8**
				4.85 mm	48%	46%	6%	5 mm	**86,1**
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	3.15 mm	50%	44%	6%	3 mm	**85,0**
				3.85 mm	45%	50%	5%	4 mm	**88,3**
				4.85 mm	39%	56%	5%	5 mm	**91,6**
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	3.15 mm	24%	71%	5%	3 mm	**99,8**
				3.85 mm	18%	77%	5%	4 mm	**103,1**
				4.85 mm	12%	83%	5%	5 mm	**106,4**

(*) Results from computational analysis
Conditions : ambient temperature (external) = 45°C ; internal car temperature = 80°C ; heat flux = 1100 W/m²

With the hypotheses of simulation, computed temperatures on glass range from 80°C (standard tint) to 106°C (thick "privacy" glass).

Influence of tint is very significant, particularly for privacy tints:

- AY17 (dark grey): + 20,3 °C on glass vs. TSA (standard tint) for 4 mm thickness

Influence of thickness is much lower but not insignificant: about 3°C for 1 mm more thickness

- 4 mm vs. 3 mm (most standard thickness) : + 3,3 °C on S71 glass
- 5 mm vs. 4 mm : + 3,3 °C on S71 glass

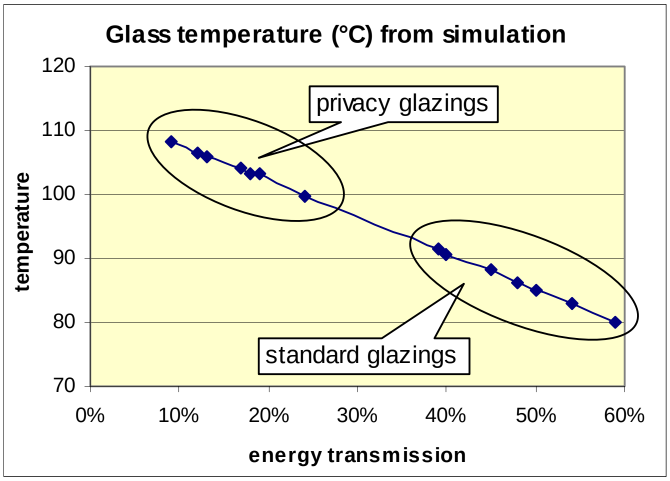
Considering also other glasses from competition, we can see in the table below that the ranking by increasing temperature result from simulation is the same as the ranking by decreasing energy transmission. The second half of the table is relative to dark glass (called "privacy").

Glazing type	Tint type (given for the reference thickness)	Tint : Commercial name or code	Glass maker	glass thickness (nominal value)	energy trans-mission (*)	glass thickness used in simulation	glass temperature (°C) from simulation	observations: from 3.15 to 3.85 mm	observations: from 3.85 to 4.85 mm	observations: same thickness 3.85 mm
tempered monolithic	light green	TSA (FGNO)	AGC	3.15 mm	59%	3 mm	80,1	~+3°C		
tempered monolithic	light green	TSA (FGNO)	AGC	3.85 mm	54%	4 mm	82,8			std tint
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	3.15 mm	50%	3 mm	85,0		~+3°C	
tempered monolithic	light green	TSA (FGNO)	AGC	4.85 mm	48%	5 mm	86,1	~+3°C		
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	3.85 mm	45%	4 mm	88,3			
tempered monolithic	deep green	Solarplus 66 (S66-FGN4)	AGC	3.85 mm	40%	4 mm	90,5		~+3°C	
tempered monolithic	intermediate green	Solarplus 71 (S71-FGN5)	AGC	4.85 mm	39%	5 mm	91,6			
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	3.15 mm	24%	3 mm	99,8			+25°C
tempered monolithic	dark glass (privacy)	Venus green 35 (VG35)	St Gobain	3.85 mm	19%	4 mm	103,1	~+3°C		
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	3.85 mm	18%	4 mm	103,1			
tempered monolithic	dark glass (privacy)	Galaxsee 418	Pilkington	3.85 mm	17%	4 mm	104,2			
laminated sunroof	dark glass	TSA3+ + Venus10	St Gobain	6.00 mm	13%	6 mm	105,8		~+3°C	
tempered monolithic	dark glass (privacy)	Athergrey 17 (AY17-FGY1)	AGC	4.85 mm	12%	5 mm	106,4			
tempered monolithic	dark glass (privacy)	Venus grey 10 (VG10)	St Gobain	3.85 mm	9%	4 mm	108,1			darkest

(*) = indicative values (a 2% absolute error vs. nominal value may be possible)

For a 3.15mm glass, we could expect 25°C more than for a standard tint

Notice that glass temperature from the simulation is linearly correlated to energy or light transmission.



Conclusions

Influence of tint is very significant, particularly for privacy tints: about + 20°C (even 25°C) on glass vs. standard tint for 4 mm thickness.

Even though the absolute figures for standard glazings given by this simplified simulation are ~20°C lower than some OEMs' recordings (i.e. maybe too low vs. the extreme possible reality), the relatives figures from this simulation are interesting to analyze. They mean that temperature over 120°C on glass is very possible in some extreme conditions when the darkest glazings are installed on a car.

Of course, these simulations assume the temperature inside the car has not changed (always 80°C) when changing glass type from standard tint to "privacy" tint, since it is difficult to simulate in a car the real inner conditions for given heat flux, external temperature and exposure time. But we may conclude the glass color influence is significant. Indeed, if the temperature inside the car is lowered by 10°C (i.e. 70°C) thanks to the use of a whole rear set of privacy glazings on the exposed car (a single "privacy" glass on a car will not lead to such a temperature reduction), the computed temperature result on the glass is lowered by only ~5°C. Thus, we still speak about a 15 to 20°C temperature increase on glass for privacy glazing vs. standard tint.

Last, influence of thickness is much lower but not insignificant: about 3°C for 1 mm thickness.

NB : For some laminated sunroofs, thickness could be up to 6 mm (and energy transmission can be as low as ~12% for dark sunroofs).

Annex : Screen shots of program (Not attached here)   …" .

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