

CO2 Emission Reductions from Tts and Weight Reductions - Windshield

Parameter	Units	Value	Formula	Comment / Source
NREL (National Renewable Energy Laboratory - US) Study				
Vehicle	–	Cadillac STS		Ref 1
Model year	–	2006		Ref 2 slide 4
Trim line	–	V6		Ref 3
Curb Weight	lbs	3960	a	OEM data
Curb Weight	kg	1796	$b = a / 2.2046$	
Fuel economy - no A/C	mpg	18.5	c	Ref 2 slide 24
Fuel use - no A/C	gpm	0.0541	$d = 1 / c$	
VMT (Vehicle Miles Traveled)	miles/yr	11998	e	Ref 1 p7 or Ref 2 slide 25
Average percent A/C use	%	26.0	f	CARB Public Workshop 12 Mar 09, p22
VMTAC (Vehicle Miles Traveled with A/C on)	miles/yr	3119	$g = e * f / 100$	
Baseline Vehicle				
Glazing material - all locations	–	Solargreen® glass		Special laminate for NREL study; Ref 2 slide 4, Ref 3, Ref 4
Tts - all locations	%	58	h	Ref 4
Fuel economy - with baseline A/C	mpg	15.4	i	Ref 2 slide 24
Fuel use - with baseline A/C	gpm	0.0649	$j = 1 / i$	
A/C fuel use when A/C running - baseline	gpm	0.0109	$k = j - d$	
Annual fuel use for A/C - baseline	gal/yr	33.9	$l = k * g$	
Modified Vehicle - IR Glass, IR Paint, Ventilation (Config. 1 in Ref 1)				
Glazing material - all locations	–	Sungate® EP		Special laminate for NREL study; Ref 2 slide 4, Ref 3, Ref 4
Tts - all locations	%	38	m	Ref 4
Fuel economy - with 70% baseline A/C	mpg	16.1	n	Ref 2 slide 24
Fuel use - with 70% baseline A/C	gpm	0.0621	$o = 1 / n$	
A/C fuel use when A/C running - modified	gpm	0.0081	$p = o - d$	
Annual fuel use for A/C - modified	gal/yr	25.1	$q = p * g$	
Impact of full vehicle modification (Config. 1 in Ref 1)				
Reduction in CBAST (Cabin Breath Air Soak Temperature)	C	12	r	Config. 1 in Ref 1 Tables 1 & 3
Reduction in A/C fuel use (per vehicle)	gal/yr	8.8	$s = l - q$	
Reduction in A/C fuel use (per vehicle) per degree C reduction in CBAST	gal/yr / C	0.7	$t = s / r$	
Impact of IR Glass sidelites & backlite (per vehicle)				
Reduction in CBAST - IR Glass all locations + IR Paint (Config. 2)	C	9.7	u	Config. 2 in Ref 1 Tables 1 & 3
Reduction in CBAST - IR Glass windshield + IR Paint (Config. 4)	C	6.7	v	Config. 4 in Ref 1 Tables 1 & 3
Reduction in CBAST due to IR Glass sidelites & backlite	C	3.0	$w = u - v$	
Annual fuel saving due to IR Glass sidelites & backlite	gal/yr	2.2	$x = t * w$	All sidelites & backlite
Material Densities				
Density - Glass	kg/m3	2500	aa	Ref 5 slide 12
Density - PVB	kg/m3	1060	bb	
Density - PC (polycarbonate)	kg/m3	1200	cc	

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Exatec Calculations				
Fuel saving referred to reduction in total transmitted power				
Heat transfer coefficient towards inside	W/m2-K	8	dd	ISO 13837, April 15, 2008, Annex B
Heat transfer coefficient towards outside (vehicle at rest)	W/m2-K	21	ee	ISO 13837, April 15, 2008, Annex B
Direct transmitted power - Baseline glass sidelites & backlite	W	488.1	ff	Ref 8 - Solargreen® glass
Absorbed power - Baseline glass sidelites & backlite	W	675.7	gg	Ref 8 - Solargreen® glass
Direct transmitted power - IR Glass sidelites & backlite	W	395.8	hh	Ref 8 - Sungate® EP
Absorbed power - IR Glass sidelites & backlite	W	270.7	ii	Ref 8 - Sungate® EP
Total transmitted power - Baseline glass sidelites & backlite	W	674.5	jj = ff + gg * dd / (dd + ee)	
Total transmitted power - IR Glass sidelites & backlite	W	470.5	kk = hh + ii * dd / (dd + ee)	
Reduction in total transmitted power - sidelites & backlite	W	204	ll = jj - kk	All sidelites & backlite
Reduction in A/C fuel use per unit reduction in total transmitted power	gal/yr / W	0.0108	mm = x / ll	Derived from sidelite/backlite results; Applied to windshield
Impact of IR Glass windshield (per vehicle)				
Windshield - Total incident power (independent of glass type)	W	944	nn	Ref 8
Windshield - Reduction in total transmitted power / unit Tts reduction	W / Tts	9.44	oo = nn / 100	Note 1
Annual fuel saving due to IR Glass windshield / unit Tts reduction	gal/yr / Tts	0.102	z = mm * oo	
Impact of PC windshield (per vehicle)				
Windshield - DLO area (Cadillac STS)	m2	0.941	pp	Ref 3
Windshield - Thickness - Glass (total)	mm	5.0	qq	
Windshield - Thickness - PVB	mm	1.0	rr	
Windshield - Weight - Glass glazing	kg	12.76	ss = pp * (aa*qq + bb*rr) / 1000	
Windshield - Thickness - PC	mm	5.0	tt	
Windshield - Weight - PC	kg	5.65	uu = pp * (cc*tt) / 1000	
Weight reduction - windshield - Glass → PC	kg	7.11	ww = ss - uu	
Weight reduction - collateral from lighter windshield peripheral hardware	%	0	xx	% of ww; non-zero value would increase PC weight benefit
Weight reduction - total - Glass → PC	kg	7.11	yy = ww * (1 + xx / 100)	
Weight reduction - % of curb weight	%	0.40	zz = 100 * yy / b	
mpg improvement (%) / Weight reduction (%)	% / %	0.7	aaa	Ref 6
Fuel economy - with baseline A/C + PC windshield	mpg	15.4427	bbb = i * (1 + zz*aaa / 100)	
Fuel use - with baseline A/C	gpm	0.06476	ccc = 1 / bbb	
Fuel use reduction from weight reduction	gpm	0.00018	ddd = j - ccc	
Annual fuel saving from replacing only windshield with PC	gal/yr	2.154	eee = e * ddd	Assumes baseline A/C usage with PC to isolate weight effect
Equivalent reduction in Tts % - windshield	–	21.1	fff = eee / z	
Tts for PC producing same CO2 lbs/yr as IR Glass per CARB Std.				
Tts - IR Glass just meeting CARB Std. for windshield	%	40	ggg	CARB 8 May 09 posting, page A-3, paragraph a-3
Tts - PC - windshield	%	61.1	hhh = fff + ggg	PC equivalent (lower actual Tts improves CO2 reduction)
CO2 (lbs) produced by fuel consumption (gal)	lbs/gal	20	iii	Ref 7
CO2 reduction per vehicle from weight benefit of PC windshield	lbs/yr	43.1	jjj = eee * iii	

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References				
(1) J Rugh (NREL) et al, Paper # 2007-01-1194 in Proceedings of SAE 2007 World Congress, April 16-19, 2007, Detroit, Michigan				
(2) J Rugh (NREL) et al, presentation of Paper # 2007-01-1194 at SAE 2007 World Congress, April 16-19, 2007, Detroit, Michigan; also presented at CARB Public Workshop, May 15, 2008				
(3) J Rugh (NREL), private communication, 13 Apr 09				
(4) J Rugh (NREL), private communication, 27 Apr 09				
(5) <a href="http://www.saint-gobain-sekurit.com/EN/downloads/glazing_manual.pdf">http://www.saint-gobain-sekurit.com/EN/downloads/glazing_manual.pdf</a>				
(6) <a href="http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/cheah_factorTwo.pdf">http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/cheah_factorTwo.pdf</a> , page 19; also, <a href="http://www.fueleconomy.gov/feg/lightweight.shtml">http://www.fueleconomy.gov/feg/lightweight.shtml</a>				
(7) <a href="http://www.fueleconomy.gov/Feg/co2.shtml">http://www.fueleconomy.gov/Feg/co2.shtml</a>				
(8) NREL's VSOLE (Vehicle Solar Load Estimator); Radiation source: Phoenix-July 6; Time of day: 11:45am; Direction of vehicle: 180 (south); Glazing areas/angles for Cadillac STS				

Notes				
(1) Derivation follows:				
	Define	nn = total incident power (W)		
		Wb = total transmitted power through baseline glazing (W)		
		Wi = total transmitted power through IR glazing (W)		
		Tb = Tts for baseline glazing (%)		
		Ti = Tts for IR glazing (%)		
	By definition	Wb = nn * Tb / 100		
		Wi = nn * Ti / 100		
	Then	oo = Reduction in total transmitted power / unit Tts reduction = (Wb - Wi) / (Tb - Ti) = nn / 100		