Proposal for Alternative Refrigerant Life Cycle Climate Performance [LCCP] Harmonization

William Hill	GM
Stella Papasavva	GM
Koji Kikuchi	Nissan
Tohru Ikegami	Toyota
Satoshi Ogihara	Nissan

Background

- Many companies have done complete life cycle (LCCP) and partial life cycle (TEWI) analysis in the recent past to evaluate the environmental impact of alternative refrigerants
- Assumptions and methodology can have a large impact on the conclusions, as it was indicated in the results presented by such studies
- JAMA and SAE have agreed to work together to agree a common approach
- GM/Toyota/Nissan have agreed on the enclosed materials and will work to get full approval from JAMA and SAE
- A new SAE J-standard will be proposed for estimating the Life Cycle Climate Performance (LCCP) of Alternative Refrigerants, considering energy consumption and Greenhouse Gas (GHG) Emissions

Outline

- Definition of TEWI and LCCP
- Parameters that affect MAC fuel consumption and refrigerant production
  - **Direct Emissions**
    - **Refrigerant Leakage [manufacturing, service, in use, end-of-life]**
  - **Indirect Emissions**
    - **Manufacturing (Refrigerant fluid, MAC components)**
    - **AC Capacity Setting**
    - **Front End Recirculation Considerations**
    - **Engine type/fuel type/efficiency**
    - **Driving cycle mode (Speed vs Time)**
    - **Environmental conditions during driving mode (Ambient vs Time)**
    - **Annual Drive Distance/Time**
    - **AC “ON” vs Ambient**
    - **Mass boundary considerations of MAC system**
    - **Energy to produce A/C components**
    - **Cooling Fan Power**
    - **Regional analysis**
    - **Vehicle life time**
- Review and comparison of results from different studies
- Impact of new assumptions on Results
- Summary

Direct Emissions Calculation

❖ Direct – refrigerant release directly to atmosphere

- Regular (e.g. seal & hose leakage)
- Irregular (e.g. accident)
- Service (e.g. loss during servicing of system due to refrigerant leakage)
- End-of-life (e.g. loss during recovery at end of life)
- Leakage during Refrigerant manufacturing

Leakage due to Vehicle Operation

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Considered	Considered.	Results are as shown below:

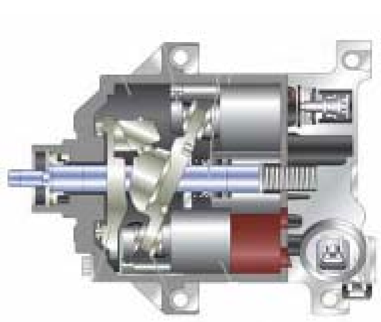
NOMINAL NUMBERS	USA	EU	Japan	India	Australia	China
REFRIGERANT LEAKAGES & SERVICE	R134a	R134a	R134a	R134a	R134a	R134a
(function of climate)	Warm	Warm	Warm	Warm	Warm	Warm
Regular [g/y]	10	10	10	10	10	10
Irregular (Accidental) [g/y]	16	16	16	16	16	16
Service [g/lifetime]	16	16	16	16	16	16
Loss in each service	35	35	35	35	35	35
EOL [g/lifetime]	30	30	30	30	30	30
Lifetime	10	10	10	10	10	10
Number of Services*	0.5	0.5	0.5	0.5	0.5	0.5
Assembly Plants (fixed loss) [g/lifetime]	3.5	3.5	3.5	3.5	3.5	3.5
Refrigerant loss before Service of AC system is required (g)	200	200	200	200	200	200

*Number of services in lifetime=Number of years in lifetime/(refrigerant loss before service/nominal regular leakage rate/yr)

Leakage rates should be less in Cool Climates

Indirect Emissions Calculation

- Indirect – energy consumption over lifetime and recycling
  - ➢ Fuel use due to power compressor corrected by engine/belt efficiency
  - ➢ Fuel use due to the cooling fan corrected by engine/belt/alternator efficiency
  - ➢ Fuel use to carry around mass of A/C system
  - ➢ Manufacturing energy of refrigerant and A/C components
  - ➢ E-O-L Re-cycling energy



TEWI vs. LCCP

TEWI and LCCP are indices that compare the global warming impact of mobile air conditioning considering various climatic conditions and driving habits in different regions of the world

❖ TEWI (Total Equivalent Warming Impact) is defined as:

TEWI = GWP (direct) + GWP (indirect)

Due to refrigerant leaks   Due to A/C operation

❖ LCCP (Life Cycle Climate Performance) is defined as:

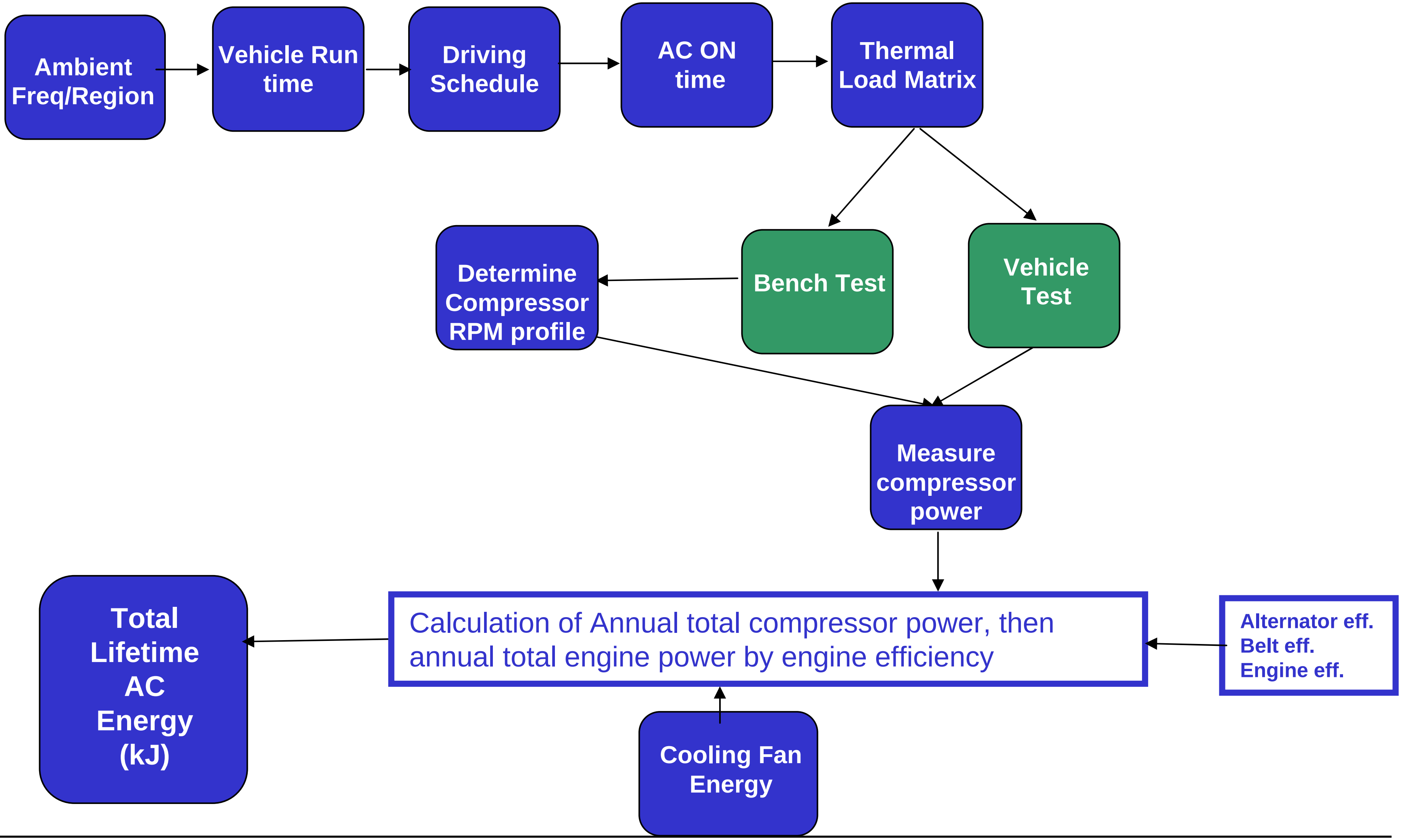
LCCP = TEWI + GWP (Indirect) [(chemical production of refrigerant & transport)+ (manufacturing A/C components & vehicle assembly)+ (end-of-life)] + GWP (direct) [(atmospheric reaction products of refrigerant) + (end-of-life) + (manufacturing leakage)]

Indirect Emissions Evaluation
Bench vs. Vehicle considerations

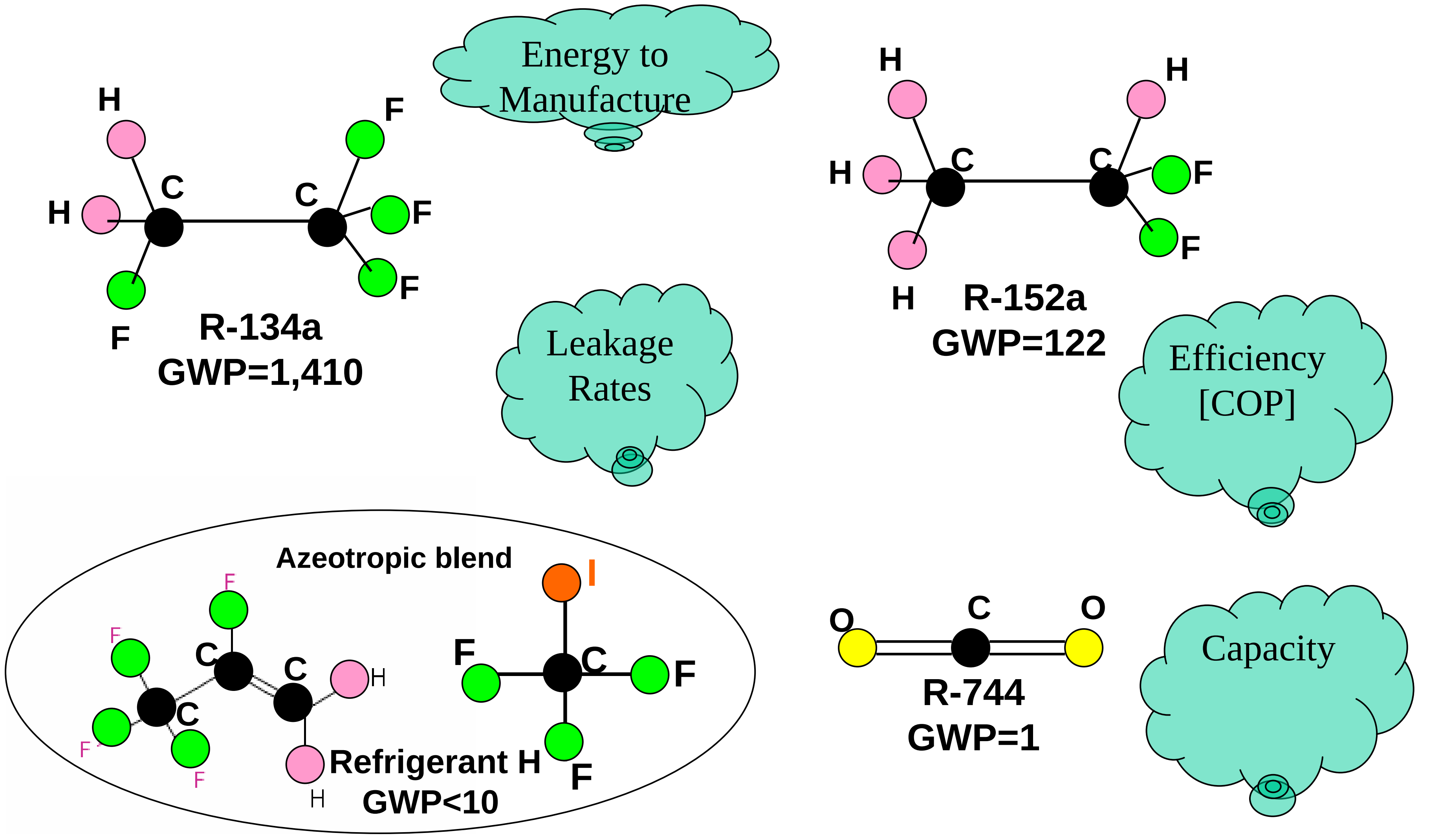
Method of Test	Pros	Cons
Bench:	High accuracy of measurements	Assumptions required relative to engine RPM for different vehicles
	Lower cost to test	Variation of front end flow is difficult to simulate
	One system can apply to many different vehicles	Relationship between CRPM and COP may be different for different systems/cooling capacity
	Conditions are easier to control	Correlation to vehicle result needs to be confirmed
	Easier to study specific parameters	Difficult to simulate dynamic drive schedules
	Can run equal capacity to compare changes to systems	
	More easily done in early phases of new vehicle development	
	Stable points are more repeatable	
Vehicle:	Considers impact of variations in vehicle impact on result	More difficult to repeat result
	*Front end flow	Automatic AC system variations will cause more variation in result
	*Recirculation in front end	Number of different vehicle/powertrain combinations required
	*Engine controls	Facility is more costly, prototype vehicle is more costly
	Re-circulation is considered as part of test	Difficult to run equal capacity to compare system/vehicle changes
	No assumptions required on cooling capacity-measured directly	Difficult to measure energy consumption of belt driven compressor
	Measurement of electric compressor can be done more easily-speed is not a function of engine	

Both approaches have some merit

Vehicle Vs Bench Indirect Analysis Flow Chart



Alternative Refrigerants



Atmospheric Reaction Products

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Should be considered	Not Considered.	Considered.

Indirect GHG emissions ($kgCO_2$-eq) per 1 kg refrigerant manufactured

	LCCP (SAE)	TEWI (JAMA)	Recommendation:
R134a	89.3 kg-CO_2/kg	6.6kg-CO_2/kg*	6.6*kg-CO_2/kg 9.4**kg-CO_2/kg
CO_2	0.45 kg CO_2/kg	Not considered	0.45 kg CO_2/kg
R152a	2.2 kg CO_2/kg	Not considered	2.2 kg CO_2/kg**

Manufacturing GHGs for Refrigerant H, is in working progress

*New Report released by McCulloch [2003]

From mine to refrigeration: a life cycle inventory analysis of the production of HFC-134a, A. McCulloch, A.A. Lindleyb,

**Life cycle analysis for production of HFC-134a and HFC-152a, T. Krieger, D. Bateman, R. Sylvester, DuPont, 2004

Testing Conditions for Setting AC Capacity

LCCP (SAE)	TEWI (JAMA)	Recommendation:
COP is considered function of temperature and compressor rpm. Testing on bench and convert based on vehicle parameters ・ Power consumption ⇒calculated from engine rpm of drive schedule. ・ Cooling capacity ⇒According to the size of vehicles	Matrix by vehicle speed and temperature. The value of matrices are measured from bench tests. or vehicle tests.	45 C x 40% R.H [as needed] 35 C x 70% R.H 25 C x 50% R.H 15 C x 80% R.H RECIRC at 35 C and 45 C Outside Air at other ambient Temperatures Run vehicle or bench test and measure compressor energy and cooling Fan power

No need to consider de-humidification loads as value is small and not so different for different refrigerants.

Front End Recirculation Considerations

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Considered 30% of time during idling conditions +15℃ [30% of time]	Considered In bench tests: Inlet air temp. is ambient temp. + 10℃ at idling condition.	Considered The method of TEWI(JAMA) is considered to be no problem. +15℃ 30% of the time for bench test [This value should be re-considered in light of vehicle data from drive schedules] Elevated temperature occurs naturally on vehicle testing, so it is considered per test and depends on vehicle configuration

Engine type / fuel type

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Engine type Fuel type considered gasoline only.	Not clear for engine type. Fuel type is Gasoline.	Consider case by case Consideration of engine efficiency is enough for LCCP. Diesel fuel should be included in the future

Engine efficiency per Vehicle Type

LCCP (SAE)	TEWI (JAMA)	Recommendation:
32%	15%	Different based on engine design/type Range can be 15-30% Use 25%

Speed vs Time

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Originally proprietary GM data Revised to Publicly available driving patterns. ex) JPN:10-15 mode USA:SCO3、FTP	・ Assumed from averaged driving mode. ・ Calculated from representative vehicle speeds. ⇒Idle, 40km/h, 100km/h	Publicly available driving patterns in all world regions. JPN：JC-08 USA: SC03 USA: FTP Europe: NEDC India: China: Australia: NEDC

Vehicle speed and ERPM profiles

	SC03	FTP city/HW	JC08	EU-NEDC	India
kph	percent	percent	percent	percent	percent
10	24%	18%	38%	32%	41%
25	9%	7%	18%	13%	23%
65	58%	41%	39%	36%	37%
80	4%	14%	4%	10%	0%
>80	4%	19%	1%	8%	0%
	100%	100%	100%	100%	100%

Depends on vehicle/Engine

	SC03	FTP city/HW	JC08	EU-NEDC	India
ERPM	percent	percent	percent	percent	percent
750	34%	17%	30%	32%	0%
1500	59%	63%	36%	6%	71%
2500	8%	20%	30%	52%	28%
4000	0%	0%	4%	9%	0%
>4000	0%	0%	0%	0%	0%
	101%	100%	100%	100%	100%

Ambient vs Time

LCCP (SAE)	TEWI (JAMA)	Recommendation:
・ Visteon analysis of Government survey, considering time of day that customer's drive.	・ 24 hours climate data.	・ Climate data except for AM 0:00 to 6:00. The evaluation of time for customers' use (like visteon analysis) is not publicly available in all regions

http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/
30 year record-need to examine a shorter time frame [3-5 years]

Annual Drive Distance and Avg. Drive Time - World

USA 2001 Household and Vehicle Characteristics	All Vehicle Types	All Vehicle Types	FTP assume for U.S Cities except Boston	SC03 assume for Boston
	mi/yr	Distance Travelled km/yr	Avg. Speed km/hr	Avg. Speed km/hr
			47	35
			Total Driving Hrs.	Representative
Census Region and Division				Cities
New England.................	12.3	19,665	562	Boston
South Atlantic................	12.4	19,832	422	Miami
East South Central.........	12.3	19,635	418	Houston
West South Central........	12.5	20,050	427	Phoenix

EU Country - 2003	Nr. of Vehicles	km/person/ Vehicle	Avg. Speed Km/hr
Belgium	4,821,000	15,197	33
Germany	44,657,000	12,751	
Greece	3,840,000	11,111	
Spain	18,688,000	12,343	
France	29,360,000	16,771	
Italy	34,310,000	13,815	
Netherlands	6,908,000	14,100	
Austria	4,054,000	13,370	
Portugal	5,996,000	10,785	
Sweeden	4,075,000	15,755	
UK	26,992,000	16,721	Total hrs. driven
TOTAL	183,701,000	km-driven Weighted Avg.	
		14,231	431
Australia		14,650	444

JAPAN	Distance Travelled	Avg. Speed
	km/person/year	Km/hr
		24
2001	11,080	
2002	10,946	
2003	10,812	
2004	10,547	Total hrs. driven
Average	10,846	452

JAMA: 10,842 km

Japan Ministry of Land Infrastructure and Transport
Ref. http://toukei.mlit.go.jp/56/monthly/geppou-e.xls

Ref. for EU http://ec.europa.eu/transport/index_en.html
Ref. for Australia http://www.environment.sa.gov.au/reporting/human/transport/total.html
Ref. for USA http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/index.html-USA -Table 15

Annual Drive Time

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Each value in each city. (Annual driving distance / Average speed.)	Annual driving distance / Average speed	Calculated by dividing annual mileage by average speed on selected drive cycle JPN: 452 hours USA: ~425 hours [FTP] ~560 hours [SC03] EU: 431 hours Australia: 444 hours

AC "ON" vs Ambient

<table>
<tr><th>LCCP
(SAE)</th><th>TEWI
(JAMA)</th><th>Recommendation:</th></tr>
<tr><td>NREL Comfort evaluation</td><td>Customer investigation of user.</td><td>
<table>
<tr><th>Ambient Range</th><th>% AC ON</th></tr>
<tr><td>>40</td><td>100%</td></tr>
<tr><td>31-40</td><td>100%</td></tr>
<tr><td>21-30</td><td>80%</td></tr>
<tr><td>13-20</td><td>45%</td></tr>
<tr><td>6-12</td><td>20%</td></tr>
<tr><td><5</td><td>0%</td></tr>
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Energy and Indirect GHG emissions due to MAC components manufacturing

	LCCP (SAE)	TEWI (JAMA)	Recommendation:
R134a, R152a	considered	Not considered	Considered
CO_2	considered	Not considered	Considered

Mass Boundaries

- ❖ **What should be included in the mass of the system?**
  - ➢ **SAE model has refrigerant system components and some air movement components**
  - ➢ **Other models only have refrigerant system components**

➢ **Recommendation:**

Include all refrigerant components and sensors and Cooling Fan [front end sealing components need to be included as they will change with CO_2]

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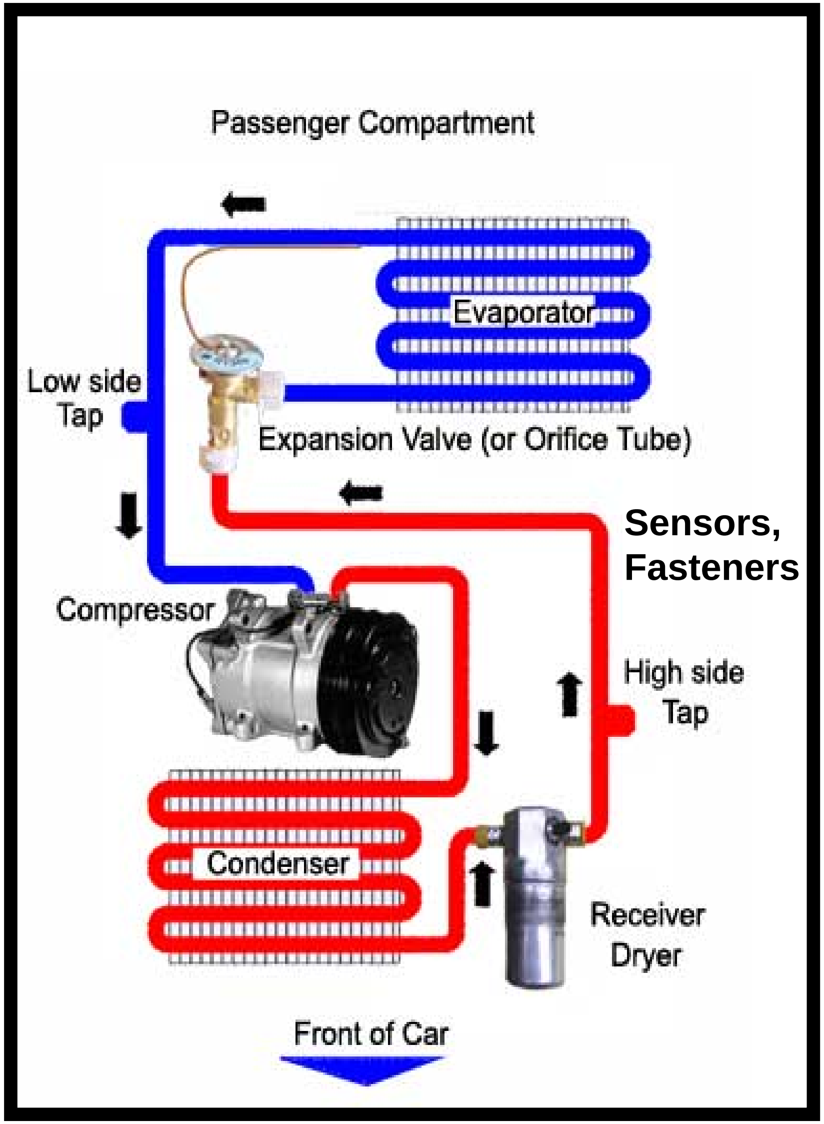


Cooling fan and blower power

LCCP (SAE)	TEWI (JAMA)	Recommendation:
Should be considered	Considered.	Considered. Alternator efficiency should be defined : ~65% Duty Cycle TBD

Cooling fan and Blower power Considerations

CRPM	Ambient [deg C]	R134a [watts]
900	15	100
1500	15	50
2500	15	0
4000	15	0
900	25	100
1500	25	50
2500	25	0
4000	25	0
900	35	100
1500	35	100
2500	35	50
4000	35	0
900	45	100
1500	45	100
2500	45	100
4000	45	0

Example

Regional analysis

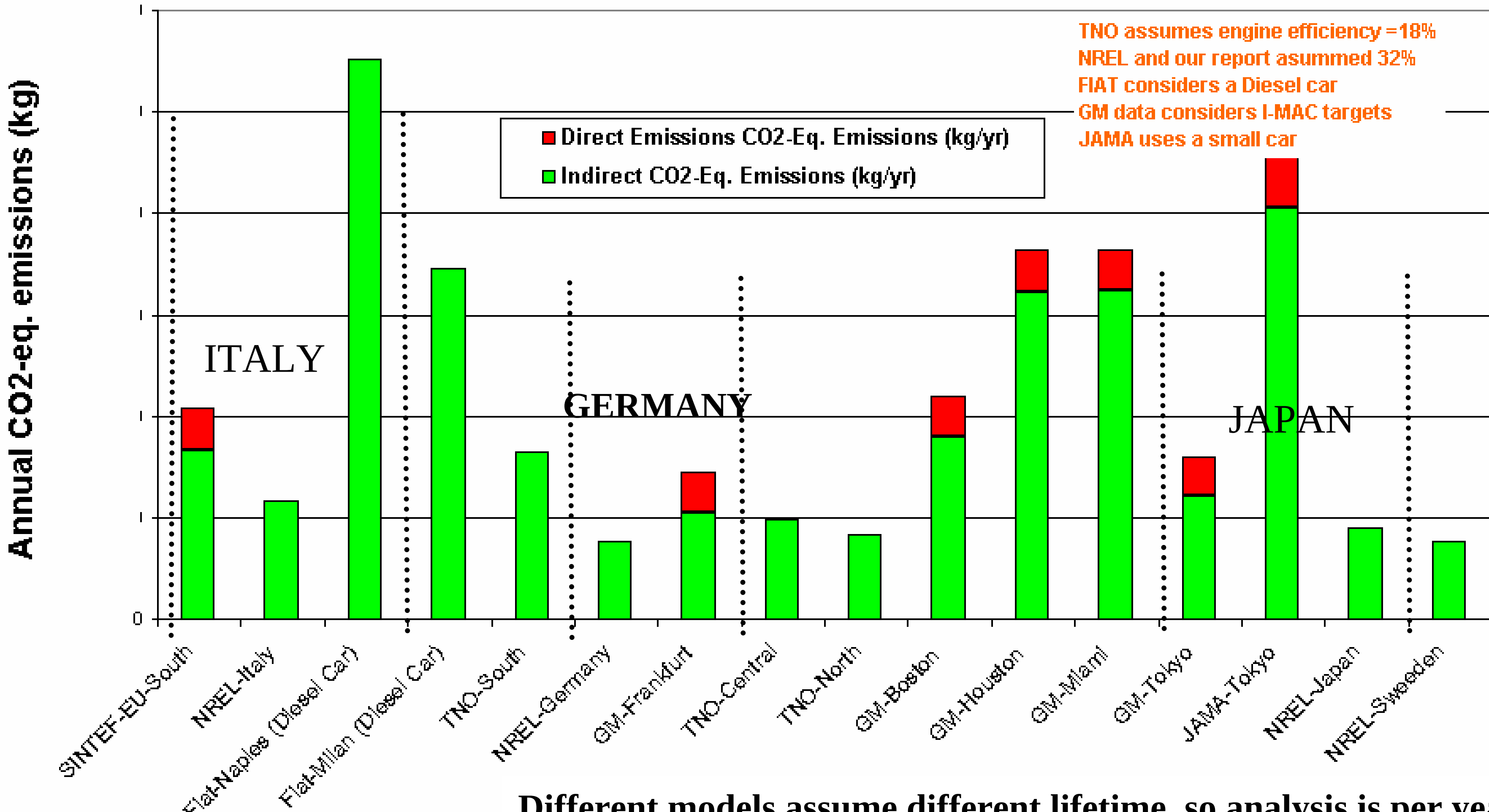
LCCP (SAE)	TEWI (JAMA)	Conclusion
Region.	・ City.	・ Region Representative cities are chosen from each region.

Vehicle life time

LCCP (SAE)	TEWI (JAMA)	Recommendation:
The lifetime difference according to regions should be considered. Propose USA=9 years	10 years	Lifetime according to regions. JPN: 11years USA: 9 years EU: 10 years

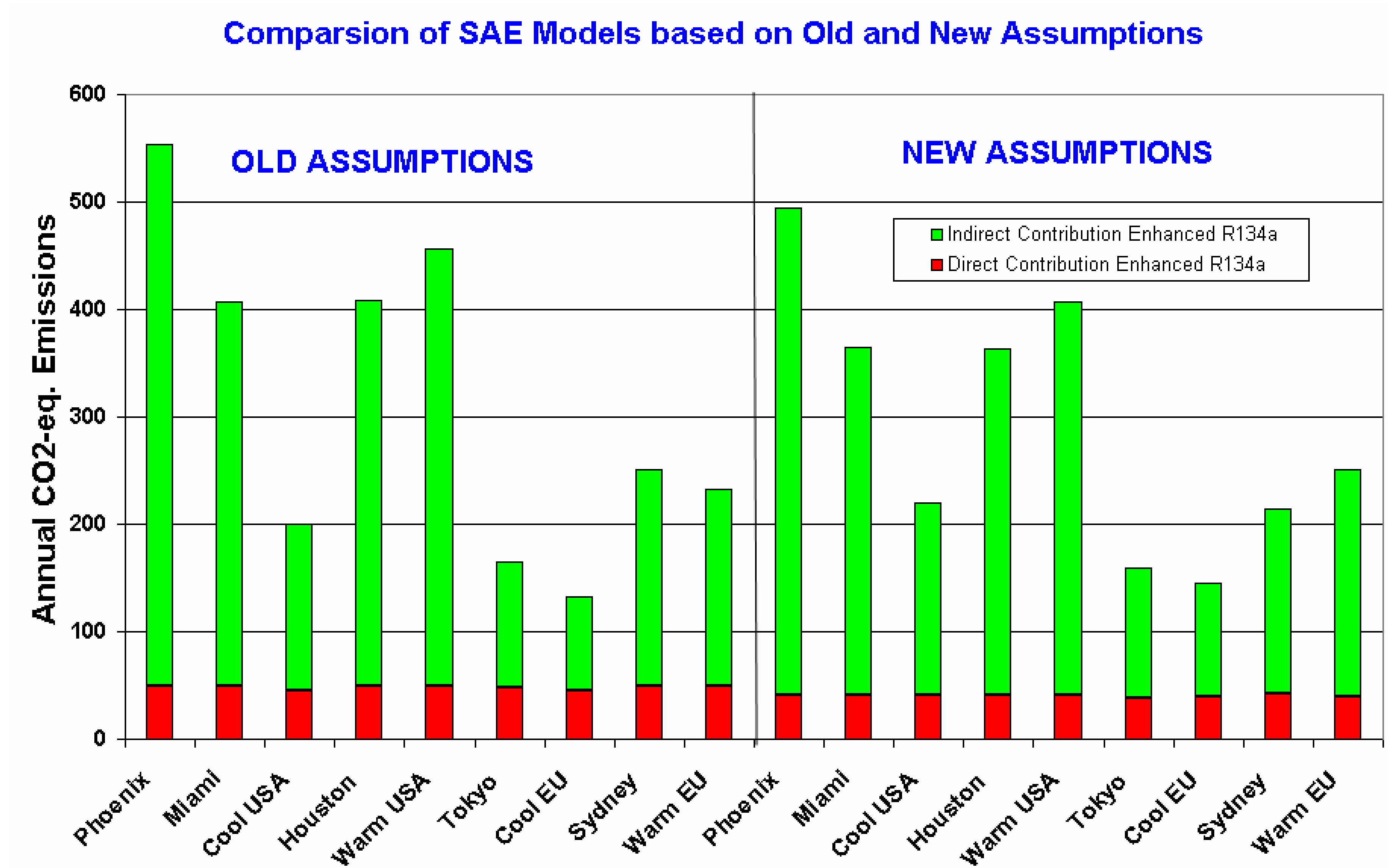
JPN Ref: Trend of vehicle possessions in Japan (AIRA); http://www.aira.or.jp
EU: Eurostat 2001; http://themes.eea.europa.eu/sectors_and_activities/transport/indicators/Technology/TERM33,2001/Average_age_of_the_vehicle_fleet_TERM_2001.pdf
USA: http://cta.ornl.gov/data/chapter3.shtml; click at Table 3.7 "Average Age of cars and trucks in USE 1970_2004

Direct and Indirect CO_2-equivalent Emissions from Different Studies

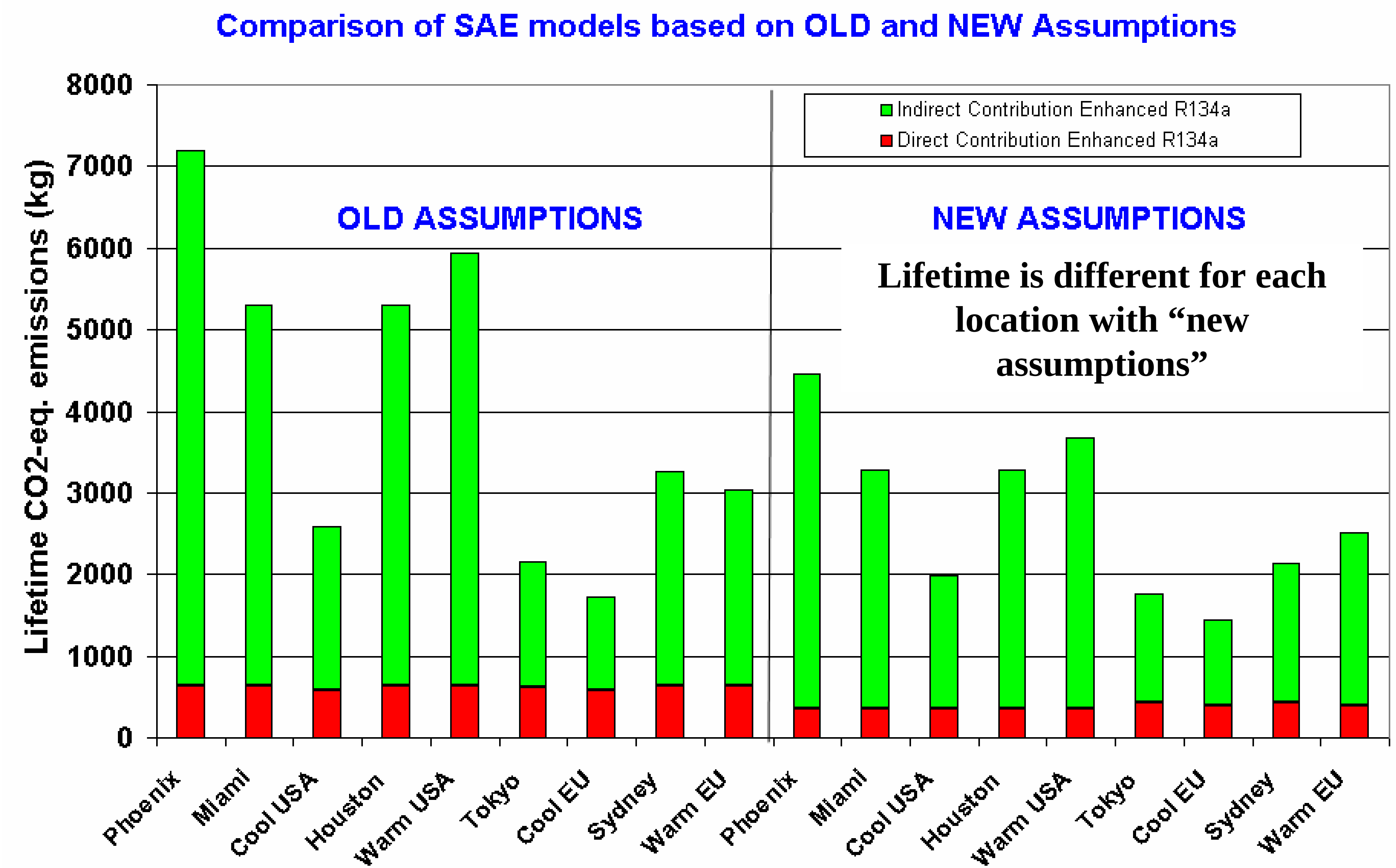


Different models assume different lifetime, so analysis is per year

Annualized Comparison



Lifetime Comparison



Comments/Conclusions

- Global Harmonization of LCCP is important to help in global selection of refrigerants
  - Results are Dependent on many parameters
  - Data from test results should be shared openly
  - Quality of data needs to be reviewed by others
- New results indicate that the previous analysis overestimated the LCCP for AC systems
  - ✓ There is a strong influence of vehicle lifetime and mileage in different regions on the result
  - ✓ Regional analysis can result in different conclusions
- Next steps
  - ✓ Get agreement from all members of SAE and JAMA
  - ✓ Meeting from 4:00 today to gather input from others

Back-up

The definition for leakage SAE vs JAMA

	JAMA's definition	SAE's definition
Production	Leakage due to vehicle assembly procedure.	Vehicle assembly leakage is not considered today. SAE accepts JAMA definition and values
Service	"Service" includes two kinds of leakage, one is leakage due to "repair" and another is leakage due to "accident". Leakage due to repair : including the following two conditions: ○Leakage from the time of malfunction to the time that vehicle enters repair plant. [this is included in the "in-use" leakage] ○Leakage during repairing process. Leakage due to accident : Assumption is following ○All of remaining refrigerant is discharged.	"Service" includes only refrigerant lost during the servicing process.. The number of services in a lifetime is calculated as follows: Number of years in lifetime/(refrigerant loss before service/nominal regular leakage rate) This should be rounded to the integer value. SAE estimate of 50 g/service is based on residual charge remaining in the system after evacuation [~40 g], plus the loss due to heels in containers and some loss due to connection to the system. [~10 g- estimate] IMAC goal is 30% improvement so this should be changed to 35 g/service]
Irregular leakage	Included in service	Based on the 2001 EU study. [1.9% yields 16 g/y based on average charge of 841 g. Needs to be adjust based on lower charge levels today of 600 grams. [1.9%=11.4 g/y]]*see page 3
In Use [Regular]	Natural leakage.	SAE number of 35 g/y was based on 30% improvement from original EU study in 2002, but, it is best to consider the recent EU study on page 4 and use 10 g/y
EOL	Residue amount of refrigerant when disposing of a vehicle （=Initial enclosed amount-Natural leakage）×（1-Recovery rate）	SAE assumed the same 5% of residual charge as unrecoverable. [5% of 600 grams is 30 grams-assumed leakage of 200 grams from base charge average of 800 in USA]

Leakage definition 2

Leakage due to vehicle assembly procedure: (3.5g per vehicle)
Not clear. The leakage is estimated within the range from 0.45 to 13.9 g per vehicle. It is still under investigation
SAE accepts 3.5 g/vehicle lifetime as we do not have better data

Leakage from service:
1. Leakage from the time of malfunction to the time that vehicle enters repair plant.
Not clear.
2. Leakage during repairing process. (= Malfunction rate*remaining amount when vehicle malfunctions*0.5)
The 4% of AC malfunction to total amount of registered vehicles is still not completely clear. It is derived from repair frequency investigations carried out by Japan Automobile Dealers Association in 1994. However, some detail of the investigation still remains unclear. The actual malfunction rate maybe much lower than 4%
3. The assumption of 50% of refrigerant leakage is just assumption, which can be illustrated as the following:
Two kinds of situation are assumed: a. If a AC system malfunctions because components malfunction, the refrigerant recovery rate would be near 100% due to the refrigerant recovery device it the vehicle enters the repair plant. b. If a AC system malfunctions because refrigerant leaks though pipe, hose... et. al., all the refrigerant in a vehicle goes outside before it enters the repair plant. The probability of situations a and b is 50% each.

Leakage due to accident:
The accident rate is calculated from number of possession and total loss rate (0.0032) in fiscal year 2004. (181,742)
SAE considers any accident that can cause loss of entire refrigerant charge. Percentage is based on EU study. It seems JAMA is considering only where vehicle is totally scrapped due to vehicle collision.

Natural (regular) leakage: (8.6 per year and per vehicle)
Air conditioner test results from JAMA (Fleet test from 2004 to 2005)

Leakage for vehicle disposal: (397.9 per year and per vehicle)
1.The initial enclosed amount of HFC-134a is calculated from the number of disposed vehicles in FY2004 and the amount of residue refrigerant in disposed vehicles (977 ton).
The actual amount of refrigerant recovery (223 ton (22.8%)) is evaluated from the amount of refrigerant disposal of annually disposed vehicles (754 ton).
The averaged refrigerant disposal for each vehicle is calculated from the annual amount of HFC134a equipped vehicle disposal. (397.9g per vehicle)

Irregular Leakage

Numbers are percentage values

Table 9: Annual Rates of Emission and Loss in Grams per Vehicle for the Three Brands of Car				
Vehicle	Normal Emission	Irregular Emission	Total Emission	Grams per Year*
Brand 1	6.2	1.5	7.7	57
Brand 2	7.0	2.2	9.2	79
Brand 3	5.8	1.9	7.7	72
All brands	**6.3**	**1.9**	**8.2**	**70**

* The respective refrigerant charges are 734 g (Brand 1), 857 g (Brand 2) and 932 g (Brand 3).

Coming from:
"Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems"
Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old
by
Dr. Winfried Schwarz
Öko-Recherche
Büro für Umweltforschung und -beratung GmbH
Environmental Research and Consultancy Office
Frankfurt am Main
September, 2001

Regular leakage

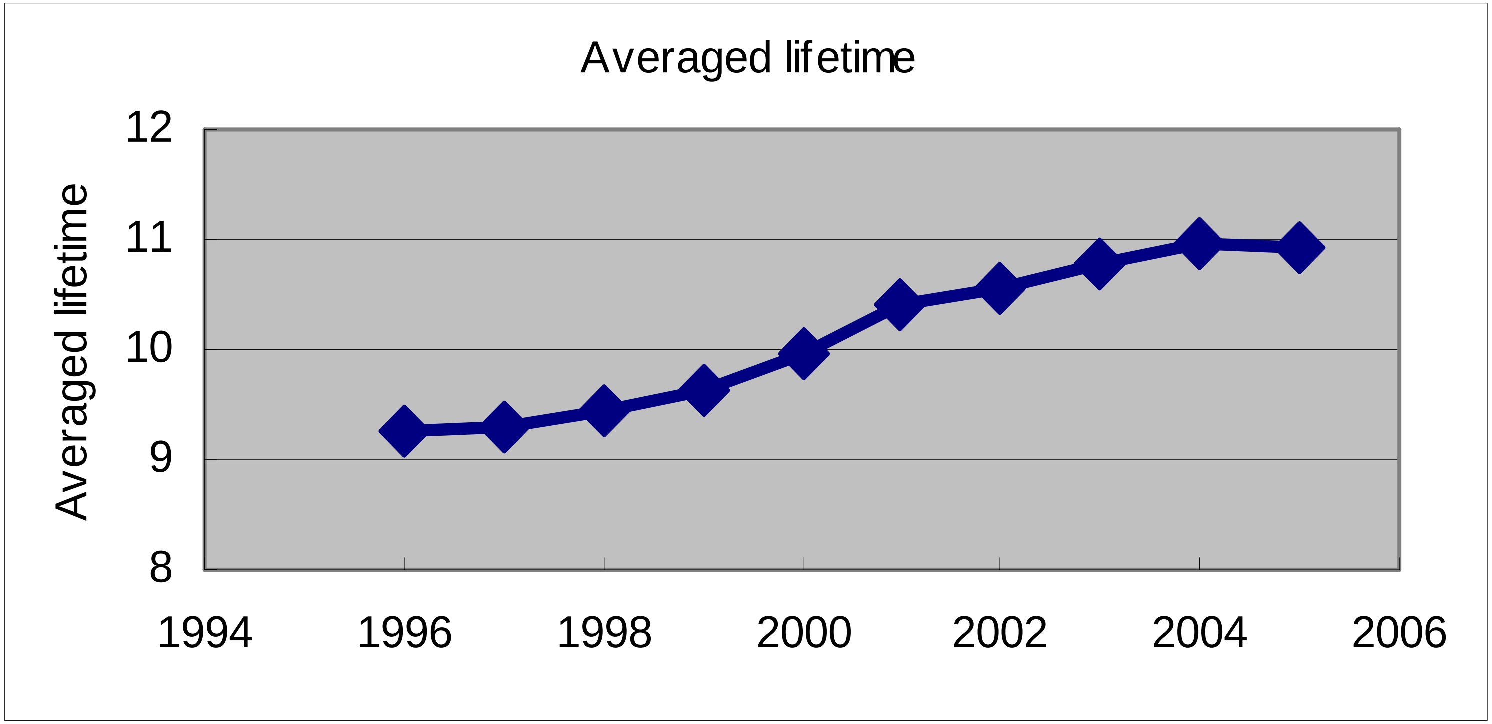
Table 4.3 – Correlation factors depending on the testing temperature.

Vehicle	LFR(g/yr) in standstill mode with preconditioning at 50°C			
	Fleet Test	Lab tests @30°C	Lab tests @40°C	Lab tests @50°C
VA	8,0	15,8	34,7	67,0
VB	7,5	18,2	45,0	82,5
VC	14,4	17,2	33,0	60,6
VD	11,5	26,5	47,5	87,2
VE	13,4	33,5	58,5	118,2
VF	8,7	22,7	33,5	52,7
VG	6,9	11,7	26,2	49,7
VH	16,6	21	45,0	80,2
VI	6,9	12,1	24,7	41,5
VJ	6,3	12,5	26,2	46,2
Mean	**10,0**	**19,1**	**37,4**	**68,6**
Calculation of Correction Factor by Method of Least Square				
Ratio=LFR/FleetTest		1,90	1,90x1,90	1,90x1,90x1,90
LFR by CF		19,0	36,1	68,6
CF=		0,526	0,277	0,146

Coming from:
"Research study on the definition
of the implementation of a method of measurement
of annual leak flow rates (LFRs) of MAC systems"
ACEA /ARMINES Contract
January, 2006

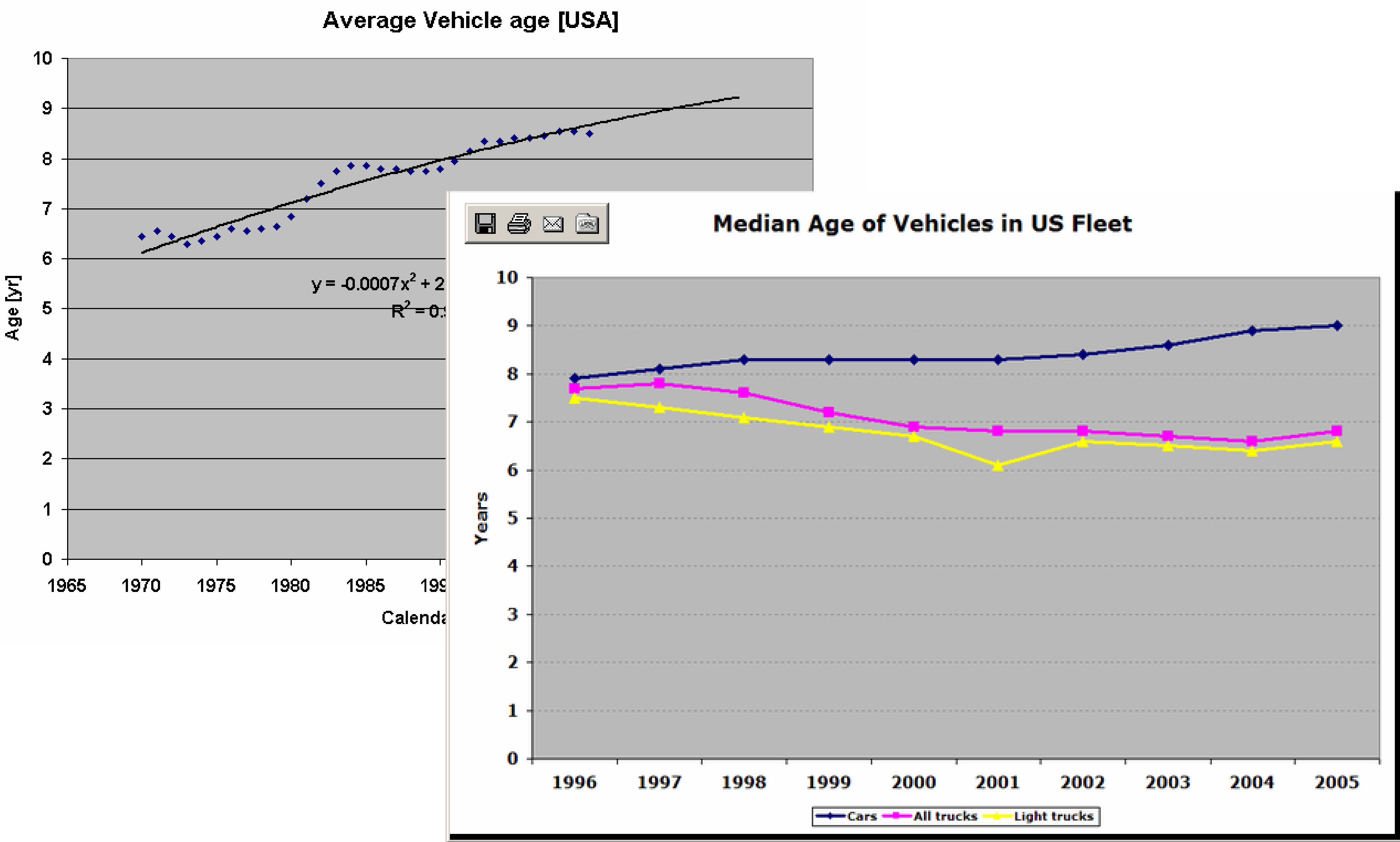
Vehicle life time

- **JAMA applies investigation results by AIRA**
  (Automobile Inspection & Registration Association).
- **From the following graph, the averaged lifetime becomes longer and longer. It is appropriate to apply 11 years.**



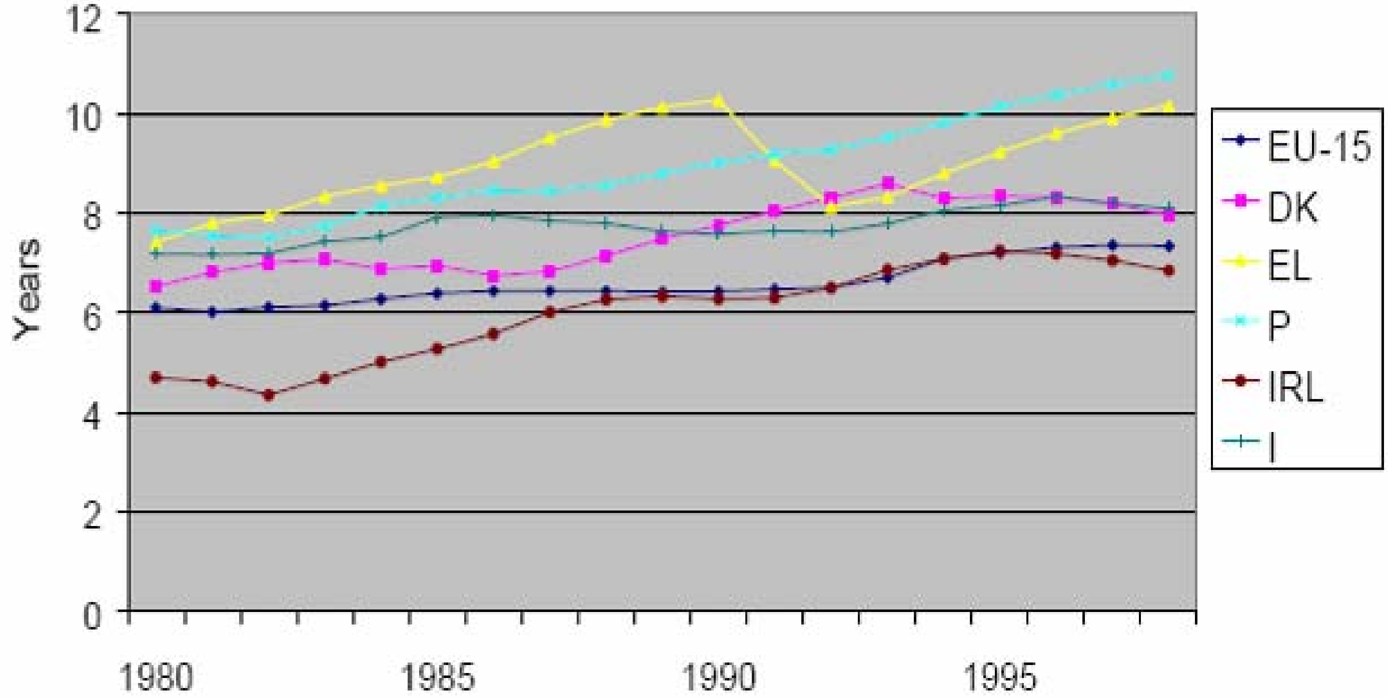
Ref:Trend of vehicle possessions in Japan (AIRA)

Vehicle Age-USA



Vehicle Age-EU

Figure 1: Average age of passenger cars in the EU and in some Member States, 1980-1998



Source: Eurostat, 2001

Speed vs ERPM JC08

Nissan TIIDA

JC 08 profile ERPM		
750	749	31.1%
1500	1380	57.4%
2500	276	11.5%
4000	1	0.0%
4000	0	0.0%
	0	
	2406	
JC 08 profile speed		
10	898	37.3%
30	595	24.7%
50	460	19.1%
80	433	18.0%
110	20	0.8%
	0	
	2406	

Toyota Corolla

JC08 profile ERPM		
750	357	29.7%
1500	439	36.5%
2500	361	30.0%
4000	47	3.9%
4000	0	0.0%
	0	
	1204	
JC08 profile speed		
10	455	37.8%
30	293	24.3%
50	228	18.9%
80	218	18.1%
110	10	0.8%
	0	
	1204	

ERPM profile is very different for these two vehicles

Ambient vs Time Regional Analysis

Ambient vs. Time

Temp (°C)	Phoenix 24 hrs	Miami 24 hrs	Boston 24 hrs	Houston 24 hrs	Tokyo 24 hrs	Frankfurt 24 hrs	Sydney 24 hrs
-5 - 0	0.0%	0.0%	15.3%	0.0%	5.6%	0%	0.0%
0 - 5	0.0%	0.0%	21.2%	0.0%	14.6%	34%	0.0%
5 - 10	9.7%	0.0%	13.5%	10.1%	19.1%	17%	3.5%
10 - 15	16.3%	0.0%	12.2%	17.7%	16.3%	22%	23.3%
15 - 20	17.4%	14.6%	19.8%	18.8%	19.4%	20%	37.5%
20 - 25	15.6%	40.3%	16.0%	27.8%	20.1%	7%	34.0%
25 - 30	16.3%	43.8%	2.1%	18.4%	4.9%	0%	1.7%
30 - 35	12.8%	1.4%	0.0%	7.3%	0.0%	0%	0.0%
35 - 40	11.8%	0.0%	0.0%	0.0%	0.0%	0%	0.0%
40 - 45	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0.0%
>45	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0.0%

24 hour

Agreement was reached on the values excluding 0-6:00AM

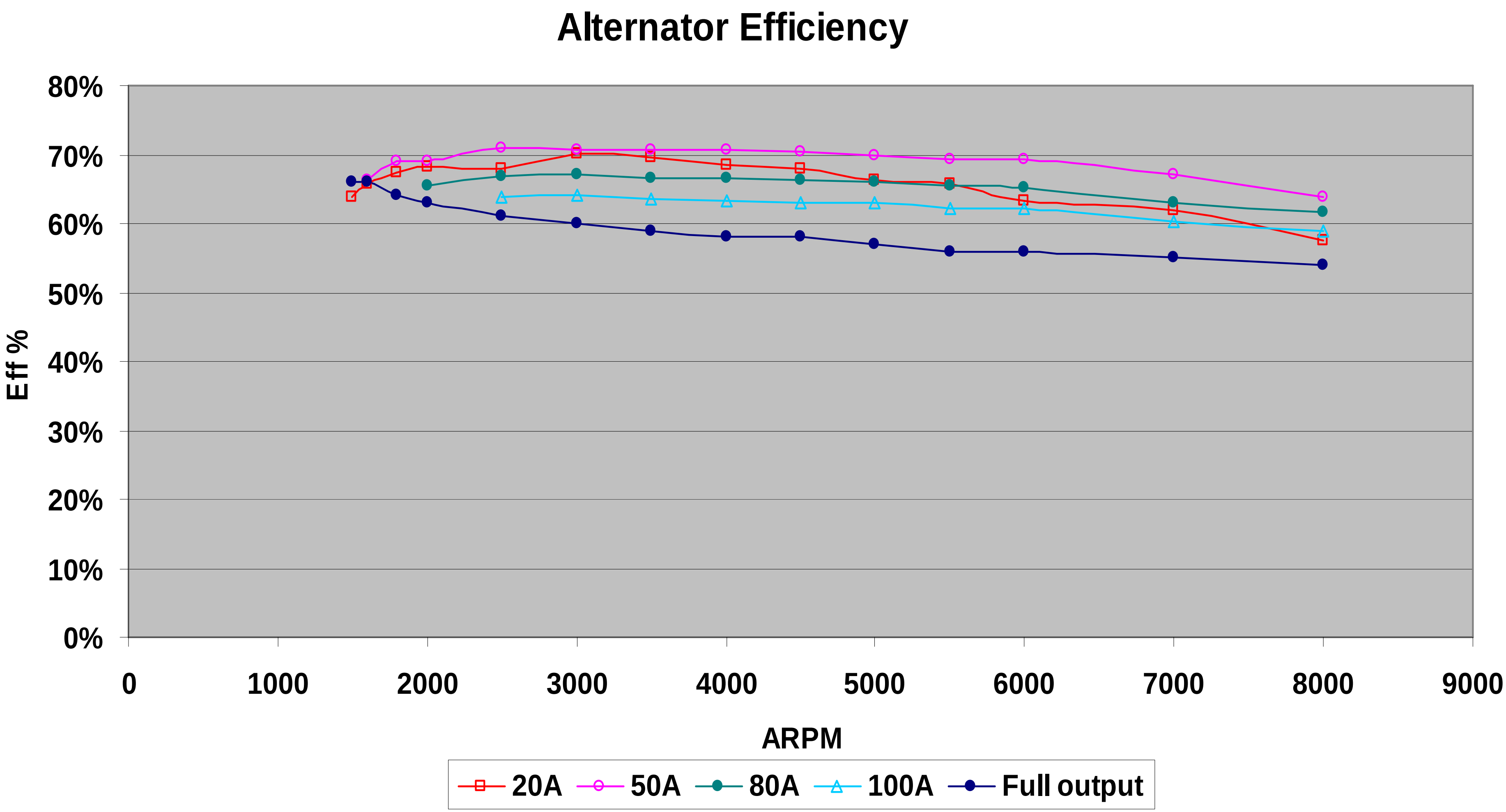
Ambient vs. Time

Temp (°C)	Phoenix except AM (0:00 - 6:00)	Miami except AM (0:00 - 6:00)	Boston except AM (0:00 - 6:00)	Houston except AM (0:00 - 6:00)	Tokyo except AM (0:00 - 6:00)	Frankfurt except AM (0:00 - 6:00)	Sydney except AM (0:00 - 6:00)
-5 - 0	0.0%	0.0%	12.0%	0.0%	2.3%	0%	0.0%
0 - 5	0.0%	0.0%	21.8%	0.0%	13.4%	31%	0.0%
5 - 10	4.6%	0.0%	14.8%	5.1%	19.9%	17%	0.5%
10 - 15	14.4%	0.0%	10.6%	18.1%	16.2%	19%	19.4%
15 - 20	17.1%	8.8%	17.6%	19.4%	20.4%	24%	35.6%
20 - 25	16.7%	39.4%	20.4%	23.1%	21.3%	10%	42.1%
25 - 30	14.4%	50.0%	2.8%	24.5%	6.5%	0%	2.3%
30 - 35	17.1%	1.9%	0.0%	9.7%	0.0%	0%	0.0%
35 - 40	15.7%	0.0%	0.0%	0.0%	0.0%	0%	0.0%
40 - 45	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0.0%
>45	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0.0%

**Proposal:
Excluding 0-6:00 AM**

http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/

Alternator Efficiency



JAMA will confirm it again.

Percent Time AC on	Percent Time Vehicle running at Ambient	Seconds traveled with AC on in year @ ambient	Seconds vehicle running at ambient in a year	Ambient T	% Time at Blower Speed and evap out temp	Blower Speed	Evap out temp control	% time non-elevated inlet air at idle [condenser/ gas cooler]	Compr RPM	Percent Time at Speed and CRPM	Evap Load	COP	Compr Energy	Compr Energy Consumed	Cooling Fan Energy consumed	Blower energy consumed	Cooling Fan Power	Blower Current
%	%	Sec	Sec	(oC)	%	(volts)	deg C			%	kW		kW	kJ	kJ	kJ	watts	Amps
15%	11%	22,469	149,796	10	100%	8	5	100%	900	17%	0.50	7.16	0.07	264	378	302	100	10
15%	11%	22,469	149,796	10	100%	8		100%	1500	24%	0.50	5.3	0.09	505	268	430	50	10
15%	11%	22,469	149,796	10	100%	8		100%	2000	38%	0.50	4.86	0.10	888	0	690	0	10
15%	11%	22,469	149,796	10	100%	8		100%	2500	16%	0.50	4.41	0.11	402	0	284	0	10
15%	11%	22,469	149,796	10	100%	8		100%	4000	5%	0.50	4.41	0.11	129	0	91	0	10
										100.0%								
25%	22%	71,444	285,775	15	10%	12.5	5	30%	900	17%	2.47	3.83	0.64	232	36	27	100	20
25%	22%	71,444	285,775	15	10%	12.5		70%	900	17%	2.8	7.16	0.39	325	84	147	100	20
25%	22%	71,444	285,775	15	10%	12.5		100%	1500	24%	2.84	5.31	0.53	913	85	427	50	20
25%	22%	71,444	285,775	15	10%	12.5		100%	2000	38%	2.89	4.86	0.59	1,629	0	686	0	20
25%	22%	71,444	285,775	15	10%	12.5		100%	2500	16%	2.93	4.41	0.66	750	0	282	0	20
25%	22%	71,444	285,775	15	10%	12.5		100%	4000	5%	2.93	4.41	0.66	240	0	90	0	20
										116.8%								
25%	22%	71,444	285,775	15	45%	8	5	100%	900	17%	0.66	3.50	0.19	1,023	541	433	100	10
25%	22%	71,444	285,775	15	45%	8		100%	1500	24%	0.7	3.2	0.21	1,636	384	615	50	10
25%	22%	71,444	285,775	15	45%	8		100%	2000	38%	0.67	2.54	0.26	3,236	0	988	0	10
25%	22%	71,444	285,775	15	45%	8		100%	2500	16%	0.66	1.92	0.34	1,742	0	406	0	10
25%	22%	71,444	285,775	15	45%	8		100%	4000	5%	0.66	1.92	0.34	558	0	130	0	10
										100.0%								
25%	22%	71,444	285,775	15	45%	8	10	100%	900	17%	0.29	4.08	0.07	378	541	433	100	10
25%	22%	71,444	285,775	15	45%	8		100%	1500	24%	0.28	2.34	0.12	928	384	615	50	10
25%	22%	71,444	285,775	15	45%	8		100%	2000	38%	0.29	2.00	0.15	1,807	0	988	0	10
25%	22%	71,444	285,775	15	45%	8		100%	2500	16%	0.30	1.67	0.18	926	0	406	0	10
25%	22%	71,444	285,775	15	45%	8		100%	4000	5%	0.30	1.67	0.18	297	0	130	0	10
										100.0%								
80%	34%	352,214	440,268	25	50%	12.5	5	30%	900	17%	3.68	3.20	1.15	10,234	889	667	100	20
80%	34%	352,214	440,268	25	50%	12.5		70%	900	17%	4.2	4.93	0.85	17,600	2,074	3,630	100	20
80%	34%	352,214	440,268	25	50%	12.5		100%	1500	24%	5.88	3.71	1.59	66,711	2,104	10,520	50	20
80%	34%	352,214	440,268	25	50%	12.5		100%	2000	38%	5.94	3.40	1.75	118,146	0	16,912	0	20
80%	34%	352,214	440,268	25	50%	12.5		100%	2500	16%	6.00	3.09	1.94	53,988	0	6,958	0	20
80%	34%	352,214	440,268	25	50%	12.5		100%	4000	5%	6.00	3.09	1.94	17,307	0	2,230	0	20
										116.8%								
80%	34%	352,214	440,268	25	25%	8	5	100%	900	17%	1.41	4.00	0.35	5,219	1,481	1,185	100	10
80%	34%	352,214	440,268	25	25%	8		100%	1500	24%	1.4	3.4	0.41	8,714	1,052	1,683	50	10
80%	34%	352,214	440,268	25	25%	8		100%	2000	38%	1.41	3.01	0.47	15,908	0	2,706	0	10
80%	34%	352,214	440,268	25	25%	8		100%	2500	16%	1.43	2.63	0.54	7,553	0	1,113	0	10
80%	34%	352,214	440,268	25	25%	8		100%	4000	5%	1.43	2.63	0.54	2,421	0	357	0	10
										100.0%								
80%	34%	352,214	440,268	25	25%	8	10	100%	900	17%	1.18	4.51	0.26	3,860	1,481	1,185	100	10
80%	34%	352,214	440,268	25	25%	8		100%	1500	24%	1.20	3.87	0.31	6,515	1,052	1,683	50	10
80%	34%	352,214	440,268	25	25%	8		100%	2000	38%	1.19	3.15	0.38	12,782	0	2,706	0	10
80%	34%	352,214	440,268	25	25%	8		100%	2500	16%	1.18	2.42	0.49	6,773	0	1,113	0	10
80%	34%	352,214	440,268	25	25%	8		100%	4000	5%	1.18	2.42	0.49	2,171	0	357	0	10
										100.0%								
100%	28%	362,429	362,429	35	100%	12.5	5	30%	900	17%	4.16	2.72	1.53	27,969	1,829	1,372	100	20
100%	28%	362,429	362,429	35	100%	12.5		70%	900	17%	4.7	3.88	1.22	51,909	4,268	7,470	100	20
100%	28%	362,429	362,429	35	100%	12.5		100%	1500	24%	6.49	3.03	2.14	185,313	8,660	21,650	100	20
100%	28%	362,429	362,429	35	100%	12.5		100%	2000	38%	6.99	2.72	2.57	357,299	6,961	34,804	50	20
100%	28%	362,429	362,429	35	100%	12.5		100%	2500	16%	7.49	2.42	3.10	177,658	0	14,319	0	20
100%	28%	362,429	362,429	35	100%	12.5		100%	4000	5%	7.49	2.42	3.10	56,952	0	4,590	0	20
										116.8%								
100%	5%	71,934	71,934	45	100%	12.5	5	30%	900	17%	3.98	2.41	1.65	5,991	363	272	100	20
100%	5%	71,934	71,934	45	100%	12.5		70%	900	17%	4.4	3.88	1.13	9,556	847	1,483	100	20
100%	5%	71,934	71,934	45	100%	12.5		100%	1500	24%	6.49	3.03	2.14	36,780	1,719	4,297	100	20
100%	5%	71,934	71,934	45	100%	12.5		100%	2000	38%	6.99	2.72	2.57	70,915	1,382	6,908	50	20
100%	5%	71,934	71,934	[illegible]	[illegible]	12.5		100%	2500	16%	7.49	2.42	3.10	35,261	0	2,842	0	20
100%	5%	71,934	71,934	[illegible]	[illegible]	12.5		100%	4000	5%	7.49	2.42	3.10	11,304	0	911	0	20

JAMA TEWI Calculation

TEWI（Total Equivalent Warming Impact）:
Equivalent CO_2 gas emission in vehicle life time

TEWI = Total Leakage x GWP + A x (1/B) x SUM(comp. power / C)

→ direct emission — **→ indirect emission**

Direct emission:
- ✓Leakage at factory charging
- ✓Annual leakage
- ✓Annual irregular leakage
- ✓EOL emission

Indirect emission:
- ✓occurrence of temperature frequency
- ✓occurrence of each vehicle speed
- ✓outlet air temperature to be fixed one
- ✓Determine each compressor displacement (so that the pull down cooling performance become the same for R134a and CO_2)

A：amount of CO2 for Fuel of 1kg
B：energy for Fuel of 1kg
C：engine efficiency

SAE vs. JAMA Indirect Analysis Flow Chart

SAE

AC running time

NREL Thermal Comfort Model (% of vehicle operating time the A/C is on in that temp. bin)
VISTEON data (% time vehicle is running at ambient)
✓Select region

Determine time (sec) traveled per year, web info
✓Select city and country
Determine time (sec) with AC on per year
✓Calculate driving time at distinct compressor RPMs (900, 1500, 2000, 2500, 40000
Determine % time at Blower Speed (low/high) and evaporator outlet Temperature (5/10C) at each Ambient and blower speed

Bench Data (Evaporator Capacity and COP)

Blower Energy/ Cooling Fan Energy

Average Compressor Power (kW)

Alternator eff.
Belt eff.
Engine eff.

Average Cooling Fan Power (kW)

Total AC Energy (kJ)

JAMA

In-direct Effect

Make table of AC running time

Determine thermal load condition
✓Select region
✓Calculate occurrence of temperature frequency

Determine driving condition
✓Select driving mode
✓Calculate occurrence of each vehicle speed
✓Calculate driving time of each vehicle speed

Determine AC the profile (AC ON vs ambient)

AC running time

Tamb	Idling	40 kmh	100 kmh
35	3.9	3.8	3.8
30	13.6	13.3	1.9
25	34.9	34.3	4.9
20	38.8	38.1	5.4
15	14.8	14.6	2.1
10	0	0	0
5	0	0	0
0	0	0	0
-5	0	0	0

Make table of compressor power

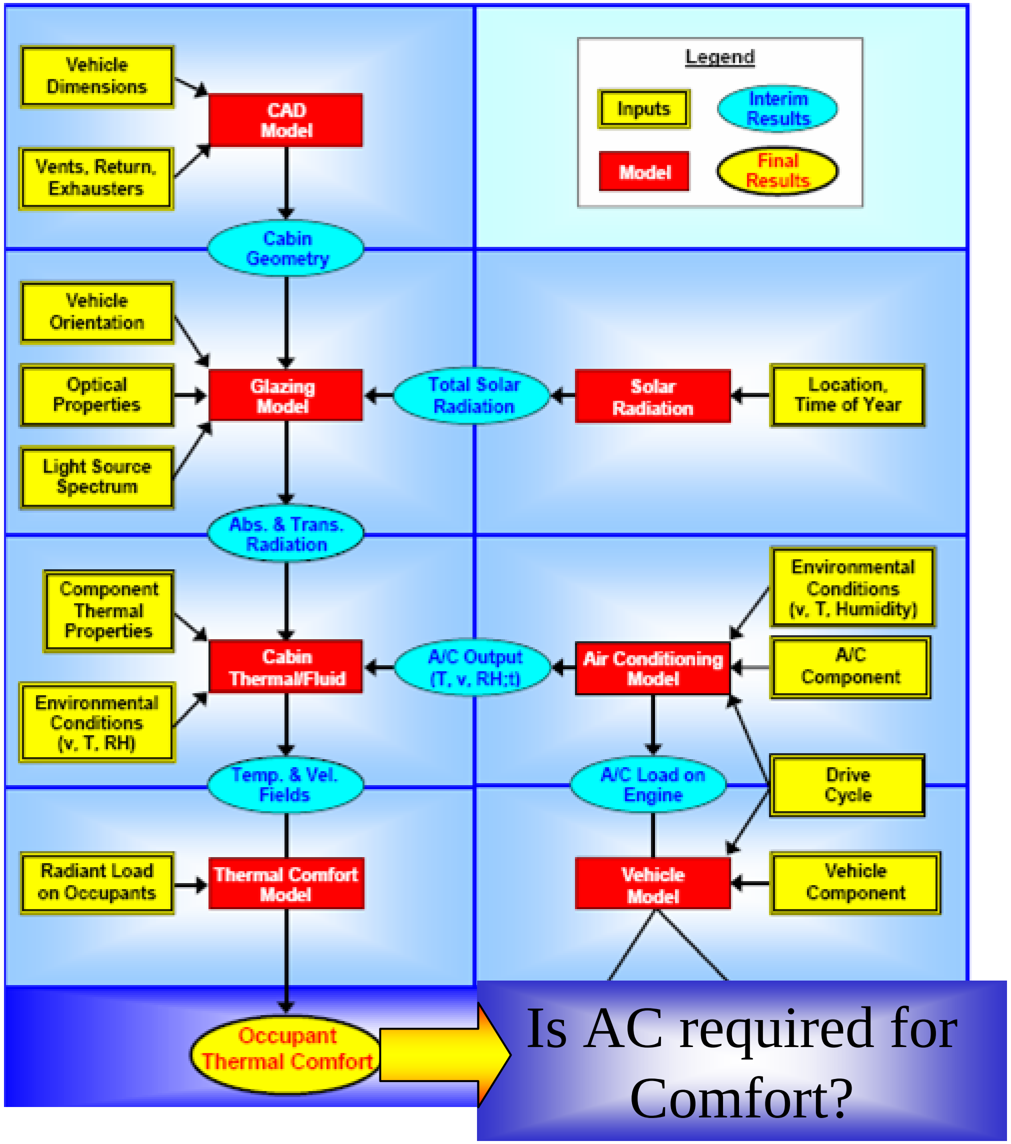
Determine AC system
✓Select the best components for R134a and CO2
✓Determine each compressor displacement so that the pull down cooling performance become the same for R134a and CO_2
✓Fix the cycle control method
✓Control expansion valve optimally
✓Control outlet air temperature to be fixed one
✓Consider cond. Air temp. rise due to hot air recirculation

R134a compressor power CO_2 compressor power

Tamb.	Idling	40 kmh	100 kmh	g	40 kmh	100 kmh
35	1.80	2.28	3.44	7	*	*
30	1.65	1.57	2.01		*	*
25	1.02	0.93	1.21		*	*
20	0.56	0.59	0.77		*	*
15	0.46	0.52	0.67		*	*
10	0	0	0		*	*
5	0	0	0		*	*
0	0	0	0		*	*
-5	0	0	0		*	*

Calculation of Annual total compressor power, then annual total engine power by engine efficiency

AC on Time



- AC on time was originally estimated per city and per temperature bin based on [National Renewable Energy Lab] NREL comfort modeling
- Percentages were changed based on consensus

Engine Efficiency

- ❖**How should engine efficiency and fuel energy content be considered?**
  - ➢**SAE model uses 32%**
    - ➢**2.33 kg CO2/liter of fuel**
    - ➢**34.7 Mj/liter of fuel**
  - ➢**JAMA uses 15%**
    - ➢**Gasoline exotherm: 44372 kJ/kg**
    - ➢**CO2 emission from gasoline: 2.31 CO2-kg/L**
  - ➢**Sintef model uses 0.78 l/100 km**

- ❖**How to consider the affect of transmission gear and related compressor RPM?**
  - ➢**Use ERPM profiles from drive cycles**

How to consider the effect of :
Belt Eff=0.95
Alternator eff=0.65