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MAC test procedure to be used in a pilot phase

Test procedure V1.11, November 5th 2010

Compiled from draft final report: *"Collection and evaluation of data and development of test procedures" in support of legislation on mobile air conditioning (MAC) efficiency and gear shift indicators (GSI), Task 1. and Task 2."* By Stefan Hausberger (TUG), Werner Stadlhofer (TUG), Klaus Martin (ViF), Robin Vermeulen (TNO), Sebastiaan Bleuanus (TNO), Zissis Samaras (LAT), Savas Geivanidis (LAT), János Kovács (KTI), Iván Pollák (KTI)

Compiled from draft final report: *"Collection and evaluation of data and development of test procedures" in support of legislation on mobile air conditioning (MAC) efficiency and gear shift indicators (GSI), Task 1. and Task 2."* Performed for European Commission - DG Enterprise and Industry under Framework Service Contract ENTR/05/18

1 Introduction

This document describes a test procedure that can be used to measure the additional fuel consumption and pollutant emissions caused by operation of a mobile air conditioning (MAC) system in a passenger car (M1). This procedure was developed in a project carried out jointly by TNO, TUG, LAT and KTI for the European commission (DG Enterprise) in 2009 and 2010. It should be viewed as a work in progress and the experience gathered in a pilot phase should be used to further refine the procedure. The procedure is a physical test with the entire vehicle on a chassis dynamometer.

The basic elements of the procedure are;

- A physical emission test on the whole vehicle
- Driving the test cycle on a chassis dynamometer, in an emission laboratory
- Driving a sequence of the test cycle two times with the same three steady state phases; the first three are run with the MAC switched on and the next three are run with the MAC switched off
- Testing under moderate ambient conditions in a test room that does not require expensive facilities
- Application of correction functions for some less stable parameters, for the improvement of the repeatability
- Application of correction values or altered MAC settings for differences in system properties (like glazing)
- Calculation of the additional fuel consumption due to MAC activity from the difference in fuel consumption between the test part with MAC on and with MAC off.

Since the additional fuel consumption from the MAC system is calculated as difference of two measured values which are approximately one order larger than the considered MAC fuel consumption value, a high accuracy is necessary in the test procedure to obtain correct results. To improve the accuracy some correction factors are proposed to be applied to the measured results to increase the repeatability (correction for deviations of the vehicle speed and of the temperature and humidity during the test). The influence of sun radiation is suggested to be depictured as function of the glazing size and quality by a variation of the air flow through the MAC or by simple look-up tables for a correction factor for the measured fuel consumption due to additional load to the MAC system to cool the heat entrance due to sun radiation.

In the following chapters the single parts of the test procedure are described. The background and details to the measurement results can be found in the report of the overall project.

2 Detailed description of the test procedure

2.1 Test bed

The test bed shall fulfil the definitions given in the EC type approval regulations for emission standards of passenger cars and light duty vehicles (EC Regulation Nr. 692/2008).

2.2 Soak Phase and Pre Conditioning Cycle

The MAC test cycle includes a preconditioning phase. Additionally, the vehicle should be soaked in advance of the actual tests to achieve a defined vehicle temperature. The preconditioning is designed to bring relevant vehicle parts to a defined status (e.g. loading of the DPF) as well as providing time to properly set the MAC system.

The following preconditioning and soak procedure should be used before the MAC test starts:

- Set up the vehicle at the test bed in the cell which has a temperature controlled between 20°C and 30°C.
- Set the driving resistance values and the fly wheel mass of the roller test bed according to the standard test procedure for cars (EC 692/2008).
- Set the MAC system of the vehicle to "automatic position"
- Start the vehicle and run one NEDC
  Park the vehicle for at least 8h at the test cell temperature, or in a room continuously controlled between 20 and 30 degrees Celsius. The humidity does not need to be controlled in this room. A battery charger should be connected to the vehicle to fully charge the battery.
- →Start the test

2.3 In-car and test cell settings for temperature, humidity and mass flow

For the MAC test, the positions of the various sensors as well as the target values for ambient and interior temperature as well as ambient humidity have been defined.

Position of the temperature and relative humidity sensors

During the soak time as well as during the MAC test cycle the temperature in the test cell[1] (T_a) has to be controlled. During the MAC test cycle, the relative humidity also has to be controlled.

The sensors used for monitoring the relative humidity and test cell temperature should be fitted at the inlet of the blower for the air flow to the vehicle. Figure 1 shows the locations of these sensors (T_a and φ_a).

[1] In case the vehicle is soaked outside the test cell, the temperature of the room in which the vehicle is soaked should of course be recorded.

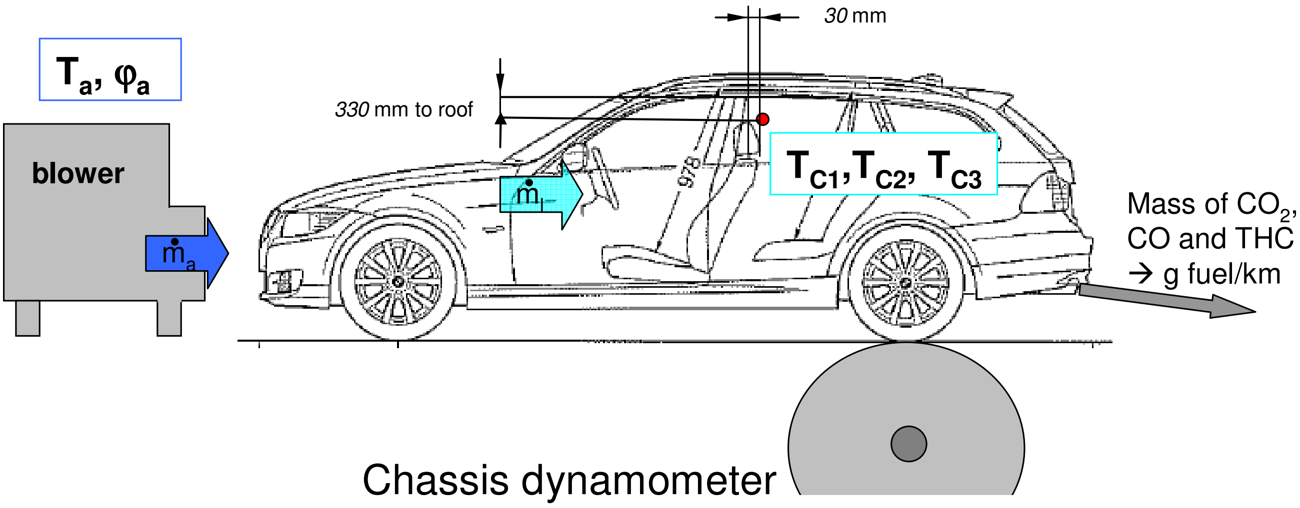

Figure 1: schematic picture of the location of the sensors for the temperature and humidity in the MAC test

During the MAC test the vehicle cabin temperature (T_{C1}, T_{C2} and T_{C3}) and the vent outlet temperatures (T_{V3}) have to be measured. Figure 1 shows the position of TC_3, which should be fitted on the centreline of the vehicle. TC_2 and TC_3 should be fitted centrally behind the driver and passenger seat. When viewed from the side, T_{C1}, T_{C2} and T_{C3} should be in line. (i.e. T_{C1}, T_{C2} and T_{C3} should be positioned at the same height and distance from the front of the vehicle, Figure 2) The vent outlet temperatures (T_{V3}) should be measured as shown in Figure 2. One temperature sensor has to be located in front of the centre of each vent outlet (here T_{V3-1} to T_{V3-4}). All other vents should remain closed, only the vent outlets on the dashboard should be opened. If other vents cannot be closed due to their design, their temperature should be measured in a similar fashion.

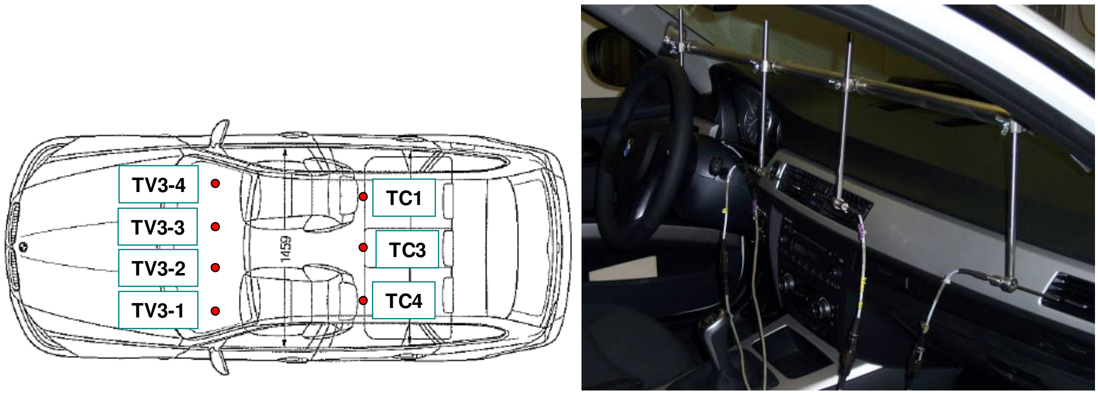

Figure 2 Thermocouple positions (T_{V3} and T_C1 to T_{C3}) to measure vent outlet temperature and cabin temperature (right picture shows T_{V3-1} to T_{V3-4} position)

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Target values for temperature, humidity and mass flow

Cabin temperature:
There are two options which have to be decided before the definition of the final test procedure.

Option 1:
The interior temperature (T_{C3}) should be measured at the height of the drivers head at three positions (behind the driver, behind the co-driver and in the middle between the front seats). The target is to have all three temperatures below 23°C.

Option 2:
The temperature (T_{V3}) should be measured at the central position of each vent outlet in the front area of the cabin. Other vent outlets shall be closed. As target value the maximum of all measured temperature values (T_{V3}) should be at or below 15°C.

During the pilot phase the MAC system shall be adjusted to meet the T_{V3} target of <15°C. T_{C3} shall also be recorded to allow the analysis of the correlations between T_{V3} and T_{C3} (i.e. during the pilot phase, option 2 shall be used).

Cabin mass flow:

The settings of the mass flow of the air conditioning system shall be adjusted to achieve more than 230 kg/h, adapted by eventual correction factors for the vehicles glazing.
The simple approach keeps the mass flow constant at >230 kg/h and uses a correction factor for the measured fuel consumption of the MAC system (Table 3 and the corresponding equations). An alternative option is described below. We suggest testing this option where possible during the pilot phase to gain experience for the final decision which approach is preferred.

Option:
At least for Option 2 above (T_{V3}) a differentiation of the demanded mass flow according to vehicle size may be useful since larger cabins need more cooling capacity to reach the same comfort than small cabins. With the differentiation one MAC system would have higher additional fuel consumption in a larger car than in a smaller car. Since the MAC test procedure will not influence the customers to buy smaller cars, the differentiation would not add incentives for more energy efficiency but would adapt the absolute values closer to the reality. The adaptation of the MAC mass flow to different glazing sizes and qualities is shown later in this document also based on Table 3 and corresponding equations. Data for the elaboration of an eventual additional adaptation of the mass flows for different vehicle size classes is not available yet and can be analysed after the pilot phase.

Ambient temperature and humidity:
Previous testing showed that the ambient temperature and relative humidity show a variation over the test cycle, due to the behaviour of the test cell climate control. Since a smaller temperature difference between the test cell and the cabin as well as a lower humidity significantly reduce the energy consumption of the MAC system, either narrow tolerances or more generous tolerances with the application of correction functions are necessary. The suggested tolerances are:

– Humidity in the test cell φ_a = 45% +/- 5% (Option > 45%)
– Temperature in the test cell T_a = 25°C +/- 2°C (Option T_a >25°C)

Additionally, the temperature in the cabin should never be above the test cell temperature during the cycle as long as the MAC is on during the test.

2.4 MAC test cycle

The test cycle is based on the "ACEA" driving cycle and consists of a preconditioning phase followed by three steady state phases. The preconditioning phase starts with MAC-on and the MAC settings have to be adjusted to meet the target temperature in the cabin (T_{C3} or T_{V3}) within the preconditioning phase. After this, the first part is measured with the MAC-on, the second part with MAC-off as depicted in Figure 3. The time and speed tolerances should be the same ones as described in EC 692/2008.

In this continuous sequential test the exhaust gas analysers should have the same calibration (span, zero) for the tests at MAC-on and MAC-off to increase the accuracy of the measurements.

For the evaluation of the test results only the phases with constant speed are used, see the evaluation periods in Figure 3. The additional fuel consumption due to the MAC is the difference in fuel consumption between the MAC-on and the MAC-off phase of the test cycle.

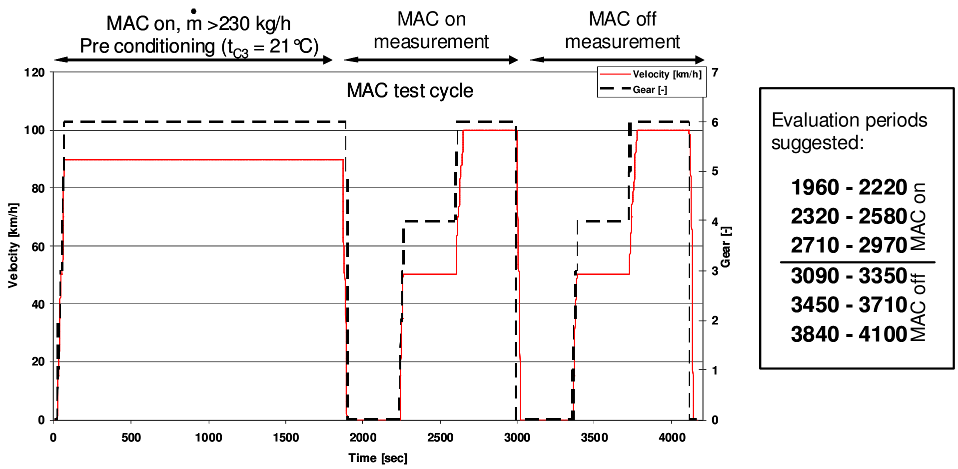

Figure 3: MAC test cycle with preconditioning and two test phases. (option: use 100km/h also for preconditioning to make tampering with battery charging/de-charging more difficult?)

During the measurement regeneration processes of the after treatment systems, non continuous OBD activities influencing the fuel consumption and any other non continuously running activities with influences on the engine work or on the engine combustion process shall be prohibited.

To get information on the repeatability of the test results it is recommended to apply 2 or 3 consecutive MAC tests during the pilot phase, each of them following the cycle shown in Figure 3.. Since the influence of the soak phase on the repeatability is unknown yet, it is suggested to start the consecutive MAC tests just after each other with less than 15 minutes idling between the tests (or minimum time necessary to finalise the emission measurement and to get the test bed ready to start the next test again if this needs more than 15 minutes).

To eliminate the possible influence of different levels of SOC (State Of Charge) of the battery at the beginning and the end of the test into consideration, the tests should always be started at 100% SOC. This is the reason for connecting a battery charger to the vehicle during the soak phase. The current flow from and to the battery shall be recorded during the test to enable an eventually necessary correction of variations of the battery loading strategy and of all energy consumers on board during the test cycle.

2.5 MAC settings

The settings of the MAC system have to be adjusted during the preconditioning phase of the MAC test cycle in the phase of constant 90 km/h , i.e. between second 100 and 1700 after test start.
Typically manual settings of the mass flow and target temperature will be necessary to reach the defined values for T_v<15°C and mass flow >230 kg/h. Recirculation of the cabin air is allowed but only to an extend that can be executed also durable in real world traffic without adverse effects on the CO_2 concentration in the cabin. As default maximum recirculation rate we suggest 90% for the pilot phase.
All flaps of the vents in the front area of the cabin shall be set in 90° position relative to the sectional area of the vent. Vents at the dashboard have to be open, all other vents, such as for the rear seats or for the footwell, can be closed and/or be deactivated by the MAC control panel. All open vents with mass flows > 5 kg/h have to be included in the temperature measurement system (see chapter 2.3).

2.6 MAC test evaluation

The results for the single speed steps of the MAC test cycle shall be weighted according to the following shares:

- Idling = 15%
- 50 km/h = 65%
- 100 km/h = 20%

Since the MAC test cycle has in total 6 phases to be evaluated, bag values can not be applied at typical CVS systems and the fuel consumption has to be calculated from the instantaneous signal of the analysers and from the CVS volume flow. The procedure shall basically follow the regulation for the emission tests for vehicle type approval to calculate the mass flows of CO_2, THC and CO. The fuel consumption shall then be calculated from the carbon balance. The concentration of CO_2, THC and CO in the dilution air shall be taken from the bag and shall be used to correct the measured concentrations of the diluted exhaust gas for the entire cycle. The correction shall be done according

692/2008/EC. The Dilution Factor shall be calculated also from the instantaneous signals of the exhaust flow and from the bag value for the air used for dilution.

6.4.1.3. Calculation of the corrected concentration of pollutants in the sampling bag

$$C_i = C_e - C_d \left(1 - \frac{1}{DF}\right) \quad (4)$$

where:

C_i = concentration of the pollutant i in the diluted exhaust gas, expressed in ppm or % volume and corrected by the amount of i contained in the dilution air;

C_e = measured concentration of pollutant i in the diluted exhaust gas, expressed in ppm, or % volume;

C_d = measured concentration of pollutant i in the air used for dilution, expressed in ppm, or % volume;

DF = dilution factor.

The time windows within the MAC test for the evaluation of the test result are shown in Table 1. This table also shows suggested limits for the maximum variation of the instantaneous CO_2 signal during each time window. An ideal test would show 0% standard deviation over the constant speed phase since prior to each test phase a period for stabilisation of the vehicles running conditions and for compensation of the running time of the exhaust gas from the engine to the analyser and for the response time of the analyser is defined. Disturbances of the ideal conditions lead to variations of the CO_2 signal and thus also to increased standard deviations. The standard deviation thus could be used as measure to exclude specific tests from the evaluation. The applicability of such tolerances shall be evaluated from the data gained during the pilot phase.

Table 1: phases of the MAC test cycle to be used fort he preconditioning (i.e. adjustment of the MAC settings) and for the testing of the MAC

Test part	**MAC status**	**Start [s]**	**End [s]**	**Result [kg/h]**	**max. CO_2 standard deviation (1)**
Precon	On, adjust TV3	90	1800	-	Not relevant
Idling	On	1960	2220	FC i-MAC	10% from average
50 km/h	On	2320	2580	FC 50-MAC	5% from average
100 km/h	On	2710	2970	FC 100-MAC	5% from average
Idling	Off	3090	3350	FC i	10% from average
50 km/h	Off	3450	3710	FC 50	5% from average
100 km/h	Iff	3840	4100	FC 100	5% from average

(1).... The tests showed no clear influence of the standard deviation of the instantaneous CO_2 signal on the test result. Since non standard events, such as a DPF regeneration, will lead to an increase of the standard deviation of the CO_2 signal during the constant speed phases, the standard deviation could be used as measure to exclude specific tests from the evaluation. Experience from more tests should be gained before a final decision on this topic is made (setting of the limits and if limits are necessary at all).

With the resulting fuel consumption in the single phases of the MAC test the evaluation for the entire test result is as follows:

$$FC_{MAC_i} = 3.6 \times C_{COPi} \times (C_{Pe_i} \times FC_{i\,Measured-AC-on} - FC_{i\,Measured-AC-off})$$

With;

i........................speed step i (0 km/h, 50 km/h, 100 km/h)

FC_{MACi}..............additional fuel consumption of the MAC system [kg/h] in step i, including all correction factors

$FC_{iMeasured\text{-}AC\text{-}on}$...average fuel consumption measured at speed step i in the phase with AC on [g/s]

$FC_{iMeasured\text{-}AC\text{-}on}$...average fuel consumption measured at speed step i in the phase with AC off [g/s]

The correction factor C_{Pei} takes variability of the vehicle speed into consideration:

$$C_{Pe\,i} = \frac{P_{B_{AC-On\_Speed\_i}}}{P_{B_{AC-Off\_Speed\_i}}}$$

$P_{B_{AC-On\_Speed\_i}}$ ......average braking power of the rollers in speed step i with MAC-on (0 km/h, 50 km/h, 100 km/h)

$P_{B_{AC-Off\_Speed\_i}}$ ......average braking power of the rollers in speed step i with MAC-off (0 km/h, 50 km/h, 100 km/h)

The braking power of the rollers P_B should be calculated from the measured braking force F and the measured speed of the rollers v (P_B = v * F). Alternatively the power can be calculated according to the driving resistance polynomial used in the set up for the tested vehicle: $P_B = v * (R_0 + R_1 * v + R_2 * v^2)$. The average power is the average of the recorded instantaneous data for the entire evaluation phase of speed step i.

The correction factor C_{COPi} takes variability of the cooling capacity demand (CAP) into consideration which occurs due to the variability from the temperature in the cabin and in the test cell as well as from the humidity in the test cell:

$$C_{COPi} = C_{COPi-T1} \times C_{COPi-RH} \times C_{COPi-TC3}$$

With;

$C_{COPi-T1}$ ....Correction factor for variation of test cell temperature T_1 with T_{C3} and RH being exactly at the target values

$C_{COPi-RH}$ ......Correction factor for variation of test cell humidity RH with T_{C3} and T_1 being exactly at the target values

$C_{COPi-TC3}$ .....Correction factor for variation of cabin temperature T_{C3} with RH and RH being exactly at the target values

The correction factors for the possible variability in the boundary conditions are shown in Table 2. This table summarises the values calculated from the simplified model as described in the report. The corresponding correction factor shall be interpolated from the values given in Table 2.

Table 2: draft for look up table for correction factors for temperature and humidity deviations

t1 [°C]	**RH1 [%]**	**t3 [°C]**	**CCOPi_T1**	**CCOPi_RH**	**CCOPi_TC3**
25	50%	21	1.000	1.000	1.000
23.00	50%	21.00	1.285	1.000	1.000
24.00	50%	21.00	1.131	1.000	1.000
25.00	50%	21.00	1.000	1.000	1.000
26.00	50%	21.00	0.888	1.000	1.000
27.00	50%	21.00	0.793	1.000	1.000
28.00	50%	21.00	0.710	1.000	1.000
29.00	50%	21.00	0.637	1.000	1.000
30.00	50%	21.00	0.574	1.000	1.000
25.00	40%	21.00	1.000	1.242	1.000
25.00	45%	21.00	1.000	1.108	1.000
25.00	50%	21.00	1.000	1.000	1.000
25.00	55%	21.00	1.000	0.912	1.000
25.00	60%	21.00	1.000	0.838	1.000
25.00	65%	21.00	1.000	0.776	1.000
25.00	70%	21.00	1.000	0.722	1.000
25.00	50%	18.00	1.000	1.000	0.893
25.00	50%	20.00	1.000	1.000	0.962
25.00	50%	22.00	1.000	1.000	1.042
25.00	50%	24.00	1.000	1.000	1.136

The weighted total test result from the three test phases before correction of the influence of the glazing quality is then

$$FC_{MAC_T} = 0.15 \times FC_{MAC_{idling}} + 0.65 \times FC_{MAC50km/h+} + 0.20 \times FC_{MAC_{100km/h}}$$

Correction for the size and quality of glazing

The specific heat entrance into the vehicle cabin in W/m² due to the sun radiation shall be extrapolated from Table 3 as function of the T_{TS} value for the glazing quality and of the installation angle. For each plane the specific heat entrance shall be calculated separately. Table 3 relates the heat entrance from a detailed simulation to the T_{Ts} value for parking and for 0° angle between sun radiation and the plane (i.e. vertical position). The T_{TS} value shall be calculated according to ISO 13837 for each plane from its glazing data (T_{ds}, R_{ds} for 0° angle from the sun radiation on the glass and heat transfer rates for parking).

Table 3: draft for look up table for the specific heat entrance $\mathbf{q_{si}}$ in [W/m²] into the vehicle cabin due to sun radiation as function of the TTS value of the glazing quality and of the installation angle (look up table calibrated for 700 W/m² sun radiation)

		Mounting angle [°] against vertical									
		0	10	20	30	40	50	60	70	80	90
TTS [%]	20	97.1	105.5	109.9	110.2	105.8	99.4	94.1	89.3	87.1	86.7
	22	104.5	113.7	118.5	118.8	114.0	107.0	101.2	96.0	93.6	93.1
	24	111.9	121.9	127.1	127.5	122.3	114.7	108.3	102.7	100.0	99.5
	26	119.3	130.1	135.7	136.1	130.5	122.3	115.4	109.3	106.5	105.9
	28	126.7	138.3	144.3	144.8	138.7	129.9	122.5	116.0	112.9	112.3
	30	134.1	146.5	153.0	153.4	146.9	137.5	129.6	122.6	119.4	118.7
	32	141.5	154.8	161.6	162.0	155.2	145.1	136.8	129.3	125.8	125.1
	34	149.0	163.0	170.2	170.7	163.4	152.8	143.9	135.9	132.3	131.5
	36	156.4	171.2	178.8	179.3	171.6	160.4	151.0	142.6	138.7	137.9
	38	163.8	179.4	187.4	188.0	179.9	168.0	158.1	149.3	145.2	144.3
	40	171.2	187.6	196.0	196.6	188.1	175.6	165.2	155.9	151.6	150.7
	42	178.6	195.8	204.6	205.2	196.3	183.3	172.3	162.6	158.0	157.1
	44	186.0	204.0	213.2	213.9	204.6	190.9	179.4	169.2	164.5	163.5
	46	193.4	212.2	221.9	222.5	212.8	198.5	186.6	175.9	170.9	169.9
	48	200.8	220.4	230.5	231.2	221.0	206.1	193.7	182.6	177.4	176.3
	50	208.2	228.6	239.1	239.8	229.2	213.7	200.8	189.2	183.8	182.7
	52	215.6	236.8	247.7	248.4	237.5	221.4	207.9	195.9	190.3	189.1
	54	223.0	245.0	256.3	257.1	245.7	229.0	215.0	202.5	196.7	195.5
	56	230.4	253.2	264.9	265.7	253.9	236.6	222.1	209.2	203.2	201.9
	58	237.8	261.4	273.5	274.4	262.2	244.2	229.2	215.9	209.6	208.3
	60	245.2	269.6	282.1	283.0	270.4	251.9	236.4	222.5	216.1	214.7
	62	252.6	277.8	290.8	291.6	278.6	259.5	243.5	229.2	222.5	221.1
	64	260.0	286.0	299.4	300.3	286.8	267.1	250.6	235.8	229.0	227.5
	66	267.4	294.2	308.0	308.9	295.1	274.7	257.7	242.5	235.4	233.9
	68	274.8	302.4	316.6	317.6	303.3	282.3	264.8	249.1	241.9	240.3
	70	282.2	310.6	325.2	326.2	311.5	290.0	271.9	255.8	248.3	246.7
	72	289.6	318.8	333.8	334.8	319.8	297.6	279.0	262.5	254.8	253.1
	74	297.0	327.0	342.4	343.5	328.0	305.2	286.1	269.1	261.2	259.5
	76	304.4	335.2	351.1	352.1	336.2	312.8	293.3	275.8	267.6	265.9
	78	311.9	343.4	359.7	360.8	344.5	320.5	300.4	282.4	274.1	272.3
	80	319.3	351.7	368.3	369.4	352.7	328.1	307.5	289.1	280.5	278.7

The total heat entrance $\mathbf{Q_S}$ from all planes in W is then:

$$Q_S = \sum_{i=1}^{n} q_{Si} \times A_i$$

With i .... index for plane number

q_{Si} .... specific heat entrance for plane I in [W/m²] according to Table 3

A_i .... sectional area of plane I in [m²]

The influence of the heat entrance from sun radiation on the cooling capacity demand of the vehicle can be taken into considerations by two options. Option one is thought to be the more robust and simpler approach at the moment. However, if also option 2 will be used at least for some vehicles during the pilot phase we can select later on the best option from the experiences in the pilot phase.

Option 1:
Calculate the correction factor F_{TTS} for the test result on the additional fuel consumption from the MAC system (FC_{MAC})

$$F_{TTS} = 0.8 + Q_S \times 3.8 \times 10^{-4}$$

The F_{TTs} depictures the relative change of the additional fuel consumption from the MAC system due to heat entrance from sun radiation against the basic MAC step test. The relative change is normalized against an estate car with average glazing quality and a plane area of 2.24m². This does mean that a Q_S of 530W leads to no correction of the test result (FTTS = 1.0) while for example a Q_S of 1000W leads to +18% (FTTS = 1.18). This normalisation of the correction factor to an average estate takes into account, that the defined MAC mass flow in the MAC test (>230 kg/h) is representing the settings of an average car under average climate conditions, i.e. includes an average effect of sun radiation already.

Option 2:
The basic setting for the mass flow of >230 kg/h during the MAC test cycle is corrected for different values of heat entrance:

$$\dot{m}_S = 230 + [0.11 \times (Q_S - 530)] \quad \text{in [kg/h]}$$

The MAC test is then performed with $\dot{m}_S$ instead of the 230 kg/h. The correction of the mass flow also takes into consideration, that the 230 kg/h are defined for average conditions of an average car. Per Watt change in heat entrance the mass flow change is 0.11 kg/h. The heat entrance due to sun radiation for the average car is 530 W in this formula. Thus for a Q_S of 530 W the equation gives the basic mass flow of 230 kg/h

The final result of the entire MAC test procedure is then:

$$FC_{MAC} = FC_{MAC_T} \times F_{TTS} \quad \text{in [kg/h]}$$

The result can be converted into other units as follows

$$FC_{MAC\,l/100km} = \frac{FC_{MAC}}{52.5} \times 100 \times \frac{1}{\rho_i} \quad \text{in [l/100km]}$$

Where 52.5 represents the average speed of the test cycle in km/h

$$FC_{MAC\,l/100km} = FC_{MAC} \times 2.567 \quad \text{for gasoline with a density of 0.742 kg/l}$$

$$FC_{MAC\,l/100km} = FC_{MAC} \times 2.289 \quad \text{for diesel with a density of 0.832 kg/l}$$

Additional CO_2 emissions from the MAC system can be computed with the specific CO_2 emissions per litre fuel (e.g. 2.34 kg CO_2/litre for fossil gasoline and 2.623 kg CO_2/litre for fossil diesel). This results in:

$$CO_{2\,MAC} = FC_{MAC} \times 60 \quad \text{in [g/km] for fossil gasoline as well as for fossil diesel.}$$