

Effects on Real Life Fuel Efficiency of Raising the MAC Engagement Temperature

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ABSTRACT

The subject addressed by this work, currently discussed in Europe following an European Commission inquiry, is the evaluation of the possibility to prevent the MAC (Mobile Air Conditioning) use below 18 °C and its benefits in terms of CO₂ emissions saving. This strategy, while providing an uncertain fuel consumption saving, has to be faced with basic safety and cabin comfort conditions. The OEMs (Original Equipment Manufacturers) may evaluate to address these concerns by controlling the cabin absolute humidity content.

In order to maintain safety it should be acceptable to turn the AC on based on other inputs, such as air distribution modes (defrost or floor/defrost), windshield wiper usage, rear defroster usage, etc. FGA (FIAT Group Automobiles) exploited our proprietary prediction tool to assessing the yearly fuel efficiency that can be achieved in real use by means of the testing results of representative vehicles. Based on a model allowing to evaluate the actual vehicle fuel consumption in a NEDC (New European Driving Cycle) with operated MAC as a function of ambient enthalpy, the FGA results show a relevant benefit in operating the MAC system only at temperatures over 18 °C ambient.

The actual impact on the fuel consumption experienced by the customer might anyway be lower than the maximum declared one, as not all drivers are used to always operate their vehicle with the A/C ON. This may explain some OEMs' concern in assessing such high a consumption reduction benefit, which may drive the consumers to false money saving expectations.

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INTRODUCTION

In the framework of the activities ongoing to complying with the European commitments to complying with Kyoto Protocol targets¹, automotive GHGE (GreenHouse Gas Emissions) reductions potentials are currently the magnifying glass target. Several interesting techs benefits, actually really appreciable in the everyday use, are thus not featured in the test cycle.

Among those are included all the MAC system efficiency improvements. The MAC fuel overconsumption measurement, being influenced by several parameters, issues variable and hardly reproducible results and therefore its figures are often not shared as commonly understandable by car manufacturers. The two basic conditions to be addressed with this strategy are safety (windscreen fogging prevention)

and cabin comfort (a 22 °C cabin temperature has to be considered together with sun radiation contribution). One of those parameters which leads to an important uncertainty in the fuel overconsumption as a first operation of the MAC in variable conditions is the subjective comfort condition judgment by the user.

European OEMs are discussing about the measuring procedure to assessing the fuel efficiency - and the correspondent bonus on the homologation CO₂ emissions - that can be achieved by means of this "eco-innovation"², a technology that is not featuring any effect during the homologation test for CO₂ emissions, thus providing an actual fuel efficiency in the vehicle real life, where the MAC is operated.

Moreover the eligibility of MAC systems other than automatic A/C for the bonus is a hot subject of discussion:

¹Regulation (EC) No 443/2009 of the Eu Parliament and of the Council of 23 April 2009 setting emission perf stds for new passenger cars as part of the Community's integrated approach to reduce CO₂ emissions from LDV; http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

²a technology that is not featuring any effect during the homologation test for CO₂ emissions, thus providing an actual fuel efficiency in the vehicle real life (operated MAC)

while it's sure that vehicle equipped with a simple HTR system are eligible for the full credit, it's not yet fully agreed that also vehicle equipped with manual A/C systems may obtain the credits - thus not equipped with in car temperature-, solar- and humidity- sensors - thanks to the MAC driver's operation in order to guarantee a safe and comfortable environment.

A first ACEA (Association des Constructeurs Européens d'Automobiles) proposal was issued last spring regarding the EC (European Commission) inquiry about the procedure to use the AC only at ambient over 18 °C. This paper evaluates the potential fuel savings and demonstrates how it varies depending on the MAC operation threshold considered as baseline.

Further concerns presented by the OEMs are related to the testing facilities: as current dynamometric bench chambers are not equipped with a temperature and humidity control, the proposed new method would cause severe cost increase in homologation tests, not clearly explained by the fuel consumption savings to be demonstrated.

The Proposed Strategy

The vehicles exploiting MAC systems operated by means of an automatic electronic control unit may feature a logic operating the systems at an ambient temperature over 18 °C. The current safety basic algorithm which is generally embedded into the engine ECU (Electronic Control Unit) controls the minimum operating temperature allowing to prevent the evaporator icing and guaranteeing the compressor lubrication and refrigeration oil return. This logic, which is always present even in vehicles equipped with a manual AC system, is set in a $-1 \div 5$ °C temp. range in the FGA vehicles, depending on the considered model. Such a temperature threshold may not reflect the user comfort, thus requiring a manual intervention activating the system in certain conditions, i.e. colder season sun radiation or heavy air moisture content.

The achievable Fuel Efficiency is influenced by two basic conditions which have to be respected:

1. Safety (windscreen fogging prevention): fuel efficiency targets to be faced with a "safe" use of the MAC system to keep visibility for the driver,
2. Comfort: in the cabin a 22 °C avg temp. value is to be maintained - sun radiation contribution to be considered while absolute humidity content shall be controlled.

The Fuel Efficiency Estimation

FGA developed a prediction tool for the assessment of the indirect contribution due to the MACs operation. It is based on the measurement of the vehicle fuel consumption w/ and w/o operated MAC in certain ambient conditions according to the NEDC in a climatic wind tunnel with dynamometer loading. These measurements determine the fuel overconsumption related to MACs during vehicle operation in a laboratory environment. The main assumption on the

FGA model is that the MACs is operated when ambient conditions reflect Air Enthalpies equal or above 25 kJ/kg (i.e. 10 °C&70% r.H., 13 °C&50% r.H. and 16 °C&30%).

Therefore, in order to determine the fuel overconsumption in each region, the necessary data are the temperature, RH (Relative Humidity) and ambient pressure figures at the latitude of interest. The key assumptions and methodological considerations are summarized next:

1. Comfort is controlled by the vehicle automatic control system with a setting of 22 °C
2. The tested vehicle results, being the output result the fuel overconsumption due to the MAC operation, are considered representative for the comparison between the alternatives to be evaluated
3. Vehicle test results plotted with respect to air enthalpy and enthalpy distribution for the considered climate are used to estimate the consumed fuel and thus determine the emitted CO₂

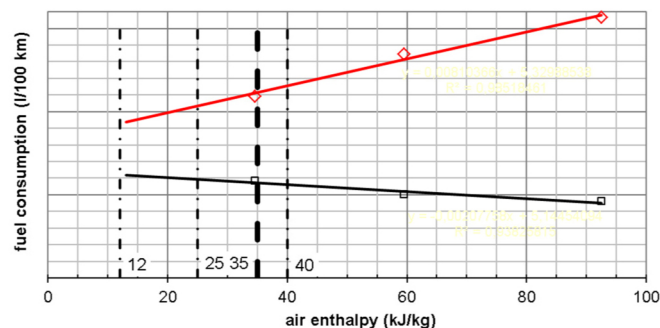


Figure 1. linear dependence of fuel consumption with respect to ambient air enthalpy using the absolute fuel consumption figures (black = MAC OFF, red = MAC ON) of a FIAT vehicle in the subcompact category

The graph in Fig. 1 shows the model's linear dependence of fuel consumption with respect to ambient air enthalpy. The following 3 MAC engagement conditions are shown:

1. 3 °C enthalpy range concentrated around 12 kJ/kg
2. 25 kJ/kg (for a reference purpose wrt previous studies)
3. 18 °C enthalpy range depending on location (the outlined 35 kJ/kg value corresponds to the lower enthalpy test condition, i.e. 15 °C&70% r.H.)

The model, firstly presented in 2007 [1], has further been exploited to assessing both direct - in the evaluation of the alternative low-GWP (Global Warming Potential) refrigerant gasses [2, 3, 4, 5, 6, 9, 10, 12, 14, 15, 18] - and indirect GHGE - in the innovative fuel efficiency systems assessment [7, 11, 13, 17, 19] prior to the concerned technical solution adoption in the FGA new vehicles development. A

comparison with the GREEN-MAC-LCCP© [8] model was also performed [16].

Thus featuring several limits in its reproducing the actual behavior of the MAC system as per its fuel consumption (no transients, no sun load, etc.), the model applied to the evaluation of the low-GWP refrigerant gasses for lower-intermediate segment cars reproduces the same overconsumption figures due to the MACS operation given available by several sources [20, 21, 22, 23, 24, 25].

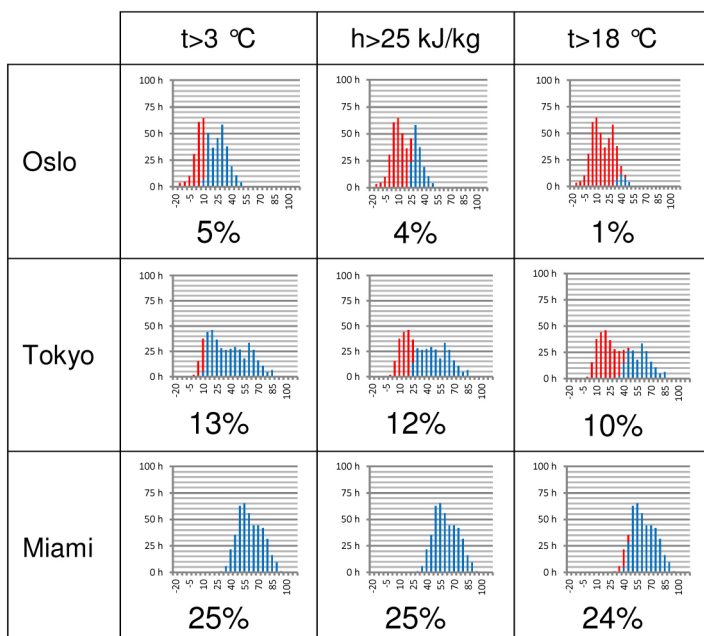
Table 1. Prediction of the Fuel Overconsumption due to the MAC operation in various ambient conditions for a subcompact vehicle equipped with small engines

Ambient Engine type	cold (Boston, Oslo, Sapporo)	intermediate (Rome, Sacramento, Tokyo)	extreme (Miami, Mumbai)
Small Diesel	3÷6%	9%	18÷21%
Small Petrol	5÷10%	14÷15%	30÷35%

MODEL ASSUMPTIONS

The FGA method for the assessment of the indirect contribution due to the MACs operation consists of determining the absolute fuel consumption of the MACs in certain ambient conditions by means of measurements according to the NEDC (any other cycle is suitable) in a climatic wind tunnel with dynamometer loading.

Table 2. Distribution of the enthalpy with MAC non operated (red columns) and operated (blue columns) according to the three strategies with corresponding Fuel Overconsumption



• Total time (hours/year) a vehicle travels, determined from the avg Eu fleet mileage (~15000 km/y) and the NEDC avg speed (~34 km/h)

• Daily hours of the vehicle operation: 8 a.m. and 6 p.m., i.e. home to travel commuting (365/365 for easiness)

• MAC engagement according to the evaluated strategy

Considering a 50/50% share among the two main conventional powertrains (petrol and gasoil), the three evaluated strategies feature the share in time w/ MAC operated and the overconsumption figures shown in table 2.

Some considerations about the water content of air and enthalpy are included in the Annex.

LCCP EVALUATION

The baseline MAC use considered as a reference for the fuel consumption comparison is the operation over 12 kJ/kg ambient enthalpy, i.e. 3 °C with 70% r.H., 4 °C w/ 60%, 5 °C w/ 50%, 6 °C w/ 40% and 7 °C w/ 30%.

It has been considered that a standard use of the MAC could be the one complying with the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) comfort condition: according to this standard, users would not need to operate their MACS below 25 kJ/kg ambient air enthalpy.

ASHRAE air enthalpy (kJ/kg)																						
temp (°C)	r.H. (%)																					
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%	
0	-4	4	4	3	3	3	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	
	-3	9	9	8	8	7	6	6	5	4	4	3	3	2	2	1	1	0	0	0	0	
	-2	14	14	13	12	11	10	9	8	7	6	5	4	3	3	2	1	1	0	0	0	
	-1	19	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
	0	24	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	
5	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	
	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	
	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	
	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	14	14	14	
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	49	49	49	50	50	51	51	52	52	53	53	54	54	55	55	56	56	57	58	59	59	
	50	50	50	51	51	52	52	53	53	54	54	55	55	56	56	57	57	58	59	60	60	

Figure 2. Air enthalpy as a function of temperature (rows) and relative humidity (columns). The 25 kJ/kg threshold corresponds to the yellow color.

The following parameters were chosen for this evaluation: