TUEV Nord Mobilitaet GmbH & Co.KG
Institute for Vehicle Technology and Mobility
Branch Noise, Measurement Technology, Modelling
Ginsterweg 5, D-52146 Wuerselen

Investigations for an Amendment of the EU Directive 93/116/EC (Measurement of Fuel Consumption and CO_2 Emission)

By order of the German Environmental Agency (UBA)

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Author: Heinz Steven

TUEV Nord Mobilitaet GmbH & Co.KG

Institute for Vehicle Technology and Mobility

Ginsterweg 5
D 52146 Wuerselen

Tel.: 0 24 05-45550
Fax: 0 24 05-455520
E-Mail: HSteven@tuev-nord.de

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TÜV Nord Mobilität GmbH & Co.KG · Am TÜV 1 · 30519 Hannover

Telefon 0511 986-2526
Fax 0511 986-1747
info@tuev-nord.de
www.tuev-nord.de

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Geschäftsführer : Dipl.-Ing. Volker Drube (Vorsitzender),
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16. Abstract

The measurement of fuel consumption and CO_2 emissions has become mandatory during the type approval procedure for M1 vehicles (cars) in the EU with the introduction of directive 93/116/EC. But the measurement method of the above mentioned directive is not suitable to consider influences of additional aggregates like air conditioning systems or the influence of new transmissions (6-speed gearboxes, advanced automatic gearboxes) allowing fuel consumption reducing gearshift strategies. Without these influences the CO_2 emissions of the car fleet cannot be calculated realistically enough. In order to get quantitative information about the variances of CO_2 emissions and fuel consumption as well as the limited pollutants the following influences should be considered within the frame of this project: different versions of a vehicle type, different gearshift strategies, Air conditioning system (AC).

Another task was related to information about the use of air conditioning system in cars. This task was performed together with IFEU, Institut für Energie- und Umweltforschung Heidelberg GmbH. IFEU developed a questionnaire about the use of the AC. This questionnaire was presented to customers at several stations of TUEV Nord, where annual inspections were performed. The questionnaires were then sent to IFEU for further analysis.

The results of this study clearly demonstrated that there are significant influences on the CO_2 emissions and the fuel consumption related to vehicle and gearshift variants in the order of 10% to 15%. Since it can be assumed that the vehicle manufacturer uses an optimised vehicle for the type approval procedure the CO_2 emissions of the same type in real traffic is higher. One can assume that the CO_2 emissions in real traffic are 15% to 20% higher than for the type approval cycle.

An optimised gearshift strategy (gearshifts at low engine speeds) results in a reduction of the CO_2 emissions in the order of 10%, but may lead to an increase of CO and NOx emissions. Campaigns like ECO driving should be supported as good measures for CO_2 reduction.

The results of the measurements performed with air conditioning systems in operation show quite clearly that their contribution to CO_2 emissions cannot be disregarded for type approval as well as for emission inventories.

Proposals for an adequate amendment of the EU Directive 93/116/EC are made.

17. Keywords

CO_2 emission, fuel consumption, proposals for amendments for EU-regulation, air conditioning systems, best case, worst case, gearshift prescriptions, driving behaviour

18.	19.	20.

Content Page

1 Introduction and tasks

The measurement of fuel consumption and CO_2 emissions has become mandatory during the type approval procedure for M1 vehicles (cars) in the EU with the introduction of directive 93/116/EC. Within the context of the discussions about the global warming of the atmosphere the lowering of the CO_2 emissions and thus the lowering of the fuel consumption has become an important target for the vehicle industry. But the measurement method of the above mentioned directive is not suitable to consider influences of additional aggregates like air conditioning systems or the influence of new transmissions (6-speed gearboxes, advanced automatic gearboxes) allowing fuel consumption reducing gearshift strategies. Without these influences the CO_2 emissions of the car fleet cannot be calculated realistically enough.

In order to get quantitative information about the variances of CO_2 emissions and fuel consumption as well as the limited pollutants the following influences should be considered within the frame of this project:

- Different versions of a vehicle type
- Different gearshift strategies
- Air conditioning system (AC)

Another task was related to information about the use of air conditioning system in cars. This task was performed together with IFEU, Institut für Energie- und Umweltforschung Heidelberg GmbH. IFEU developed a questionnaire about the use of the AC. This questionnaire was presented to customers at several stations of TUEV Nord, where inspections at regular intervals were performed. The questionnaires were then sent to IFEU for further analysis.

2 Test vehicles and measurement programme

The influences of vehicle version and gearshift strategy can be measured on ordinary test benches. But the influence of an air conditioning system requires a special test bench with solar radiation equipment if the worst case shall be included. Since TUEV Nord does not have such a test bench, it was originally planned that vehicle manufacturers would allow TUEV Nord to use their test benches for the measurements and that they support the project by additional funding in order to increase the number of test vehicles.

Unfortunately the vehicle industry refused to co-operate so that only four cars could be measured during this project. The technical specifications are shown in Table 1. All of them were equipped with an air conditioning system. Two of them (no. 3 and 4) were measured with the air conditioning systems working on a test bench with solar radiation at the Delphi facilities in Luxembourg.

veh. no	manufacturer	type	engine type	engine capacity in cm^3	rated power in kW	rated speed in min^{-1}	max. speed in km/h	emission stage
1	BMW	325i	petrol	2494	141	6000	> 200	EURO IV
2	Volkswagen	Golf IV TDI	Diesel	1896	74	4000	188	EURO III and D4
3	Ford	Fiesta	petrol	1299	44	5000	155	EURO IV
4	DaimlerChrysler	E 240T	petrol	2398	125	5900	215	D4

Table 1: Technical data of the test vehicles

The following driving cycles were included in the test bench measurements:

- The European type approval test cycle (NEDC), consisting of four urban cycles and an additional extra urban cycle (see **Figure 1**)
- The US type approval test cycle (US FTP 75, see Figure 2)
- The Common Artemis driving cycle (CADC), consisting of an urban, a rural and a motorway part (see Figure 3)

The CADC was created within the 5th framework project "Artemis" and was used for the development of emission factors for modelling purposes.

Since the measurements of the first vehicle were already started when the negotiations with the vehicle manufacturers were still ongoing the measurement programmes for the vehicles vary with respect to driving cycles and parameter variation.

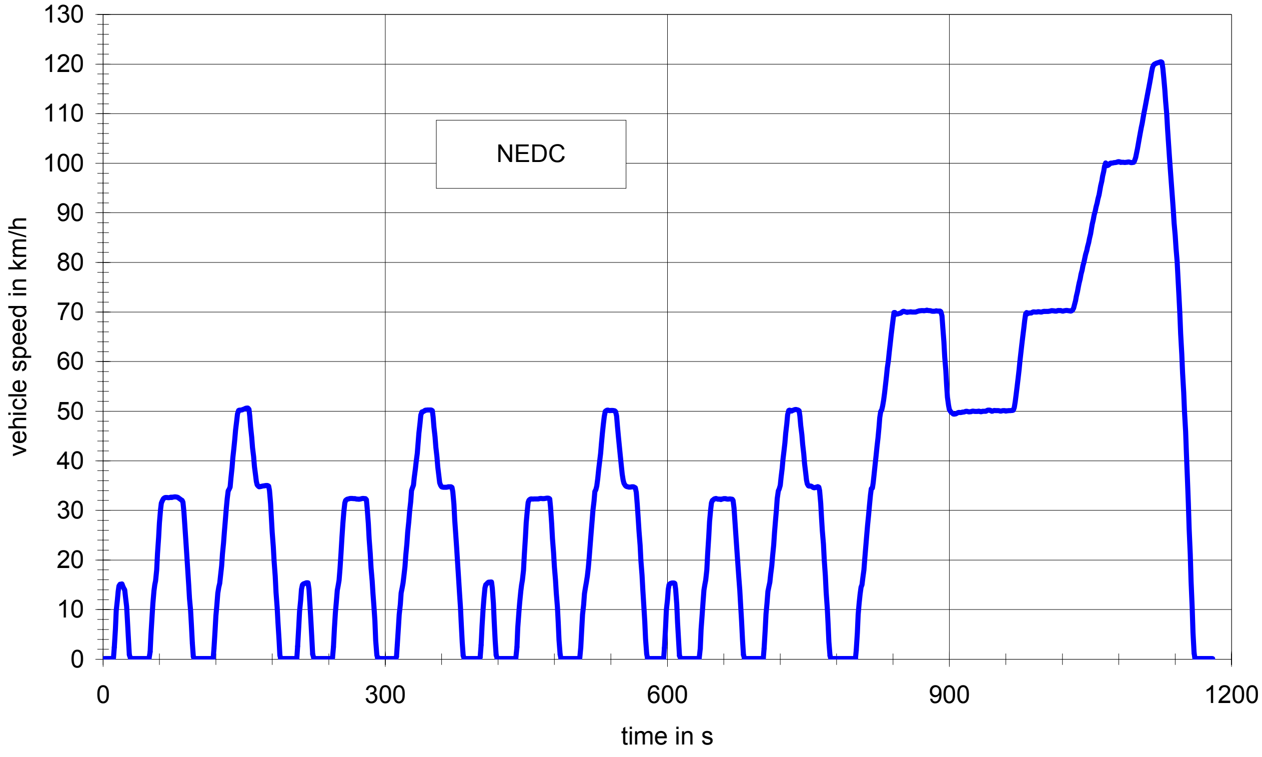


Figure 1: The European type approval test cycle (NEDC)

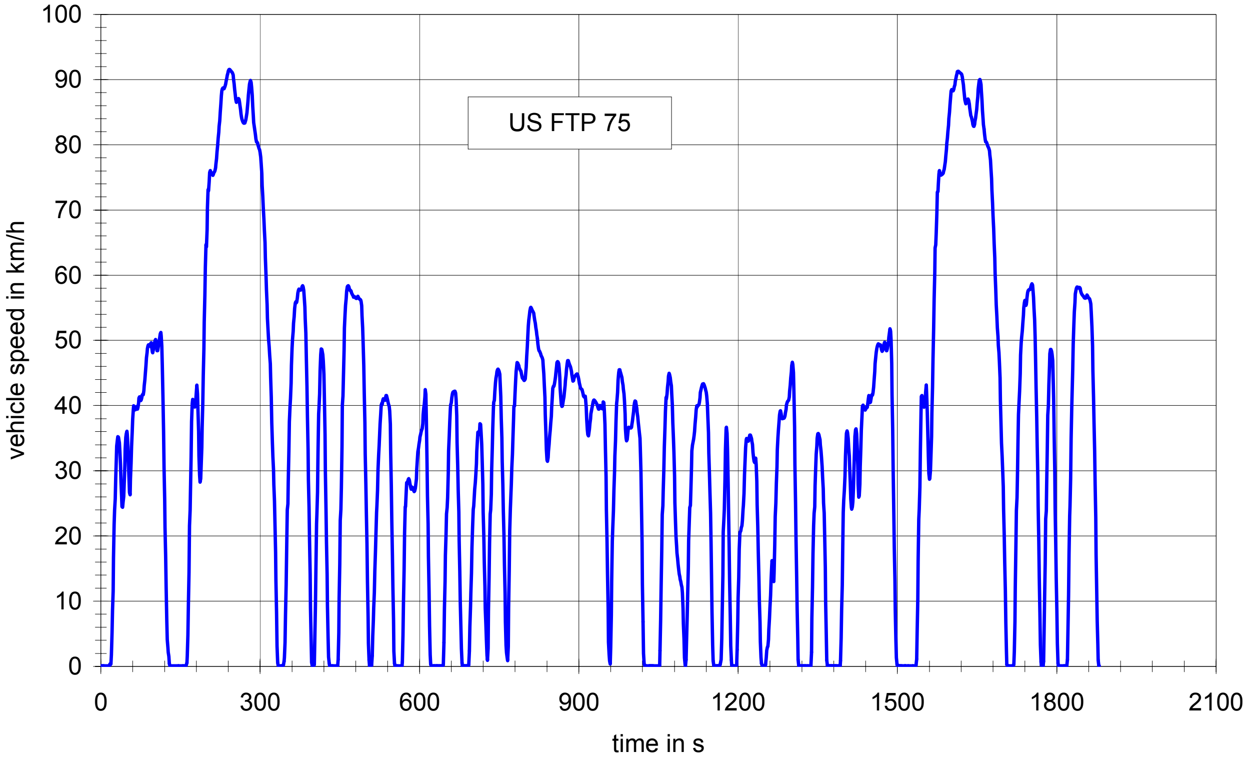


Figure 2: The US type approval test cycle (US FTP 75)

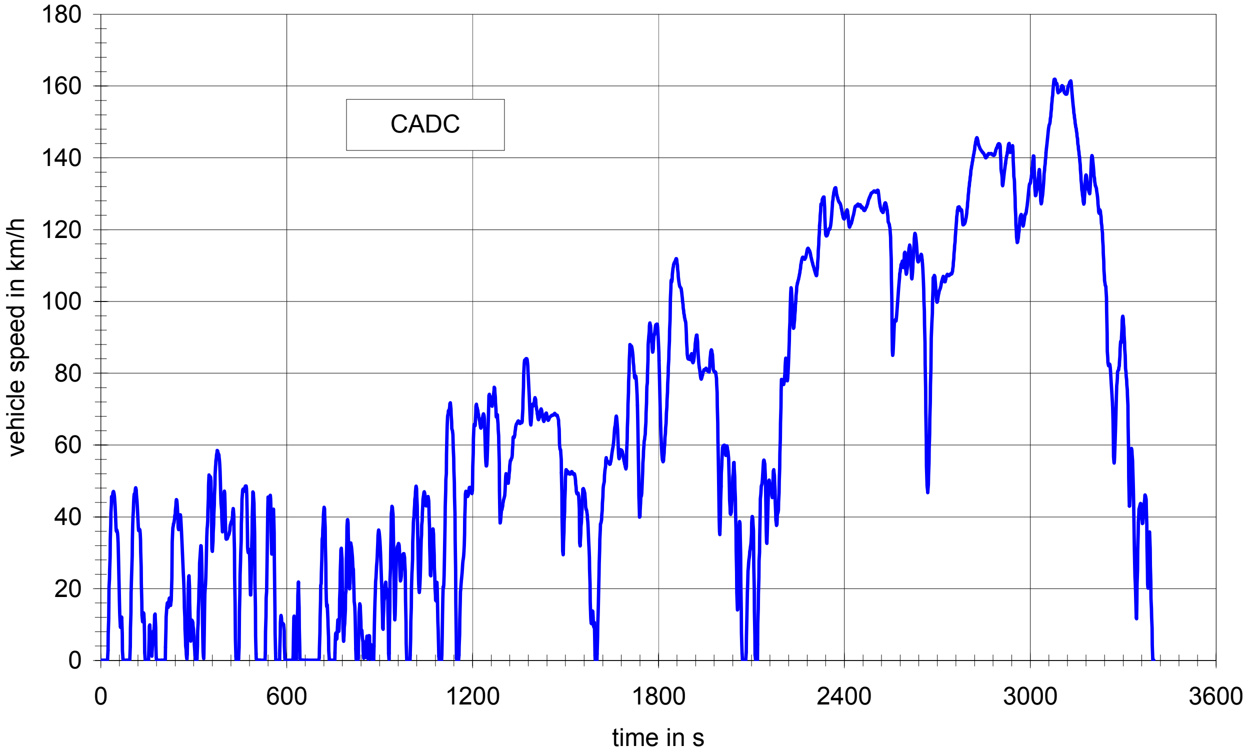


Figure 3: The Common Artemis driving cycle (CADC)

The following variants were measured for vehicle 1:

case	test mass in kg	tyre dimensions
base case	1590	205/55 R16
Best Case (Eco-Reifen)	1590	205/55 R16
Worst Case (wide tyres + aerodynamic kit)	1590	front 225/40 R 18, rear 255/35 R 18
Worst Case (wide tyres + aerodynamic kit)	1815	205/55 R16
Best Case with air conditioning system (delta T at start 6 °C)	1590	205/55 R16
Best Case with optimised gearshifts, driver 1	1590	205/55 R16
Best Case with optimised gearshifts, driver 2	1590	205/55 R16

Table 2: Variants of the test bench measurements of vehicle 1

The variants for the other vehicles are listed below:

- Vehicle 2
  - base case (cold start)
  - optimised gearshifts, driver 1
  - optimised gearshifts, driver 2
  - unpractised driver
  - 29 °C start temperature
  - hot start, with AC at full cooling capacity (Delta T at start 6 °C)
  - hot start, without AC
- Vehicle 3
  - base case (cold start)
  - hot start, with AC
  - hot start, without AC
  - optimised gearshifts
  - hot start, without AC at Delphi
  - hot start with AC and solar radiation of 850 W/m² at Delphi
- Vehicle 4
  - base case
  - best case
  - optimised gearshifts
  - unpractised driver
  - 29 °C start temperature
  - 30% battery capacity
  - engine oil minimum
  - hot start, with AC

- hot start, without AC
- hot start, without AC at Delphi
- hot start with AC and solar radiation of 850 W/m² at Delphi

The above mentioned variants were fully applied to the NEDC but only partly to the other cycles for time reasons. The US FTP 75 cycle was always driven with a cold start, the NEDC also, except hot start condition is mentioned. The CADC was always driven in hot condition except for the first vehicle, where cold start was also executed for the urban part of the cycle.

3 Results

3.1 Bag results

The bag results for the pollutants CO, HC, NOx, the CO_2 emissions and the fuel consumption are summarised in the following tables. The CO_2 emissions include the HC- and CO-contributions. The fuel consumption is calculated from the CO_2 emission as foreseen in 93/116/EC. The major part of the measurements was carried out two times. The test bench settings were adjusted to the results of coast down measurements on a test track.

The results for vehicle 1 are shown in Table 3 to Table 5. The measurement results for the base case (vehicle is almost identical to type approval conditions) and the NEDC for HC and NOx are far below the EURO IV limit values (see Table 3). Even the results for the other variants do not reach the limit values for both pollutants. The situation is a bit different for CO. The base case result is below the limit value, but for engine speed optimised gearshifts the CO emission exceeds the limit value and also the HC emissions are significantly higher, although this operation results in a CO_2 emission reduction of about 10%.

The best case (ECO tyres) shows only small differences to the base case for the NEDC, but the worst case has significantly higher NOx emissions and 6% higher CO_2 emissions. The air conditioning system set on max. cooling capacity led to an increase of CO_2 emissions of 7,4 % (9,1 % for the urban and 5,4 % for the extra urban part) compared to the corresponding variant without AC operation. It has to be mentioned that these measurements were carried out with cold start. For the other vehicles the comparison of measurement results with and without AC is based on hot start conditions.

There is a general tendency for the NEDC that HC and CO emissions decrease with increasing CO_2 emissions while NOX follows the CO_2 trend. And it must also be mentioned that the emissions of HC and NOx tend to zero for extra urban driving conditions. This is also the case for CO, but only for the NEDC.

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
1	BMW	NEDC	base case	0.8400	0.0398	0.0323	220.0	9.17	0.0%	0.0%	0.0%	0.0%
1	BMW		optimised gearshifts driver 1	1.2610	0.0670	0.0170	199.8	8.35	50.1%	68.6%	-47.3%	-9.2%
1	BMW		optimised gearshifts driver 2	1.6050	0.0850	0.0260	196.7	8.22	91.1%	113.8%	-19.4%	-10.6%
1	BMW		best case	0.8720	0.0455	0.0295	216.0	9.02	3.8%	14.5%	-8.5%	-1.8%
1	BMW		worst case	0.7990	0.0340	0.0375	228.6	9.55	-4.9%	-14.5%	16.3%	3.9%
1	BMW		worst case, SM, 1850 kg	0.8040	0.0350	0.0470	233.8	9.77	-4.3%	-11.9%	45.7%	6.3%
1	BMW		best case with AC	0.7735	0.0555	0.0370	231.9	9.69	-7.9%	39.6%	14.7%	5.4%
1	BMW	UDC	base case	2.2208	0.1283	0.0745	315.2	13.10	0.0%	0.0%	0.0%	0.0%
1	BMW		optimised gearshifts driver 1	3.3260	0.1790	0.0410	272.5	11.39	49.8%	39.6%	-45.0%	-13.5%
1	BMW		optimised gearshifts driver 2	4.2800	0.2290	0.0660	266.9	11.15	92.7%	78.6%	-11.4%	-15.3%
1	BMW		best case	2.3130	0.1650	0.0750	311.8	13.03	4.2%	28.7%	0.7%	-1.1%
1	BMW		worst case	2.1200	0.0920	0.0700	320.2	13.38	-4.5%	-28.3%	-6.0%	1.6%
1	BMW		worst case, SM, 1850 kg	2.0920	0.0940	0.1100	327.8	13.70	-5.8%	-26.7%	47.7%	4.0%
1	BMW		best case with AC	2.0295	0.1520	0.0930	340.3	14.22	-8.6%	18.5%	24.8%	8.0%
1	BMW	EUDC	base case	0.0435	0.0005	0.0078	165.0	6.90	0.0%	0.0%	0.0%	0.0%
1	BMW		optimised gearshifts driver 1	0.0550	0.0010	0.0030	157.2	6.57	26.4%	100.0%	-61.3%	-4.7%
1	BMW		optimised gearshifts driver 2	0.0540	0.0010	0.0020	156.0	6.52	24.1%	100.0%	-74.2%	-5.4%
1	BMW		best case	0.0435	0.0000	0.0035	160.9	6.72	0.0%	-100.0%	-54.8%	-2.5%
1	BMW		worst case	0.0365	0.0010	0.0185	175.7	7.34	-16.1%	100.0%	138.7%	6.5%
1	BMW		worst case, SM, 1850 kg	0.0560	0.0010	0.0110	179.3	7.49	28.7%	100.0%	41.9%	8.7%
1	BMW		best case with AC	0.0510	0.0000	0.0050	169.6	7.09	17.2%	-100.0%	-35.5%	2.8%
			limit values, EURO IV	**1.0000**	**0.1000**	**0.0800**						

Table 3: Measurement results for vehicle 1, NEDC

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to case without AC			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
1	BMW	FTP 75	best case	0.5852	0.0206	0.0308	228.6	9.55	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, with AC	0.5177	0.0325	0.0431	241.0	10.07	-11.5%	57.6%	40.1%	5.4%
1	BMW		worst case	0.6177	0.0231	0.0372	239.0	9.99	0.0%	0.0%	0.0%	0.0%
1	BMW		worst case, with AC	0.4191	0.0269	0.0462	249.9	10.44	-32.2%	16.2%	24.4%	4.5%
1	BMW	part 1	best case	1.1054	0.0656	0.0751	232.4	9.71	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, with AC	1.1185	0.0981	0.1037	247.0	10.32	1.2%	49.5%	38.0%	6.2%
1	BMW		worst case	1.1691	0.0674	0.0906	246.2	10.29	0.0%	0.0%	0.0%	0.0%
1	BMW		worst case, with AC	0.8231	0.0806	0.1162	255.4	10.67	-29.6%	19.4%	28.3%	3.7%
1	BMW	part 2	best case	0.3088	0.0012	0.0112	250.5	10.47	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, with AC	0.2423	0.0012	0.0187	262.4	10.96	-21.5%	0.0%	66.7%	4.8%
1	BMW		worst case	0.3594	0.0016	0.0125	257.4	10.75	0.0%	0.0%	0.0%	0.0%
1	BMW		worst case, with AC	0.1836	0.0006	0.0181	270.5	11.30	-48.9%	-60.0%	45.0%	5.1%
1	BMW	part 3	best case	0.3607	0.0037	0.0071	201.5	8.42	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, with AC	0.2136	0.0012	0.0087	212.0	8.86	-40.8%	-66.7%	22.5%	5.2%
1	BMW		worst case	0.3438	0.0016	0.0109	212.2	8.86	0.0%	0.0%	0.0%	0.0%
1	BMW		worst case, with AC	0.2661	0.0019	0.0069	222.1	9.28	-22.6%	20.0%	-37.1%	4.7%

Table 4: Measurement results for vehicle 1, US FTP 75

The results for the US FTP 75 cycle show similar differences with and without AC as the NEDC results. Due to the higher speed range and dynamics the CADC cycle results show generally higher emission levels and variances between the variants than the other two cycles. The HC and NOx emissions are still low compared to the EURO IV limit values. But the CO emissions are high, even in hot conditions. For the urban part with cold start the CO emissions are between 1,2 and 3,7 g/km with the opposite rank order as for the CO_2 emission (lowest CO emission in case of highest CO_2 emission and vice versa). If the AC operation variant is disregarded, the two extremes are formed by the different gearshift prescriptions: optimised gearshifts leading to the lowest CO_2 emission and gearshifts at 4000 min^{-1} leading to the highest CO_2 emission.

The total gearshift related differences for the CO_2 emission are about 25% for urban and rural operation. For motorway operation the gearshift related differences are below 2%, which can be expected because motorway operation is predominantly carried out in the highest gear.

On the other hand, the vehicle related differences (worst case versus best case) increase with increasing speed. For urban operation the CO_2 emission difference is only 1,3 % growing to 7,2 % for rural and 11 % for motorway operation. This tendency can also be found in the NEDC results.

The differences between the best case with and without AC operation are significantly higher for CO_2 emissions than for the other cycles. They decrease with increasing speed (13,7 % for urban hot, 9,9 % for rural and 5,2 % for motorway operation. For the pollutant emissions there is no general tendency, but one can state that there is no influence of the AC on HC and NOx emissions.

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to best case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
1	BMW	urban, hot	best case	0.7650	0.0060	0.0360	344.9	14.41	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, gearshifts at 4000 min	0.6310	0.0000	0.0740	366.4	14.41	-17.5%	-100.0%	105.6%	6.3%
1	BMW		optimised gearshifts driver 2	0.8010	0.0130	0.0330	287.4	11.30	4.7%	116.7%	-8.3%	-16.7%
1	BMW		worst case	0.7780	0.0090	0.0190	349.2	14.59	1.7%	50.0%	-47.2%	1.3%
1	BMW		best case, with AC	1.0820	0.0310	0.0520	392.1	16.38	41.4%	416.7%	44.4%	13.7%
1	BMW	rural	best case	0.3640	0.0005	0.0215	180.6	7.54	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, gearshifts at 4000 min	0.3780	0.0000	0.0160	199.2	7.83	3.8%		-25.6%	10.3%
1	BMW		optimised gearshifts driver 2	0.2750	0.0010	0.0060	149.8	5.89	-24.5%		-72.1%	-17.0%
1	BMW		worst case	0.4280	0.0010	0.0130	193.6	8.09	17.6%		-39.5%	7.2%
1	BMW		best case, with AC	0.3330	0.0000	0.0190	198.5	8.29	-8.5%		-11.6%	9.9%
1	BMW	motor-way	best case	0.4830	0.0020	0.0070	193.2	8.07	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, gearshifts at 4000 min	0.6710	0.0000	0.0050	192.6	7.58	38.9%		-28.6%	-0.3%
1	BMW		optimised gearshifts driver 2	0.5200	0.0010	0.0040	189.0	7.43	7.7%		-42.9%	-2.2%
1	BMW		worst case	0.4320	0.0010	0.0080	214.5	8.96	-10.6%		14.3%	11.0%
1	BMW		best case, with AC	0.4470	0.0070	0.0070	203.3	8.50	-7.5%		0.0%	5.2%
1	BMW	urban, cold	best case	1.6615	0.0175	0.0185	373.8	15.62	0.0%	0.0%	0.0%	0.0%
1	BMW		best case, gearshifts at 4000 min	1.2720	0.0130	0.0230	405.3	15.94	-23.4%	-25.7%	24.3%	8.4%
1	BMW		optimised gearshifts driver 2	3.7050	0.0550	0.0440	321.9	12.66	123.0%	214.3%	137.8%	-13.9%
1	BMW		worst case	2.0840	0.0150	0.0370	385.8	16.1	25.4%	-14.3%	100.0%	3.2%
1	BMW		best case, with AC	1.7130	0.0000	0.0460	422.2	17.64	3.1%	-100.0%	148.6%	12.9%

Table 5: Measurement results for vehicle 1, CADC

The results for vehicle 2 are shown in Table 6 to Table 8. This vehicle is equipped with a Diesel engine. The NEDC results for the base case are below the EURO IV limit values (see Table 6). For CO and particulates the measured values for the NEDC are below the limit values for all variants. The sum of HC and NOx exceeds the limit value only for three variants. One is with AC operation and the others are related to optimised gearshift strategy, which leads on the other hand to about 10% lower CO_2 emissions compared to the base case. Also a start temperature of 29 °C led to a slight reduction of CO_2 emissions (4,2% for the NEDC and 2,5% for the US FTP 75).

In general Co and HC emissions are close to zero, also for the other test cycles. For this vehicle it was also tried to investigate the drivers influence by additional measurements with untrained or inexperienced drivers. But the differences are not significant for all cycles.

Operation with and without AC was only measured for the NEDC. The difference in CO_2 emission (22%) is higher than for vehicle 1. AC operation leads also to an increase in NOx and particulate emissions (28% for NOx and 10% for particulates).

For the base case the differences in the CO_2 emissions between the cycles are as follows: +3% for the US FTP 75 and +6% for the CADC compared to the NEDC. The differences for NOx are much higher: +28% for the US FTP 75 and +229% for the CADC. The NOx emissions of the CADC cycle are in all parts, even the urban hot part, higher than for the NEDC. The reduction strategy for NOx seems to be optimised for the type approval test cycle.

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	HC + NOx	CO2	fuel consumption	particulates	Difference to base case				
				g/km	g/km	g/km	g/km	g/km	l/100 km	g/km	CO	HC	NOx	part	CO2
2	Golf TDI	NEDC	29 °C start temperature	0.0490	0.0075	0.2535	0.2610	133.0	4.99	0.0160	-43.0%	66.7%	0.8%	-3.0%	-4.2%
2	Golf TDI	NEDC	base case	0.0860	0.0045	0.2515	0.2560	138.8	5.21	0.0165	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI	NEDC	optimised gearshifts, driver 1	0.0330	0.0050	0.3035	0.3085	122.7	4.60	0.0175	-61.6%	11.1%	20.7%	6.1%	-11.7%
2	Golf TDI	NEDC	hot start, with AC	0.0100	0.0000	0.3670	0.3670	160.4	6.02	0.0220	-88.4%	-100.0%	45.9%	33.3%	15.6%
2	Golf TDI	NEDC	hot start, without AC	0.0040	0.0000	0.2870	0.2870	131.5	4.94	0.0200	-95.3%	-100.0%	14.1%	21.2%	-5.3%
2	Golf TDI	NEDC	optimised gearshifts, driver 2	0.0500	0.0080	0.3190	0.3270	126.3	4.74	0.0175	-41.9%	77.8%	26.8%	6.1%	-9.0%
2	Golf TDI	NEDC	unpractised driver	0.0735	0.0080	0.2850	0.2930	136.3	5.12	0.0165	-14.5%	77.8%	13.3%	0.0%	-1.8%
2	Golf TDI	UDC	29 °C start temperature	0.1325	0.0185	0.2675	0.2860	166.6	6.25	0.0200	-42.8%	42.3%	-0.2%	-81.8%	-6.6%
2	Golf TDI	UDC	base case	0.2315	0.0130	0.2680	0.2810	178.3	6.69	0.1100	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI	UDC	optimised gearshifts, driver 1	0.0850	0.0120	0.3380	0.3500	142.9	5.37	0.0215	-63.3%	-7.7%	26.1%	-80.5%	-19.8%
2	Golf TDI	UDC	hot start, with AC	0.0080	0.0000	0.4320	0.4320	210.8	7.92	0.0270	-96.5%	-100.0%	61.2%	-75.5%	18.3%
2	Golf TDI	UDC	hot start, without AC	0.0100	0.0000	0.3390	0.3390	161.0	6.04	0.0260	-95.7%	-100.0%	26.5%	-76.4%	-9.7%
2	Golf TDI	UDC	optimised gearshifts, driver 2	0.1150	0.0175	0.3615	0.3790	149.9	5.63	0.0205	-50.3%	34.6%	34.9%	-81.4%	-15.9%
2	Golf TDI	UDC	unpractised driver	0.1865	0.0190	0.3305	0.3495	174.1	6.53	0.0210	-19.4%	46.2%	23.3%	-80.9%	-2.4%
2	Golf TDI	EUDC	29 °C start temperature	0.0000	0.0010	0.2455	0.2465	113.1	4.25	0.0135			1.7%	-3.6%	-2.1%
2	Golf TDI	EUDC	base case	0.0000	0.0000	0.2415	0.2415	115.6	4.34	0.0140			0.0%	0.0%	0.0%
2	Golf TDI	EUDC	optimised gearshifts, driver 1	0.0010	0.0010	0.2830	0.2840	110.5	4.15	0.0145			17.2%	3.6%	-4.5%
2	Golf TDI	EUDC	hot start, with AC	0.0120	0.0000	0.3280	0.3280	130.5	4.90	0.0190	no emission	no emission	35.8%	35.7%	12.9%
2	Golf TDI	EUDC	hot start, without AC	0.0000	0.0000	0.2570	0.2570	114.1	4.28	0.0170			6.4%	21.4%	-1.3%
2	Golf TDI	EUDC	optimised gearshifts, driver 2	0.0115	0.0030	0.2935	0.2965	112.3	4.21	0.0155			21.5%	10.7%	-2.9%
2	Golf TDI	EUDC	unpractised driver	0.0055	0.0010	0.2580	0.2590	113.8	4.27	0.0135			6.8%	-3.6%	-1.5%
			limit values, EURO IV	**0.5000**			**0.3000**			**0.0250**					

Table 6: Measurement results for vehicle 2, NEDC

IDveh	vehicle	subcycle	mode	CO	HC	NOx	HC + NOx	CO2	fuel consumption	particulates	Difference to base case				
				g/km	g/km	g/km	g/km	g/km	l/100 km	g/km	CO	HC	NOx	part	CO2
2	Golf TDI	FTP 75	29 °C start temperature	0.0124	0.0050	0.3268	0.3318	139.9	3.24	0.0155	-35.5%	-11.1%	1.3%	-3.8%	-2.5%
2	Golf TDI	FTP 75	base case	0.0193	0.0056	0.3225	0.3281	143.5	3.32	0.0162	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI	FTP 75	best case	0.0019	0.0019	0.3722	0.3741	125.0	2.89	0.0174	-90.3%	-66.7%	15.4%	7.7%	-12.9%
2	Golf TDI	FTP 75	optimised gearshifts	0.0267	0.0019	0.3629	0.3647	125.1	2.90	0.0180	38.7%	-66.7%	12.5%	11.5%	-12.8%
2	Golf TDI	FTP 75	unpractised driver	0.0236	0.0012	0.3815	0.3828	142.3	3.29	0.0174	22.6%	-77.8%	18.3%	7.7%	-0.8%
2	Golf TDI	phase 1	29 °C start temperature	0.0137	0.0068	0.3256	0.3324	141.1	3.27	0.0168	-76.8%	-8.3%	3.1%	12.5%	-4.0%
2	Golf TDI	phase 1	base case	0.0590	0.0075	0.3157	0.3231	147.0	3.40	0.0149	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI	phase 1	best case	0.0037	0.0062	0.3797	0.3859	129.6	3.00	0.0137	-93.7%	-16.7%	20.3%	-8.3%	-11.8%
2	Golf TDI	phase 1	optimised gearshifts	0.0826	0.0050	0.4126	0.4176	132.3	3.06	0.0168	40.0%	-33.3%	30.7%	12.5%	-10.0%
2	Golf TDI	phase 1	unpractised driver	0.0609	0.0031	0.3983	0.4014	146.5	3.39	0.0205	3.2%	-58.3%	26.2%	37.5%	-0.3%
2	Golf TDI	phase 2	29 °C start temperature	0.0236	0.0043	0.2964	0.3007	147.0	3.40	0.0162			0.4%	-3.7%	-1.8%
2	Golf TDI	phase 2	base case	0.0000	0.0056	0.2952	0.3007	149.8	3.47	0.0168	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI	phase 2	best case	0.0025	0.0000	0.3492	0.3492	123.3	2.85	0.0193			18.3%	14.8%	-17.7%
2	Golf TDI	phase 2	optimised gearshifts	0.0000	0.0000	0.2914	0.2914	124.2	2.87	0.0193			-1.3%	14.8%	-17.1%
2	Golf TDI	phase 2	unpractised driver	0.0112	0.0000	0.3436	0.3436	147.6	3.42	0.0149			16.4%	-11.1%	-1.4%
2	Golf TDI	phase 3	29 °C start temperature	0.0000	0.0037	0.3604	0.3641	130.9	3.03	0.0143			0.3%	-14.8%	-1.8%
2	Golf TDI	phase 3	base case	0.0000	0.0031	0.3592	0.3623	133.2	3.08	0.0168	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI	phase 3	best case	0.0000	0.0000	0.3896	0.3896	122.1	2.83	0.0186			8.5%	11.1%	-8.3%
2	Golf TDI	phase 3	optimised gearshifts	0.0000	0.0012	0.3908	0.3921	118.9	2.75	0.0174			8.8%	3.7%	-10.7%
2	Golf TDI	phase 3	unpractised driver	0.0000	0.0000	0.4058	0.4058	132.4	3.06	0.0174			13.0%	3.7%	-0.6%

Table 7: Measurement results for vehicle 2, US FTP 75

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	HC + NOx	CO2	fuel consump-tion	particu-lates	Difference to base case				
				g/km	g/km	g/km	g/km	g/km	l/100 km	g/km	CO	HC	NOx	part	CO2
2	Golf TDI	CADC	base case	0.0098	0.0007	0.8276	0.8283	147.7	5.54	0.0404	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI		optimised gearshifts	0.0158	0.0000	0.8516	0.8516	142.0	5.33	0.0233			2.9%	-42.2%	-3.8%
2	Golf TDI		unpractised driver	0.0348	0.0035	0.8423	0.8458	146.5	5.50	0.0216			1.8%	-46.4%	-0.8%
2	Golf TDI	urban, hot	base case	0.0000	0.0000	0.6000	0.6000	194.0	7.28	0.0320	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI		optimised gearshifts	0.0250	0.0000	0.6460	0.6460	169.5	6.36	0.0240			7.7%	-25.0%	-12.6%
2	Golf TDI		unpractised driver	0.2080	0.0030	0.6610	0.6640	185.2	6.95	0.0300			10.2%	-6.3%	-4.6%
2	Golf TDI	rural	base case	0.0430	0.0000	0.3690	0.3690	115.7	4.34	0.0160	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI		optimised gearshifts	0.0000	0.0000	0.4240	0.4240	105.2	3.95	0.0180			14.9%	12.5%	-9.0%
2	Golf TDI		unpractised driver	0.0000	0.0020	0.4130	0.4150	113.9	4.28	0.0150			11.9%	-6.3%	-1.5%
2	Golf TDI	motor-way	base case	0.0000	0.0010	0.9960	0.9970	153.6	5.77	0.0490	0.0%	0.0%	0.0%	0.0%	0.0%
2	Golf TDI		optimised gearshifts	0.0200	0.0000	1.0080	1.0080	151.3	5.68	0.0250			1.2%	-49.0%	-1.5%
2	Golf TDI		unpractised driver	0.0300	0.0040	0.9970	1.0010	153.3	5.76	0.0230			0.1%	-53.1%	-0.2%

Table 8: Measurement results for vehicle 2, CADC

Vehicle 3 was the smallest vehicle of the sample. It was equipped with a simple air conditioning system that was controlled by on and off operation. The other vehicles had more advanced systems with variable compressor capacity. The results for vehicle 3 are shown in Table 9 to Table 11.

The NEDC test results for all variants are below the limit values except for the case with AC operation and solar radiation.

Optimised gearshift strategy led to a reduction of the CO_2 emissions of about 10% for the NEDC and the US FTP 75, while there is nearly no difference for the CADC compared to the base case. The surprising result for the CADC is caused by the fact that an increase of CO_2 emissions was measured for motorway operation (+2,3%), but reductions for urban and rural operation (-6,7% for urban and -10,1% for rural). For the CADC cycle the optimised gearshifts led also to an increase in NOx emissions.

The NEDC was driven with and without AC operation at the TUEV Nord test bench with a start temperature of 23 °C and the AC set to full cooling capacity. Already this operation led to significant differences in the emissions. With AC the CO_2 emissions were 37,4% higher. The CO emission was increased by 141%, the NOx emissions were 10,9 times higher than without AC. The differences with and without AC were much more drastic for the tests with solar radiation. In this case the room temperature was set to 35 °C and the solar radiation was 850 W/m². This operation led to extremely high emissions (+53% for CO_2, 9,5 times higher value for HC, 63 times higher value for NOx and 193 times higher value for CO). The NOx emission with solar radiation and a starting temperature of 35 °C was 0,45 g/km instead of 0,08 g/km, the CO emission 9,9 g/km instead of 0,12 g/km. This leads to the conclusion that the catalyst was out of operation during this test.

The test with solar radiation was also performed for the CADC. The differences to the base case are comparable to the NEDC if one takes into account the differences in speed and dynamics between the cycles. The differences between the cases with and without AC and solar radiation are highest for the urban part and lowest for the motorway part. It should be mentioned that this vehicle could not reach the maximum speed of the CADC. With AC and solar radiation the maximum speed was even more reduced (see Figure 4).

Another phenomenon is the CO emission for the CADC compared with the base case. It amounts 0,1 g/km for the urban part and reaches 1,5 g/km for the rural and 7,6 g/km for the motorway part.

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
3	Fiesta	NEDC	base case	0.2710	0.0400	0.0310	159.3	6.69	0.0%	0.0%	0.0%	0.0%
3	Fiesta		hot start, with AC	0.1230	0.0070	0.0830	202.8	8.52	-54.6%	-82.5%	167.7%	27.3%
3	Fiesta		hot start, without AC	0.0510	0.0110	0.0070	147.7	6.20	-81.2%	-72.5%	-77.4%	-7.3%
3	Fiesta		optimised gearshifts	0.2725	0.0445	0.0310	144.6	6.08	0.6%	11.3%	0.0%	-9.2%
3	Fiesta		Solartest with AC and radiation	9.9070	0.1155	0.4499	226.1	9.60	3555.7%	188.6%	1351.3%	41.9%
3	Fiesta	UDC	base case	0.5970	0.0895	0.0670	205.5	8.63	0.0%	0.0%	0.0%	0.0%
3	Fiesta		hot start, with AC	0.1880	0.0120	0.1640	273.6	11.49	-68.5%	-86.6%	144.8%	33.1%
3	Fiesta		hot start, without AC	0.0750	0.0260	0.0080	180.9	7.60	-87.4%	-70.9%	-88.1%	-12.0%
3	Fiesta		optimised gearshifts	0.6805	0.1120	0.0710	171.9	7.22	14.0%	25.1%	6.0%	-16.3%
3	Fiesta		Solartest with AC and radiation	17.9860	0.1895	0.5040	313.2	13.30	2912.7%	111.7%	652.2%	52.4%
3	Fiesta	EUDC	base case	0.0795	0.0010	0.0090	132.1	5.55	0.0%	0.0%	0.0%	0.0%
3	Fiesta		hot start, with AC	0.0850	0.0040	0.0360	161.1	6.77	6.9%	300.0%	300.0%	22.0%
3	Fiesta		hot start, without AC	0.0370	0.0030	0.0060	128.1	5.38	-53.5%	200.0%	-33.3%	-3.0%
3	Fiesta		optimised gearshifts	0.0370	0.0055	0.0080	128.9	5.41	-53.5%	450.0%	-11.1%	-2.4%
3	Fiesta		Solartest with AC and radiation	5.1765	0.0725	0.4190	175.1	7.43	6411.3%	7150.0%	4555.6%	32.6%
			limit values, EURO IV	**1.0000**	**0.1000**	**0.0800**						

Table 9: Measurement results for vehicle 3, NEDC

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
3	Fiesta	FTP 75	base case	0.3629	0.0367	0.0889	163.1	4.32	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	0.4803	0.0516	0.0814	146.0	3.86	32.4%	40.7%	-8.4%	-10.5%
3	Fiesta	phase 1	base case	0.9700	0.1031	0.1746	169.3	4.48	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	1.3409	0.1516	0.1578	154.0	4.07	38.2%	47.0%	-9.6%	-9.1%
3	Fiesta	phase 2	base case	0.0590	0.0019	0.0118	169.3	4.48	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	0.0659	0.0012	0.0398	143.4	3.79	11.6%	-33.3%	236.8%	-15.3%
3	Fiesta	phase 3	base case	0.0826	0.0075	0.0870	150.3	3.97	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	0.0646	0.0050	0.0497	140.7	3.72	-21.8%	-33.3%	-42.9%	-6.4%

Table 10: Measurement results for vehicle 3, US FTP 75

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
3	Fiesta	CADC	base case	5.8359	0.0193	0.0332	174.6	7.33	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	6.7776	0.0198	0.0754	173.3	7.28	16.1%	2.3%	127.1%	-0.8%
3	Fiesta		Solartest with AC and radiation	12.2140	0.0865	0.3445	224.2	9.52	109.3%	347.1%	937.8%	28.4%
3	Fiesta	urban	base case	0.0970	0.0050	0.0850	221.2	9.29	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	0.1670	0.0080	0.1440	206.5	8.67	72.2%	60.0%	69.4%	-6.7%
3	Fiesta		Solartest with AC and radiation	11.9015	0.1450	0.5675	354.8	15.07	12169.6%	2800.0%	567.6%	60.4%
3	Fiesta	rural	base case	1.5120	0.0090	0.0220	145.7	6.12	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	0.8020	0.0070	0.0600	131.1	5.51	-47.0%	-22.2%	172.7%	-10.1%
3	Fiesta		Solartest with AC and radiation	9.6975	0.0800	0.4275	206.0	8.75	541.4%	788.9%	1843.2%	41.3%
3	Fiesta	motor-way	base case	7.7560	0.0240	0.0320	179.6	7.54	0.0%	0.0%	0.0%	0.0%
3	Fiesta		optimised gearshifts	9.3090	0.0250	0.0740	183.7	7.72	20.0%	4.2%	131.3%	2.3%
3	Fiesta		Solartest with AC and radiation	13.3840	0.0825	0.2790	215.9	9.17	72.6%	243.8%	771.9%	20.2%

Table 11: Measurement results for vehicle 3, CADC

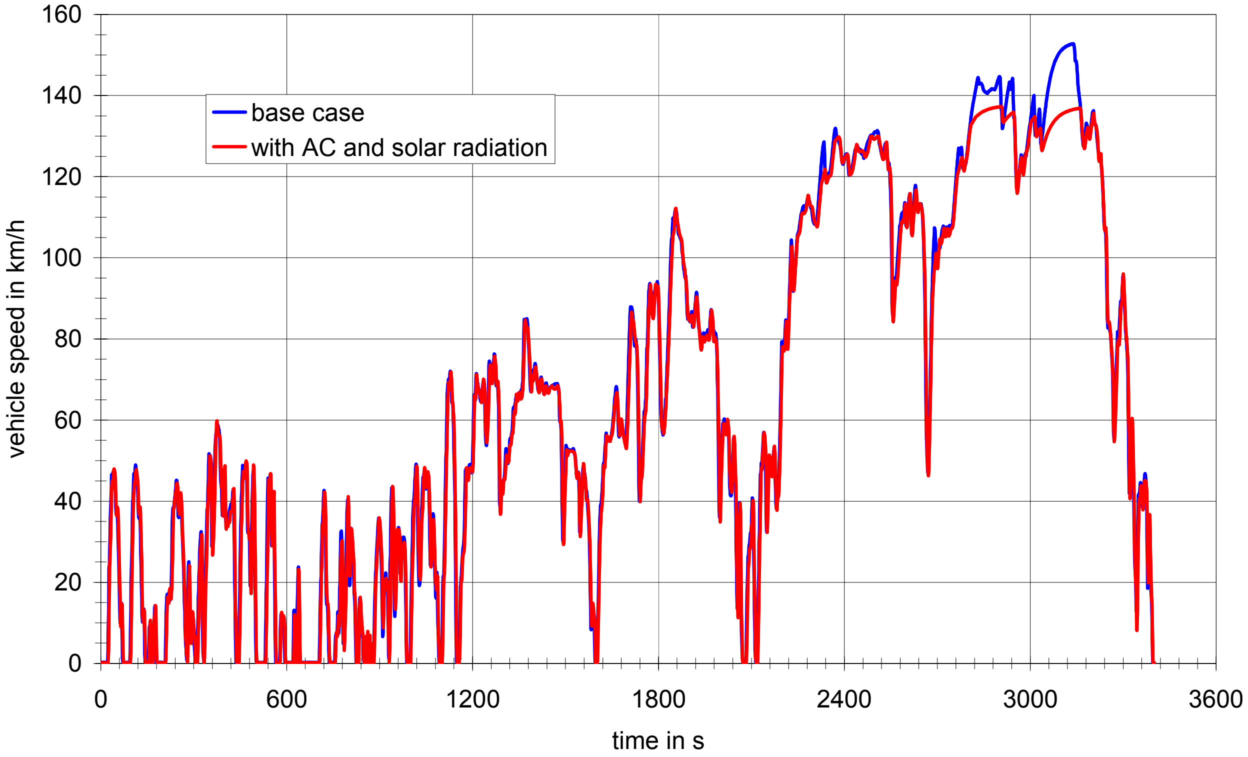


Figure 4: Vehicle speed pattern for vehicle 3 for the CADC

The results for vehicle 4 are shown in Table 12 to Table 14. The NEDC test results are far below the EURO IV limit values for all variants except for the test with AC and solar radiation. Vehicle modifications like ECO tyres etc and optimised gearshift strategies (best case) lead to lower CO_2 emissions. The pollutant emissions show no clear tendencies with respect to this influence. For the NEDC the NOx emissions show the same trend as the CO_2 emissions (reduction), while the CO and HC emissions increase compared to the base case. But the US FTP 75 as well as the CADC results do not show these trends.

With respect to the drivers influence (unpractised driver versus base case) the results for vehicle 4 are in line with the results for vehicle 2: This influence is not significant.

A higher start temperature leads to a slight reduction of the CO_2 emissions, but there is no uniform tendency for the pollutant emissions. For this vehicle an additional parameter was varied, the capacity of the battery. Additional tests were performed where the battery was unloaded so that the capacity was only 30% of the full capacity. This led to significantly higher CO_2 emissions (9% to 21%, depending on the cycle part). For the NEDC an increase in the pollutant emissions can also be seen, but there is no clear trend for the US FTP 75.

The NEDC was driven with and without AC operation at the TUEV Nord test bench in hot condition with a start temperature of 23 °C and the AC set to full cooling capacity. With the AC in operation the CO_2 emissions were 17% higher (25% for the urban part of the NEDC (UDC) and 10% for the extra urban part (EUDC) than with the AC switched off. The increase of the pollutant emissions was even more severe (50% for NOx, 167% for HC and 176% for CO). But the increase for CO and HC are only related to the UDC (Urban Driving Cycle).

The differences with and without AC were higher for the tests with solar radiation, but not as drastic as for vehicle 3. As already mentioned the room temperature was set to 35 °C for this test and the solar radiation was 850 W/m². This operation led for the NEDC to the following differences compared to the hot start test without AC:

- CO_2 +21,2% (+28,8% for the UDC and +14,4% for the EUDC)
- NOx +116,5% (+180% for the UDC and +35% for the EUDC)

The differences for CO and HC are even higher, but the values with AC and radiation are still below the limit values.

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
4	E 240 T	NEDC	29 °C start temperature	0.2165	0.0230	0.0540	250.6	10.53	-20.1%	-35.2%	-11.5%	-1.8%
4	E 240 T	NEDC	30% battery capacity	0.3745	0.0515	0.0700	295.9	12.43	38.2%	45.1%	14.8%	16.0%
4	E 240 T	NEDC	base case	0.2710	0.0355	0.0610	255.1	10.72	0.0%	0.0%	0.0%	0.0%
4	E 240 T	NEDC	best case	0.5885	0.0455	0.0475	216.2	9.08	117.2%	28.2%	-22.1%	-15.2%
4	E 240 T	NEDC	engine oil minimum	0.2560	0.0315	0.0490	255.0	10.71	-5.5%	-11.3%	-19.7%	0.0%
4	E 240 T	NEDC	hot start, with AC	0.0690	0.0080	0.0830	265.8	11.16	-74.5%	-77.5%	36.1%	4.2%
4	E 240 T	NEDC	hot start, without AC	0.0250	0.0030	0.0550	226.9	9.53	-90.8%	-91.5%	-9.8%	-11.0%
4	E 240 T	NEDC	optimised gearshifts	0.4305	0.0335	0.0435	236.8	9.95	58.9%	-5.6%	-28.7%	-7.2%
4	E 240 T	NEDC	Solartest with AC and radiation	0.2560	0.0117	0.1439	275.0	11.68	-5.5%	-67.2%	135.8%	7.8%
4	E 240 T	NEDC	unpractised driver	0.2410	0.0310	0.0650	258.2	10.85	-11.1%	-12.7%	6.6%	1.2%
4	E 240 T	UDC	29 °C start temperature	0.5630	0.0625	0.1380	354.5	14.89	-19.6%	-34.2%	-8.3%	-3.1%
4	E 240 T	UDC	30% battery capacity	1.0205	0.1405	0.1830	442.7	18.60	45.8%	47.9%	21.6%	21.0%
4	E 240 T	UDC	base case	0.7000	0.0950	0.1505	365.8	15.37	0.0%	0.0%	0.0%	0.0%
4	E 240 T	UDC	best case	1.5150	0.1205	0.1215	283.1	11.89	116.4%	26.8%	-19.3%	-22.6%
4	E 240 T	UDC	engine oil minimum	0.6700	0.0845	0.1270	366.5	15.40	-4.3%	-11.1%	-15.6%	0.2%
4	E 240 T	UDC	hot start, with AC	0.1700	0.0210	0.1960	373.4	15.68	-75.7%	-77.9%	30.2%	2.1%
4	E 240 T	UDC	hot start, without AC	0.0340	0.0080	0.1310	299.0	12.56	-95.1%	-91.6%	-13.0%	-18.3%
4	E 240 T	UDC	optimised gearshifts	1.1305	0.0915	0.1145	331.1	13.91	61.5%	-3.7%	-23.9%	-9.5%
4	E 240 T	UDC	Solartest with AC and radiation	0.6835	0.0230	0.3675	385.0	16.35	-2.4%	-75.8%	144.2%	5.3%
4	E 240 T	UDC	unpractised driver	0.6505	0.0825	0.1225	369.8	15.53	-7.1%	-13.2%	-18.6%	1.1%
4	E 240 T	EUDC	29 °C start temperature	0.0140	0.0000	0.0050	189.7	7.97	-24.3%	-100.0%	-37.5%	-0.1%
4	E 240 T	EUDC	30% battery capacity	0.0000	0.0005	0.0040	210.9	8.86	-100.0%	-50.0%	-50.0%	11.1%
4	E 240 T	EUDC	base case	0.0185	0.0010	0.0080	189.8	7.97	0.0%	0.0%	0.0%	0.0%
4	E 240 T	EUDC	best case	0.0375	0.0005	0.0040	176.5	7.41	102.7%	-50.0%	-50.0%	-7.1%
4	E 240 T	EUDC	engine oil minimum	0.0150	0.0005	0.0040	189.9	7.98	-18.9%	-50.0%	-50.0%	0.1%
4	E 240 T	EUDC	hot start, with AC	0.0100	0.0010	0.0170	202.6	8.51	-45.9%	0.0%	112.5%	6.7%
4	E 240 T	EUDC	hot start, without AC	0.0210	0.0010	0.0100	184.4	7.75	13.5%	0.0%	25.0%	-2.9%
4	E 240 T	EUDC	optimised gearshifts	0.0290	0.0010	0.0030	182.7	7.67	56.8%	0.0%	-62.5%	-3.8%
4	E 240 T	EUDC	Solartest with AC and radiation	0.0070	0.0050	0.0135	211.0	8.96	-62.2%	400.0%	68.8%	11.1%
4	E 240 T	EUDC	unpractised driver	0.0015	0.0005	0.0315	192.9	8.10	-91.9%	-50.0%	293.8%	1.6%
			limit values, EURO IV	**1.0000**	**0.1000**	**0.0800**						

Table 12: Measurement results for vehicle 4, NEDC

The test with solar radiation was also performed for the CADC. The differences to the base case are comparable to the NEDC if one takes into account the differences in speed and dynamics between the cycles. The differences between the cases with and without AC and solar radiation are highest for the urban part and lowest for the motorway part. The differences for HC and CO are insignificant because of the low levels, but the increase in NOx is significant, whereas it should be mentioned that with one exception the NOx values for the CADC are all above the limit value for EURO IV.

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
4	E 240 T	FTP 75	29 °C start temperature	0.1094	0.0249	0.2113	263.6	6.97	-40.9%	-52.9%	27.8%	-1.9%
4	E 240 T		30% battery capacity	0.2510	0.0497	0.1802	302.3	8.00	35.6%	-5.9%	9.0%	12.5%
4	E 240 T		base case	0.1852	0.0528	0.1653	268.8	7.11	0.0%	0.0%	0.0%	0.0%
4	E 240 T		best case	0.4362	0.0385	0.2280	215.8	5.71	135.6%	-27.1%	38.0%	-19.7%
4	E 240 T		engine oil minimum	0.1901	0.0597	0.2007	267.3	7.07	2.7%	12.9%	21.4%	-0.5%
4	E 240 T		unpractised driver	0.1945	0.0454	0.2237	280.1	7.41	5.0%	-14.1%	35.3%	4.2%
4	E 240 T	phase 1	29 °C start temperature	0.3169	0.0739	0.3747	274.3	7.26	-42.2%	-53.0%	73.8%	-4.5%
4	E 240 T		30% battery capacity	0.7133	0.1491	0.2691	321.8	8.51	30.2%	-5.1%	24.8%	12.0%
4	E 240 T		base case	0.5481	0.1572	0.2156	287.3	7.60	0.0%	0.0%	0.0%	0.0%
4	E 240 T		best case	1.1744	0.1087	0.2585	237.7	6.29	114.3%	-30.8%	19.9%	-17.3%
4	E 240 T		engine oil minimum	0.5344	0.1777	0.3057	284.2	7.52	-2.5%	13.0%	41.8%	-1.1%
4	E 240 T		unpractised driver	0.5387	0.1355	0.2672	282.6	7.47	-1.7%	-13.8%	23.9%	-1.6%
4	E 240 T	phase 2	29 °C start temperature	0.0112	0.0000	0.0342	283.9	7.51	200.0%	-100.0%	-17.9%	-0.7%
4	E 240 T		30% battery capacity	0.0348	0.0006	0.0298	329.9	8.73	833.3%	-50.0%	-28.4%	15.4%
4	E 240 T		base case	0.0037	0.0012	0.0416	285.9	7.56	0.0%	0.0%	0.0%	0.0%
4	E 240 T		best case	0.0404	0.0019	0.0739	213.1	5.64	983.3%	50.0%	77.6%	-25.5%
4	E 240 T		engine oil minimum	0.0367	0.0006	0.0466	286.1	7.57	883.3%	-50.0%	11.9%	0.1%
4	E 240 T		unpractised driver	0.0298	0.0006	0.1274	287.1	7.60	700.0%	-50.0%	206.0%	0.4%
4	E 240 T	phase 3	29 °C start temperature	0.0075	0.0031	0.2386	231.0	6.11	-57.1%	-37.5%	-3.8%	-0.3%
4	E 240 T		30% battery capacity	0.0230	0.0037	0.2541	253.2	6.70	32.1%	-25.0%	2.5%	9.3%
4	E 240 T		base case	0.0174	0.0050	0.2479	231.7	6.13	0.0%	0.0%	0.0%	0.0%
4	E 240 T		best case	0.1268	0.0087	0.3647	196.9	5.21	628.6%	75.0%	47.1%	-15.0%
4	E 240 T		engine oil minimum	0.0099	0.0043	0.2616	230.3	6.09	-42.9%	-12.5%	5.5%	-0.6%
4	E 240 T		unpractised driver	0.0273	0.0043	0.2840	270.0	7.14	57.1%	-12.5%	14.5%	16.5%

Table 13: Measurement results for vehicle 4, US FTP 75

IDveh	vehicle	sub-cycle	mode	CO	HC	NOx	CO2	fuel consump-tion	Difference to base case			
				g/km	g/km	g/km	g/km	l/100 km	CO	HC	NOx	CO2
4	E 240 T	CADC	30% battery capacity	0.1679	0.0010	0.1683	243.9	10.25	172.1%	-57.6%	73.7%	2.4%
4	E 240 T		base case	0.0617	0.0025	0.0969	238.1	10.00	0.0%	0.0%	0.0%	0.0%
4	E 240 T		optimised gearshifts	0.0890	0.0028	0.1044	214.1	8.99	44.2%	14.2%	7.7%	-10.1%
4	E 240 T		Solartest with AC and radiation	0.1570	0.0119	0.2078	272.8	11.58	154.5%	382.2%	114.5%	14.5%
4	E 240 T		unpractised driver	0.1072	0.0012	0.1076	235.6	9.90	73.7%	-52.6%	11.0%	-1.1%
4	E 240 T	urban, hot	30% battery capacity	0.0690	0.0090	0.4850	406.6	17.08	11.3%	0.0%	174.0%	13.6%
4	E 240 T		base case	0.0620	0.0090	0.1770	358.1	15.04	0.0%	0.0%	0.0%	0.0%
4	E 240 T		optimised gearshifts	0.0410	0.0070	0.2600	327.4	13.75	-33.9%	-22.2%	46.9%	-8.6%
4	E 240 T		Solartest with AC and radiation	0.2940	0.0310	0.6745	448.3	19.04	374.2%	244.4%	281.1%	25.2%
4	E 240 T		unpractised driver	0.0330	0.0070	0.3350	348.8	14.65	-46.8%	-22.2%	89.3%	-2.6%
4	E 240 T	rural	30% battery capacity	0.0000	0.0020	0.2120	235.9	9.91	-100.0%	0.0%	86.0%	5.7%
4	E 240 T		base case	0.0420	0.0020	0.1140	223.1	9.37	0.0%	0.0%	0.0%	0.0%
4	E 240 T		optimised gearshifts	0.0000	0.0010	0.0390	182.1	7.65	-100.0%	-50.0%	-65.8%	-18.4%
4	E 240 T		Solartest with AC and radiation	0.1325	0.0080	0.2565	255.6	10.85	215.5%	300.0%	125.0%	14.6%
4	E 240 T		unpractised driver	0.0140	0.0000	0.1310	220.0	9.24	-66.7%	-100.0%	14.9%	-1.4%
4	E 240 T	motor-way	30% battery capacity	0.2310	0.0000	0.1250	231.4	9.72	239.7%	-100.0%	48.8%	-0.2%
4	E 240 T		base case	0.0680	0.0020	0.0840	231.9	9.74	0.0%	0.0%	0.0%	0.0%
4	E 240 T		optimised gearshifts	0.1220	0.0030	0.1110	214.0	8.99	79.4%	50.0%	32.1%	-7.7%
4	E 240 T		Solartest with AC and radiation	0.1505	0.0110	0.1285	258.6	10.98	121.3%	450.0%	53.0%	11.5%
4	E 240 T		unpractised driver	0.1440	0.0010	0.0790	230.1	9.67	111.8%	-50.0%	-6.0%	-0.8%

Table 14: Measurement results for vehicle 4, CADC

3.2 Analysis of modal data

3.2.1 General

For the major part of the measurements second by second emission data was also measured and analysed, except for particulates. This data gives some explanations for unexpected results related to the pollutant emissions. An example of the time series of the CO emissions for the NEDC and vehicle 2 is shown in Figure 5. It shows that the CO emissions of this vehicle for this cycle are just a cold start problem, because the emission tends to zero after the second UDC. But it is hard to assess differences between the several variants.

In order to get the best information, the second by second emissions were cumulated over the time for each part of the cycles. Figure 6 shows an example for the NOx emissions of the NEDC for vehicle 4. Here one can clearly see that the NOx emissions of this vehicle are predominantly related to acceleration phases and that catalyst was out of operation for the last acceleration phase of the EUDC for the untrained driver.

Figure 7 shows a similar example for the HC emissions of vehicle 2. The importance of the cold start is obvious. Examples for the CADC are shown in Figure 8 and Figure 9 for HC and CO respectively. Figure 8 shows a clear increase of the HC emissions with vehicle speed, Figure 9 shows that the CO emission could have some “bursts” for short time periods.

Corresponding figures for all vehicles, cycles, pollutants and CO_2 can be found in Annex A.

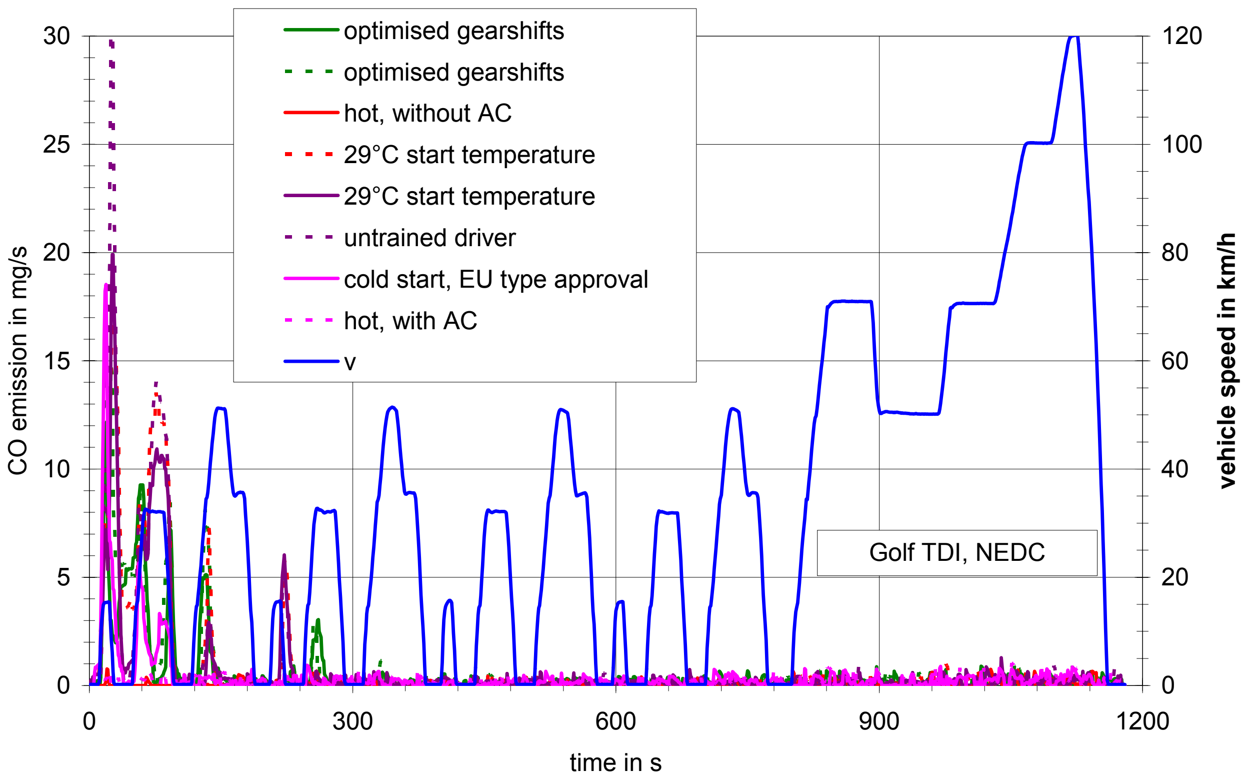


Figure 5: Time pattern of the CO emissions for the NEDC and vehicle 2

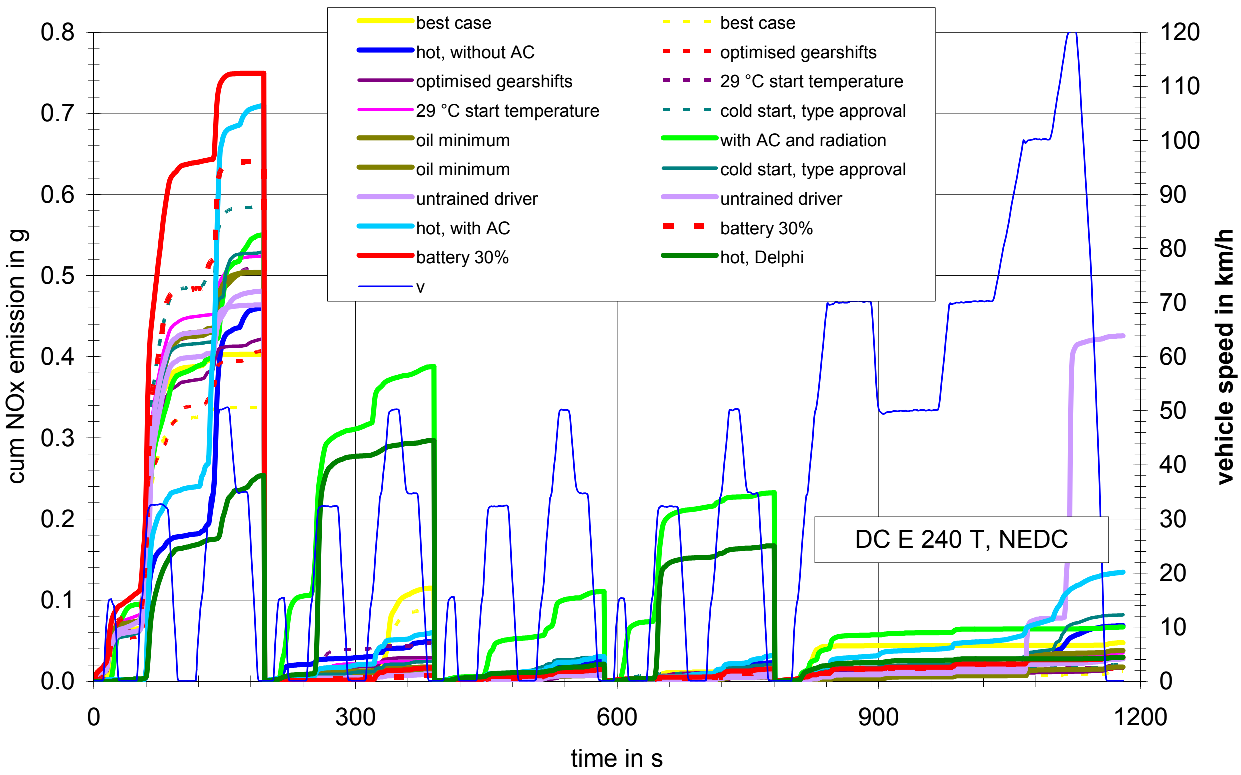


Figure 6: Cumulative NOx emission for the different NEDC parts, vehicle 4

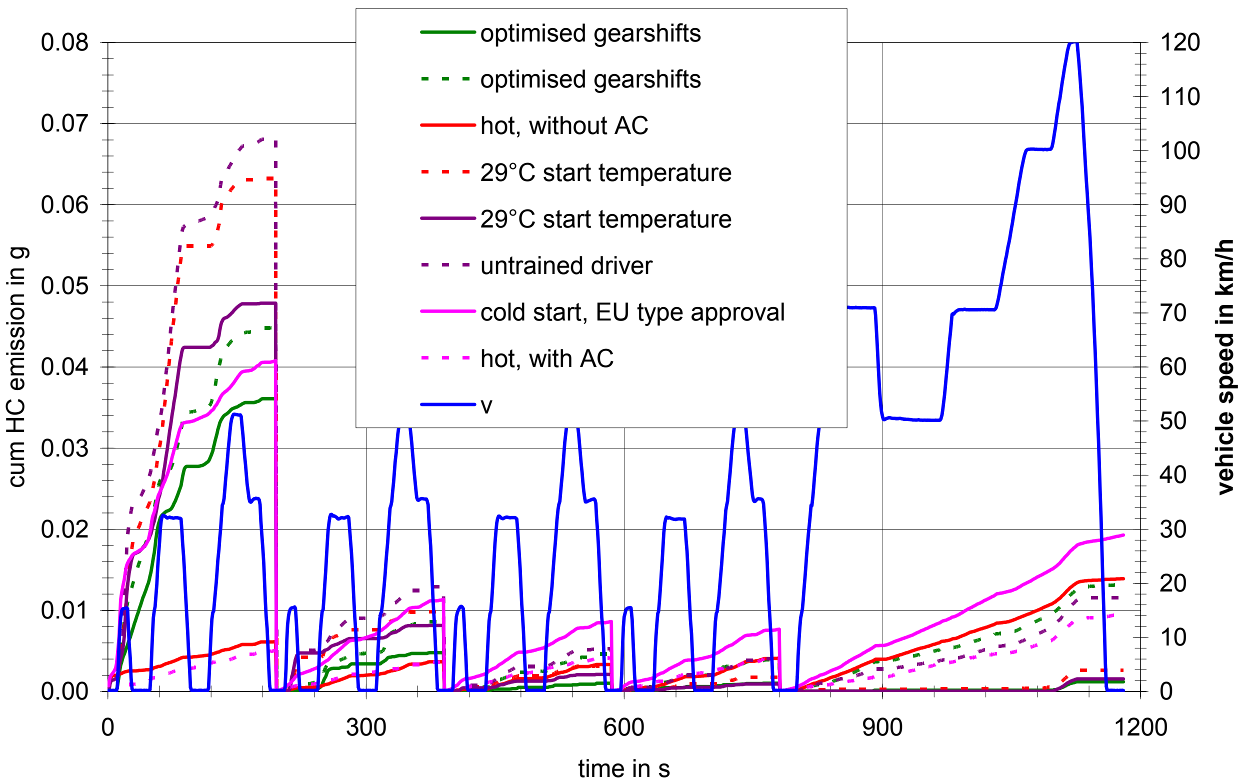


Figure 7: Cumulative HC emission for the different NEDC parts, vehicle 2

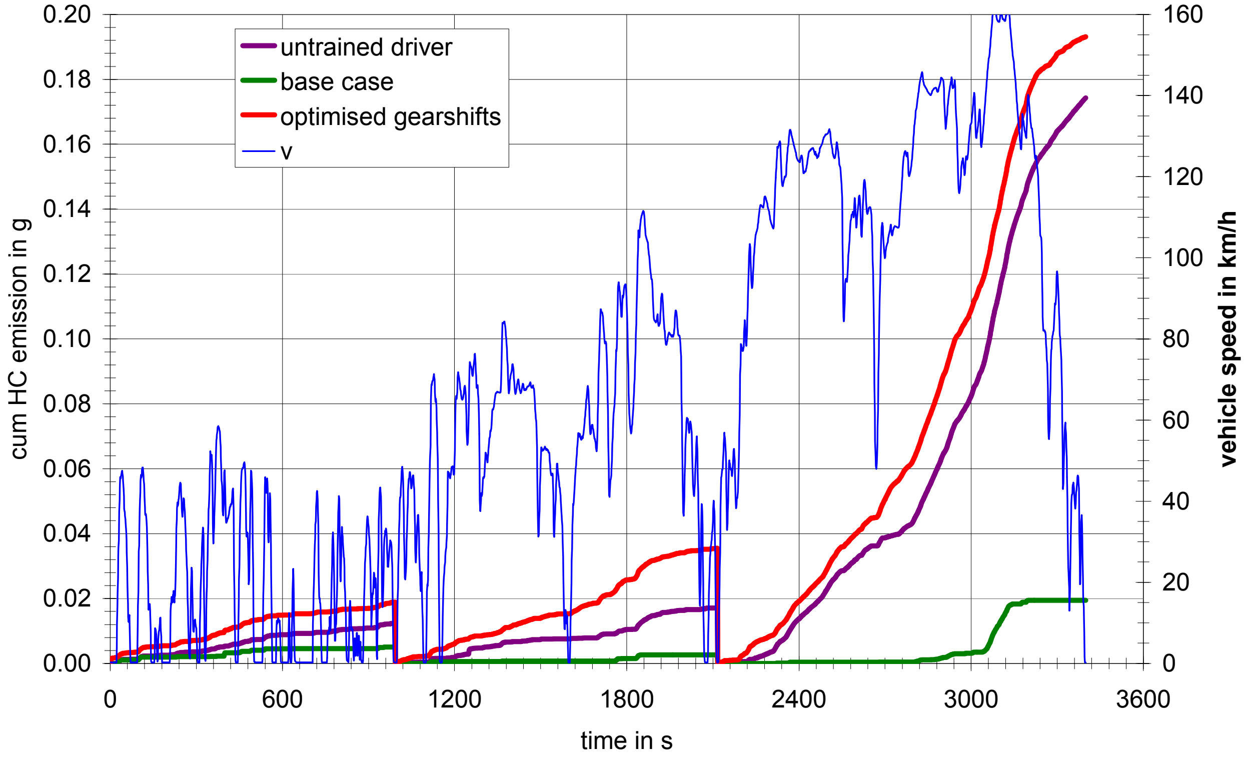


Figure 8: Cumulative HC emission for the different CADC parts, vehicle 2

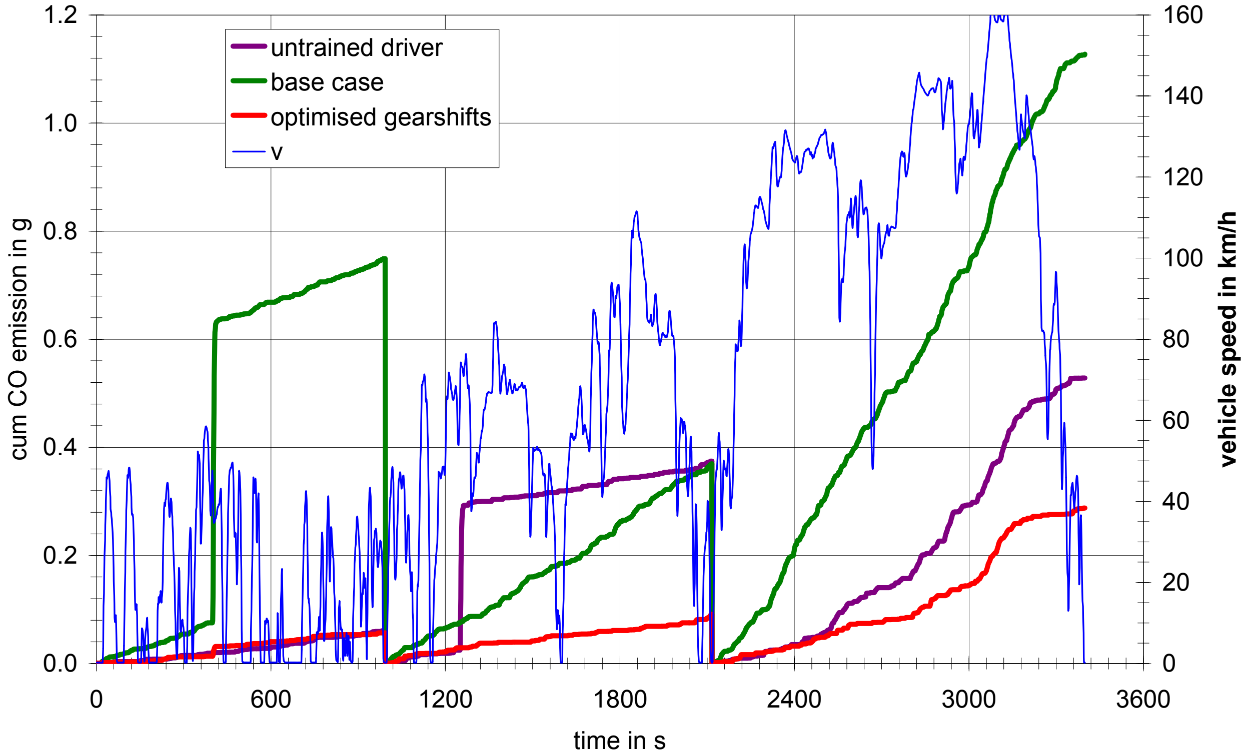


Figure 9: Cumulative CO emission for the different CADC parts, vehicle 2

The analysis of the modal data was focussed on two main issues:

- Cold start influence
- Influence of air conditioning systems

3.2.2 Cold start influence

In order to assess the cold start influence the emissions were summarised for each cycle part separately. For the NEDC the emissions of the first two UDCs and the last two UDCs were added. The cold start contribution could then be calculated by the differences between both values. A similar approach could be used for the US FTP cycle by comparing the emissions of the first and the third cycle phase. The same could be done for the CADC and vehicle 1.

The results were averaged over the different variants, because no significant variant influence could be found. These averages are listed in Table 15. The cold start HC emissions can reach 0,8 g, the CO emissions up to 6,5 g, the NOx emissions up to 0,6 g and the CO_2 emissions up to 320 g. The Diesel vehicle (no. 2) shows the lowest values.

More informative than the absolute values are the percentages of the cold start emissions on the total emissions of the cycle part. These results are listed in Table 16. The cold start contributions are related to the total emissions of the cycle parts that are influenced by the cold start. In case of the NEDC the first two UDCs were chosen, in case of the US FTP 75 the first cycle phase and in case of the CADC the urban part with cold start. It can clearly be seen that for HC and CO the major part of the emissions is caused by the cold start. If one disregards the significantly lower values for the CADC that are caused by the fact that the approximately the second half of the urban part is already hot condition the values vary between 64% and 98% for HC and CO.

For NOx the situation is different. There is only a slight effect of the cold start contribution on the total emissions for the Diesel vehicle, but a significant effect for the petrol vehicles (varying between 29% and 96%. The cold start increases the CO_2 emissions by between 9% and 22%.

		Cold start emission in g			
		veh. no			
pollutant	**Cycle**	1	2	3	4
HC	NEDC		0.052	0.406	0.376
	US FTP 75	0.403	0.026	0.690	0.755
	CADC	0.371			
CO	NEDC		0.582	0.406	3.705
	US FTP 75	4.523	0.268	6.530	3.477
	CADC	5.603			
NOx	NEDC		0.072	0.228	0.513
	US FTP 75	0.473	0.000	0.557	0.435
	CADC	0.473			
CO_2	NEDC		42.576	52.777	182.305
	US FTP 75	184.385	73.164	98.105	320.875
	CADC	202.821			

Table 15: Cold start emission in g for different pollutants, cycles and vehicles

		Cold start emission in % of total emission (of the cycle parts influenced by cold start)			
		veh. no			
pollutant	Cycle	1	2	3	4
HC	NEDC		87.3%	96.3%	98.6%
	US FTP 75	93.6%	63.8%	92.0%	95.5%
	CADC	79.7%			
CO	NEDC		91.8%	96.3%	97.4%
	US FTP 75	70.7%	78.0%	93.1%	91.8%
	CADC	52.5%			
NOx	NEDC		9.3%	93.7%	95.8%
	US FTP 75	89.8%	0.0%	58.7%	29.0%
	CADC	69.3%			
CO_2	NEDC		11.2%	13.1%	21.9%
	US FTP 75	13.2%	8.9%	10.3%	19.2%
	CADC	10.1%			

Table 16: Cold start contribution in % of total emission (of the cycle parts influenced by cold start) for different pollutants, cycles and vehicles

	Cold start emission in % of total emission for the whole NEDC		
	veh. no		
pollutant	2	3	4
HC	71.8%	85.5%	95.7%
CO	77.4%	85.5%	92.1%
NOx	2.1%	72.7%	84.7%
CO_2	2.8%	3.2%	6.5%

Table 17: Cold start contribution in % of total emission of the whole NEDC

3.2.3 Influence of air conditioning systems

The significant influence of air conditioning systems was already discussed in chapter 3.1 for each single vehicle. In this chapter the results shall be analysed more detailed. For that reason the second by second CO_2 emissions with and without AC operating are plotted versus vehicle speed for the NEDC and the CADC. “With AC” means tests at the TUEV Nord test bench with a room temperature of 23 °C, “with AC and solar radiation” means tests at the Delphi test bench with solar radiation of 850 W/m² and a room temperature of 35 °C.

The results can be seen in Figure 10 to Figure 16. The regression curves show that the AC causes higher CO_2 emissions over the whole speed range and that there are significant differences between the individual vehicles.

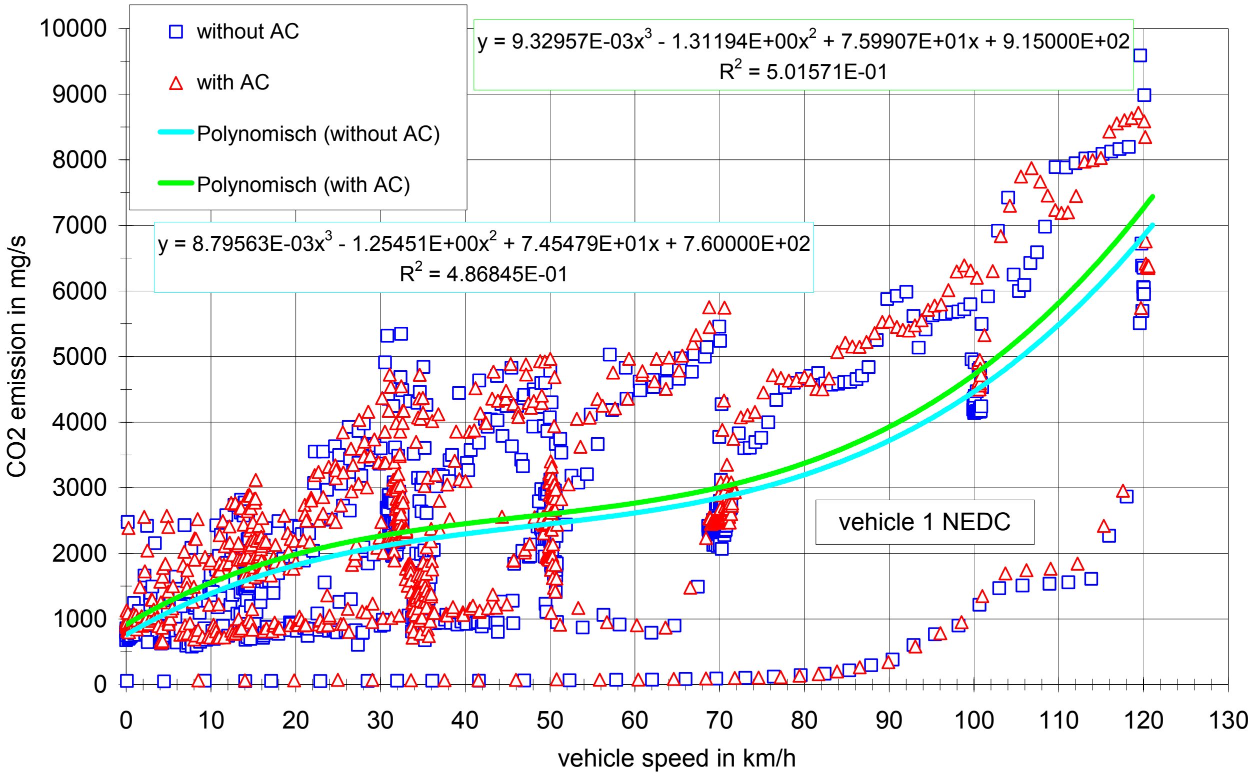


Figure 10: CO_2 emissions versus vehicle speed, NEDC, vehicle 1

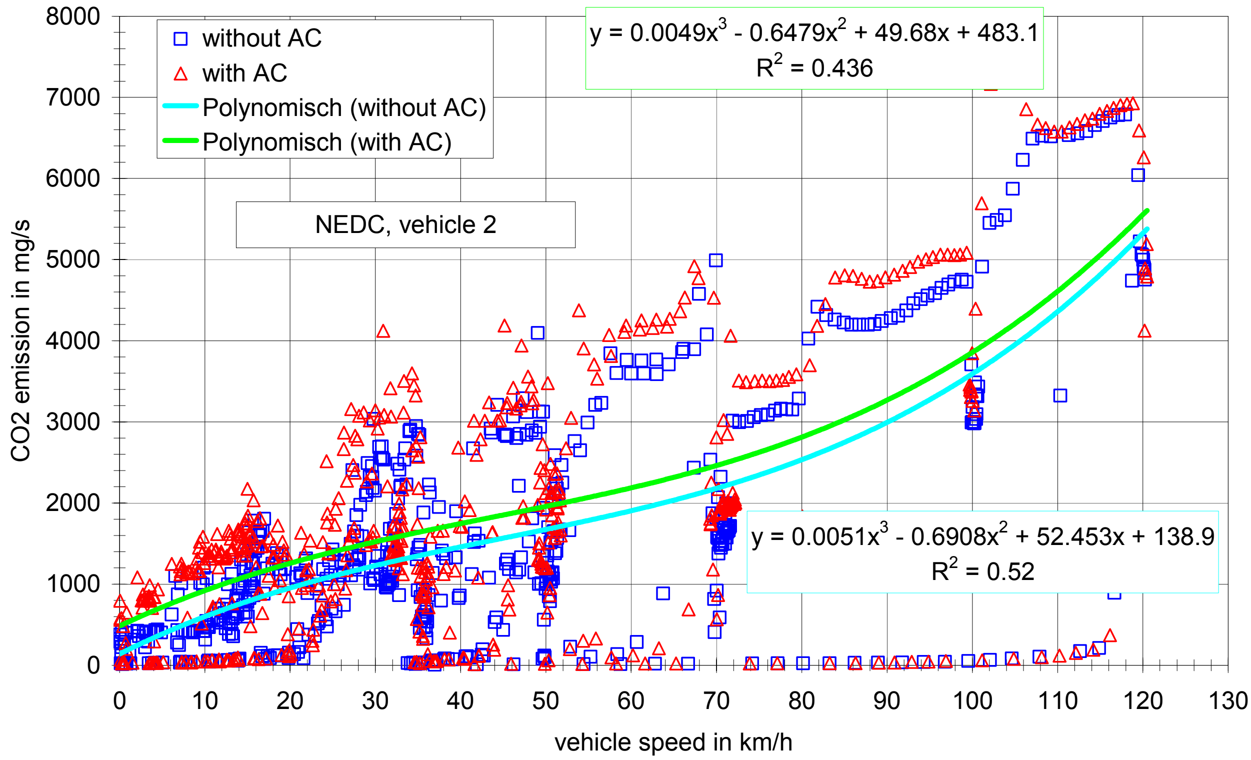


Figure 11: CO_2 emissions versus vehicle speed, NEDC, vehicle 2

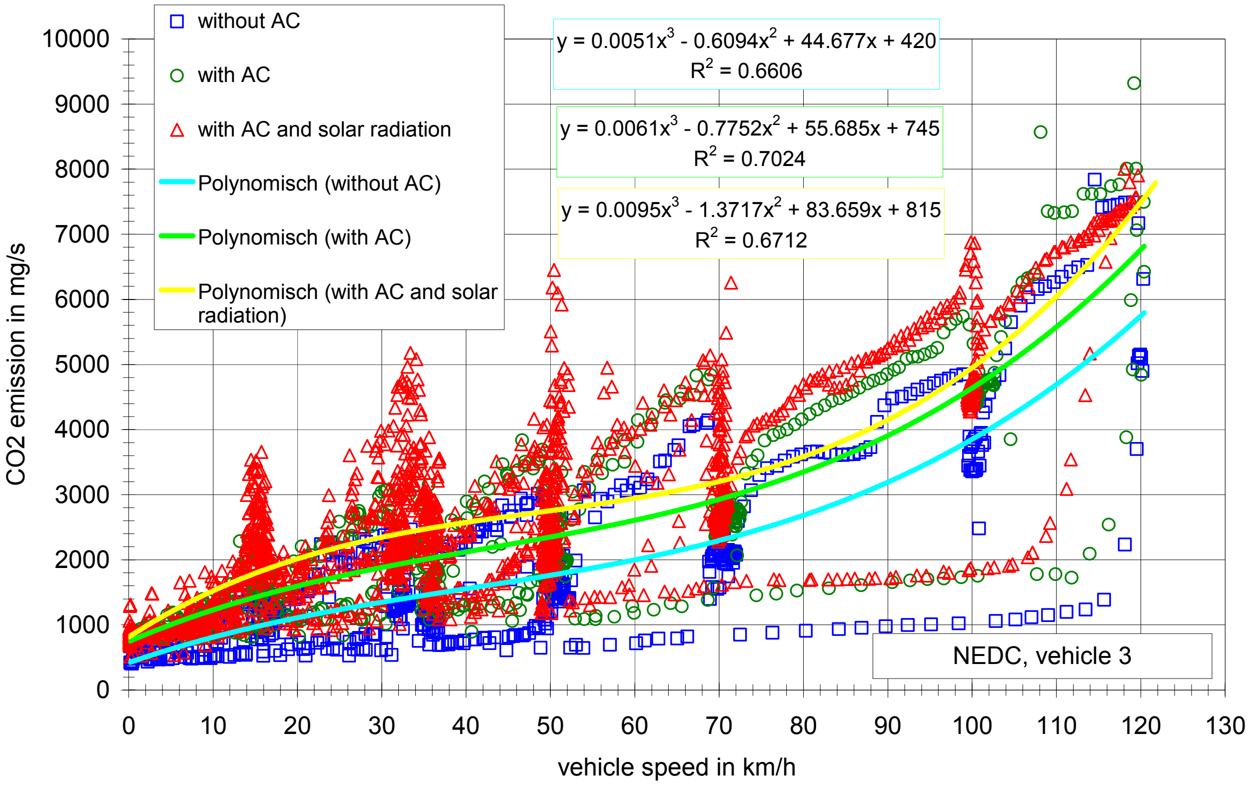


Figure 12: CO_2 emissions versus vehicle speed, NEDC, vehicle 3

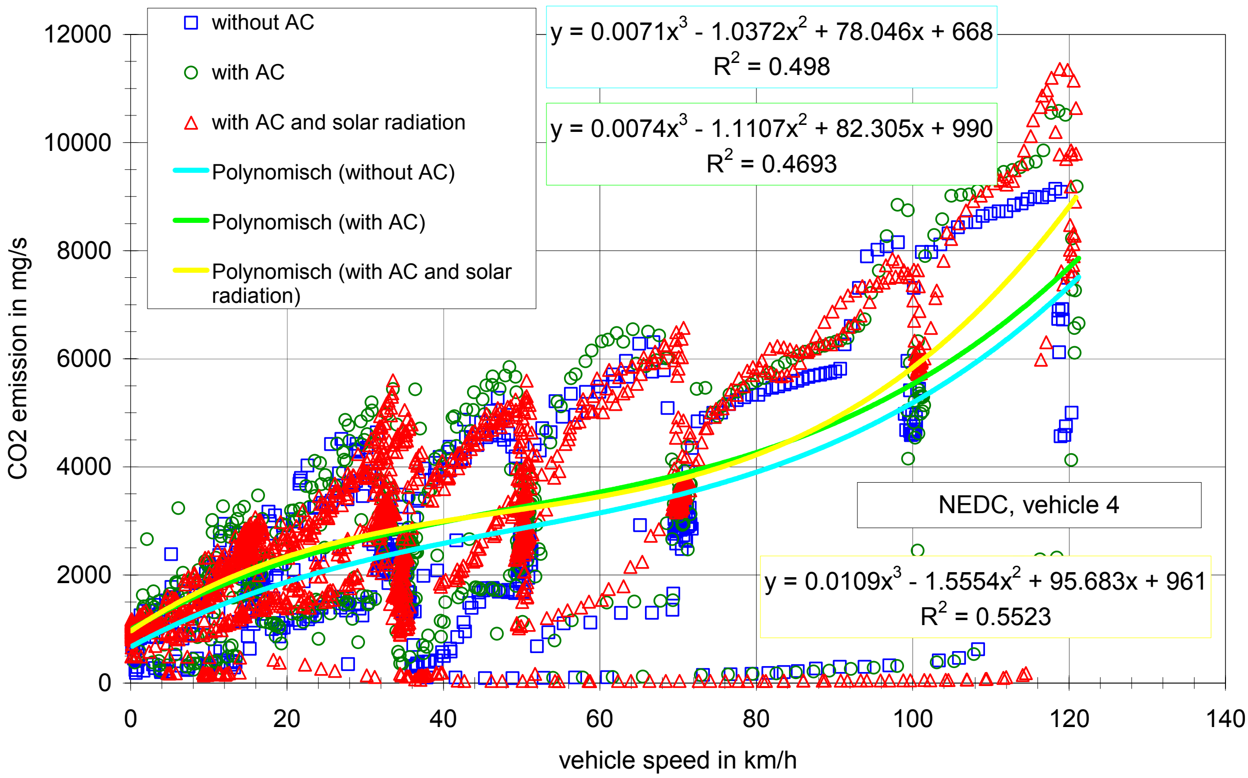


Figure 13: CO_2 emissions versus vehicle speed, NEDC, vehicle 4

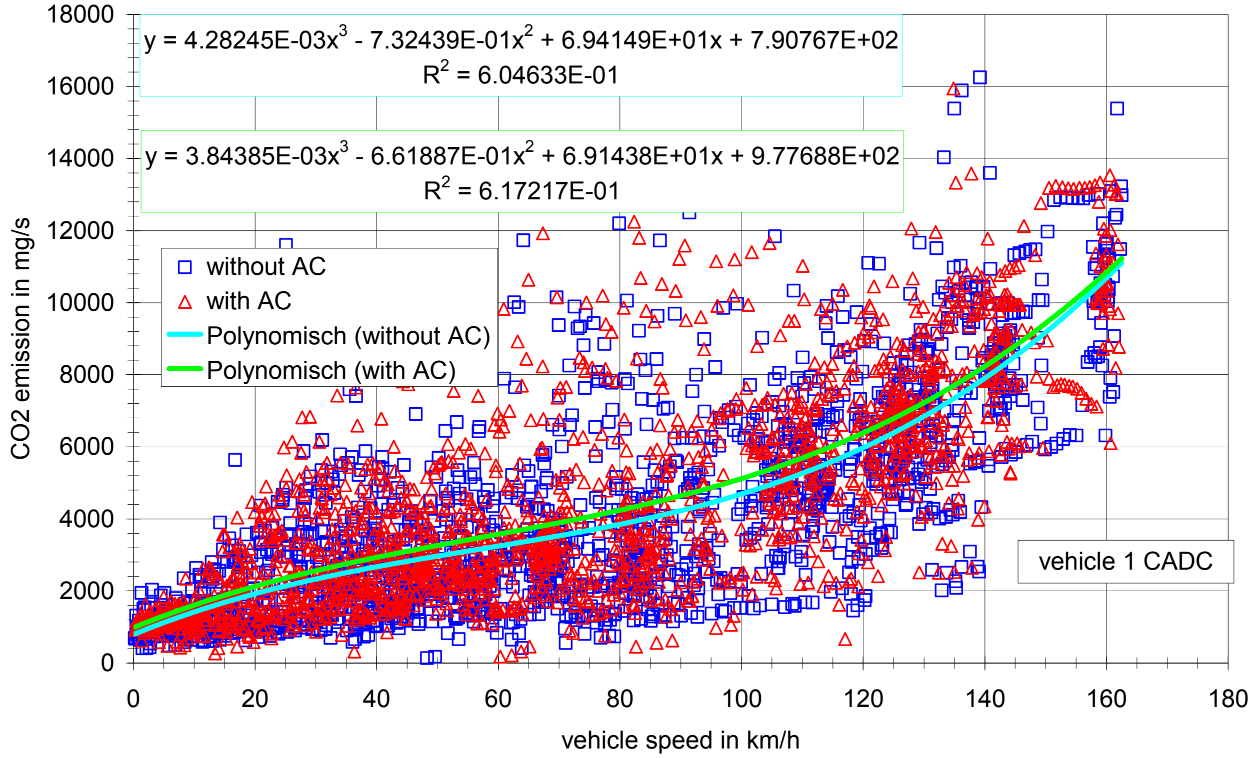


Figure 14: CO_2 emissions versus vehicle speed, CADC, vehicle 1

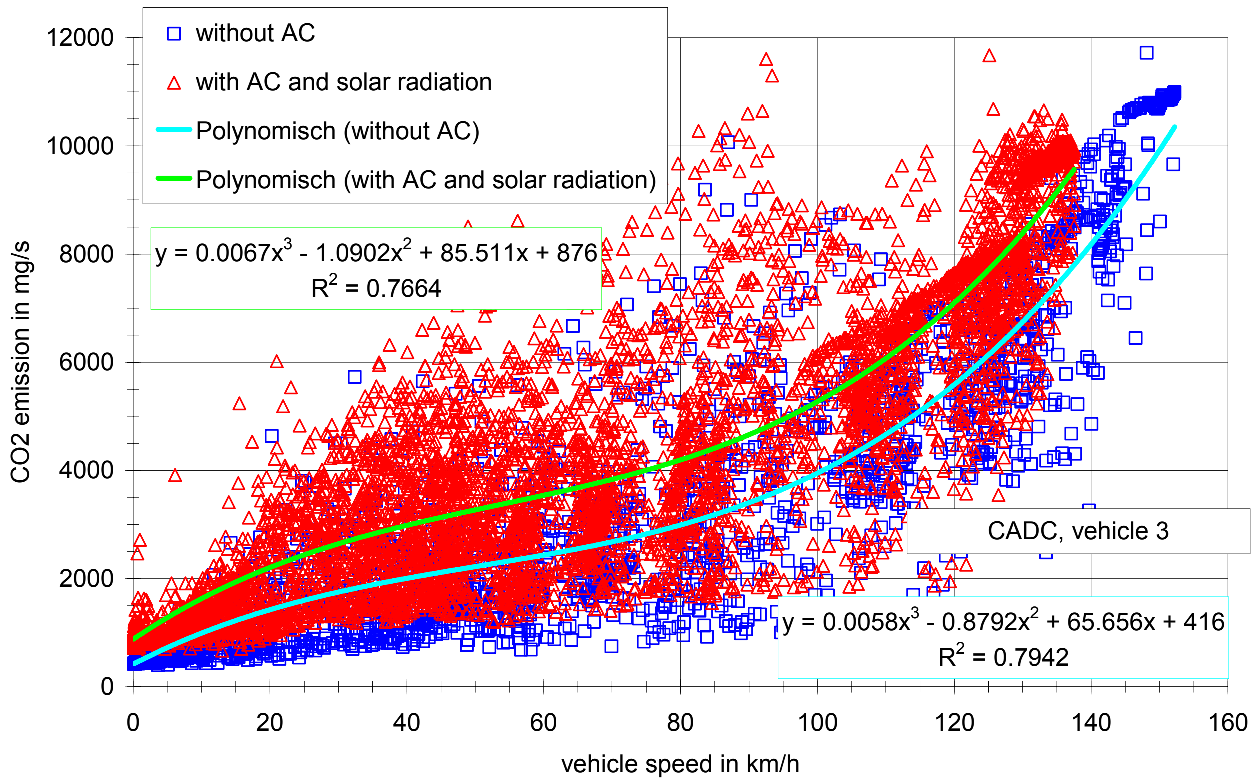


Figure 15: CO_2 emissions versus vehicle speed, CADC, vehicle 3

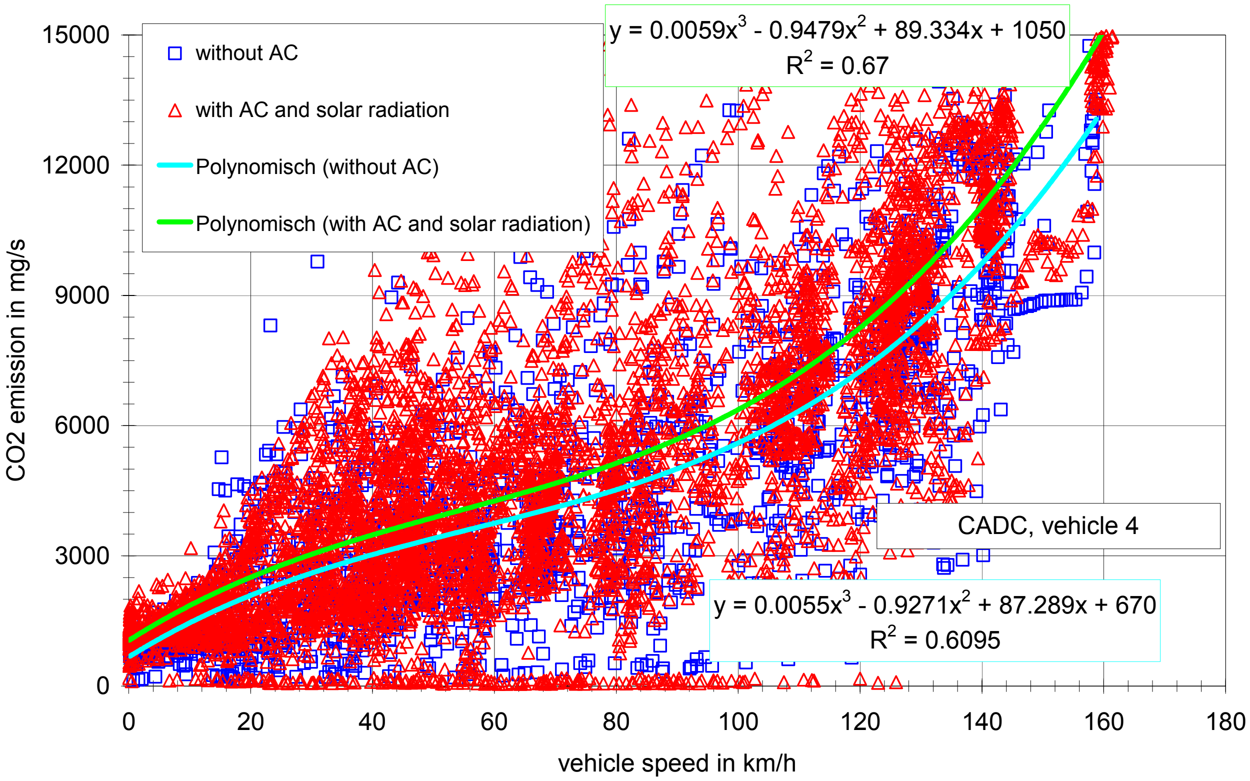


Figure 16: CO_2 emissions versus vehicle speed, CADC, vehicle 4

The figures support the hypothesis that the extra emission of CO_2 in g/h is roughly constant over the vehicle speed.

The differences with and without AC operation are summarised in Table 18. The lowest influence on the emissions was found for vehicle 1, the highest for vehicle 3. One could assume that the influence on the emissions decreases with increasing rated power of the vehicle, but the vehicle sample is too small and inhomogeneous to support this hypothesis.

With respect to the pollutant emissions it should be mentioned first that there was an increase of the HC emissions in the major part of the results but on such low levels, that this is no issue of concern.

Vehicle 3 shows already a high influence of the AC on the emissions for a temperature of 23 °C and no solar radiation. The CO_2 emission was increased by 50% for the UDC and 25% for the EUDC. The CO emission was increased by more than 100%, the NOx emission by the factor 20 for the UDC and the factor 5 for the EUDC. At a temperature of 35 °C and with solar radiation the additional load on the engine was that high that catalytic converter light off occurred, resulting in a tremendous increase of all pollutant emissions. It should be proven in the future whether this behaviour is typical for small cars or whether this vehicle was just an outlier.

		Differences with and without AC				
vehicle	cycle	CO	HC	NOx	CO2	particulates
1	NEDC	-11.3%		25.4%	7.4%	
	UDC	-12.3%		24.0%	9.1%	
	EUDC	17.2%		42.9%	5.4%	
2	NEDC			27.9%	22.0%	10.0%
	UDC			27.4%	31.0%	3.8%
	EUDC			27.6%	14.4%	11.8%
3	NEDC	141.2%		1085.7%	37.4%	
	UDC	150.7%		1950.0%	51.2%	
	EUDC	129.7%		500.0%	25.8%	
	NEDC, with radiation	19325.5%	949.5%	6327.1%	53.1%	
	UDC, with radiation	23881.3%	628.8%	6200.0%	73.2%	
	EUDC, with radiation	13890.5%	2316.7%	6883.3%	36.6%	
4	NEDC	176.0%		50.9%	17.1%	
	UDC	400.0%		49.6%	24.9%	
	EUDC	-52.4%		70.0%	9.9%	
	NEDC, with radiation	924.0%		161.5%	21.2%	
	UDC, with radiation	1910.3%		180.5%	28.8%	
	EUDC, with radiation	-66.7%		35.0%	14.4%	
1	CADC, urban	41.4%		44.4%	13.7%	
	CADC, rural	-8.5%		-11.6%	9.9%	
	CADC, motorway	-7.5%		0.0%	5.2%	
3	CADC, urban, with radiation	12169.6%	2800.0%	567.6%	60.4%	
	CADC, rural, with radiation	541.4%	788.9%	1843.2%	41.3%	
	CADC, motorway, with radiation	72.6%	243.8%	771.9%	20.2%	
4	CADC, urban, with radiation	374.2%		281.1%	25.2%	
	CADC, rural, with radiation	215.5%		125.0%	14.6%	
	CADC, motorway, with radiation	121.3%		53.0%	11.5%	
1	US FTP 75, phase 1	1.2%		38.0%	6.2%	
	US FTP 75, phase 2	-21.5%		66.7%	4.8%	
	US FTP 75, phase 3	-40.8%		22.5%	5.2%	

Table 18: Differences between the emissions with and without AC operation. The table shows the percentage differences between the measurements with and without the air conditioning system in operation. “With radiation means that the measurements were carried out at the Delphi test bench with solar radiation of 850 W/m² and a room temperature of 35 °C. In all other cases the measurements were carried out at the test bench of TUEV Nord with a room temperature of 23 °C and the AC set to maximum cooling capacity. Missing values for the HC-emission means that the emission levels were so low that the differences are influenced by measurement uncertainties rather than by the air conditioning system. Since only vehicle 2 was equipped with a Diesel engine, differences for particulates can only be shown for this vehicle.

For the other vehicles there is no uniform trend for the influence of the AC on the CO emissions, but at 35 °C and with solar radiation the CO emissions can be tremendously increased (up to a factor of 20) even if vehicle 3 is disregarded.

The NOx emissions show a general trend to higher values with AC operation, but the increase depends very much on the individual vehicle. For vehicle 1 increase in the range of 22% to 67% are found for the NEDC and the US FTP 75, but even a decrease of 11% for the rural part of the CADC. The Diesel vehicle (no. 2) shows an increase of NOx in the order of 27% without radiation, vehicle 4 shows NOx increases between 50% and 70% without radiation. With radiation the increase in NOx emissions can amount up to 280%.

Values for the additional emissions in g/h are shown in Table 19 and Table 20.

		Additional emission due to air conditioning in g/h			
		veh. no			
pollutant	**Cycle**	1	2	3	4
HC	NEDC		0.000	0.000	0.185
	US FTP 75	1.077			
	CADC	0.000			
CO	NEDC		0.361	0.000	1.764
	US FTP 75	0.000			
	CADC	1.888			
NOx	NEDC		3.052	2.536	1.042
	US FTP 75	0.405			
	CADC	0.000			
CO_2	NEDC		997.564	1925.256	1328.946
	US FTP 75	498.543			
	CADC	1028.438			

Table 19: Additional emissions due to air conditioning systems for 23 °C start temperature and no solar radiation

		Additional emission due to air conditioning in g/h	
		veh. no	
pollutant	**Cycle**	3	4
HC	NEDC	-	-
	CADC	-	-
CO	NEDC	392.06	6.07
	CADC	479.60	12.42
NOx	NEDC	8.82	1.77
	CADC	12.73	4.15
CO_2	NEDC	2610.40	1503.15
	CADC	3735.89	1081.64

Table 20: Additional emissions due to air conditioning systems for 35 °C start temperature and solar radiation of 850 W/m²

4 Questionnaires about the use of air conditioning systems in cars

Between summer 2003 and spring 2004 a questioning was accomplished by TUEV Nord during the vehicle general inspection, in order to be able to estimate the utilisation of air conditioning systems in passenger cars. Basis of the questioning was a questionnaire, which was developed by IFEU and co-ordinated with the Federal Environmental Agency and TUEV Nord. It contained questions to the clients of TUEV Nords inspection stations related to the vehicle (manufacturer, type, key number, drive system, capacity, registration year, mileage), to the air conditioning system (type and manufacturer of the air conditioning system) as well as questions to the customers about the use of the air conditioning system. The questionnaire is shown in Figure 17 and Figure 18.

Altogether 388 questionnaires were filled out and evaluated. Due to this number and to the circumstance that only tester and customers of the RWTUEV were asked, the results can not clearly be regarded as representative for the use behaviour in Germany. Since it concerns qualitative statements however predominantly, the evaluation gives a good reference point for the user behaviour, particularly since no investigations were available for us, which determined the air conditioning system use more comprehensively.

The questions were predominantly completely answered, so that nearly all inquired information could be evaluated.

In the questioning only vehicles with air conditioning system were seized. For this reason the seized vehicle fleet contains rather newer vehicles with emphasis with the years of construction 1997 to 2001 (see Figure 19). Vehicles of the years of construction starting from 2002 were represented only to small extent. While one can assume that older vehicles are underrepresented due to the smaller equipment degree, the newer vehicles (from 2002) are underrepresented, since these vehicles in 2003/2004 were not obliged to carry out the technical inspection procedure. Thus the results of the sample for the newest vehicles are more uncertain than those of the years of construction before 2002.

The partitioning of the vehicles with respect to drive system and size class results in the following picture (see Table 21):

- Diesel passenger cars had a portion of 18% in total stocks in Germany, 20% in the questioning.
- The distribution according to size classes differs in the questioning in relation to the vehicle stock in Germany only for the petrol passenger cars: the passenger cars < 1,4l are clearly underrepresented with 13%, while the central and upper class show higher portions than the German stock.

To the indication of the middle yearly road performance four categories were placed to the customer to the selection (see Figure 20). The result shows a clearly larger portion with higher yearly road performances for diesel passenger car. This corresponds to the characteristic values, which were determined up-to-date during the road performance collection 2002/IVT 2005a/ (see [4]).

In the tendency: from the questioning a middle yearly road performance of 13.000 km for petrol passenger car and 19,000 km for the Diesel passenger cars can be measured. The road performance collection 2002 resulted in middle yearly road performance of 12.000 km for petrol passenger cars and 21.000 km/year for diesel passenger cars.

4.1 Type of AC system

In the questionnaire the type of A/C-system was asked. Altogether 227 vehicles were equipped with a manual and 159 vehicles with an automatic A/C-system. Manual systems were most frequently found in smaller petrol vehicles.

Differentiated with respect to the year of construction a trend to automatic systems is recognisable for newer vehicles: Their share rose from 30% in the year 1997 to 60% in the year 2002.

Befragung zur Nutzung von Klimaanlagen

Der RWTÜV führt in Zusammenarbeit mit dem IFEU Heidelberg im Auftrag des Umweltbundesamtes eine Untersuchung zur Nutzung von Klimaanlagen in Pkw durch. Dazu benötigen wir Ihre Mithilfe. Wir möchten Sie daher bitten, ein paar Fragen zu beantworten.

Wichtige Hinweise:
Die Teilnahme an der Befragung ist freiwillig.
Ihre Angaben werden selbstverständlich vertraulich behandelt.
Es werden weder ihre persönlichen Daten noch das Kennzeichen Ihres Kfzs erfasst.

Die folgenden Fragen richten sich an die Mitarbeiter des TÜV.
Die Fragen an den Kunden befinden sich auf der Rückseite

Hersteller des Fahrzeugs: ______________________

Typ/Handelsbezeichnung
(z.B. "Passat") ______________________

Schlüsselnummern lt. Fahrzeugschein   zu 1: ☐   zu 2: ☐   zu 3: ☐

Antriebsart: ☐ Benzin   ☐ Diesel   ☐ andere: ________________

Hubraum (cm^3): ___________________

Leistung (kW): ___________________

Zulassungsjahr: ___________________

Tachostand (km): ______________________

Anlagentyp Klimaanlage: ☐ Ein-/Ausschalter (ungeregelte Anlage)
☐ Temperaturvorwahl (geregelte Anlage)

Hersteller der Klimaanlage (falls Information verfügbar): ______________________________________

Figure 17: Part 1 of the questionnaire about the use of AC systems in cars

Fragen an den Kunden:

Wieviel Kilometer sind Sie im vergangenen Jahr mit dem Fahrzeug gefahren?

☐ bis zu 5.000 km ☐ 5.000-10.000 km ☐ 10.000-20.000km ☐ mehr als 20.000 km

Wie alt ist die Klimaanlage in Ihrem Fahrzeug?

☐ War vom Werk her eingebaut ☐ Wurde nachgerüstet im Jahr ________ ☐ nicht bekannt

Wie oft ist die Klimaanlage schon aufgefüllt worden?

☐ gar nicht ☐ einmal ☐ zweimal ☐ mehr als zweimal ☐ nicht bekannt

Wissen Sie, wo Ihre Klimaanlage ein- und ausgeschaltet wird?

☐ Ja ☐ Nein

Wie regulieren Sie die Klimaanlage?

☐ Durch Ein- und Ausschalten

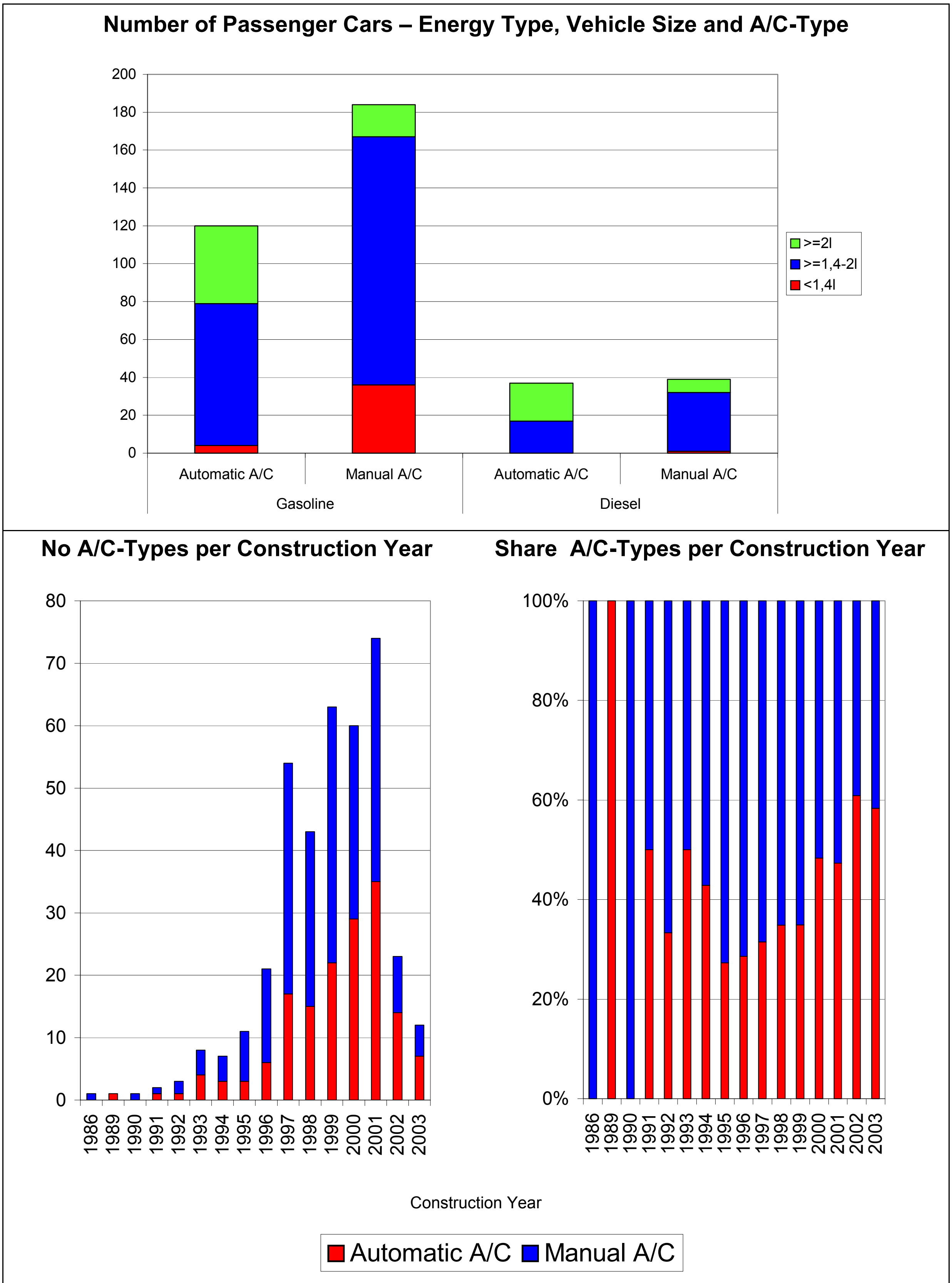
☐ Wenn möglich: durch Vorwahl der Temperatur: im Winter: ______°C im Sommer: ______°C
(Bitte Temperaturen eintragen)

☐ Wenn möglich: Durch Betätigen des Eco-Schalters

Wann benutzen Sie Ihre Klimaanlage? (Bitte kreuzen Sie je Zeile ein Kästchen an)

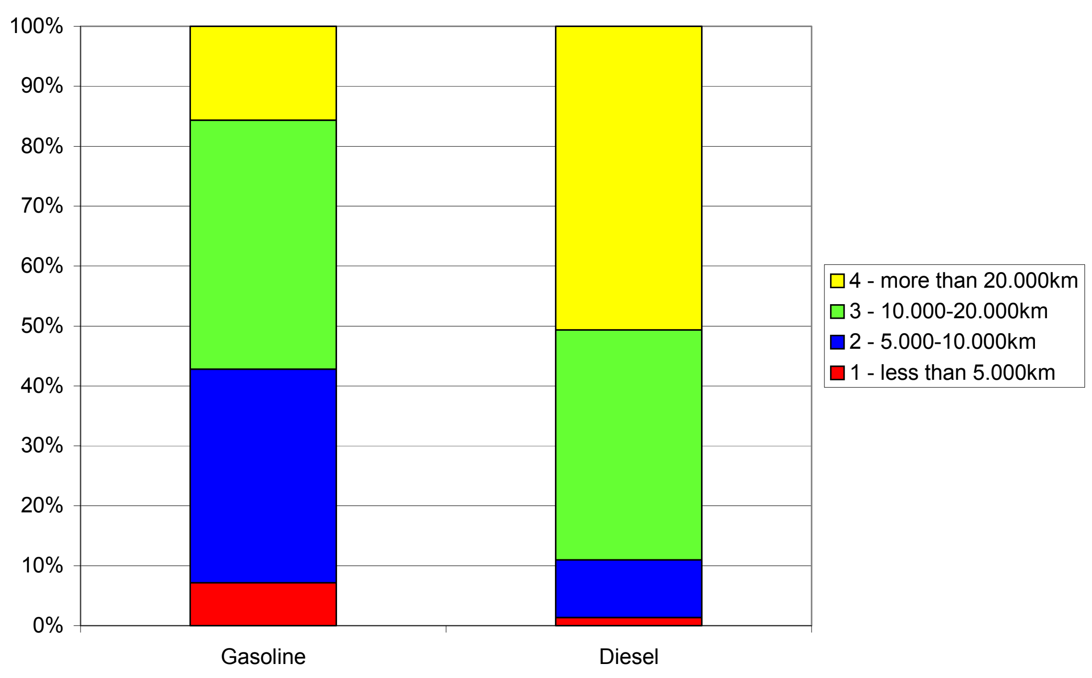
Häufigkeit der Nutzung:	immer	häufig	manchmal	selten	nie
Bei Außentemeraturen von					
weniger als 15 °C (Winter)	☐	☐	☐	☐	☐
15 bis 25 °C (Frühjahr, Herbst)	☐	☐	☐	☐	☐
mehr als 25 °C (Sommer)	☐	☐	☐	☐	☐
Bei beschlagenen Scheiben	☐	☐	☐	☐	☐
Bei kurzen Fahrstrecken (weniger als 5 km)	☐	☐	☐	☐	☐
Bei mittleren Fahrstrecken (5 bis 20 km)	☐	☐	☐	☐	☐
Bei langen Fahrstrecken (mehr als 20 km)	☐	☐	☐	☐	☐
Innerhalb von Ortschaften	☐	☐	☐	☐	☐
Außerhalb von Ortschaften	☐	☐	☐	☐	☐
Auf Autobahnen	☐	☐	☐	☐	☐

Figure 18: Part 2 of the questionnaire about the use of AC systems in cars



Source: Questionnaire RWTÜV/IFEU

Figure 19: Share of A/C-Types – Results of the Questionnaires



Source: Questionnaire RWTÜV/IFEU

Figure 20: Average Annual Mileage of Vehicles

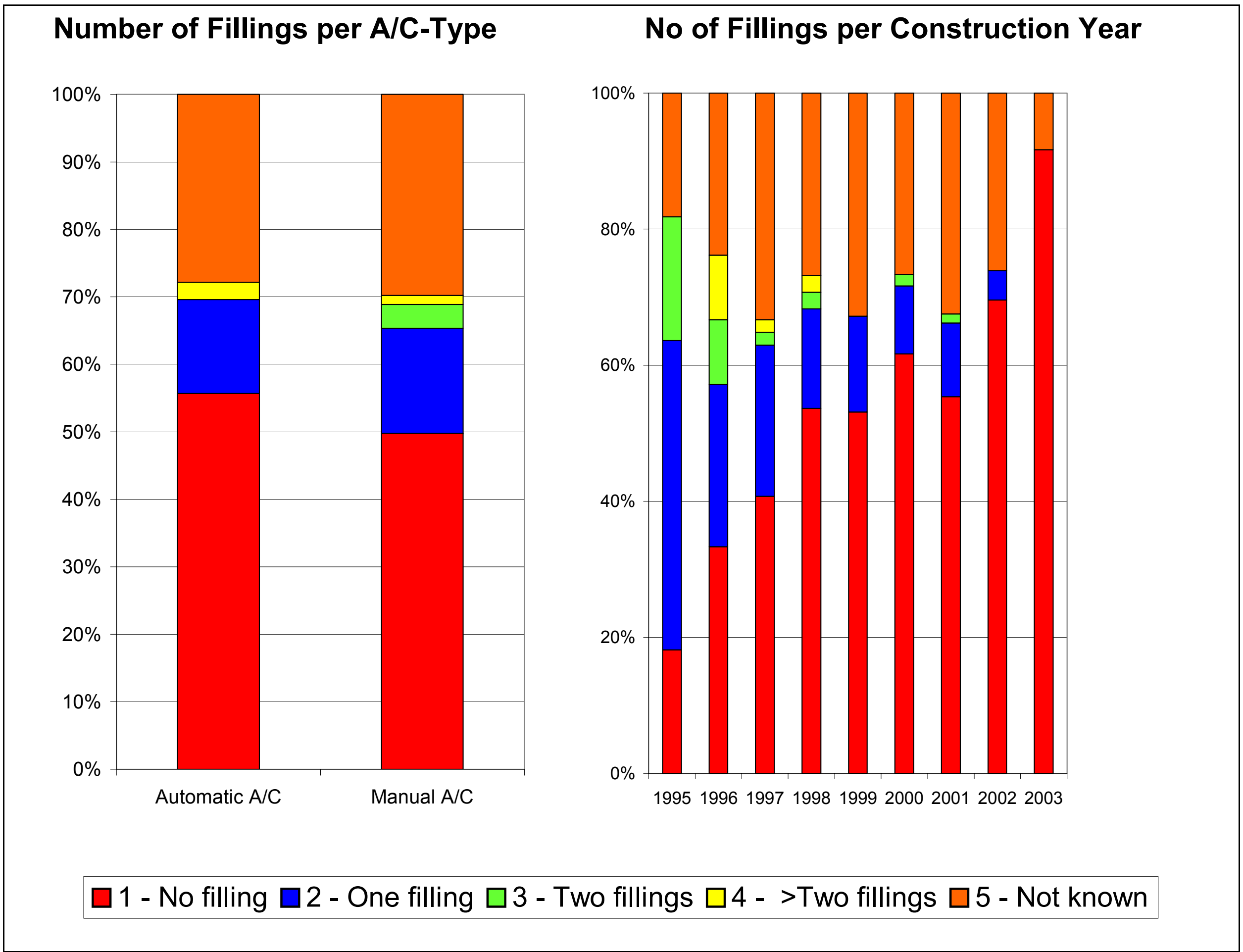
	Questionnaire RWTÜV/IFEU		Vehicle Stock Germany 2003	
	Gasoline	**Diesel**	**Gasoline**	**Diesel**
Share of Energy Types	79%	20%	82%	18%
Share of vehicle Size				
<1,4l	13%	1%	36%	2%
1,4-2l	67%	63%	53%	66%
>2l	19%	36%	11%	33%
Source: Questionnaire RWTÜV/IFEU and KBA				

Table 21: Share of Energy Types and Vehicle Sizes – Result Questionnaire compared with Passenger Car Stock Germany 2003

4.2 Number of replenishments / temperature range

No significant difference between manual and automatic systems was found in the number of replenishments. About 70% of the owner knew something about the replenishments. Half of the owners indicated that the system had never been refilled. As expected the number of systems, which were already refilled, increases with the age (see Figure 21).

Most vehicle owners with automatic systems adjust actively the target temperature. Most frequently a temperature between 20 and 22 degrees is selected. In the summer period the target temperature is slightly higher than in the winter period (see Figure 22).



Source: Questionnaire RWTÜV/IFEU

Figure 21: Number of replenishments per A/C-Type (Share in %)

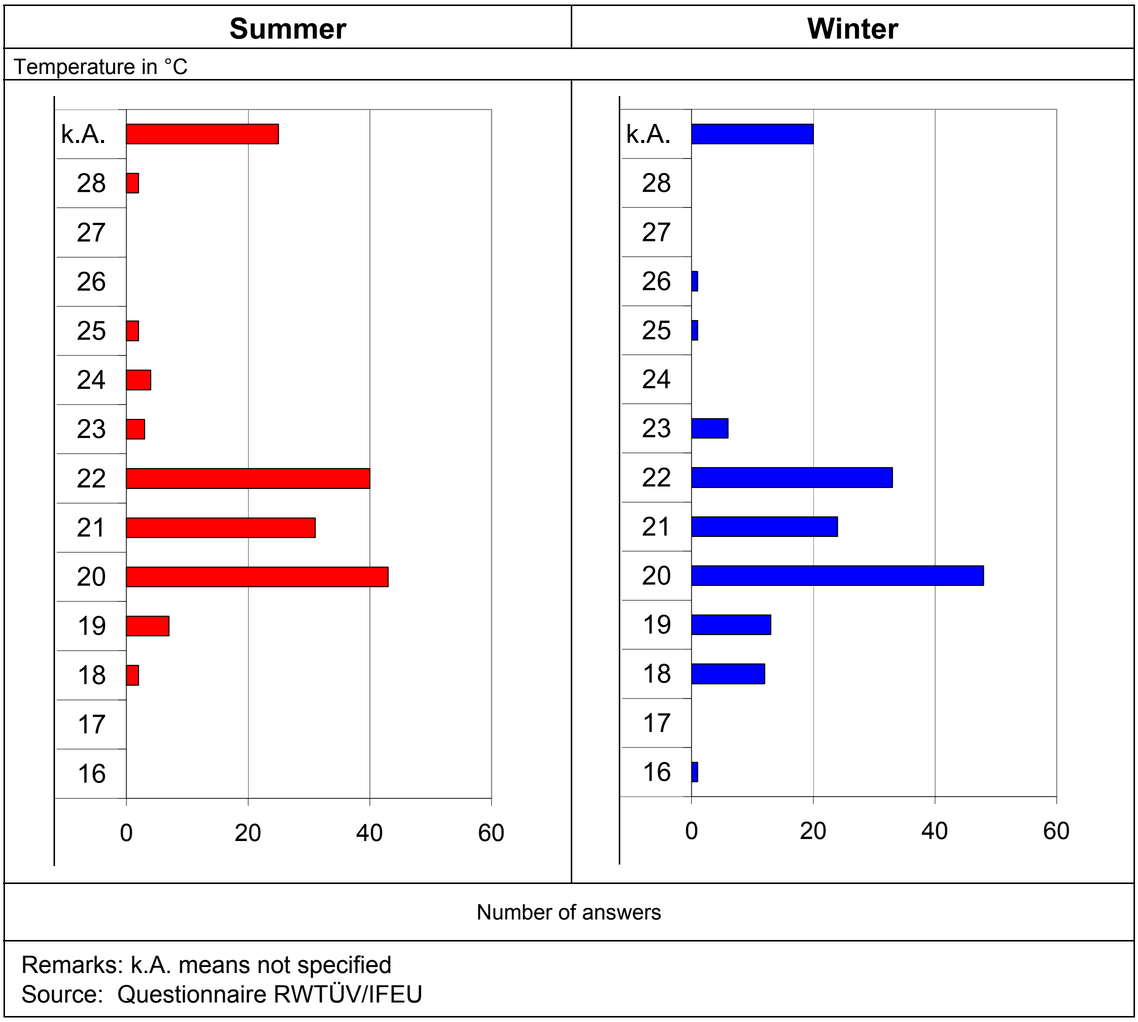
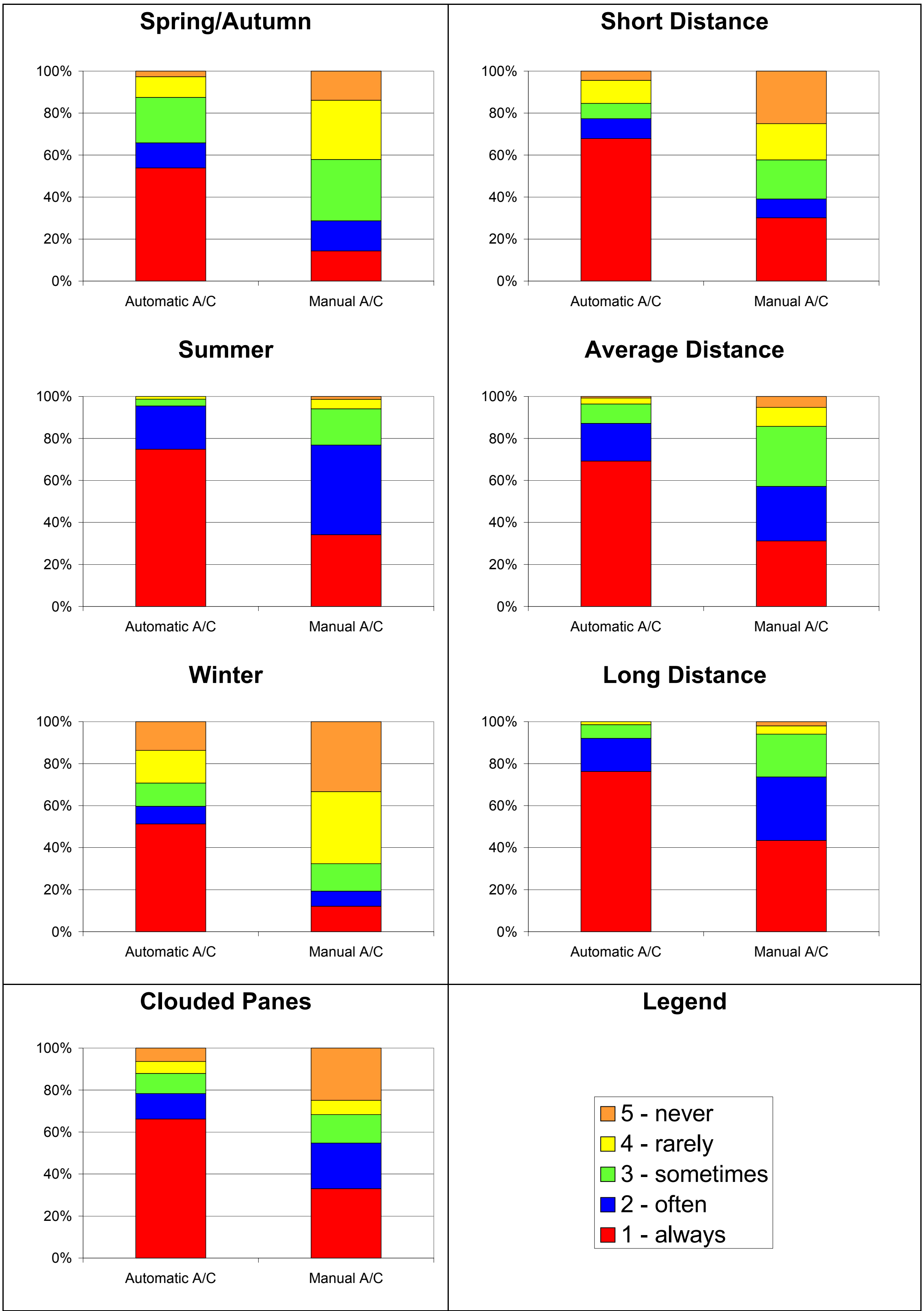


Figure 22: Pre-selected target temperatures for Automatic A/Cs

4.3 Use frequencies

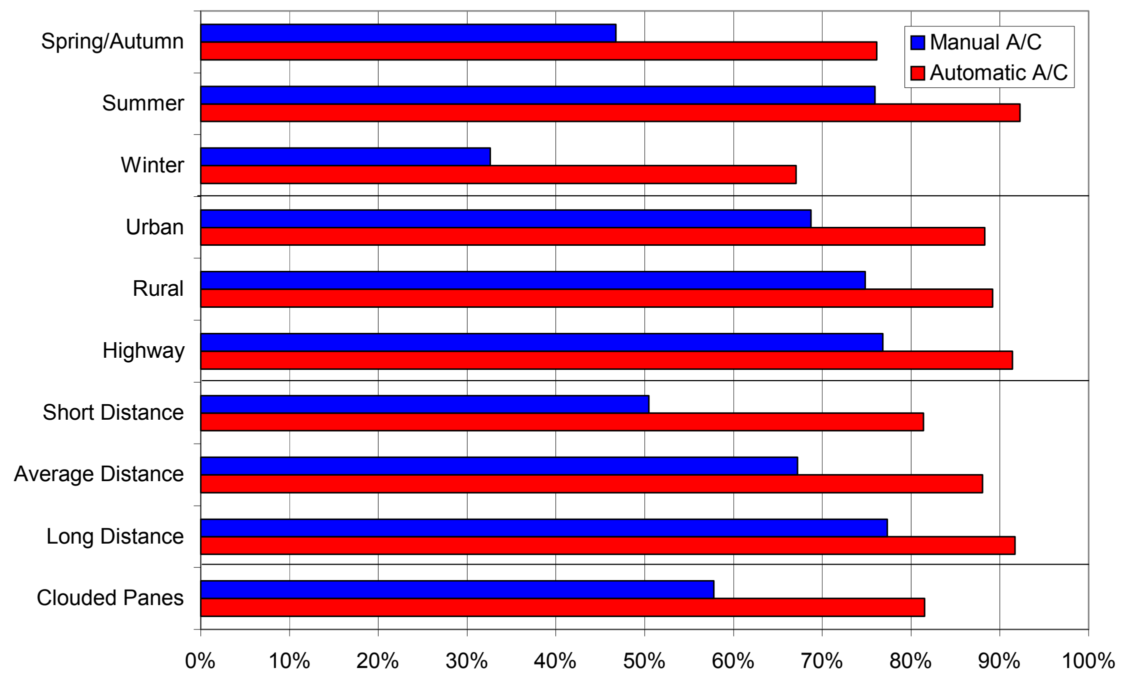
The frequency of the use was queried for three different situation types (season, route distance, high air humidity). The vehicle owners could select between five qualitative categories (see Figure 23). The following results can be stated:

- As expected air conditioning systems are more frequently used at high outside temperatures than at low temperatures in the winter.
- The distance driven has smaller influence on the frequency of use, but the use is a little bit higher for longer distances.
- The road categories do not have significant influence on the switch on/off behaviour of automatic systems; manual systems are switched on more often on urban roads.
- A clear difference is visible between automatic and manual systems: Manual systems are switched off more frequently, while automatic systems are predominantly switched on.



Source: Questionnaire RWTÜV/IFEU

Figure 23: Frequency of A/C-Utilisation in certain Situations



Remark: k.A. means not specified
Source: Questionnaire RWTÜV/IFEU

Figure 24: Average share of utilisation in different situations

If the different use frequencies are proportionally weighted and interpreted as time shares ("always" = 100%,"never"= 0%, the other options evenly distributed), this results in the following average use frequency for different situations (see Figure 24):

- Automatic systems are usually switched on (frequency: over 80%, except in the winter with scarcely 70%).
- Manual systems are switched on clearly more rarely (frequency between 47 and 78%; winter: 33%).
- On long-distances and/or motorways the frequency of use is somewhat higher than on short distances and/or inner urban.
- There is a significant difference of the frequency of use between summer and winter: (Manual systems 33%, automatic systems 68%). In the summer period the automatic systems are switched on for more than 90%, the manual systems approximately 3/4.

5 Results from other investigations

5.1 USA

The first exhaust emission measurements on vehicles equipped with AC systems aiming at the determination of the AC influence were carried out in the US. Measurement results that were used for the revision of the Federal test Procedure are described in [6].

Some of the results are shown in the following tables, which were listed in [6]. They show a tremendous increase in NOx emissions that concerned the US EPA and led to a revision of the Federal test Procedure.

Table 22 shows the results of measurements performed at the environmental testing facility of General Motors at AC Rochester (ACR) in New York.

Test Cycle	A/C	HC	NMHC	CO	NOx
Composite FTP	Off	0.108	0.088	0.965	0.214
	On	0.129	0.110	1.460	0.411
	Diff	19.4%	25.0%	51.3%	92.1%
FTP bag 1	Off	0.389	0.349	3.256	0.416
	On	0.452	0.417	4.715	0.672
	Diff	16.2%	19.5%	44.8%	61.5%
FTP bag 2 & 3	Off	0.036	0.02	0.374	0.164
	On	0.045	0.031	0.631	0.349
	Diff	25.0%	55.0%	68.7%	112.8%
Start cycle (bag 1 of REM01)	Off	0.579	0.523	3.038	0.822
	On	0.549	0.505	3.866	1.569
	Diff	-5.2%	-3.4%	27.3%	90.9%
High speed (bag 1 of REP05)	Off	0.065	0.050	2.033	0.224
	On	0.08	0.062	3.523	0.321
	Diff	23.1%	24.0%	73.3%	43.3%
High load (bag 2 of REP05)	Off	0.283	0.219	17.254	1.029
	On	0.400	0.313	30.504	1.210
	Diff	41.3%	42.9%	76.8%	17.6%

Table 22: Average Bag Emission Data from ACR Test Program (from [6])

The tests were performed under the following side conditions:

- Air temperature 96 °F (35,6 °C)
- Interior temperature 130 °F (54,4 °C)
- Pavement temperature 135 °F (57,2 °C)
- Relative humidity 40%
- Solar radiation 850 W/m²
- Vehicle cooling air flow proportional to vehicle speed

The AC settings were as follows:

- Manual AC:
  - Highest mode (coldest)

- Lowest temperature
- Fan speed between 75% of maximum and maximum
- Recirculation

- Automatic AC:
  - Automatic mode
  - Target temperature 72 °F (22 °C)
  - Other settings like manual, if applicable

The effects of A/C operation on NOx emission levels were more pronounced on the slower speed cycles. For both the FTP and the Start Cycle the NOx emissions increased by about 90 percent. Only half as much percentage increase was seen on the high speed cycle and an even lower increase was seen on the high load cycle. CO emissions also increased during the FTP, however much of that increase may be due to the load effect of air conditioning triggering periods of enrichment.

EPA also analysed the modes of driving where emissions increased. Table 23 summarises the average modal breakdown of NOx emissions calculated from the second-by-second ACR data for the hot stabilized portion of the FTP (bags 2 and 3). As seen in this table, almost half of the emission increase is due to idles and accelerations. This percentage is likely to be higher because the modes which are identified as "Cruises" contain some accelerations and decelerations that contribute to the emissions increase but that are categorized as cruises. EPA has analysed the range of accelerations which occur during a defined "Cruise" mode, finding that emission results peak during the small accelerations included in the cruise, indicating that most cruise-related emissions occur during these acceleration modes. Consequently, the values in the previous table overestimate the effect of true cruises and underestimate the effect of accelerations on NOx emission formation.

A/C	Idle	Acc	Cruise	Dec	Total
Off	0.039	0.581	0.697	0.065	1.382
On	0.286	1.011	1.426	0.222	2.945
Diff	633.3%	74.0%	104.6%	241.5%	113.1%

Table 23: Modal Distribution of NOx Emissions on Bags 2 & 3 (hot stabilized driving) of the FTP (grams)

The most significant impacts from A/C operation were seen at lower speeds, accelerations, and idle. Increases of more than 90% in tailpipe NOx were seen at ACR on both cycles - the LA4 (for passenger cars normally called US FTP 75) and ST01 (Start Cycle) - while the average increase on the higher speeds and accelerations of the REP05 cycle was approximately 38%. Given this, the Agency supposed that a cycle with slow to moderate speeds and a reasonable number of accelerations and idles could address the emissions increases associated with A/C operation.

Since tests with simulation of solar radiation require additional equipment and increase the costs significantly, EPA performed additional tests without solar radiation using the above mentioned settings for the AC systems. A first series of tests were carried out with an ambient air temperature of

75 °F (24 °C). The results only represented about 30 percent of the NOx emissions impact observed on the ACR test (95 °F ambient temperature and with solar radiation), and therefore failed to capture the full amount of NOx emissions increase seen at ACR.

The next condition EPA explored was running with the A/C on in the standard test cell but with the temperature elevated to 95 °F. The test conditions were: temperature was 95 °F, the humidity was 50 grains/pound of dry air (equivalent to about 20 percent relative humidity), there was no sun load, cooling was provided by means of a 15,000 CFM fan, and the drivers' side window was open (other windows were closed). The A/C-on test was run with the A/C mode switch in the maximum/recirculation condition, the temperature slide bar was fully to the cold side, and the fan was set in the third position of four.

A comparison between the NOx emissions on the FTP Bags 2+3 of the ACR data and the 75 °F and 95 °F EPA test program is summarised in Table 24.

	ACR Data, 35 °C			EPA Data, 24 °C			EPA Data, 35 °C		
Test vehicle	**AC off**	**AC on**	**Difference**	**AC off**	**AC on**	**Difference**	**AC off**	**AC on**	**Difference**
Astro van	0.451	0.836	85.4%	0.180	0.298	65.6%	0.180	0.554	207.8%
Transport	0.088	0.404	359.1%	0.286	0.420	46.9%	0.286	0.632	121.0%
Grand Prix	0.144	0.431	199.3%	0.250	0.407	62.8%	0.250	0.594	137.6%
Civic	0.045	0.171	280.0%	0.046	0.154	234.8%	0.046	0.194	321.7%
Intrepid	0.181	0.256	41.4%	0.176	0.092	-47.7%	0.176	0.248	40.9%
Saturn	0.153	0.261	70.6%	0.205	0.242	18.0%	0.205	0.339	65.4%
Caprice	0.084	0.084	0.0%	0.038	0.038	0.0%	0.038	0.027	-28.9%
Average	0.164	0.349	113.2%	0.169	0.236	39.8%	0.169	0.370	119.1%

Table 24: NOx Emissions (g/mi) in the Weighted FTP Bag 2 + Bag 3

The data shows a very close match of the NOx emissions increase seen at ACR with the NOx emissions identified by a 95 °F test without sun load. Individually, all the vehicles had similar emission differences as those seen at ACR. The 95 °F differences split evenly between higher and lower than ACR data. Although the number of points is small, there is over 85 percent statistical probability that the two tests yield identical differential NOx emission results.

EPA concluded that the 95 °F test without solar radiation would be sufficient enough for the determination of the AC influence on exhaust emissions. But this method does not take into account the positive effect of specialized glass that transmits less heat from the sun to the interior of the vehicle on the emissions and the fuel consumption.

5.2 EMPA measurement results

The EMPA in Dübendorf carried out exhaust emission and fuel consumption measurements for a fleet of six modern gasoline passenger cars equipped with AC systems within the DACH+NL (German, Austrian, Swiss, and Dutch) co-operation on vehicle emission monitoring. The vehicles were tested in different weather conditions (see [1]). Separate test series were carried out for the initial cool down and for the stationary situation of keeping the interior of the vehicle cool. As assumed, CO_2 emissions and fuel consumption rise with the thermal load. This also causes a notable rise in CO and hydrocarbons (HC). Moreover, A/Cs do not stop automatically at low ambient temperatures; if necessary, they produce dry air to demist the windscreen. A model is proposed that shows a constant load for lower temperatures and a linear trend for higher temperatures. The initial cool down tests highlight significant differences among cars but show that A/C operation for the initial cooling of an overheated passenger compartment does not result in any extra emissions for the fleet as a whole.

The results can be summarised as follows:

- A/Cs cause extra CO_2 emissions in g/km and thus fuel consumption that increase:
  - significantly with temperature
  - sharply with solar irradiation
  - significantly with lower vehicle speed, but A/C efficiency decreases significantly with higher vehicle speed
- The maximum average extra CO_2 results in urban driving at 37 °C and with the sun shining. It amounts to 82.7 g/km (26%). Extra CO_2 emissions are not zero but 2.4-18 g/km (1.5-7%) at 13 °C and below, owing to demisting activity. This highlights the difference compared to the American situation.
- For fleet statistics this finding will significantly increase the extra fuel consumption due to A/C activity. On the basis of specific temperatures in the A/C systems, the influence of humidity is estimated. This shows that for high humidity the load almost doubles and that for low humidity the load is reduced by some 10-50% in relation to the measured case of 50% relative humidity.
- CO and HC emissions show a relevant trend towards higher emissions (factor 2 between 23 °C with the A/C off and 37 °C with the A/C on) over A/C activity. However, the vehicle sample is too small for a statistically reliable model. The trend in NOx emissions is quite small.
- For the stationary situation of keeping the interior cool at already reached target temperature, a model is suggested that shows a constant A/C load at low temperatures and a linearly increasing trend at higher temperatures. This model is to be individually applied to the sunny and shady situation as well as to urban, rural, and highway driving. For the emission model of CO, HC, and NOx, more vehicles need to be measured to reach statistical significance.
- For the emissions CO_2, CO, HC, and NOx roughly no additional extra portions are emitted for the initial cool down situation. No calculation model is therefore necessary for this case. The influence on particulate emissions cannot be described because only vehicles with petrol engines were investigated.

6 Summary, conclusions and recommendations

6.1 Tasks and measurement programme

The measurement of fuel consumption and CO_2 emissions has become mandatory during the type approval procedure for M1 vehicles (cars) in the EU with the introduction of directive 93/116/EC. Within the context of the discussions about the global warming of the atmosphere the lowering of the CO_2 emissions and thus the lowering of the fuel consumption has become an important target for the vehicle industry. But the measurement method of the above mentioned directive is not suitable to consider influences of additional aggregates like air conditioning systems or the influence of new transmissions (6-speed gearboxes, advanced automatic gearboxes) allowing fuel consumption reducing gearshift strategies. Without these influences the CO_2 emissions of the car fleet cannot be calculated realistically enough.

In order to get quantitative information about the variances of CO_2 emissions and fuel consumption as well as the limited pollutants the following influences should be considered within the frame of this project:

- Different versions of a vehicle type
- Different gearshift strategies
- Air conditioning system (AC)

Another task was related to information about the use of air conditioning system in cars. This task was performed together with IFEU, Institut für Energie- und Umweltforschung Heidelberg GmbH. IFEU developed a questionnaire about the use of the AC. This questionnaire was presented to customers at several stations of TUEV Nord, where inspections at regular intervals were performed. The questionnaires were then sent to IFEU for further analysis.

The influences of vehicle version and gearshift strategy can be measured on ordinary test benches. But the influence of an air conditioning system requires a special test bench with solar radiation equipment if the worst case shall be included. Since TUEV Nord does not have such a test bench, it was originally planned that vehicle manufacturers would allow TUEV Nord to use their test benches for the measurements and that they support the project by additional funding in order to increase the number of test vehicles.

Unfortunately the vehicle industry refused to co-operate so that only four cars could be measured during this project. All of them were equipped with an air conditioning system. Two of them (no. 3 and 4) were measured with the air conditioning systems working on a test bench with solar radiation at the Delphi facilities in Luxembourg.

The following driving cycles were included in the test bench measurements:

- The European type approval test cycle (NEDC), consisting of four urban cycles and an additional extra urban cycle
- The US type approval test cycle (US FTP 75)
- The Common Artemis driving cycle (CADC), consisting of an urban, a rural and a motorway part

The vehicles were tested in different vehicle modifications (tyres, mass, spoiler etc.), different gearshift strategies (as foreseen in the directive and with gearshifts at lower/higher engine speeds), two different start temperatures and with and without AC operation and in one case in some additional conditions.

The above mentioned variants were not fully applied to each vehicle and cycle.

6.2 Results of the test bench measurements

6.2.1 Bag results

The bag results for the pollutants CO, HC, NOx, the CO_2 emissions and the fuel consumption were measured/calculated and analysed. The CO_2 emissions include the HC- and CO-contributions. The fuel consumption is calculated from the CO_2 emission as foreseen in 93/116/EC. The major part of the measurements was carried out two times. The test bench settings were adjusted to the results of coast down measurements on a test track.

With one exception the measurement results for the base case (type approval variant) and the other variants for HC and NOx are far below the EURO IV limit values for the NEDC. Even the results for the other variants do not reach the limit values for both pollutants, if the AC is switched off. The situation is a bit different for CO. The base case result is below the limit value, but for optimised gearshifts the CO emission exceeds the limit value and also the HC emissions are significantly higher, although this operation results in a CO_2 emission reduction.

There is a general tendency for the NEDC that HC and CO emissions decrease with increasing CO_2 emissions while NOx follows the CO_2 trend. And it must also be mentioned that the emissions of HC and NOx tend to zero for extra urban driving conditions. This is also the case for CO, but only for the NEDC.

Due to the higher speed range and dynamics the CADC cycle results show generally higher emission levels and variances between the variants than the other two cycles. The HC and NOx emissions are still low compared to the EURO IV limit values. But the CO emissions are high, even in hot conditions. If the AC operation variant is disregarded, the two extremes are formed by the two extreme gearshift prescriptions: optimised gearshifts leading to the lowest CO_2 emission and gearshifts at 4000 min^{-1} leading to the highest CO_2 emission.

The total gearshift related differences for the CO_2 emission are about 25% for urban and rural operation. For motorway operation the gearshift related differences are below 2%, which can be expected because motorway operation is predominantly carried out in the highest gear.

On the other hand, the vehicle related differences (worst case versus best case) increase with increasing speed. For urban operation the CO_2 emission difference is lowest and highest for motorway operation. This tendency can also be found in the NEDC results.

One of the vehicles was equipped with a Diesel engine. For this vehicle the CO and HC emissions are close to zero for all cycles. On the other hand, the reduction strategy for NOx seems to be optimised for the type approval test cycle.

The smallest vehicle was equipped with a simple air conditioning system that was controlled by on and off operation. The NEDC was driven with and without AC operation at the TUEV Nord test bench with a start temperature of 23 °C and the AC set to full cooling capacity. Already this operation led to significant differences in the emissions. With AC the CO_2 emissions were 37,4% higher. The CO emission was increased by 141%, the NOx emissions were 10,9 times higher than without AC.

The differences with and without AC were much more drastic for the tests with solar radiation. In this case the room temperature was set to 35 °C and the solar radiation was 850 W/m². This operation led to extremely high emissions (+53% for CO_2, 9,5 times higher value for HC, 63 times higher value for NOx and 193 times higher value for CO). The NOx emission with solar radiation and a starting temperature of 35 °C was 0,45 g/km instead of 0,08 g/km, the CO emission 9,9 g/km instead of 0,12 g/km. This leads to the conclusion that the catalytic converter was totally out of operation during this test.

In several cases the NOx values for the CADC were significantly higher than for the NEDC and sometimes far above the limit values for EURO IV. The CADC was created within the 5th framework project "Artemis" and was used for the development of emission factors for modelling purposes.

6.3 Analysis of modal data

6.3.1 General

For the major part of the measurements second by second emission data was also measured and analysed. This data gives some explanations for unexpected results related to the pollutant emissions. The analysis showed for example that in some cases the CO and HC emission is just a cold start problem, because the emission tends to zero after the second UDC.

The analysis of the modal data was focussed on two main issues:

- Cold start influence
- Influence of air conditioning systems

6.3.2 Cold start influence

In order to assess the cold start influence the emissions were summarised for each cycle part separately. For the NEDC the emissions of the first two UDCs and the last two UDCs were added. The cold start contribution could then be calculated by the differences between both values. A similar approach could be used for the US FTP cycle by comparing the emissions of the first and the third cycle phase. The results were averaged over the different variants, because no significant variant influence could be found.

The cold start contributions varied between 64% and 98% for HC and CO.

For NOx the situation is different. There is only a slight effect of the cold start contribution on the total emissions for the Diesel vehicle, but a significant effect for the petrol vehicles (varying between 29% and 96%. The cold start increases the CO_2 emissions by between 9% and 22%.

6.3.3 Influence of air conditioning systems

The significant influence of air conditioning systems was already discussed in chapter 3.1 for each single vehicle. In this chapter the results shall be analysed more detailed. For that reason the second by second CO_2 emissions with and without AC operating are plotted versus vehicle speed for the NEDC and the CADC. “With AC” means tests at the TUEV Nord test bench with a room temperature of 23 °C, “with AC and solar radiation” means tests at the Delphi test bench with solar radiation of 850 W/m² and a room temperature of 35 °C.

The regression curves of the second by second data plotted versus vehicle speed show that the AC causes higher CO_2 emissions over the whole speed range. In addition there are distinctly different results between the vehicles and driving cycles on the TUEV Nord test bench with a room temperature of 23 °C and the Delphi test bench with solar radiation of 850 W/m² and a room temperature of 35 °C. The differences between both situations can be explained by the different start temperatures and cool down conditions. The results support the hypothesis that the extra emission of CO_2 in g/h is roughly constant over the vehicle speed.

The lowest influence on the emissions was found for vehicle 1, the highest for vehicle 3. One could assume that the influence on the emissions decreases with increasing rated power of the vehicle, but the vehicle sample is too small and inhomogeneous to support this hypothesis.

With respect to the pollutant emissions it should be mentioned first that there was an increase of the HC emissions in the major part of the results but on such low level, that this is no issue of concern.

Vehicle 3 showed already a high influence of the AC on the emissions for a temperature of 23 °C and no solar radiation. At a temperature of 35 °C and with solar radiation the additional load on the engine was that high that catalytic converter light off occurred, resulting in a tremendous increase of all pollutant emissions. It should be proven in the future whether this behaviour in typical for small cars and non automatic systems or if the vehicle was just an outlier.

For the other vehicles there is no uniform trend for the influence of the AC on the CO emissions, but at 35 °C and with solar radiation the CO emissions can be tremendously increased (up to a factor of 20).

The NOx emissions show a general trend to higher values with AC operation, but the increase depends very much on the individual vehicle. With solar radiation and a start temperature of 35 °C the increase in NOx emissions can amount up to 280%.

6.4 Questionnaires about the use of air conditioning systems in cars

Between summer 2003 and spring 2004 a questioning was accomplished by TUEV Nord during the vehicle general inspection, in order to be able to estimate the utilisation of air conditioning systems in passenger cars. Basis of the questioning was a questionnaire, which was developed by IFEU and co-ordinated with the Federal Environmental Agency and TUEV Nord. It contained questions to the clients of TUEV Nords annual inspection stations related to the vehicle (manufacturer, type, key number, drive system, capacity, registration year, mileage), to the air conditioning system (type and manufacturer of the air conditioning system) as well as questions to the customers about the use of the air conditioning system.

Altogether 388 questionnaires were filled out and evaluated. Due to this number and to the circumstance that only tester and customers of the RWTUEV/TUEV Nord were asked, the results can not clearly be regarded as representative for the use behaviour in Germany. Since it concerns qualitative statements however predominantly, the evaluation gives a good reference point for the user behaviour, particularly since no investigations were available for us, which determined the air conditioning system use more comprehensively.

The questions were predominantly completely answered, so that nearly all inquired information could be evaluated.

Type of AC system

In the questionnaire the type of A/C-system was asked. Altogether 227 vehicles were equipped with a manual and 159 vehicles with an automatic A/C-system. Manual systems were most frequently found in smaller petrol vehicles. Differentiated with respect to the year of construction a trend to automatic systems is recognisable for newer vehicles: Their share rose from 30% in the year 1997 to 60% in the year 2002.

If the different use frequencies are proportionally weighted and interpreted as time shares ("always" = 100%,"never"= 0%, the other options evenly distributed), this results in the following average use frequency for different situations:

- Automatic systems are usually switched on (frequency: over 80%, except in the winter with scarcely 70%)
- Manual systems are switched on clearly more rarely (frequency between 47 and 78%; winter: 33%)

6.5 Conclusions and recommendations for emission inventory modelling

The results of this study clearly demonstrated that there are significant influences on the CO_2 emissions and the fuel consumption related to vehicle and gearshift variants in the order of 10% to 15%. Since it can be assumed that the vehicle manufacturer uses an optimised vehicle for the type approval procedure the CO_2 emissions of the same type in real traffic is higher. In addition to that a comparison of the results for the NEDC and CADC leads to the conclusion that the CO_2 emissions in real traffic are systematically higher than indicated by the type approval results. To be on the safe side one can assume that the CO_2 emissions in real traffic are 15% to 20% higher than for the type approval cycle.

An optimised gearshift strategy (gearshifts at low engine speeds) results in a reduction of the CO_2 emissions in the order of 10%, but may lead to an increase of CO and NOx emissions. It should be discussed with vehicle manufacturers whether this increase can be avoided by further optimisations of the emission reduction systems. Anyway, campaigns like ECO driving should be supported as good measures for CO_2 reduction.

The results of the measurements performed with air conditioning systems in operation show quite clearly that their contribution to CO_2 emissions cannot be disregarded for emission inventories. If one considers in addition the results from EMPA (see [1]), where measurements were carried out at a series of different room temperatures one has to take into account the fact that the air conditioning systems even consume power and thus increase the CO_2 emissions, if the temperature is below the target temperature (20 °C to 23 °C), because the AC is used to dry the air of the vehicle compartment.

For modelling purposes the following approach is proposed. From the existing results estimates should be derive about the additional CO_2 emission in g/h caused by the air conditioning system as function of the temperature with and without solar radiation. These functions can then be combined with the statistical information from the questionnaire and additional information about the annual variations of the temperature and sunny/cloudy days in a specific region in order to estimate the air conditioning contribution to the CO_2 emission for emission inventories.

But more measurement results are necessary in order to bring the uncertainty of such a calculation down to a reasonable level.

6.6 Proposals for an amendment of the EU Directive 93/116/EC

6.6.1 Best case / worst case measurements

The results of this research project have clearly shown that the CO_2 emissions for the NEDC test cycle can vary up to 30% for a specific vehicle type, due to vehicle and driving behaviour variations. Vehicle variations are related to differences in tyres, kerb mass, battery capacity etc., driving behaviour variations are related to different gearshift strategies. The vehicle variations influence increases the driving behaviour variations influence decrease with increasing speed. It is very likely that the CO_2 emission obtained by the current EU Directive 93/116/EC for a vehicle type is at the lower end of the variation range.

That means that this result cannot be used as a representative value for the whole range of different variants of the vehicle type. In order to get information about the variation range for the CO_2 emissions it is proposed to amend the regulation in that way that the best and the worst case of a vehicle type family has to be measured.

Furthermore in order to improve the precision of the measurement tolerances for influencing parameters should be reduced.

In particular the following requirements are proposed:

- The test bench settings shall be adjusted on the basis of on road cost down measurements, individually applied to the best and the worst case vehicles.
- For both variants (best and worst case vehicle) only OEM tyres with an inflation pressure as recommended by the manufacturer shall be used. The settings for chassis and brakes shall comply with the normal settings of these variants.
- The capacity of the electric battery shall be between 80% and 90% of maximum capacity for both variants in order to be better in line with practical use.
- The worst case shall include all power consumptive auxiliaries such as power steering compressor, suspension compressor, air compressor, seat heatings etc.
- The gearshift prescriptions for manual transmissions shall be brought more in line with practical use as proposed in Annex B – Proposal for realistic gearshift prescriptions. Corresponding gearshift prescriptions, based on the same approach as described in Annex B, are used, accepted and validated for the ECE global technical regulation for the exhaust emission measurements for motorcycles (WMTC, see [7]). The gearshift prescriptions in Annex B represent two different driving behaviours: “average” and “high revs”. The best case measurements shall be carried out using the gearshift prescriptions for “average” driving behaviour, the worst case measurements shall be carried out using the gearshift pre-

scriptions for “high revs”. For automatic transmissions the manufacturers recommendations shall be used for the best case, the most “sporty” mode shall be used for the worst case. Adaptive transmissions need to be conditioned accordingly before the measurements.

It may be discussed whether the measurement of the best case could be skipped in order to keep the measurement effort low.

6.7 Air conditioning systems

Air conditioning systems shall be covered by a third test. There is no need to include a cold start in this test, because the investigations reported in [1] did not show significant differences in the emissions with and without air conditioning systems during the cold start phase. The following parameters are proposed for the test with air conditioning system:

- Hot start condition
- Vehicle, test bench settings and gearshift prescriptions as for the best case, because only the influence of the air conditioning system shall be measured. If only the worst case has to be measured, this case has also to be used for the measurements with the air conditioning system working
- Air temperature 35 °C
- Relative humidity between 40% and 50%
- Solar radiation of 850 W/m², directed to the front screen of the vehicle
- Vehicle cooling air flow proportional to vehicle speed
- The AC settings shall be as follows:
  - Manual AC:
    - Highest mode (coldest)
    - Lowest temperature
    - Fan speed max.
    - recirculation
  - Automatic AC:
    - Automatic mode
    - Target temperature 72 °F (22 °C)
    - Other settings like manual, if applicable

The solar radiation is necessary in order to take into account the positive effect of specialized glass that transmits less heat from the sun to the interior of the vehicle. The radiation shall be activated three hours before the measurements in order to heat the interior of the vehicle. This requires that the windows are closed.

6.8 Conclusion

The results for best case (if to be measured) and worst case as well as for the extra emissions of the air conditioning system shall be made mandatory for declaration and shall be available as information for customers.

6.9 More realistic driving cycle

On a long term perspective the current type approval cycle (NEDC) shall be replaced by a more realistic cycle based on real world driving behaviour data analysis, as already done for motorcycles.

7 Literature

[1] **Martin Weilenmann et al.** Influence of Mobile Air-Conditioning on Vehicle Emissions and Fuel Consumption: A Model Approach for Modern Gasoline Cars Used in Europe

Published in ENVIRON. SCI. & TECHNOL., American Chemical Society, 2005

[2] **Heusch-Boesefeldt 1993a** Bartelt et. al., Heusch-Boesefeldt, Jost, P. et al., TÜV Rheinland: Untersuchungen des repräsentativen Fahrverhaltens von Pkw auf Stadt- und Landstraßen; im Auftrag des Umweltbundesamtes; Köln 1993

[3] **IFEU 2005a** Knörr, W: et al., IFEU: Fortschreibung „Daten- und Rechenmodell": Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2030; im Auftrag des Umweltbundesamtes; F+E Vorhaben 204 45 139; Dessau/Heidelberg, Dezember 2005

[4] **IVT 2005a** Hautzinger, H. et al, IVT: Fahrleistungserhebung 2002 – Inländerfahrleistung; Im Auftrag der Bundesanstalt für Straßenwesen ; Berichte der Bundesanstalt für Straßenwesen, Verkehrstechnik, Heft V 120; Bergisch Gladbach, Mai, 2005

[5] **Öko-Recherche 2001** Schwarz, W., Öko-Recherche: Emissionen des Kältemittels R134a aus mobilen Klimaanlagen; im Auftrag des Umweltbundesamtes; Frankfurt a.M., September 2001

[6] **Final Technical Report on Air Conditioning for the Federal Test Procedure Revisions**, Notice of Proposed Rulemaking, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, January 1995

[7] **H. Steven**, Worldwide Harmonised Motorcycle Emissions Certification Procedure, Technical report for the ECE-GRPE, Document TRANS/WP.29/GRPE/2004/10, March 2004

[8] **ROTRANOMO**, Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures, DELIVERABLE 42 - INTERMEDIATE REPORT ON THE POWERTRAIN MODEL, June 2004

8 Annex A – Figures with results of the modal data analysis

8.1 CO_2 emission

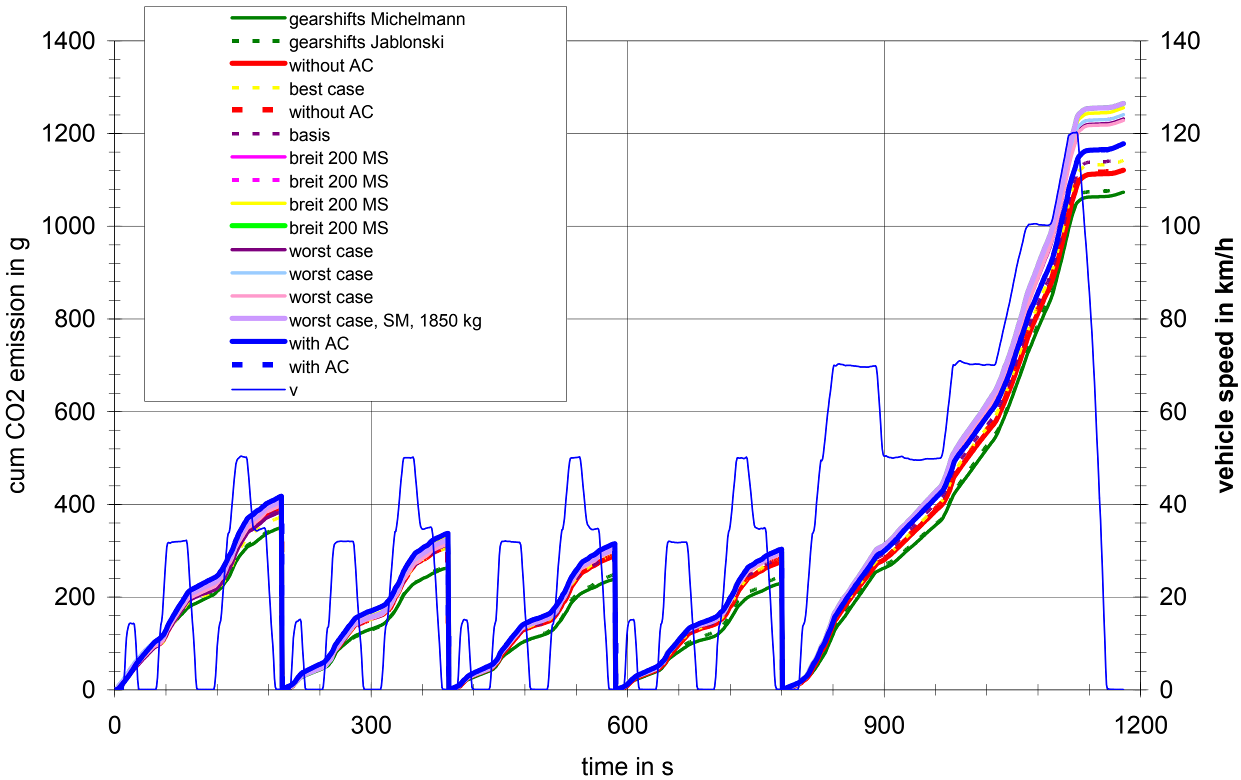


Figure 25: Cumulative CO_2 emission for the different NEDC parts, vehicle 1

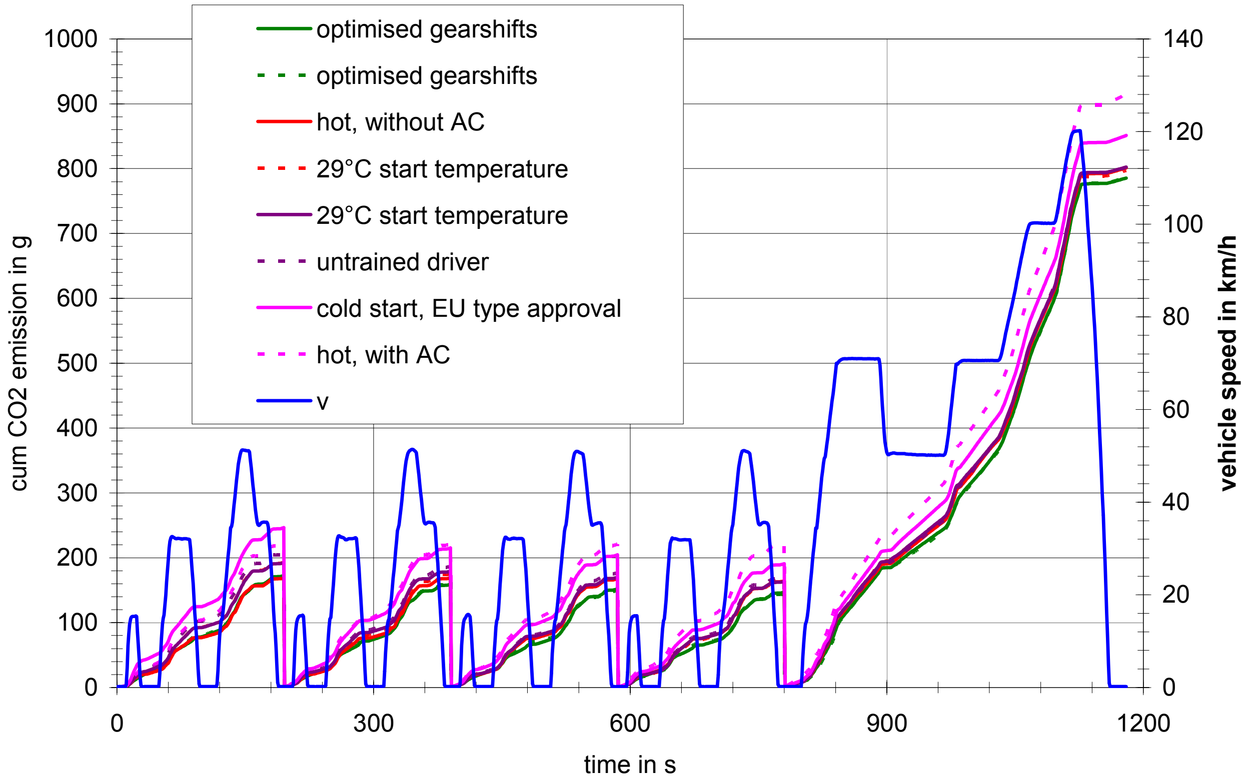


Figure 26: Cumulative CO_2 emission for the different NEDC parts, vehicle 2

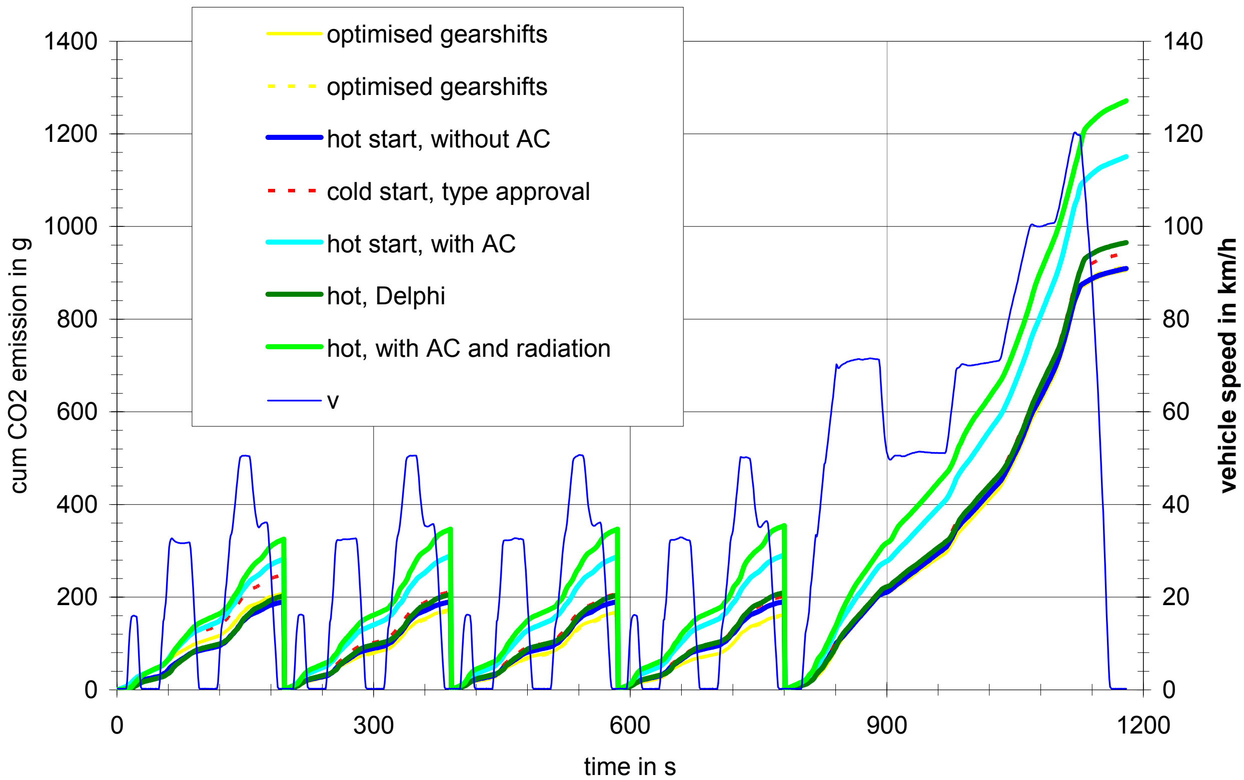


Figure 27: Cumulative CO_2 emission for the different NEDC parts, vehicle 3

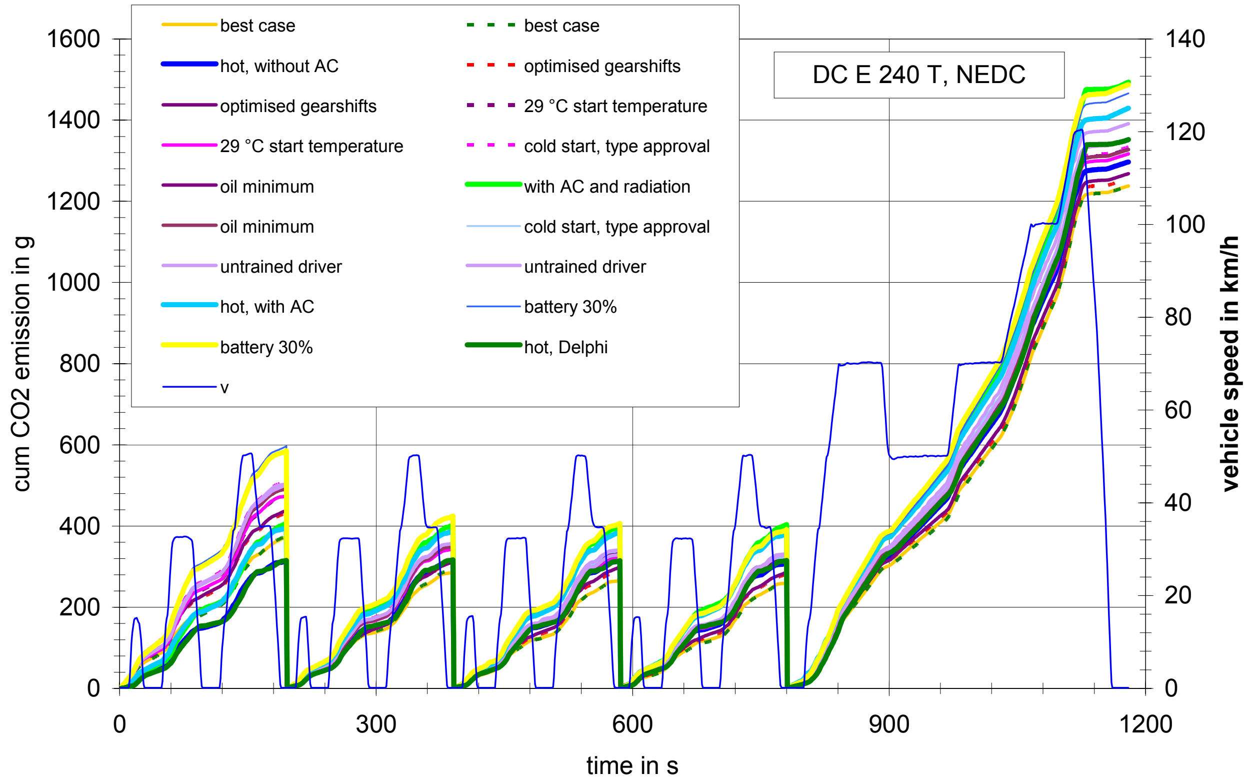


Figure 28: Cumulative CO_2 emission for the different NEDC parts, vehicle 4

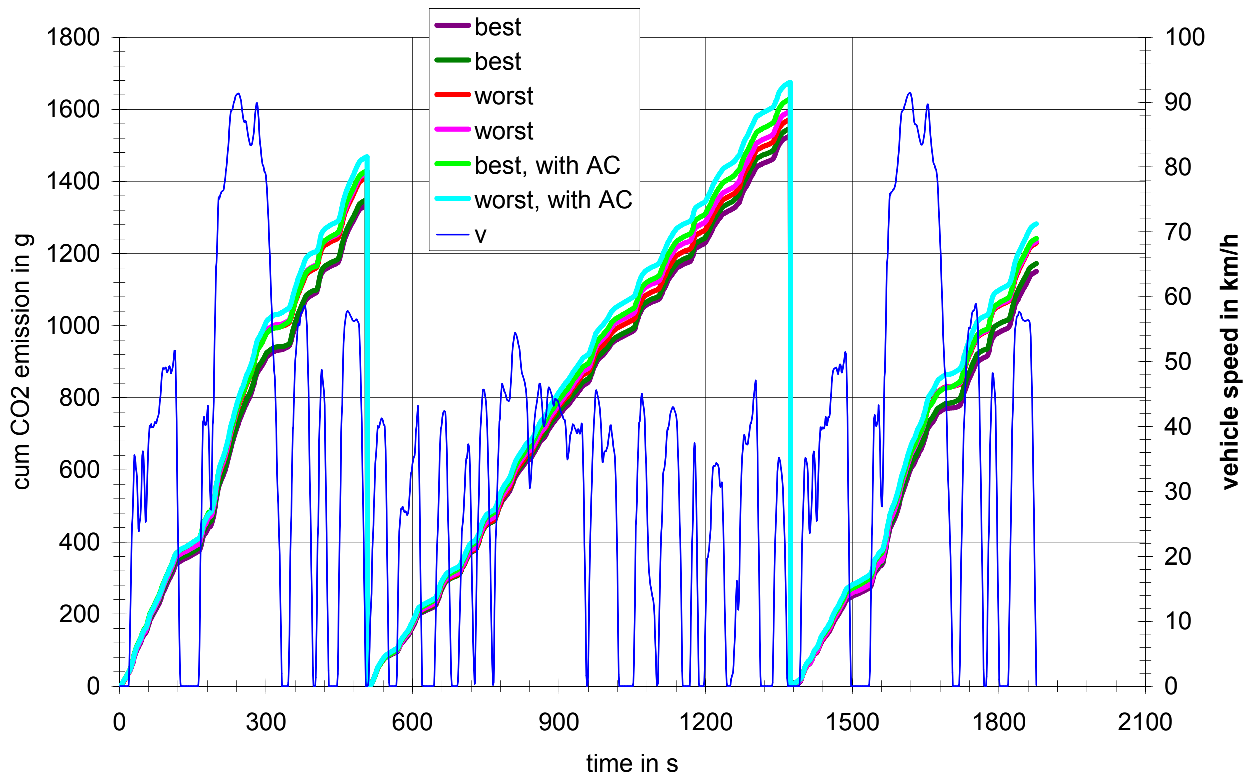


Figure 29: Cumulative CO_2 emission for the different US FTP 75 parts, vehicle 1

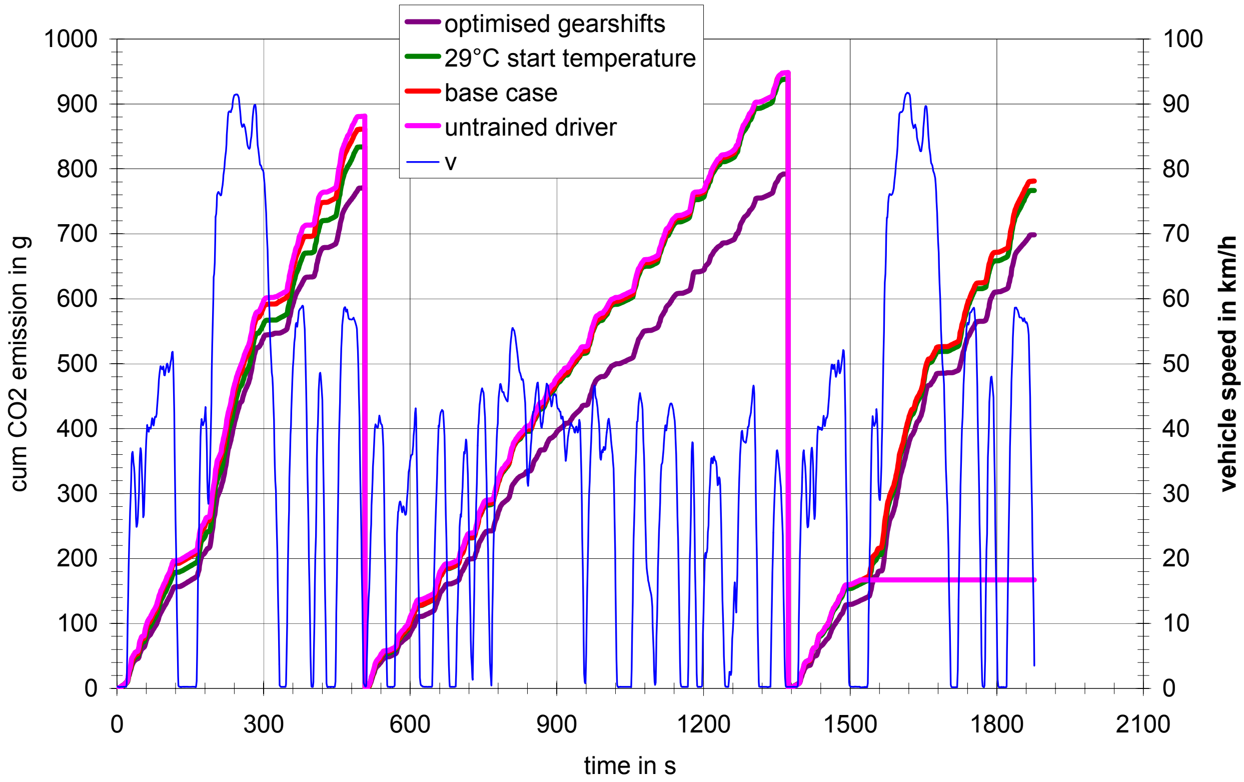


Figure 30: Cumulative CO_2 emission for the different US FTP 75 parts, vehicle 2

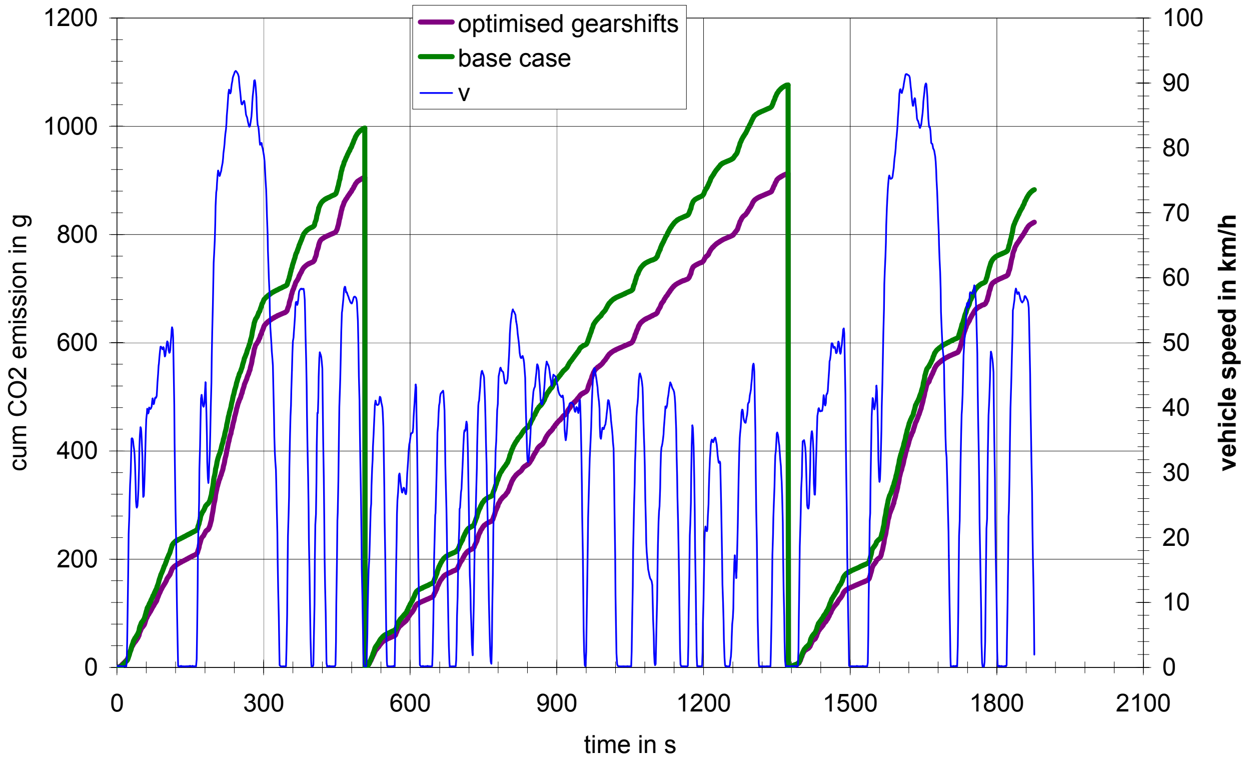


Figure 31: Cumulative CO_2 emission for the different US FTP 75 parts, vehicle 3

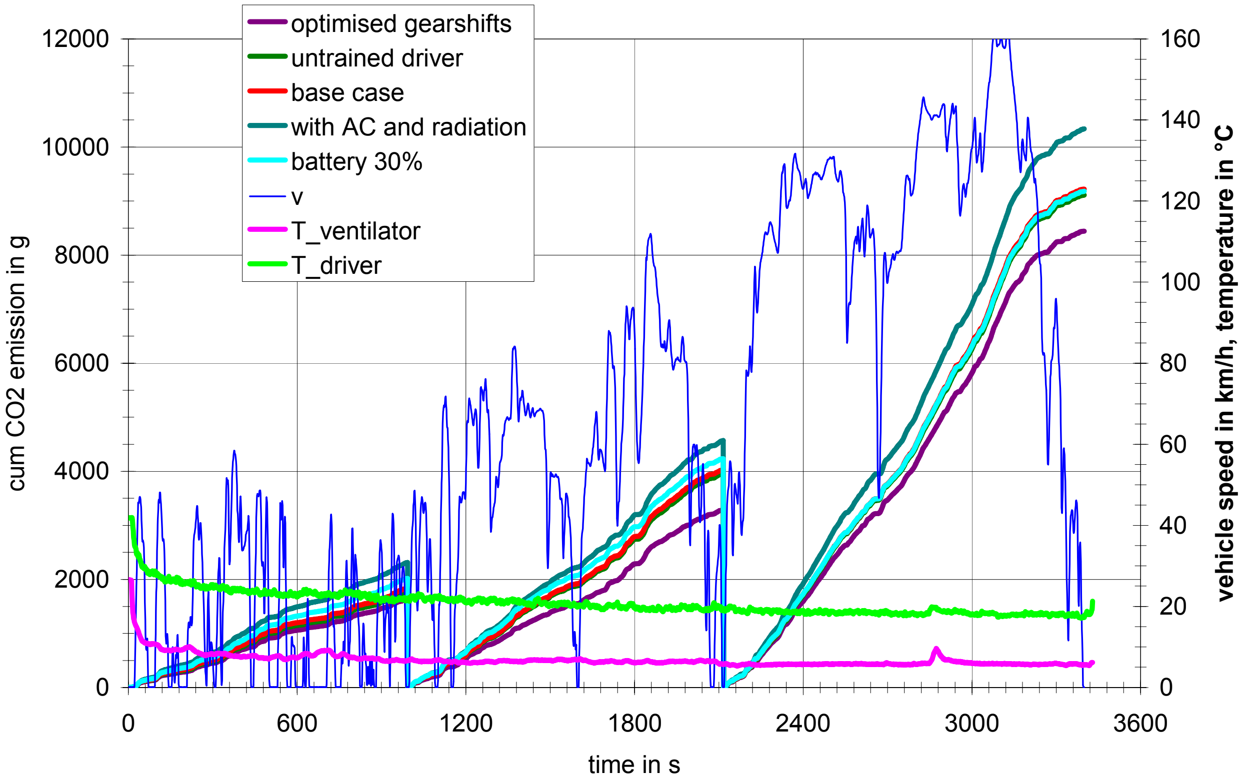


Figure 32: Cumulative CO_2 emission for the different US FTP 75 parts, vehicle 4

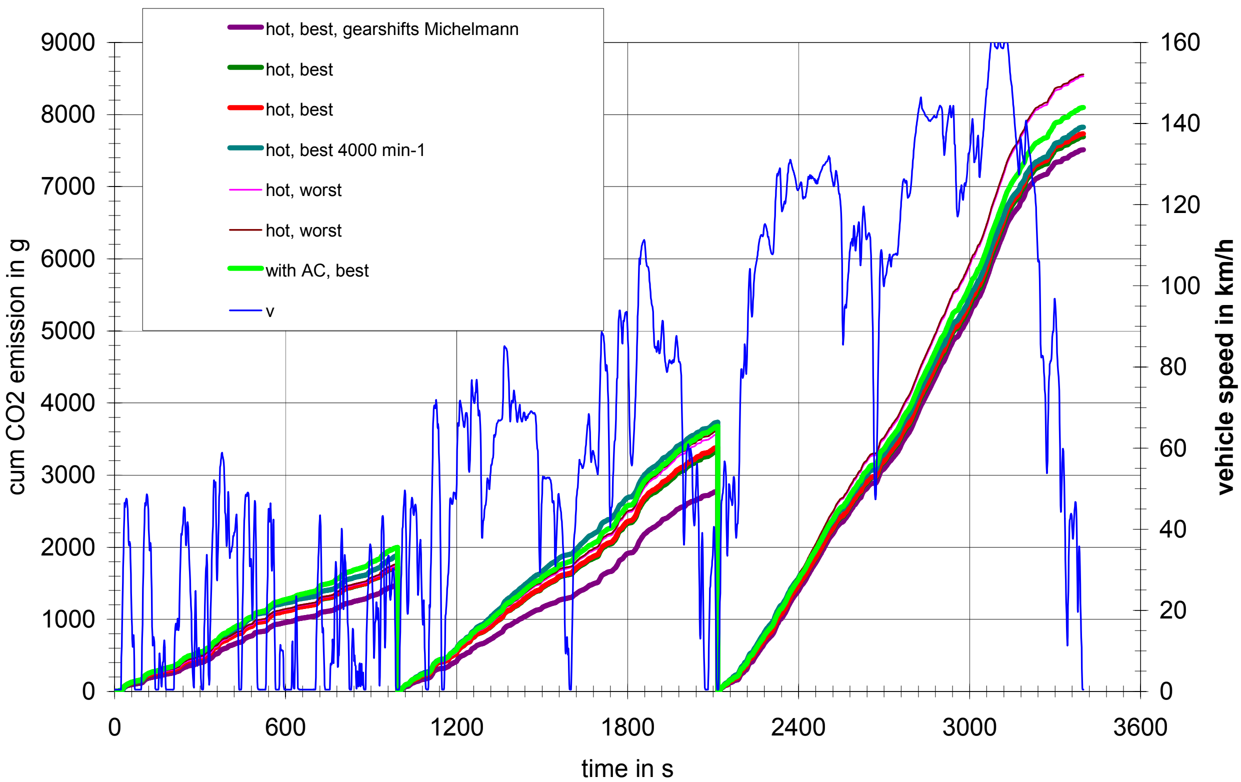


Figure 33: Cumulative CO_2 emission for the different CADC parts, vehicle 1

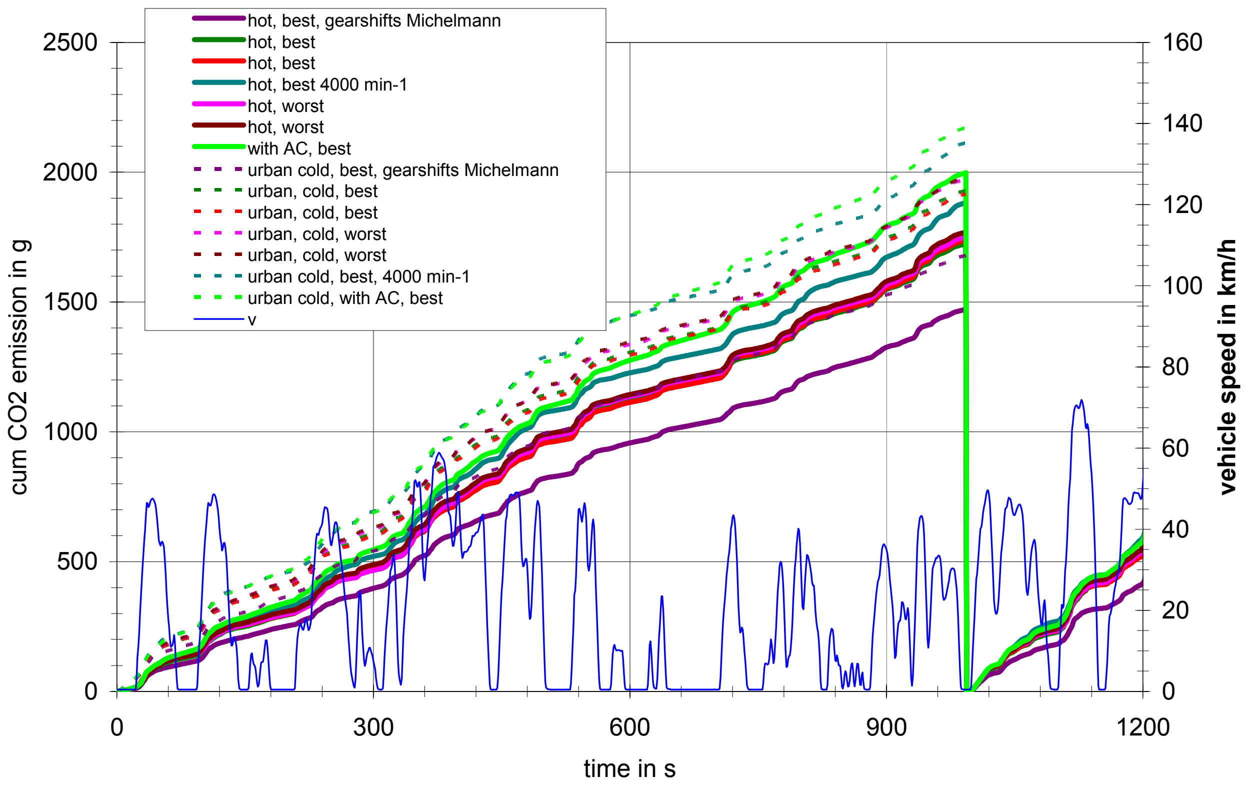


Figure 34: Cumulative CO_2 emission for the CADC urban part, vehicle 1

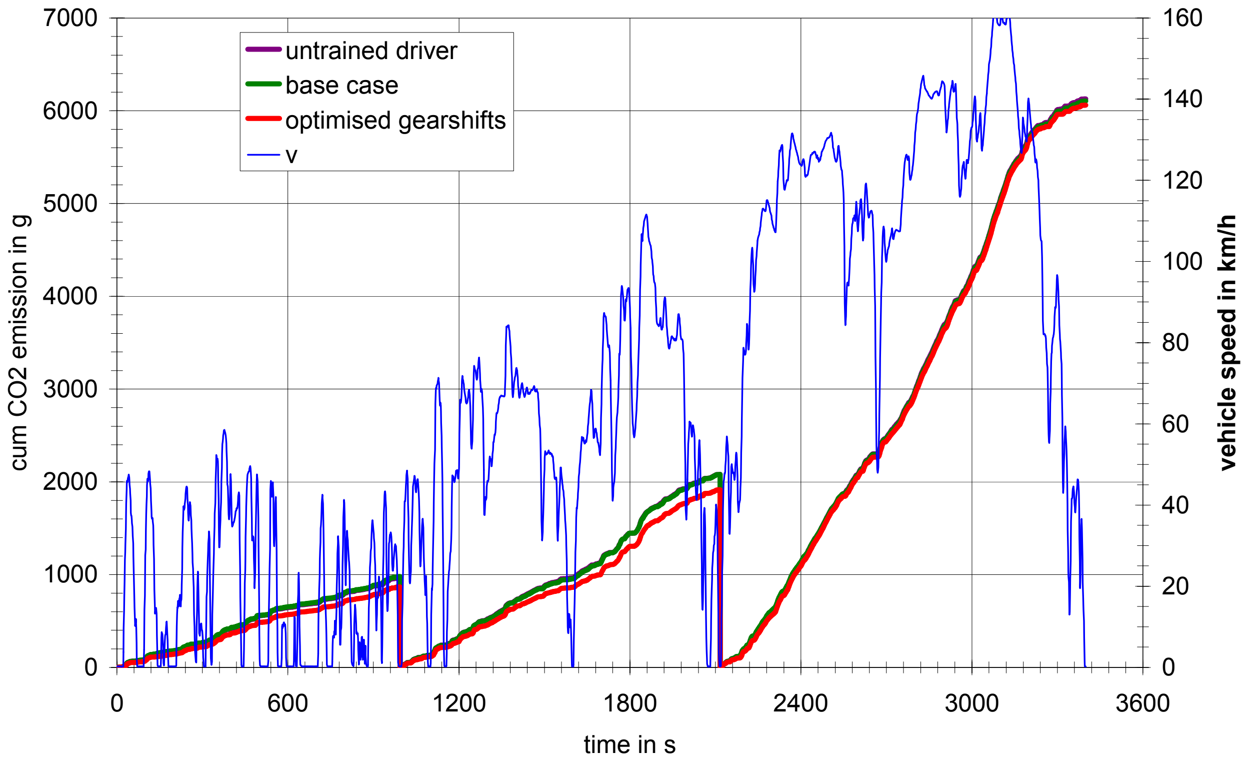


Figure 35: Cumulative CO_2 emission for the different CADC parts, vehicle 2

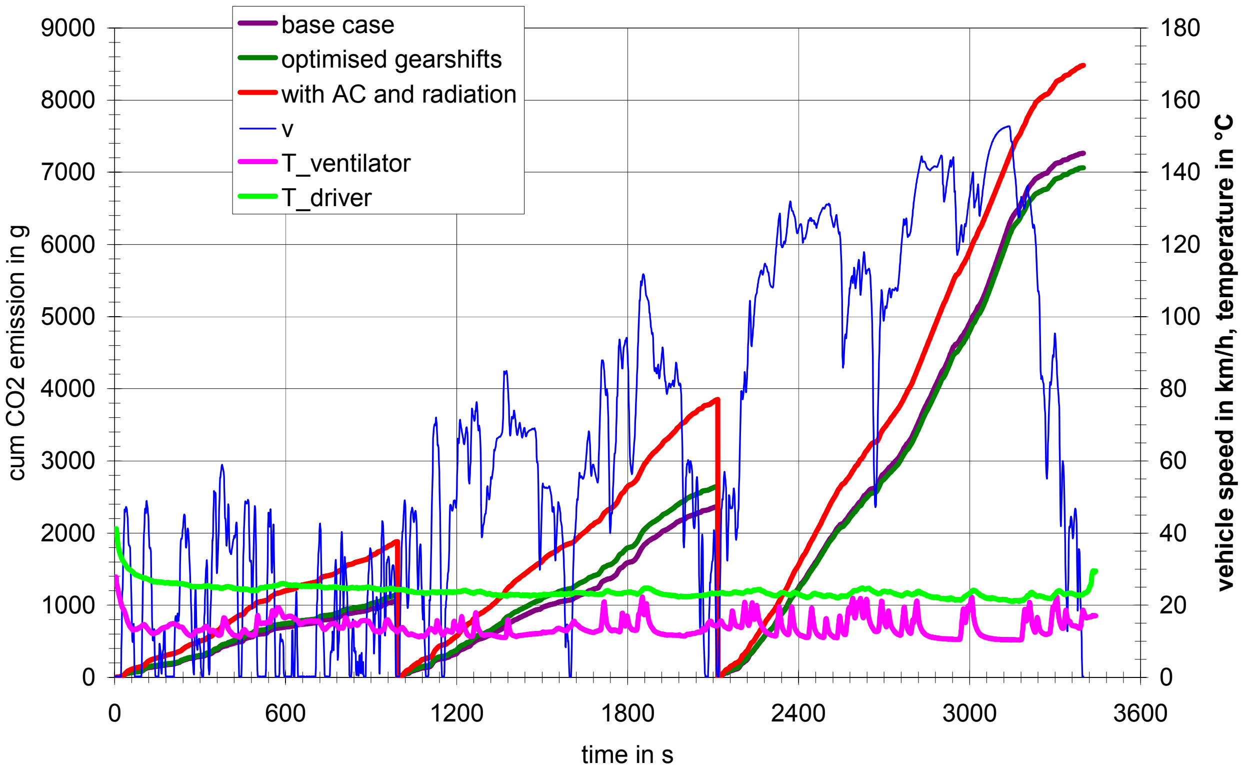


Figure 36: Cumulative CO_2 emission for the different CADC parts, vehicle 3

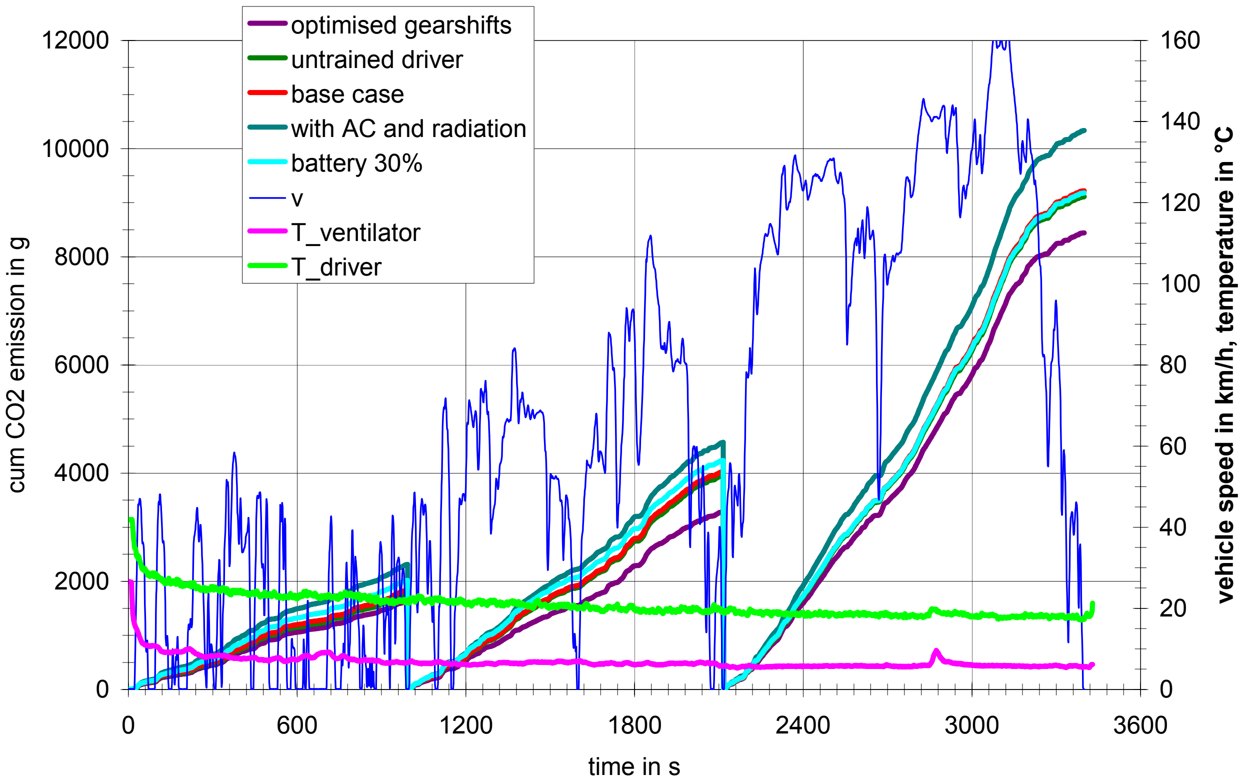


Figure 37: Cumulative CO_2 emission for the different CADC parts, vehicle 4

8.2 NOx emission

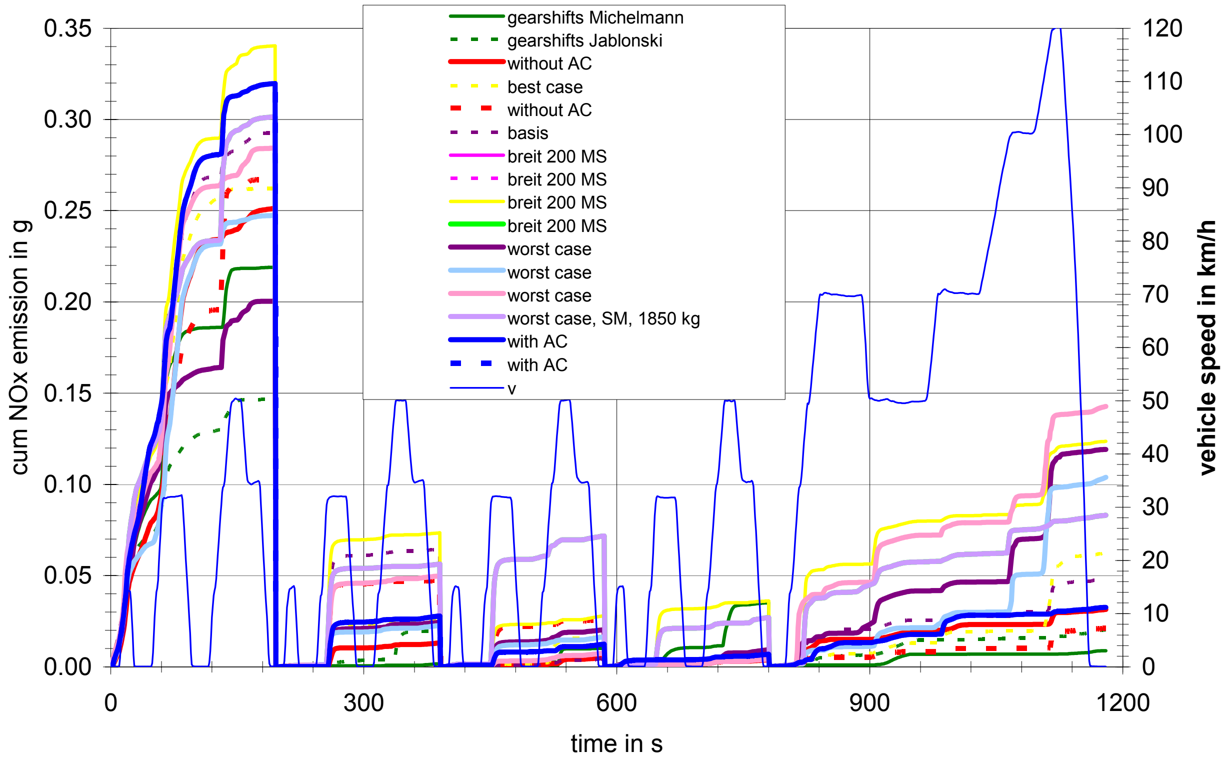


Figure 38: Cumulative NOx emission for the different NEDC parts, vehicle 1

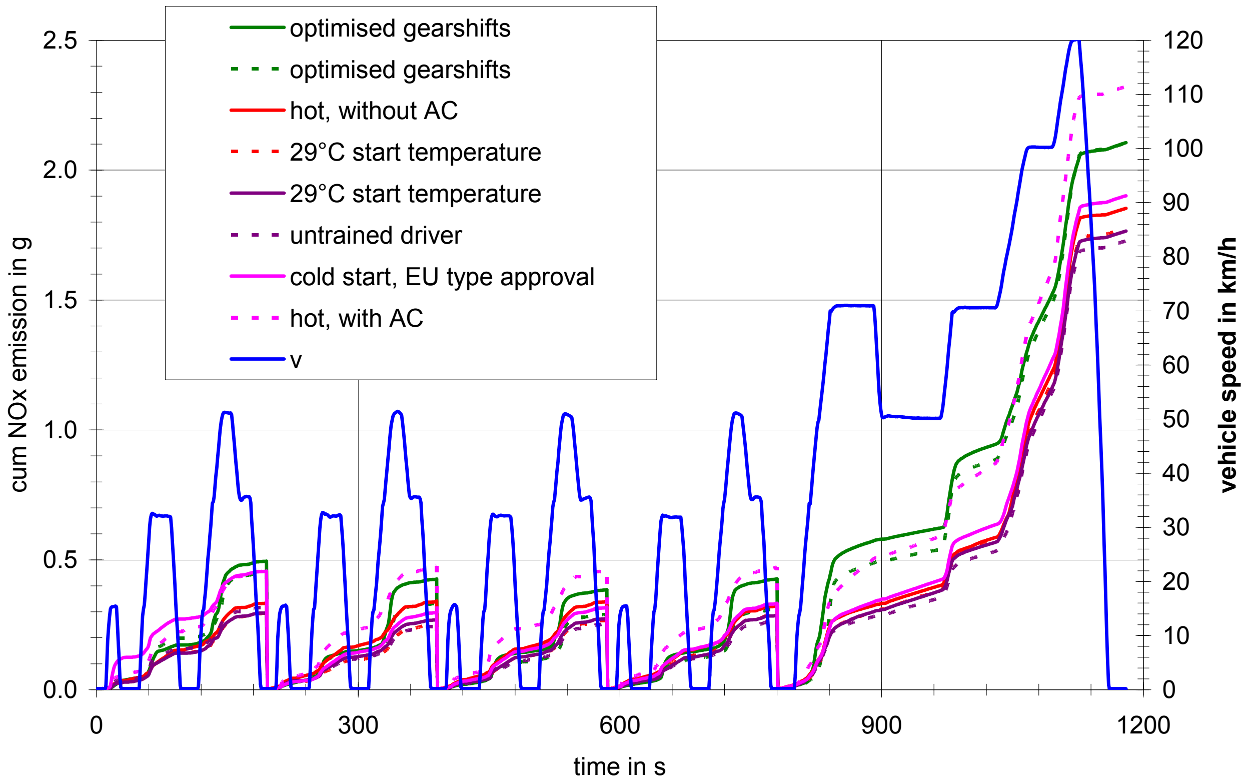


Figure 39: Cumulative NOx emission for the different NEDC parts, vehicle 2

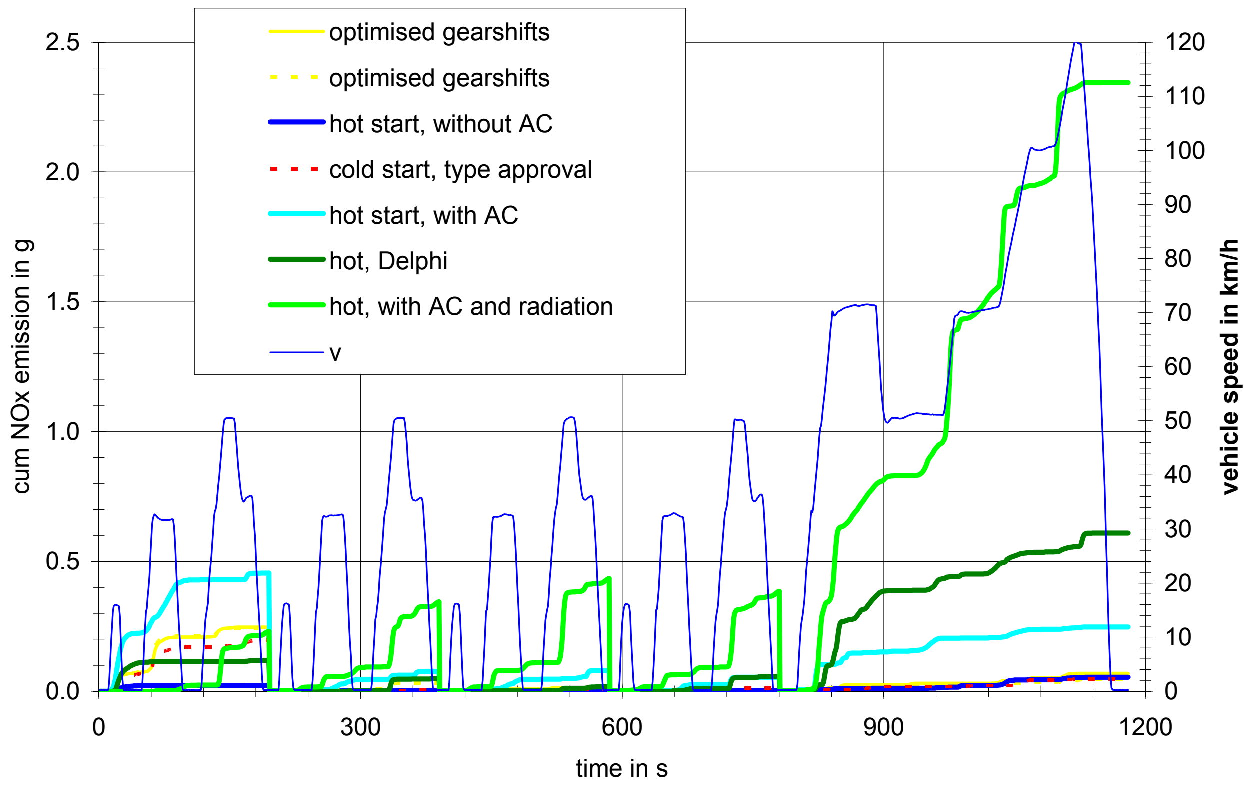


Figure 40: Cumulative NOx emission for the different NEDC parts, vehicle 3

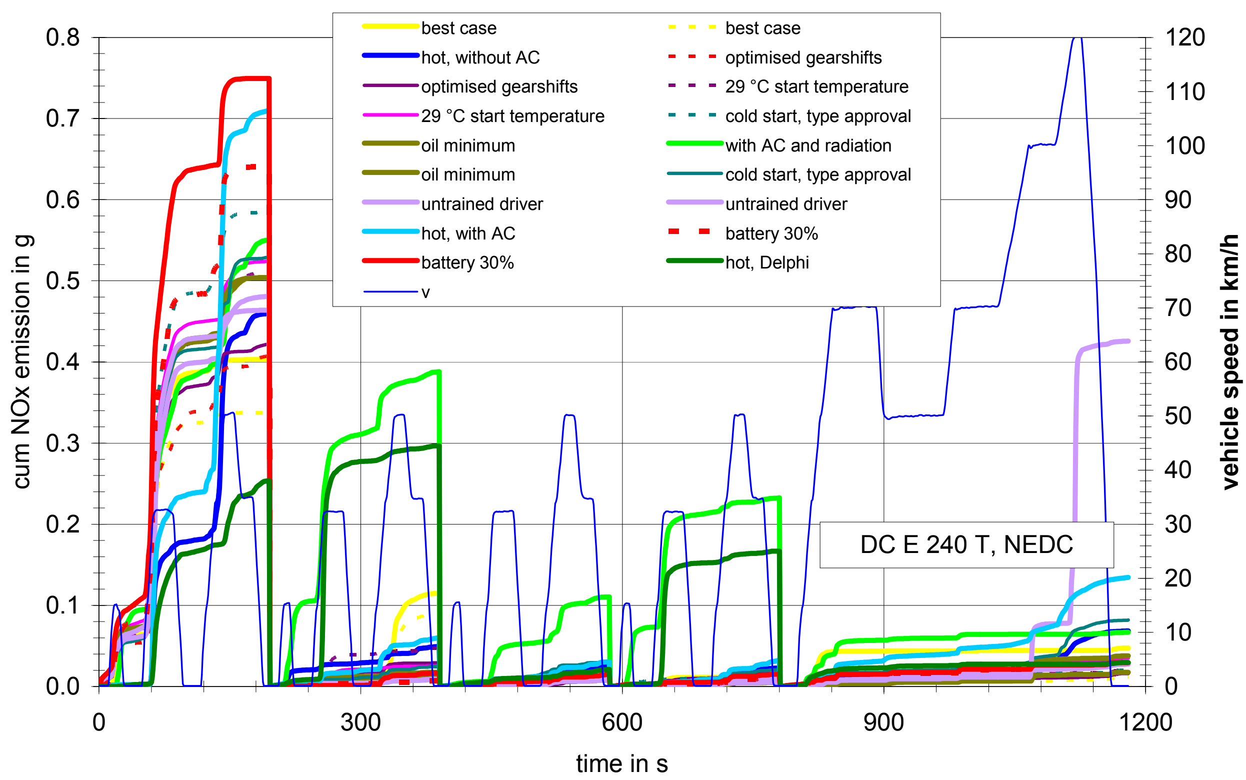


Figure 41: Cumulative NOx emission for the different NEDC parts, vehicle 4

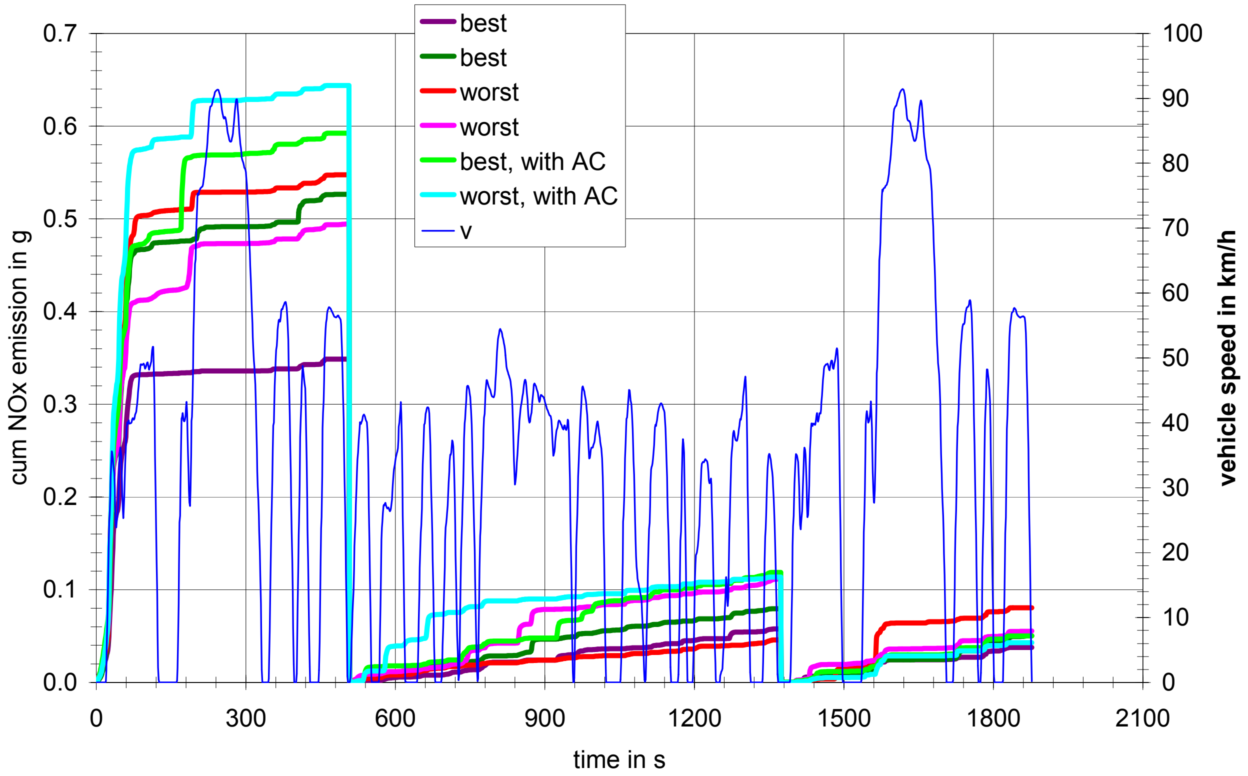


Figure 42: Cumulative NOx emission for the different US FTP 75 parts, vehicle 1

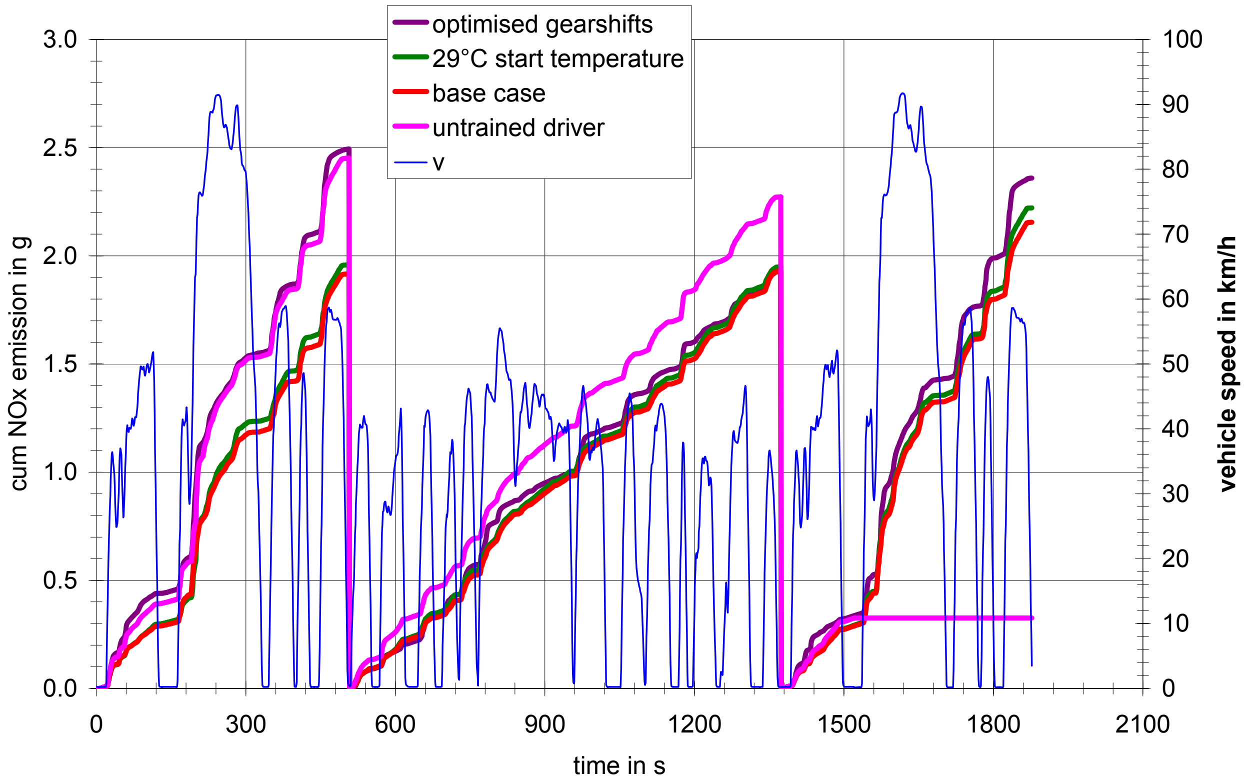


Figure 43: Cumulative NOx emission for the different US FTP 75 parts, vehicle 2

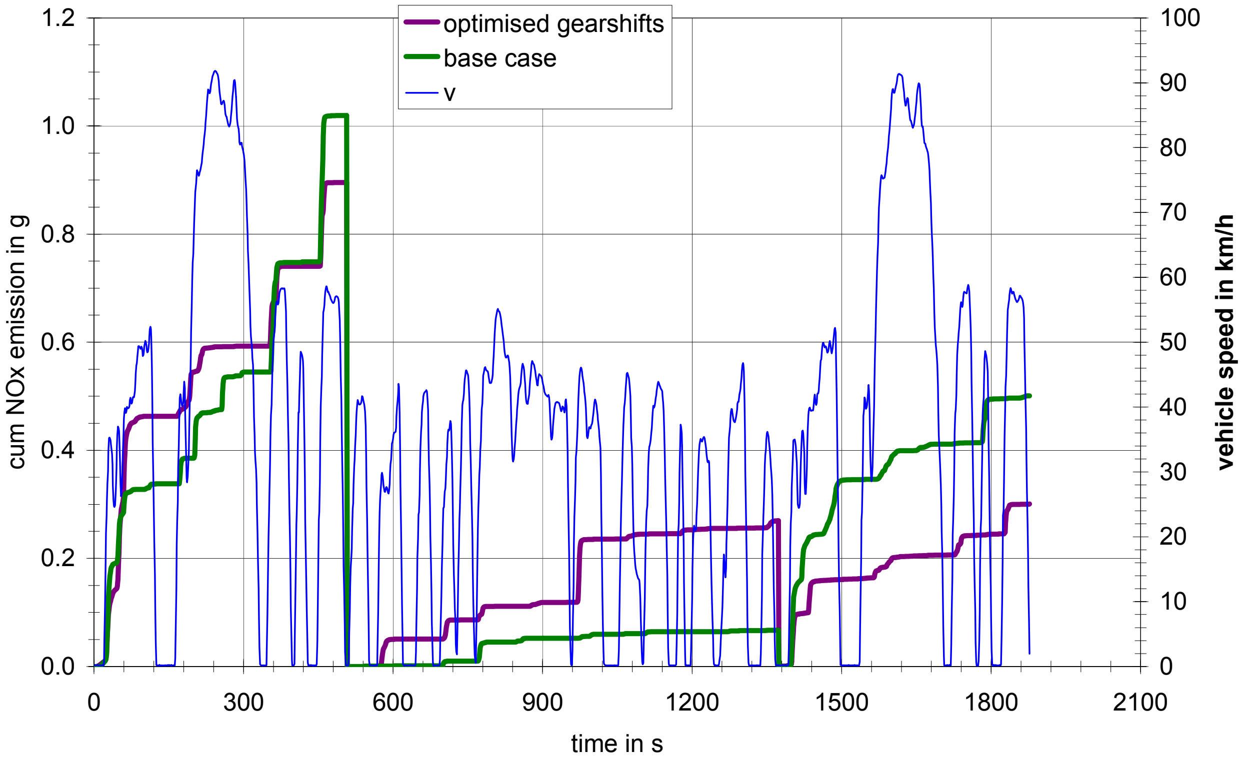


Figure 44: Cumulative NOx emission for the different US FTP 75 parts, vehicle 3

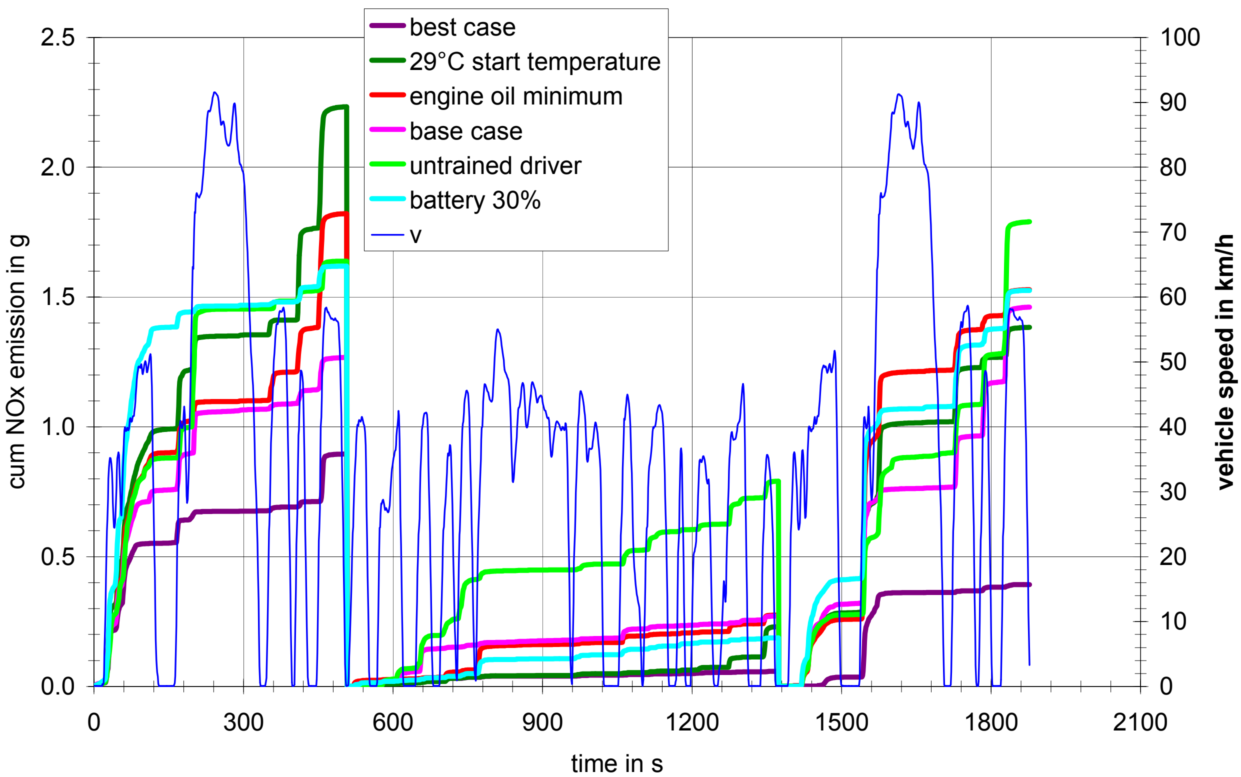


Figure 45: Cumulative NOx emission for the different US FTP 75 parts, vehicle 4

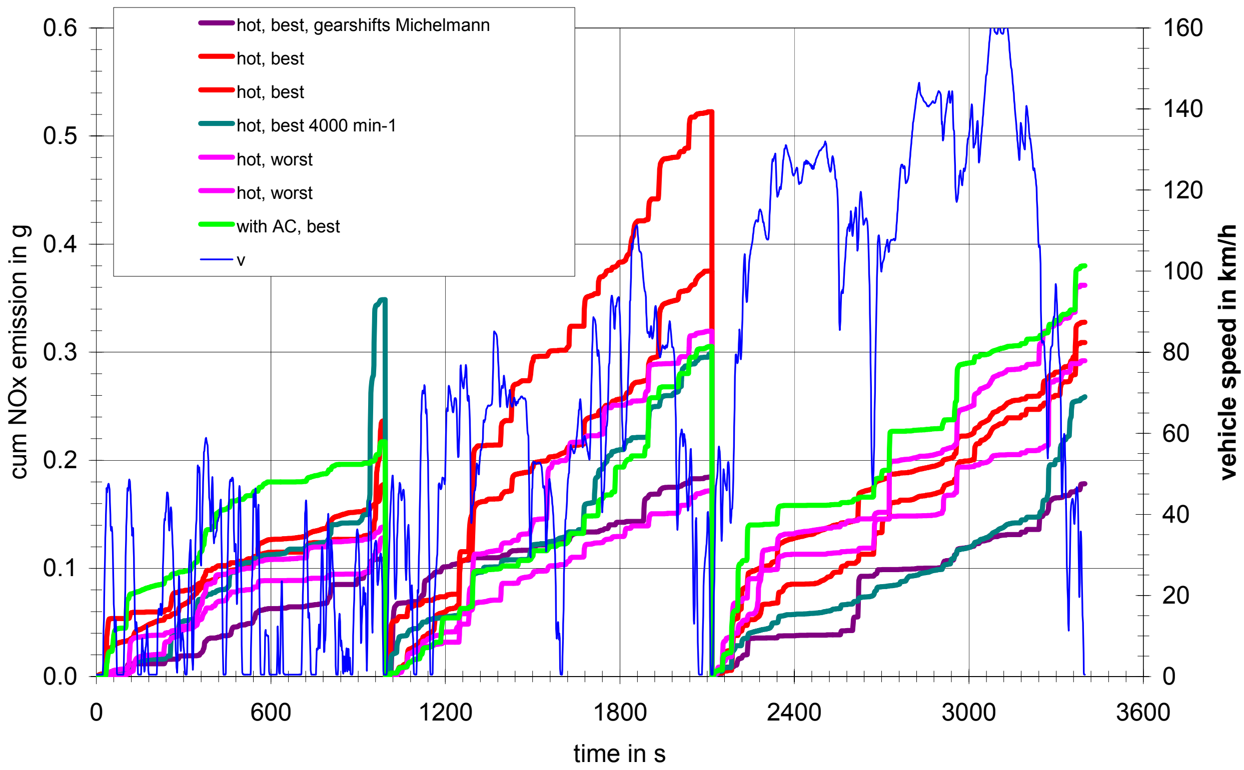


Figure 46: Cumulative NOx emission for the different CADC parts, vehicle 1

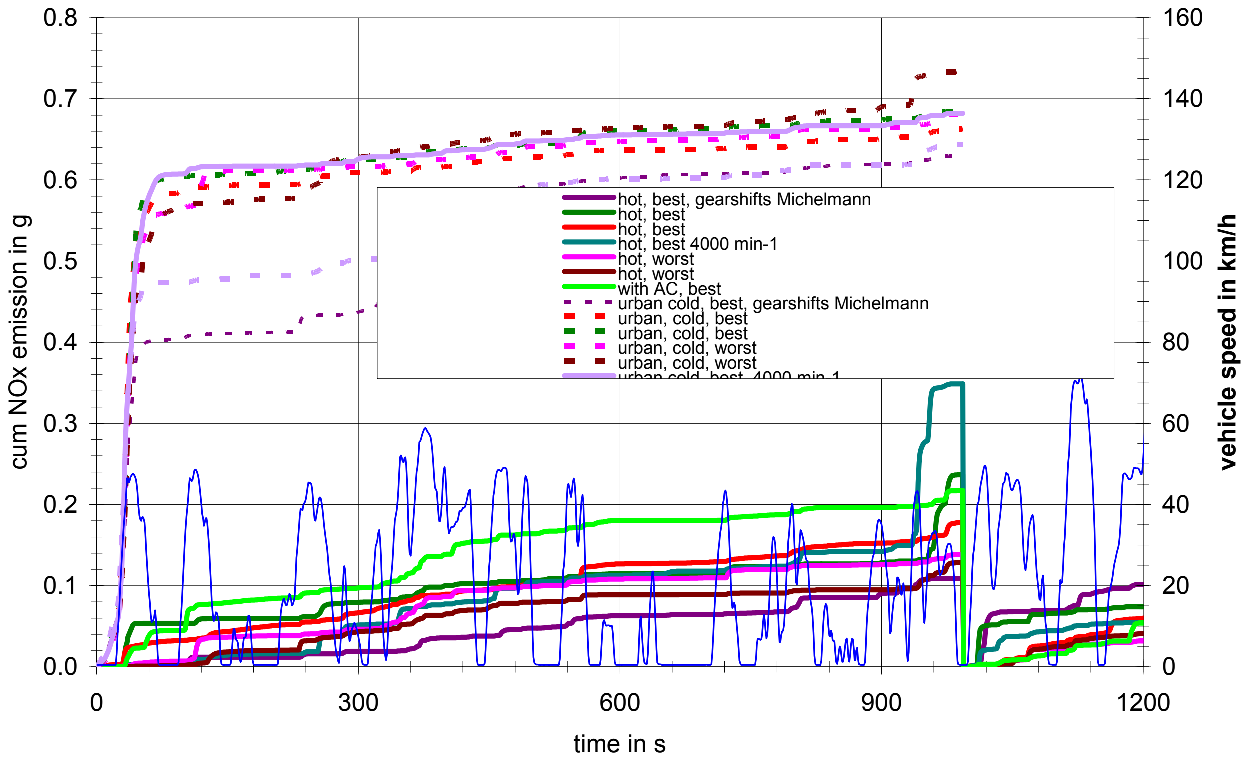


Figure 47: Cumulative NOx emission for the CADC urban part, vehicle 1

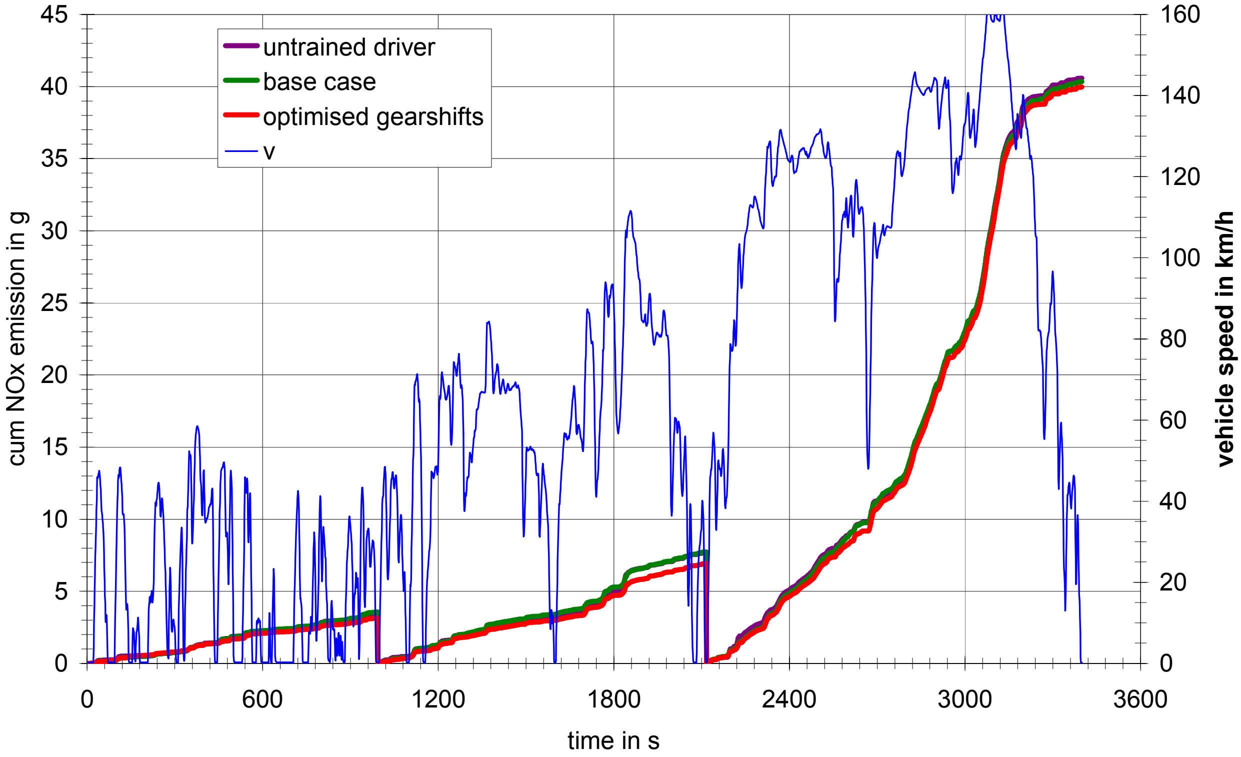


Figure 48: Cumulative NOx emission for the different CADC parts, vehicle 2

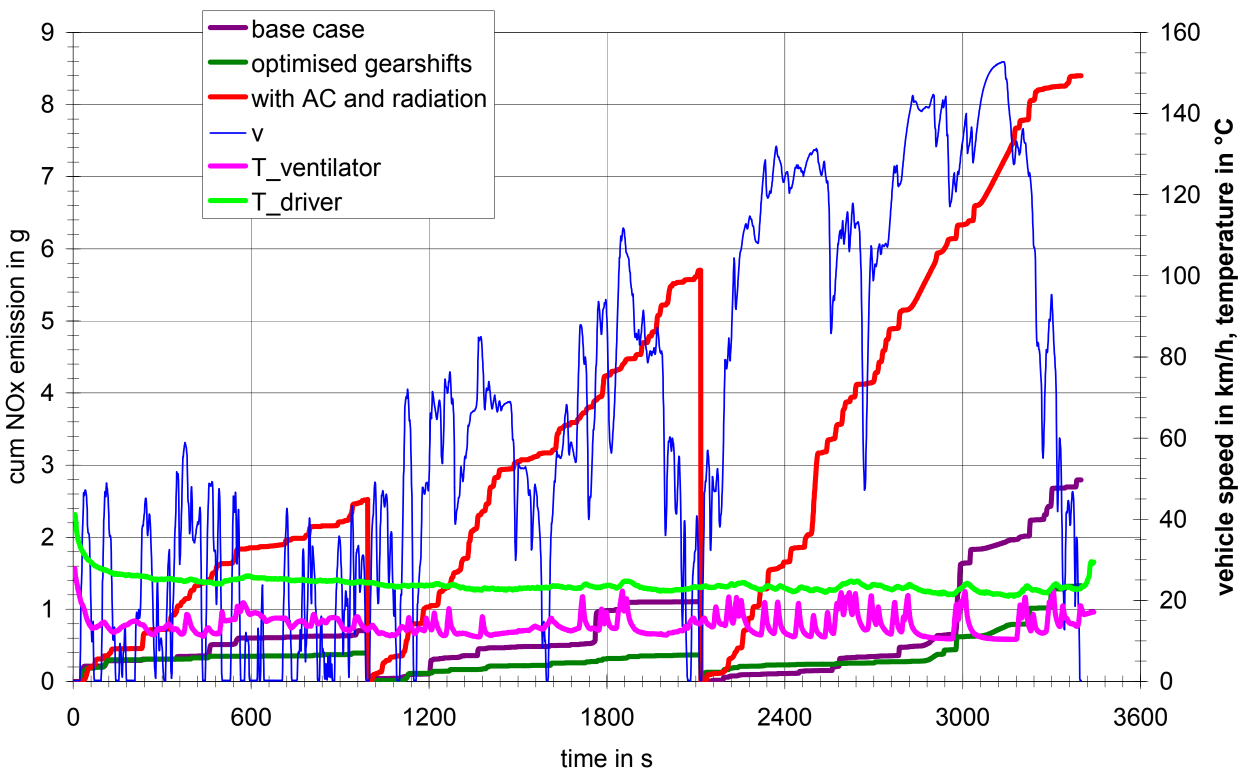


Figure 49: Cumulative NOx emission for the different CADC parts, vehicle 3

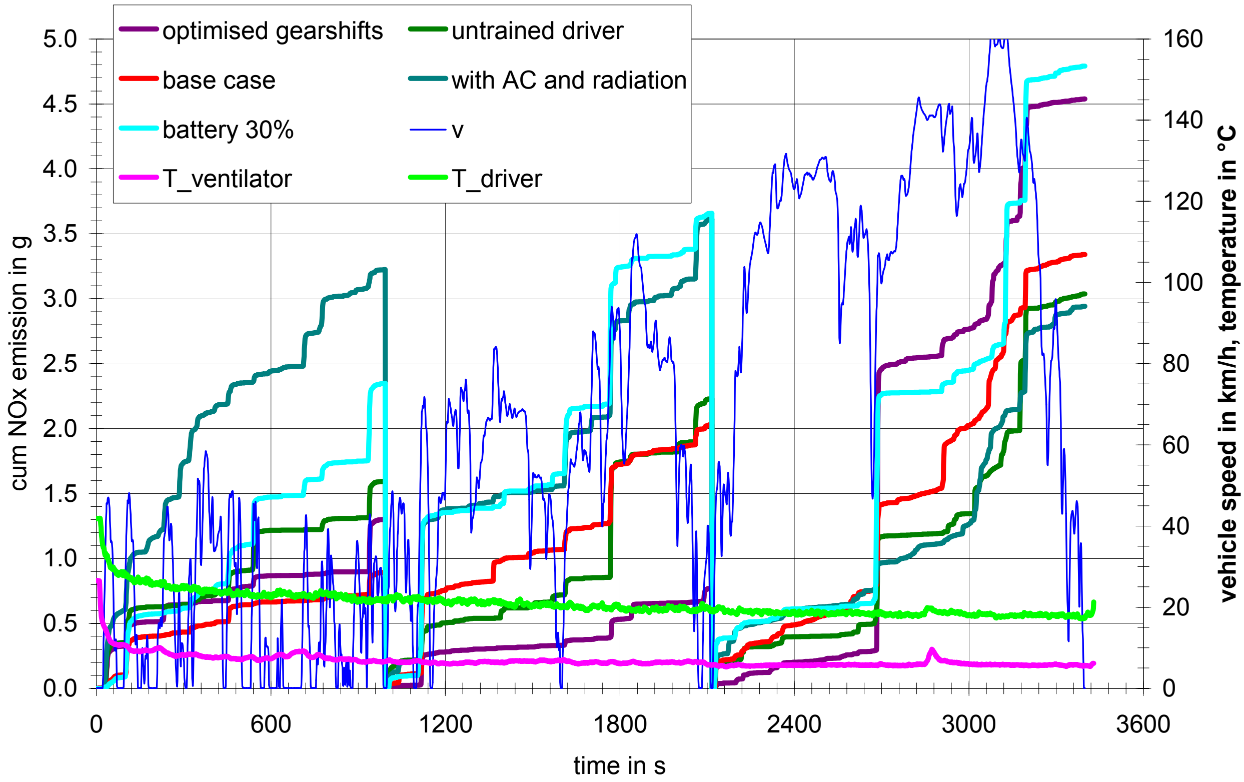


Figure 50: Cumulative NOx emission for the different CADC parts, vehicle 4

8.3 HC emission

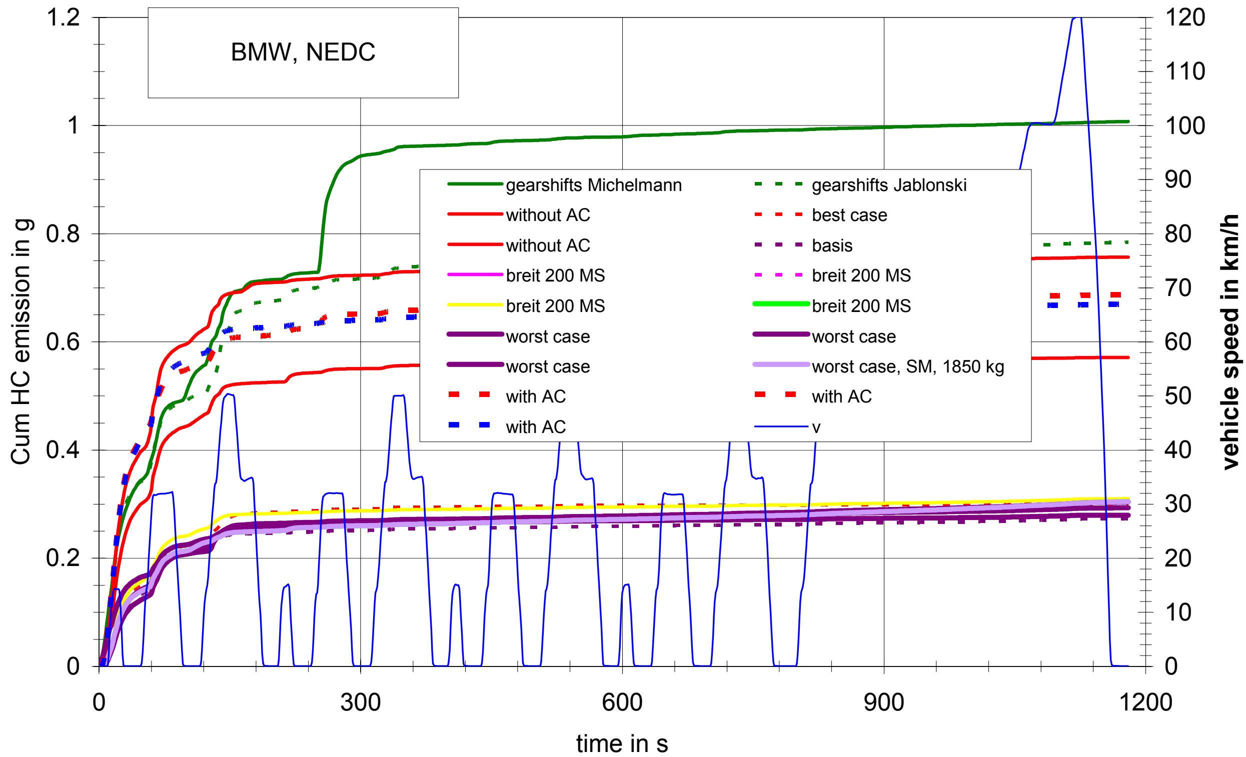


Figure 51: Cumulative HC emission for the different NEDC parts, vehicle 1

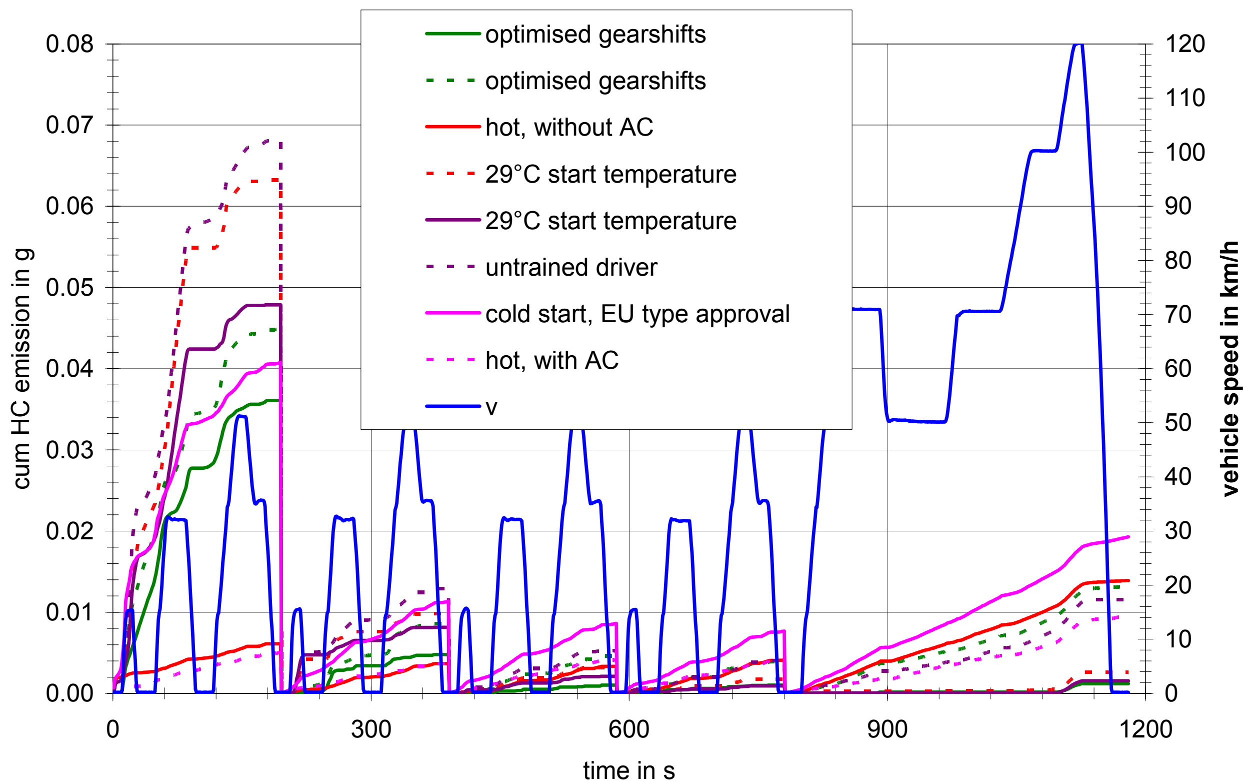


Figure 52: Cumulative HC emission for the different NEDC parts, vehicle 2

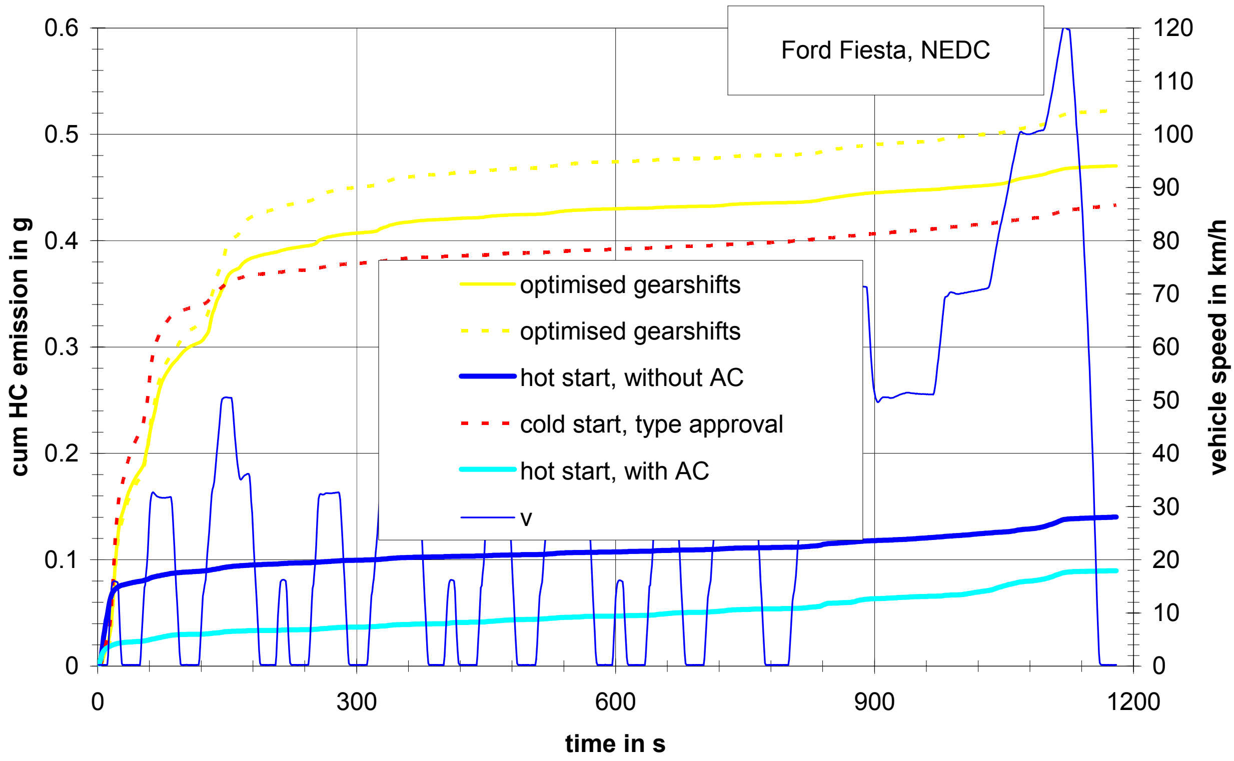


Figure 53: Cumulative HC emission for the different NEDC parts, vehicle 3

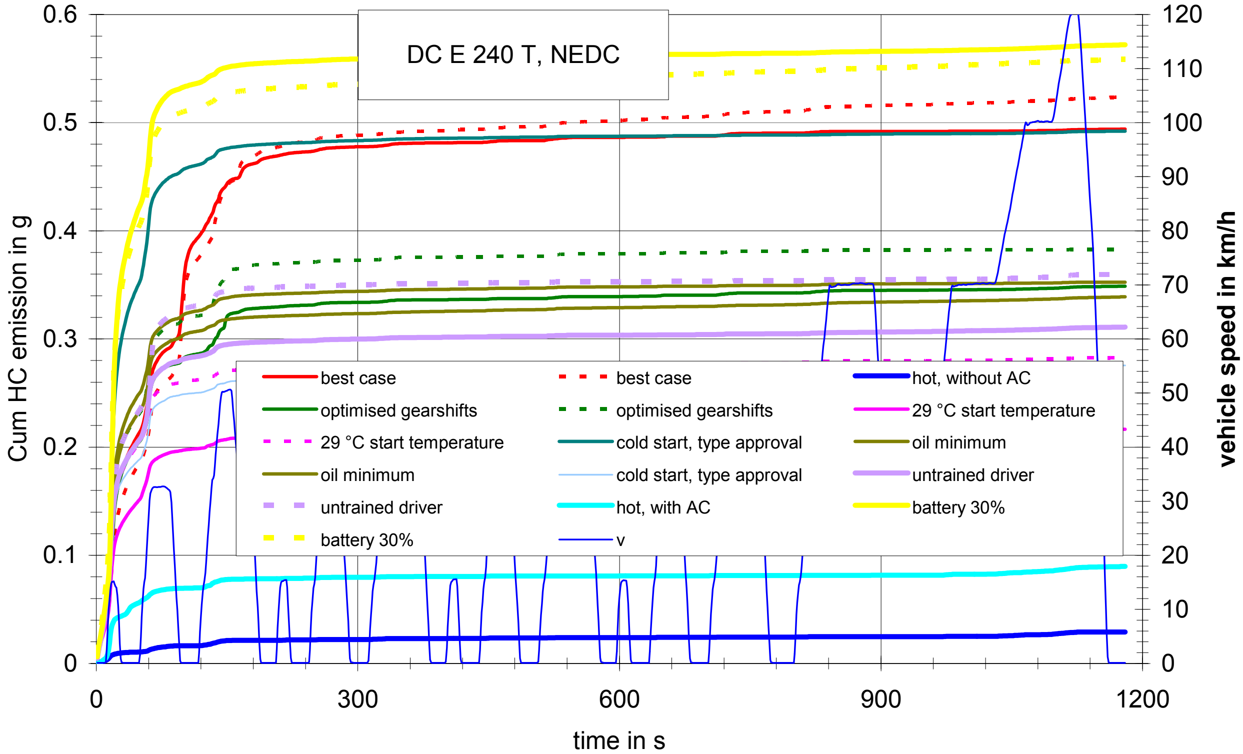


Figure 54: Cumulative HC emission for the different NEDC parts, vehicle 4

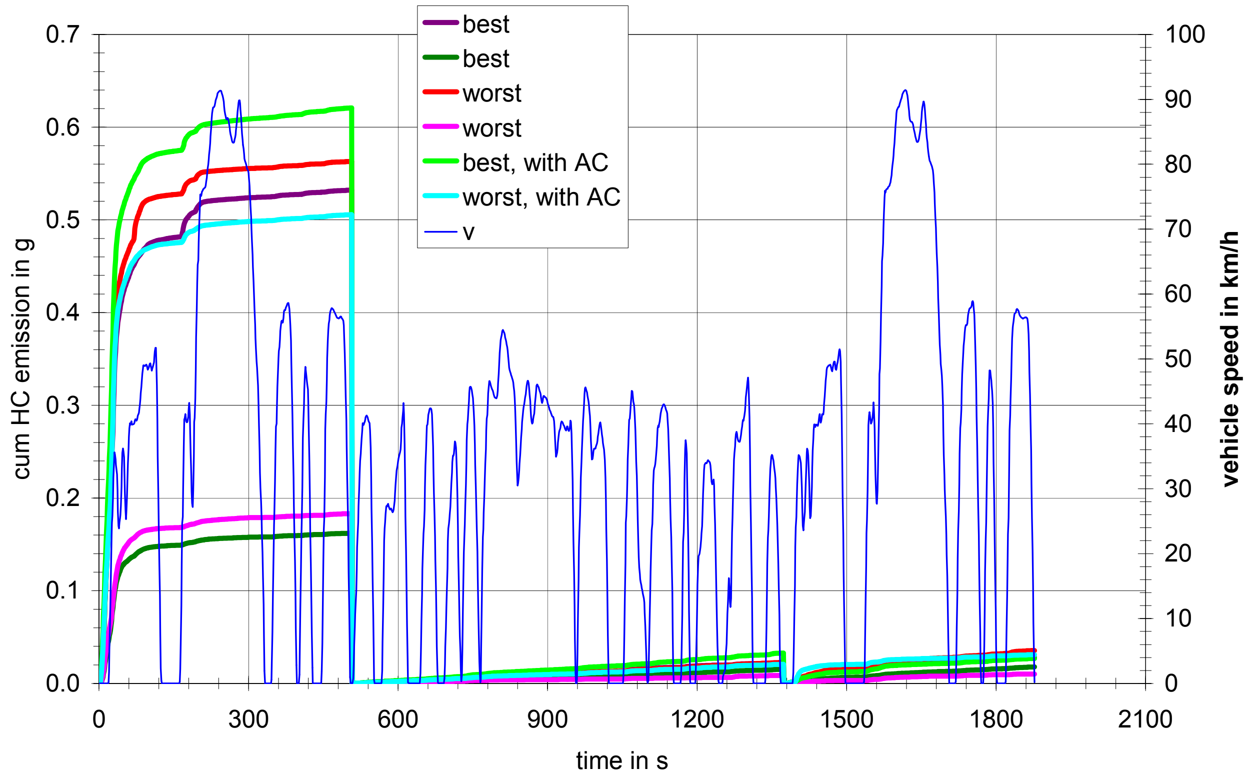


Figure 55: Cumulative HC emission for the different US FTP 75 parts, vehicle 1

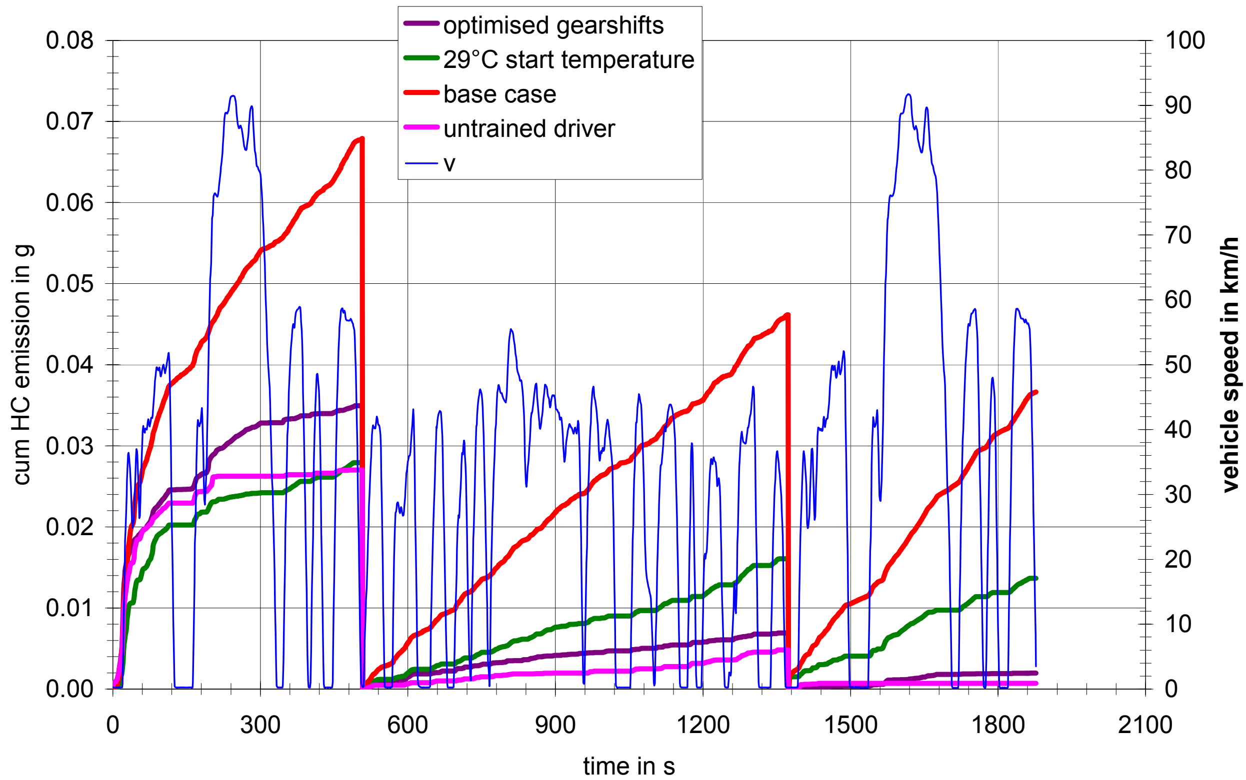


Figure 56: Cumulative HC emission for the different US FTP 75 parts, vehicle 2

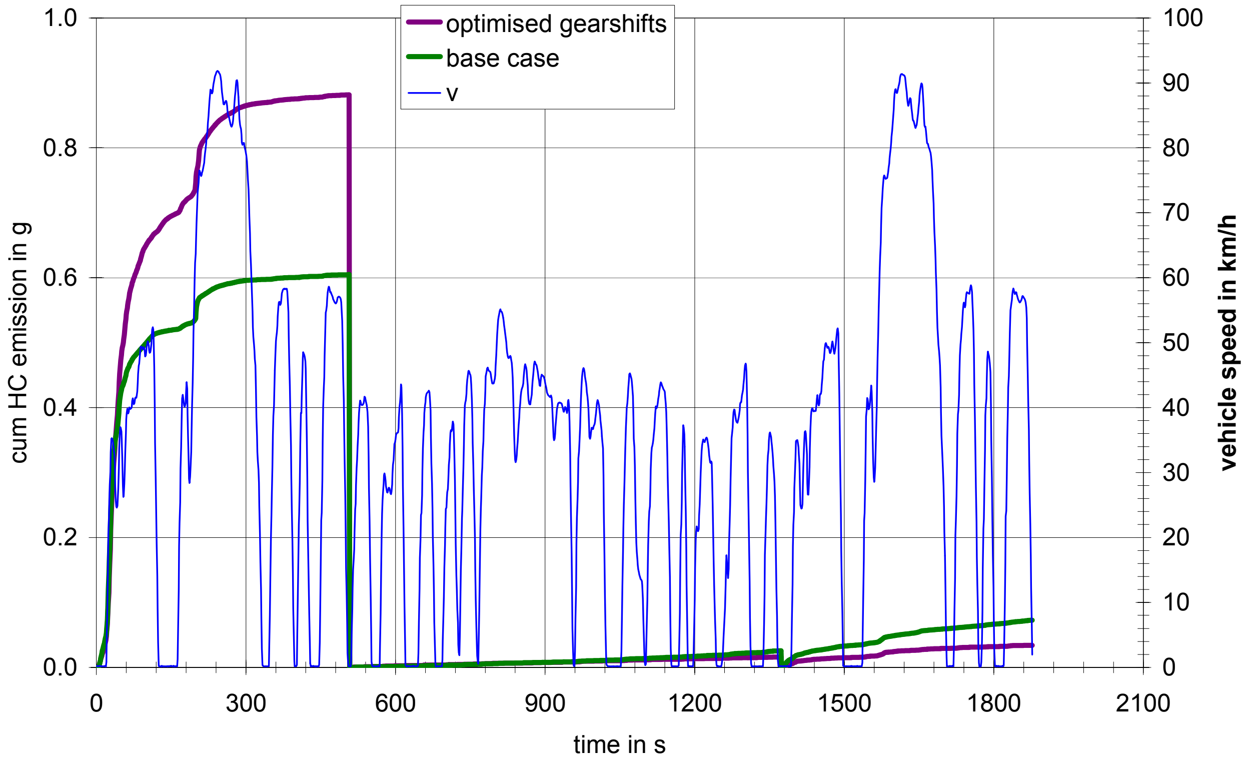


Figure 57: Cumulative HC emission for the different US FTP 75 parts, vehicle 3

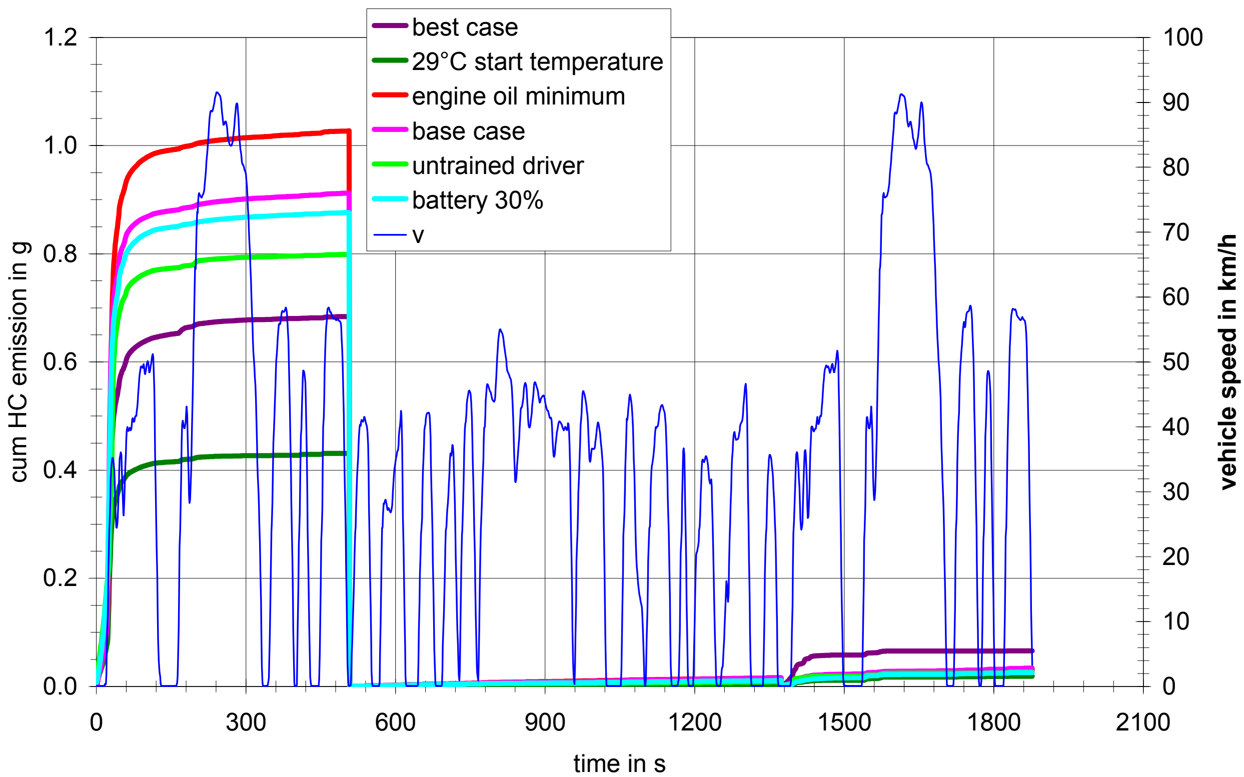


Figure 58: Cumulative HC emission for the different US FTP 75 parts, vehicle 4

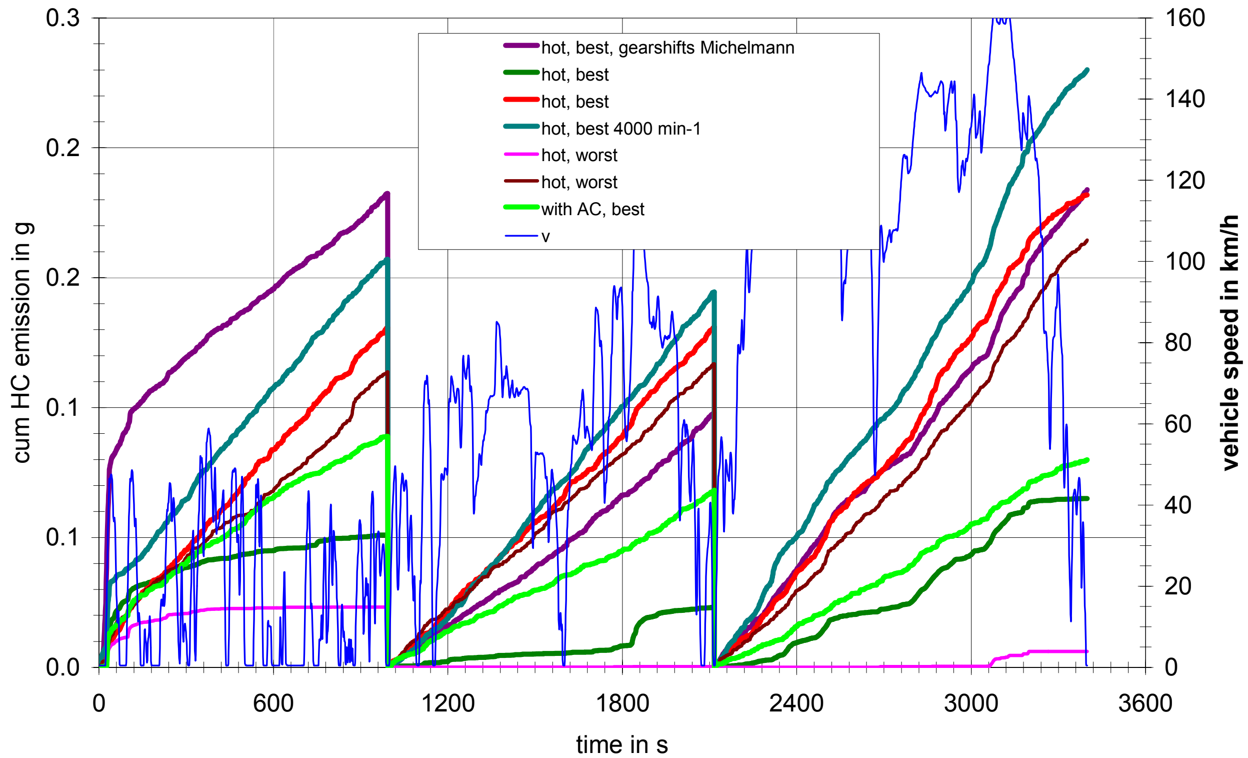


Figure 59: Cumulative HC emission for the different CADC parts, vehicle 1

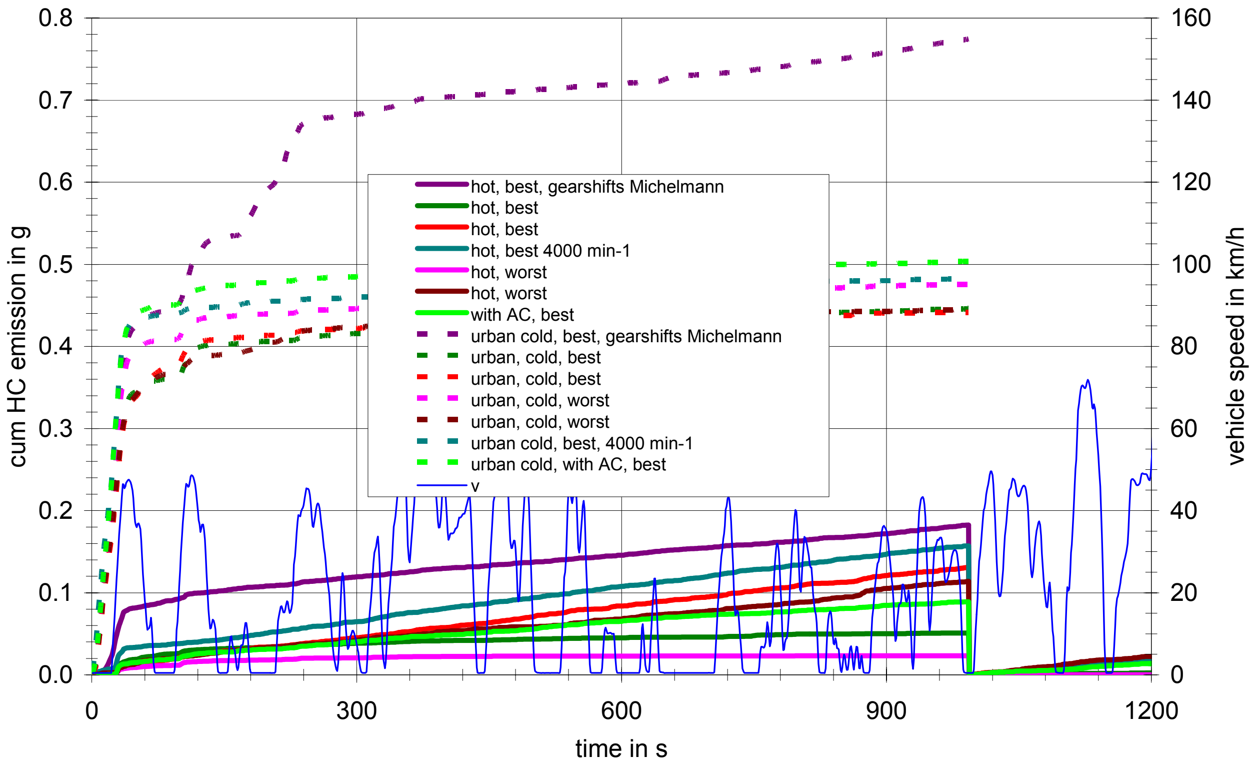


Figure 60: Cumulative HC emission for the CADC urban part, vehicle 1

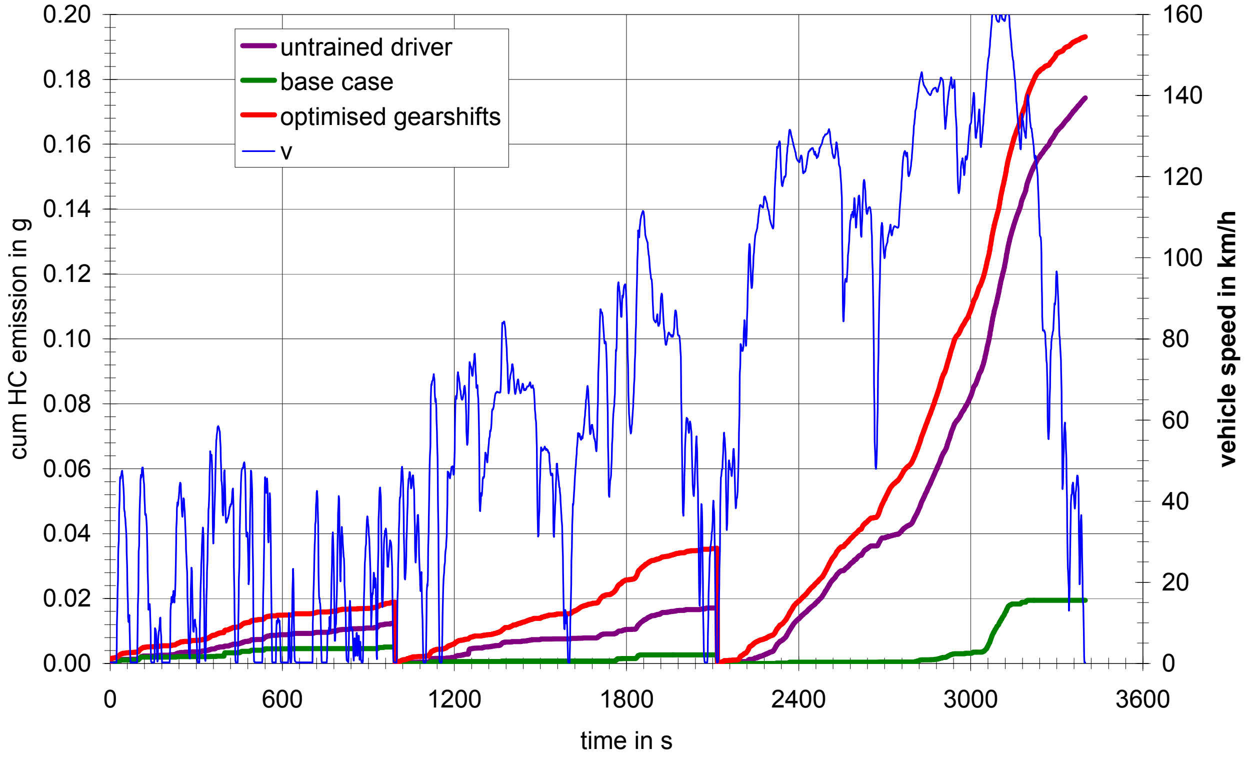


Figure 61: Cumulative HC emission for the different CADC parts, vehicle 2

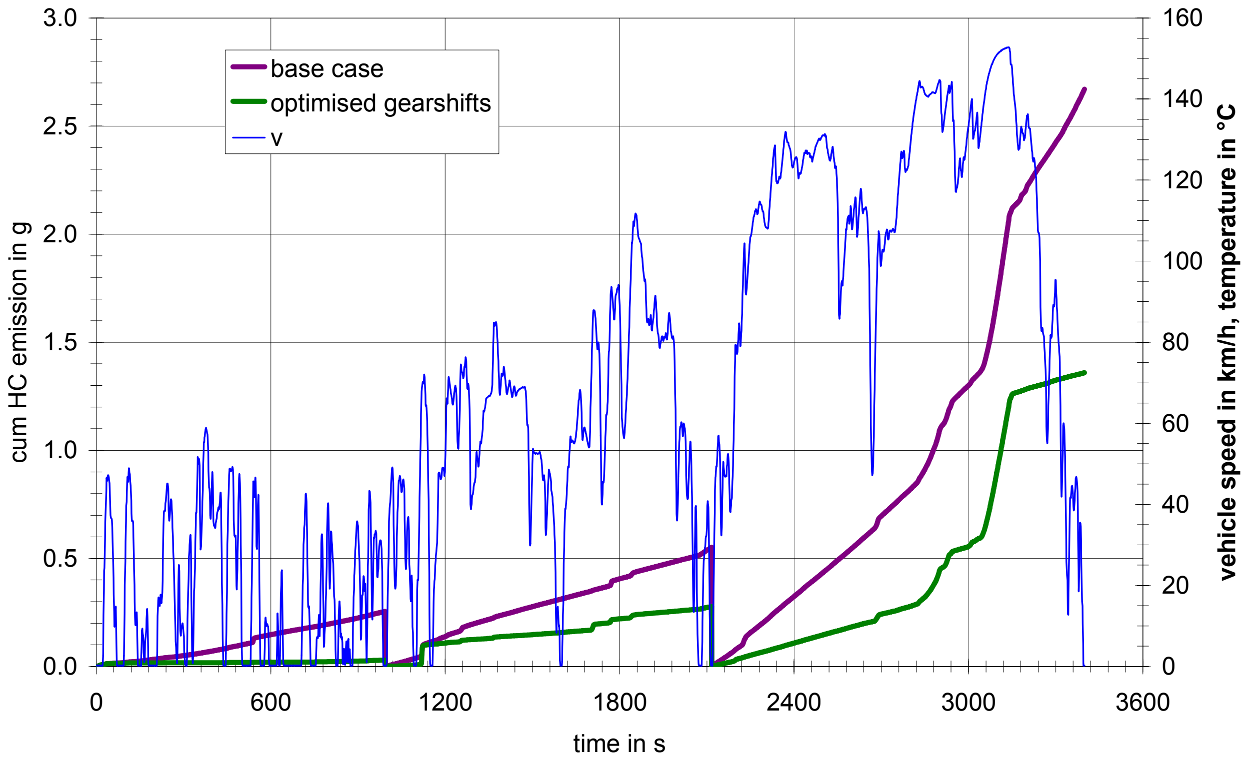


Figure 62: Cumulative HC emission for the different CADC parts, vehicle 3

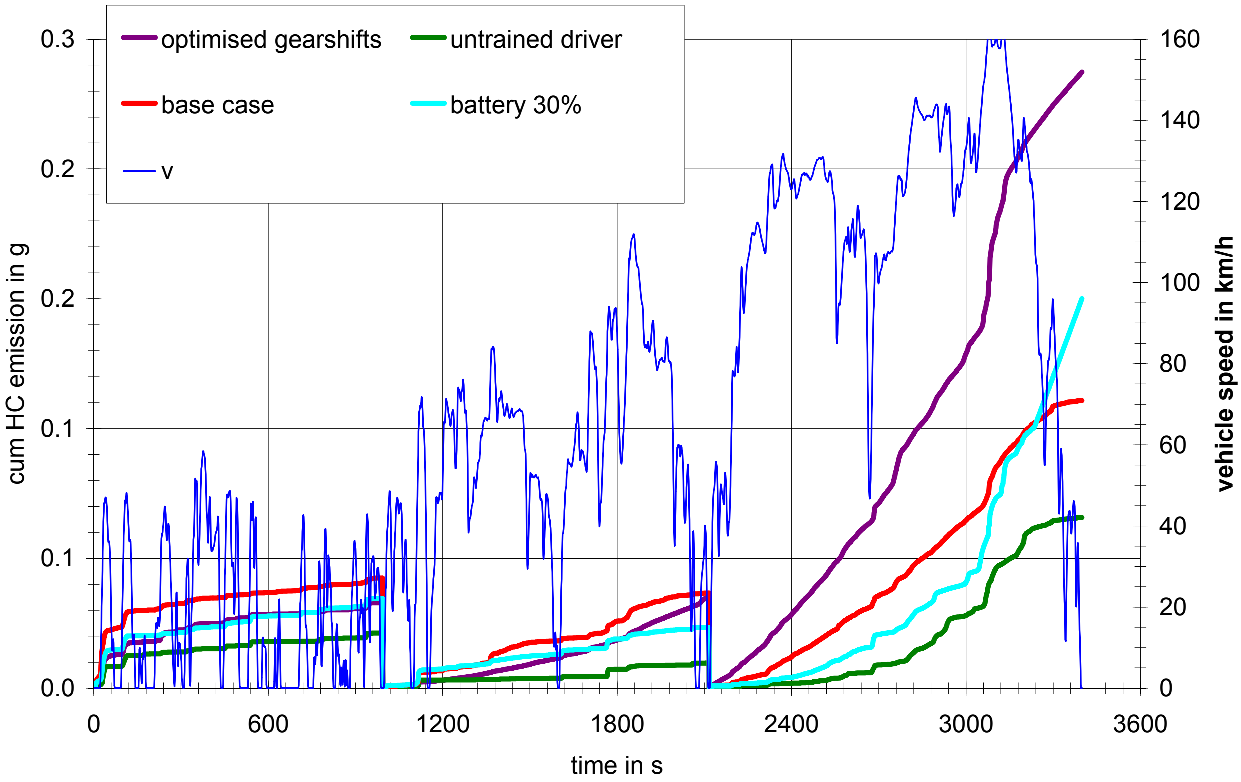


Figure 63: Cumulative HC emission for the different CADC parts, vehicle 4

8.4 CO emission

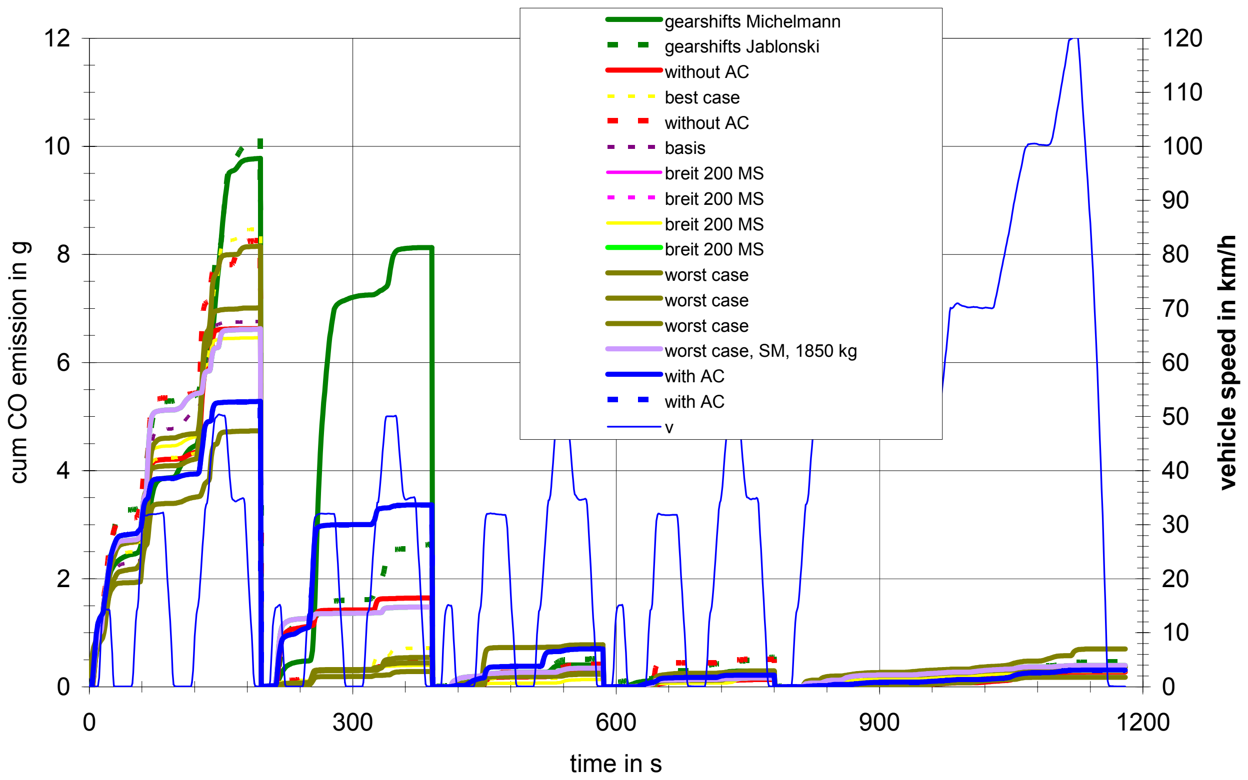


Figure 64: Cumulative CO emission for the different NEDC parts, vehicle 1

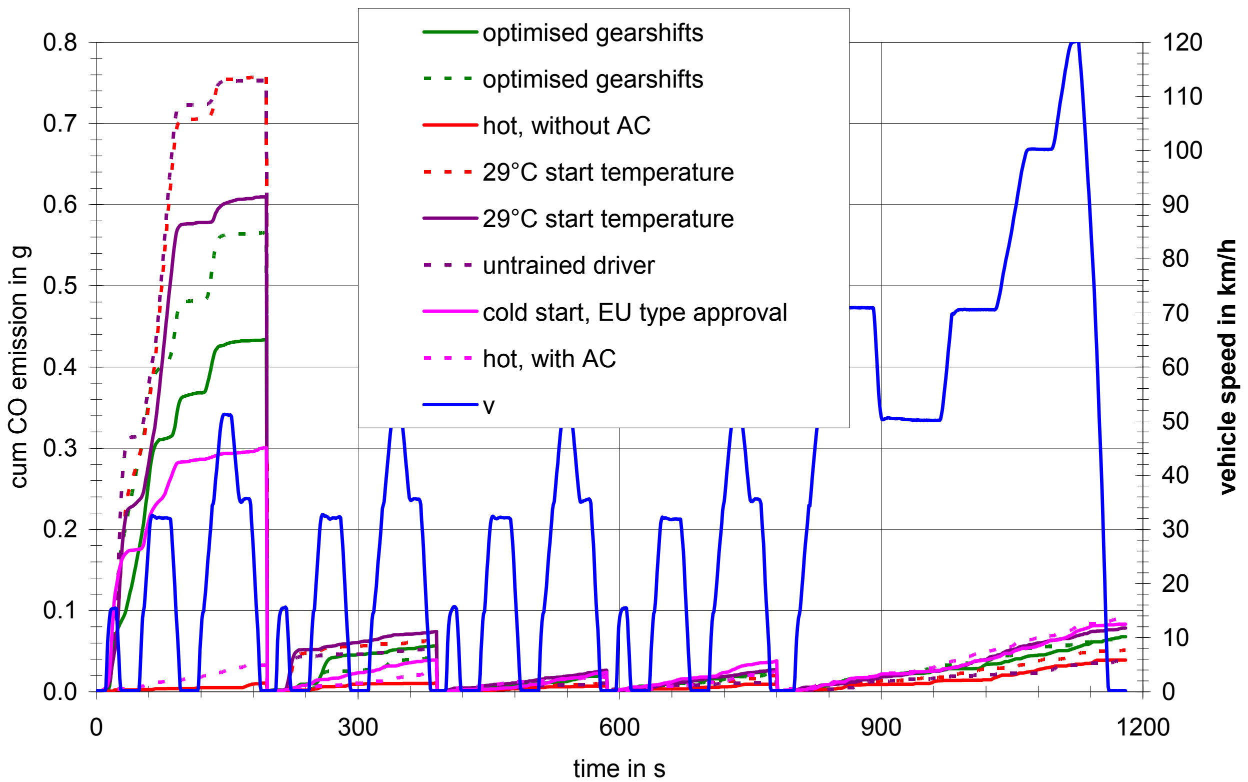


Figure 65: Cumulative CO emission for the different NEDC parts, vehicle 2

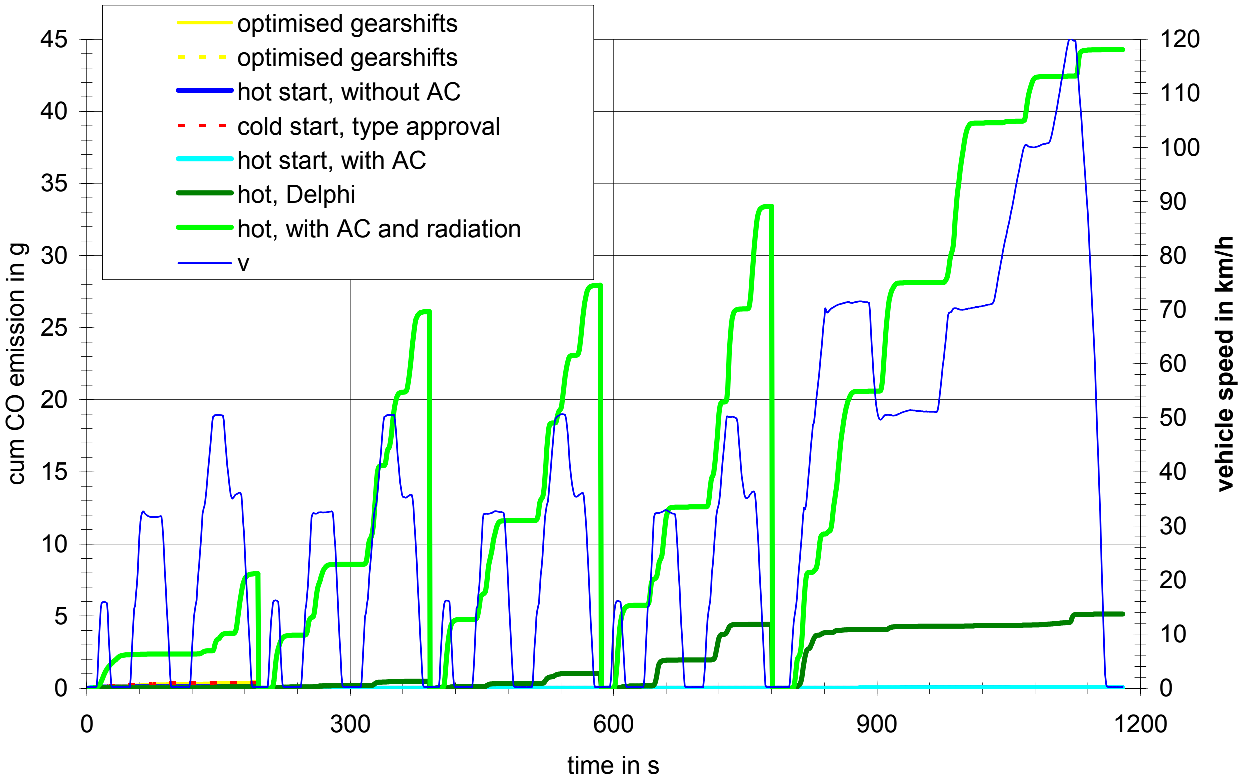


Figure 66: Cumulative CO emission for the different NEDC parts, vehicle 3

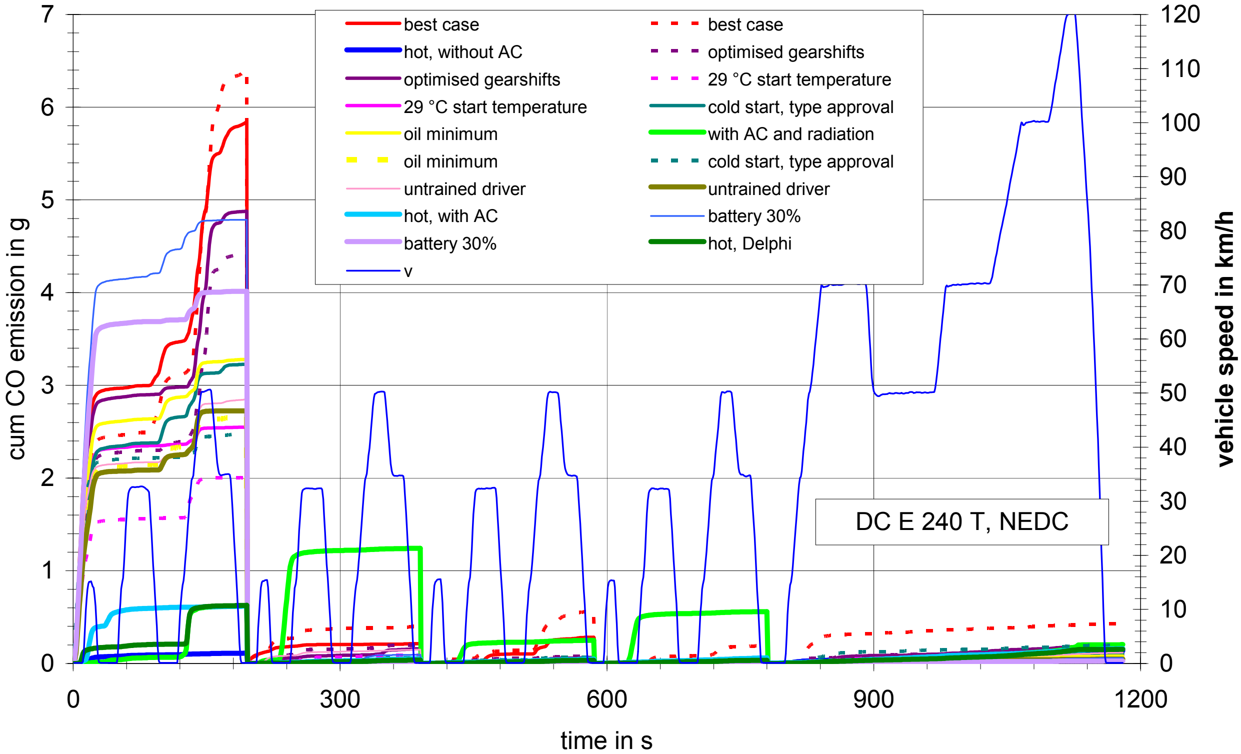


Figure 67: Cumulative CO emission for the different NEDC parts, vehicle 4

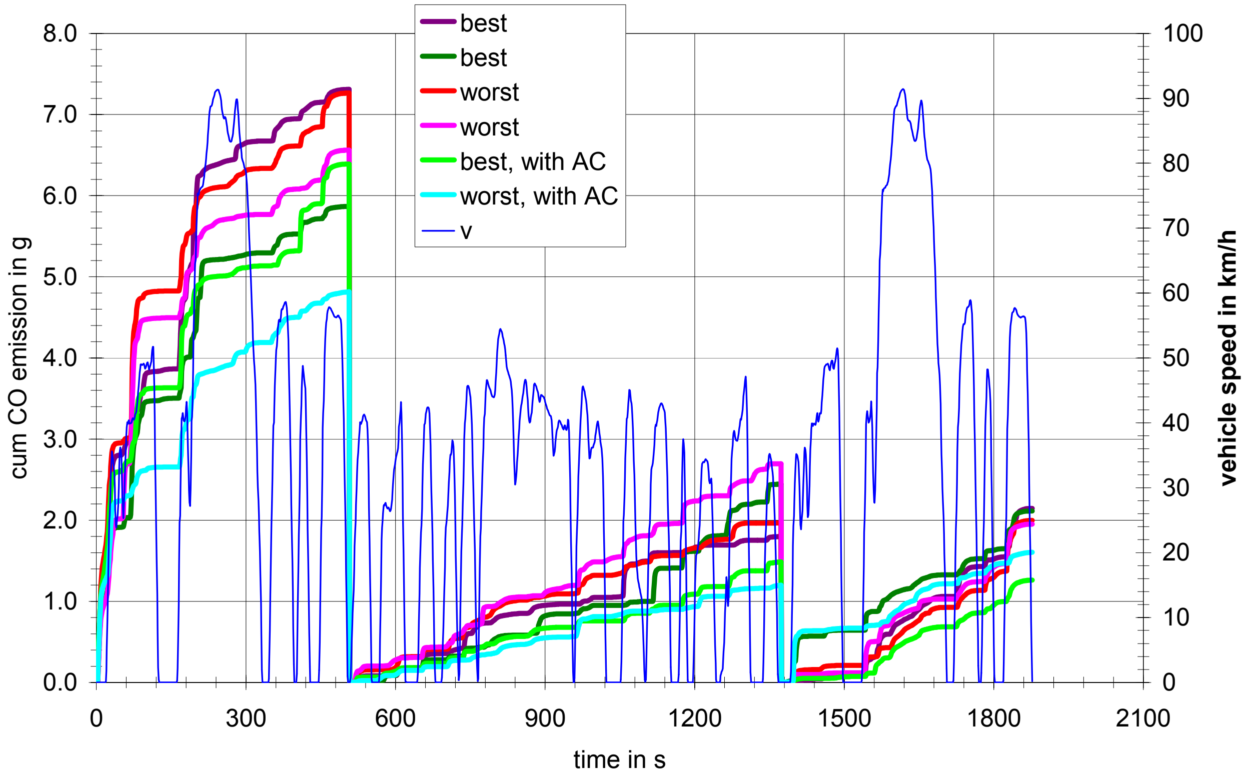


Figure 68: Cumulative CO emission for the different US FTP 75 parts, vehicle 1

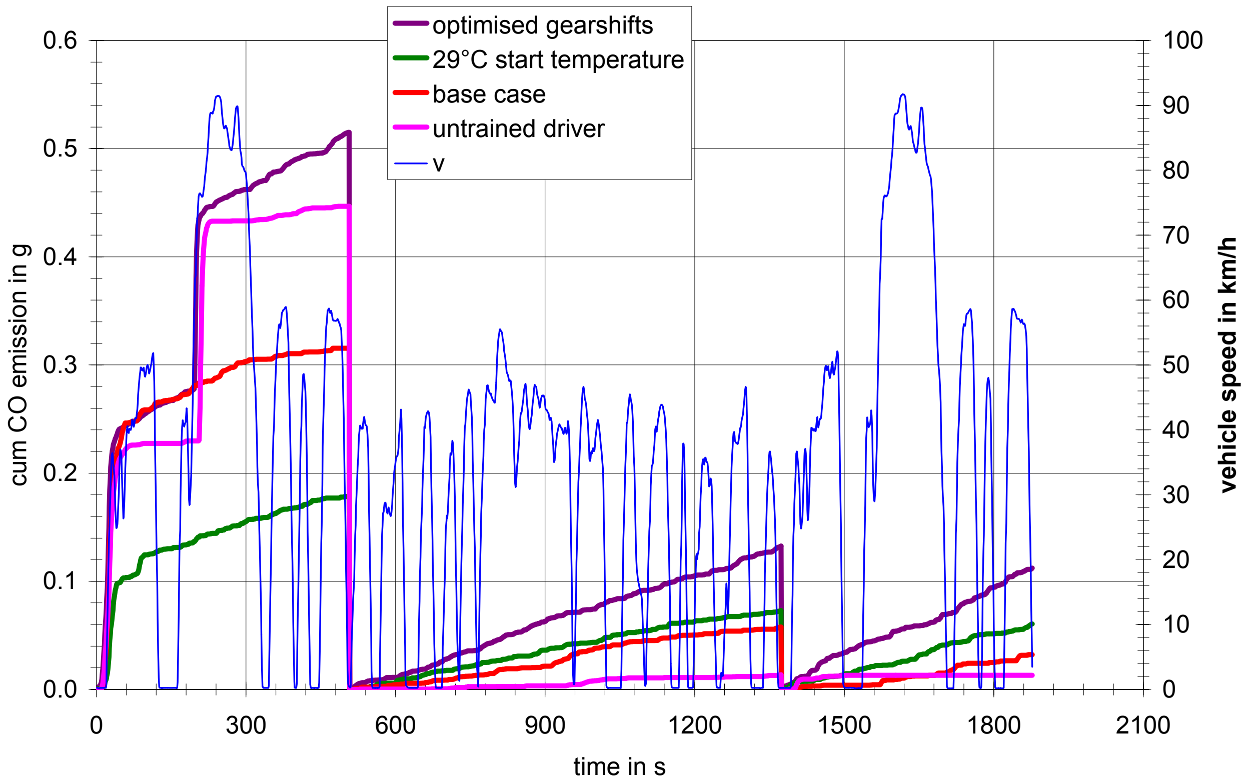


Figure 69: Cumulative CO emission for the different US FTP 75 parts, vehicle 2

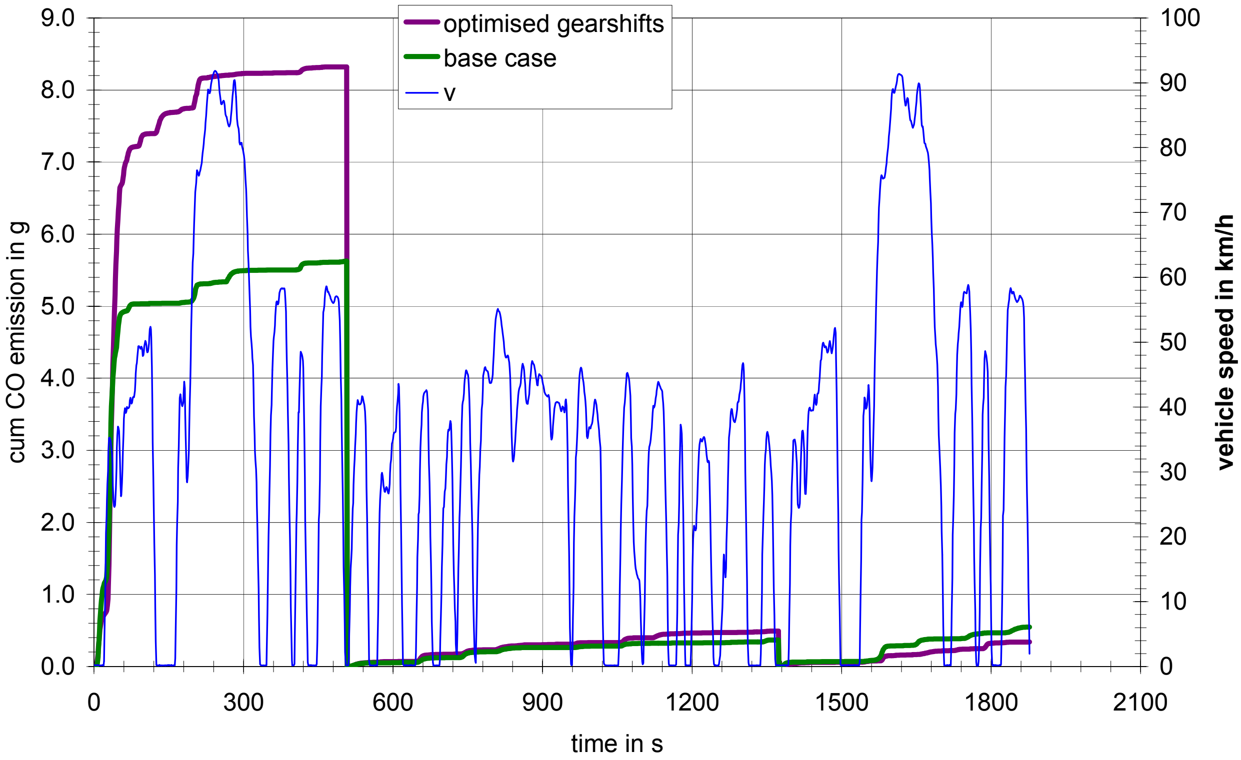


Figure 70: Cumulative CO emission for the different US FTP 75 parts, vehicle 3

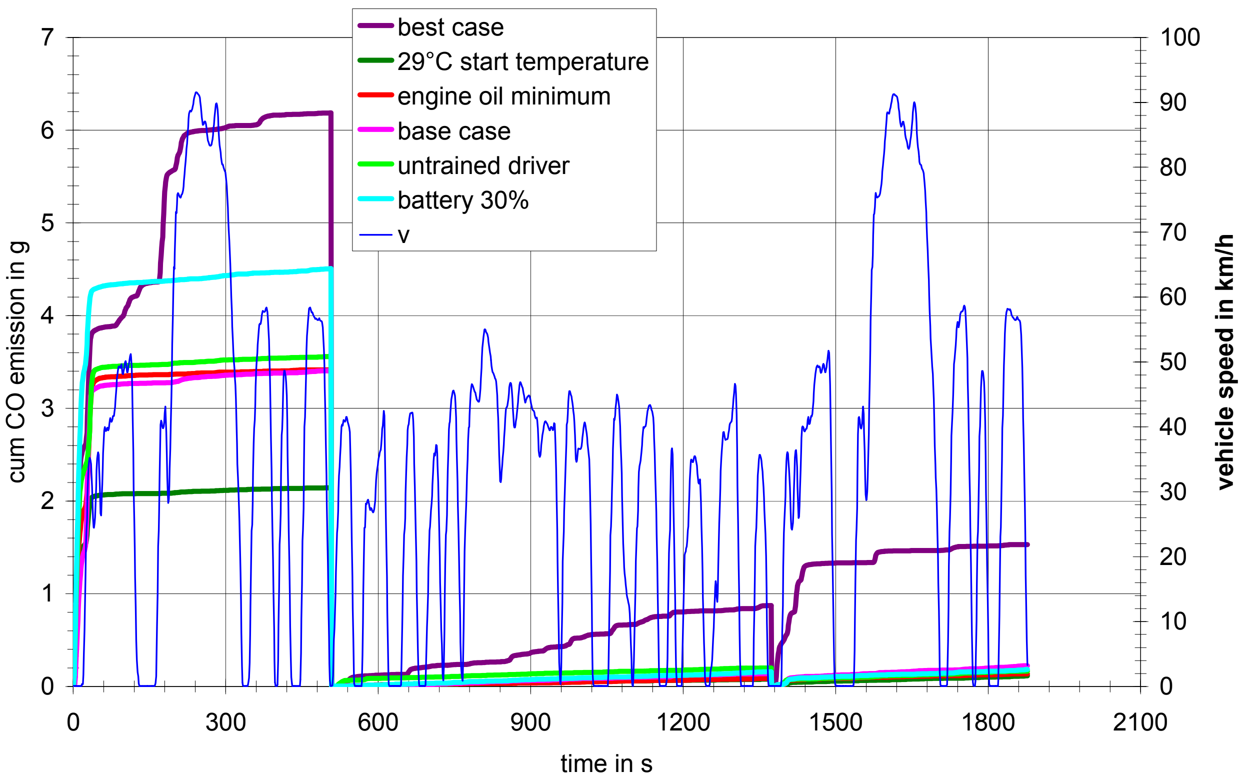


Figure 71: Cumulative CO emission for the different US FTP 75 parts, vehicle 4

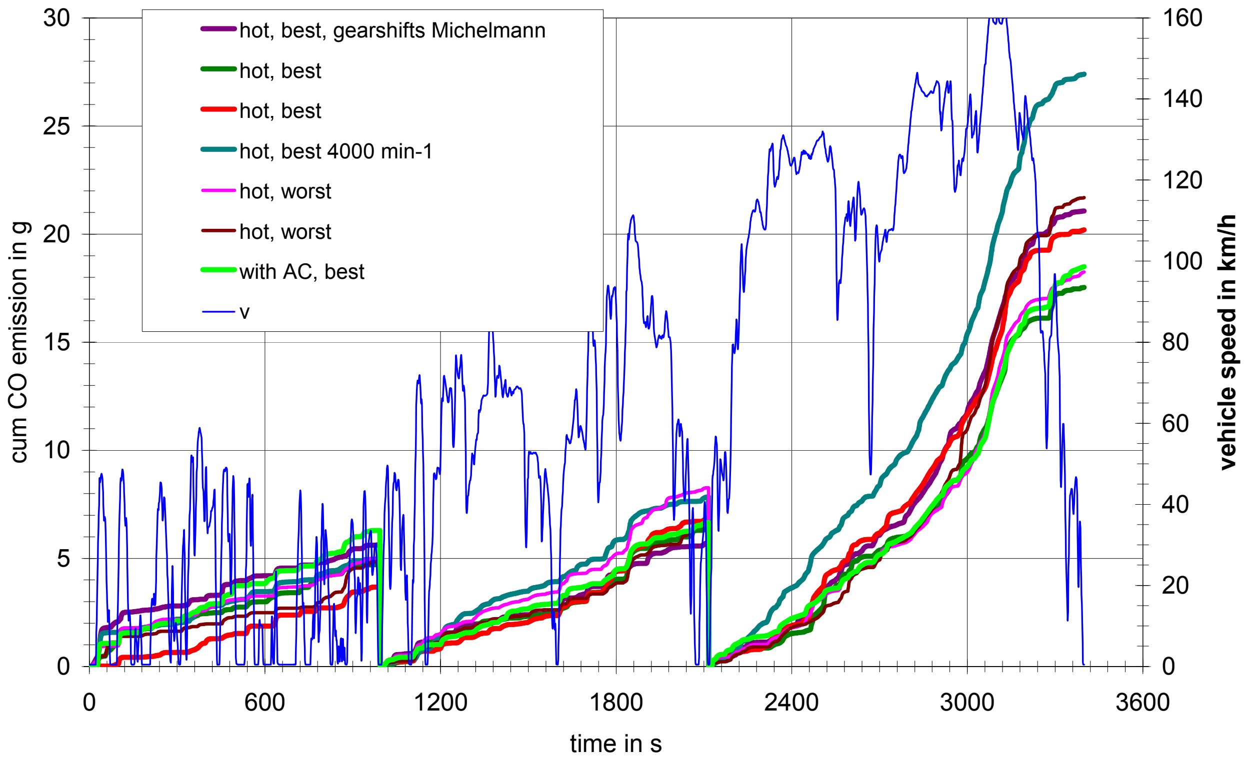


Figure 72: Cumulative CO emission for the different CADC parts, vehicle 1

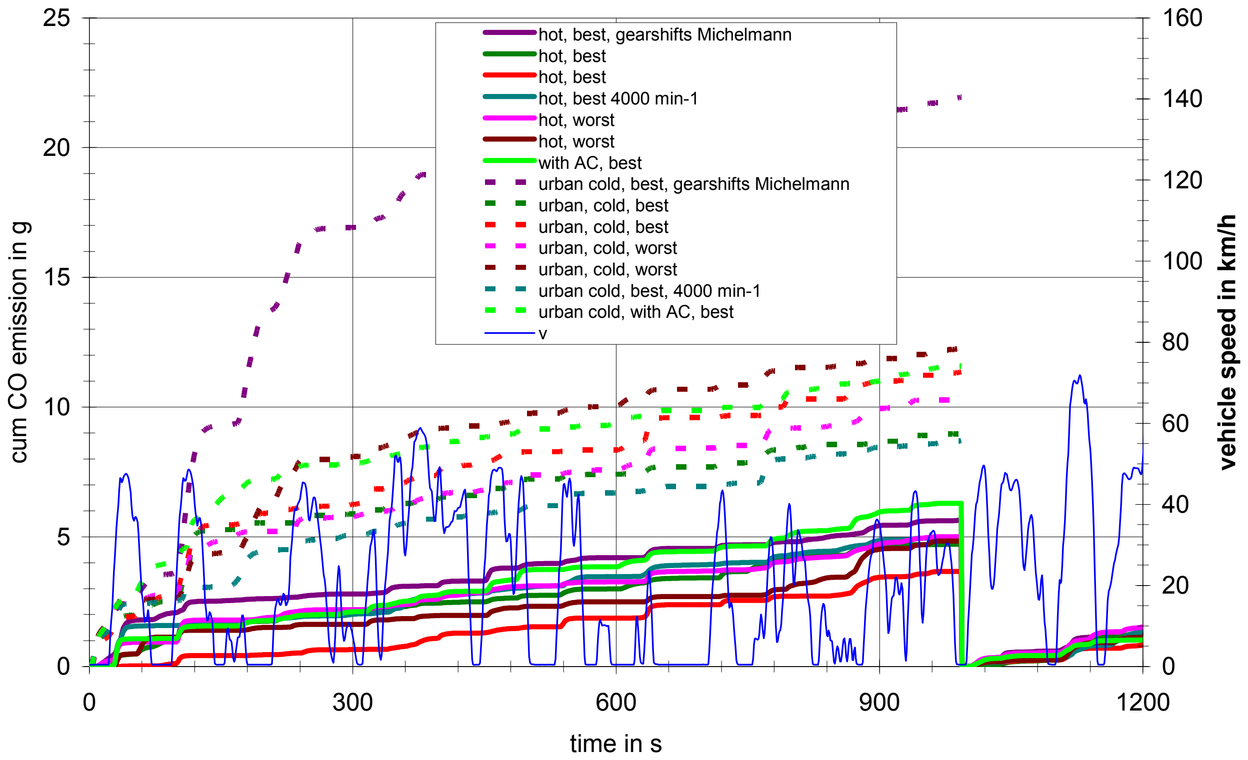


Figure 73: Cumulative CO emission for the CADC urban part, vehicle 1

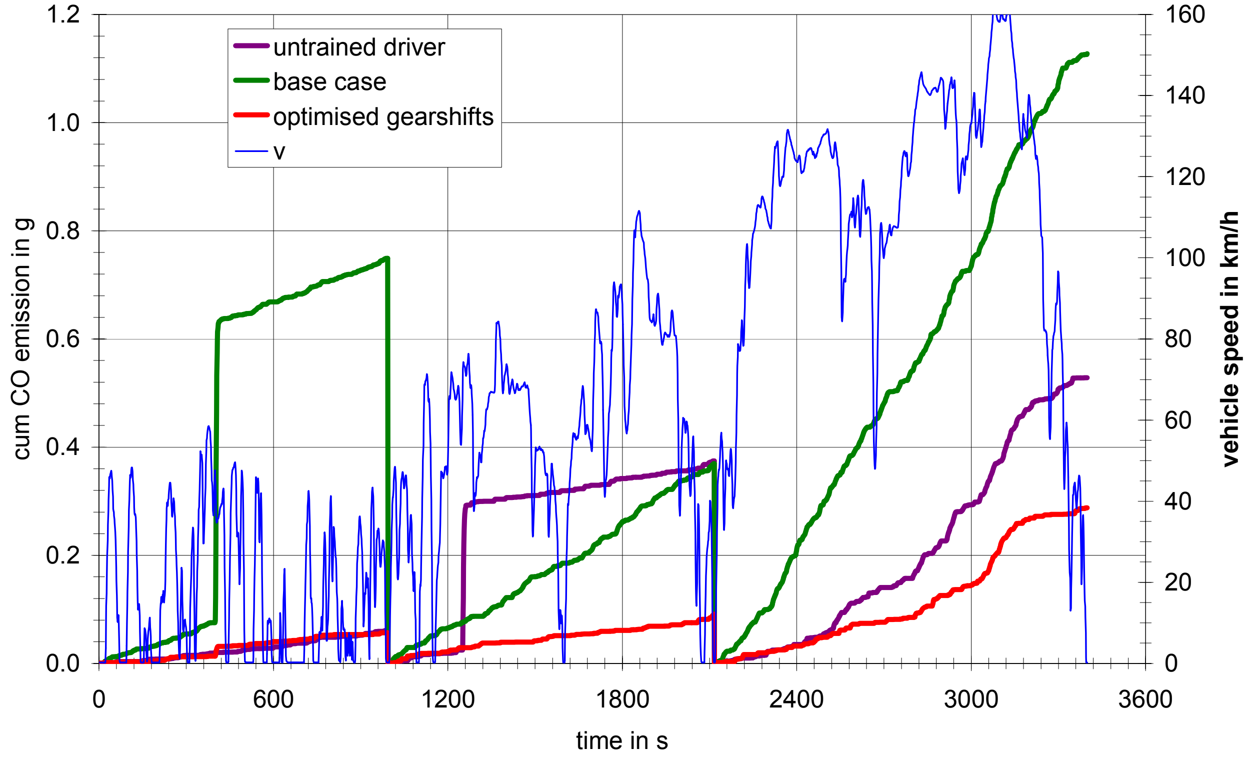


Figure 74: Cumulative CO emission for the different CADC parts, vehicle 2

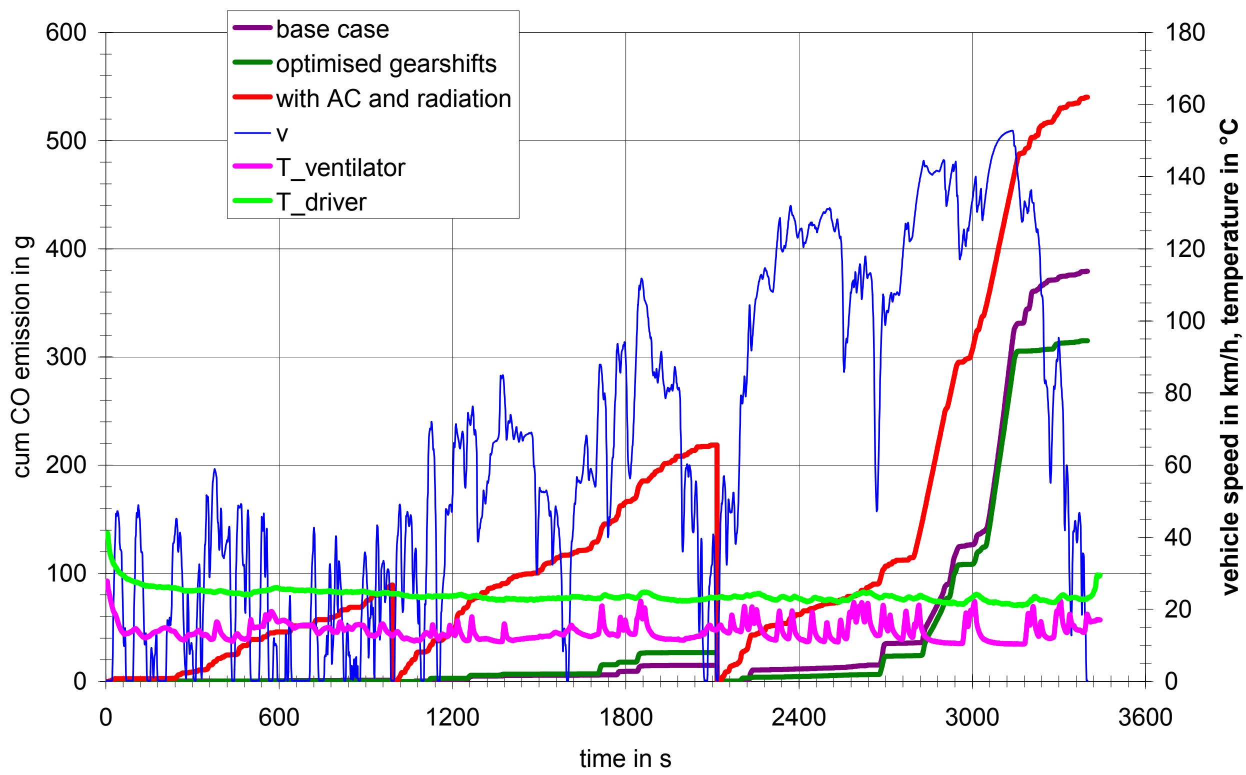


Figure 75: Cumulative CO emission for the different CADC parts, vehicle 3

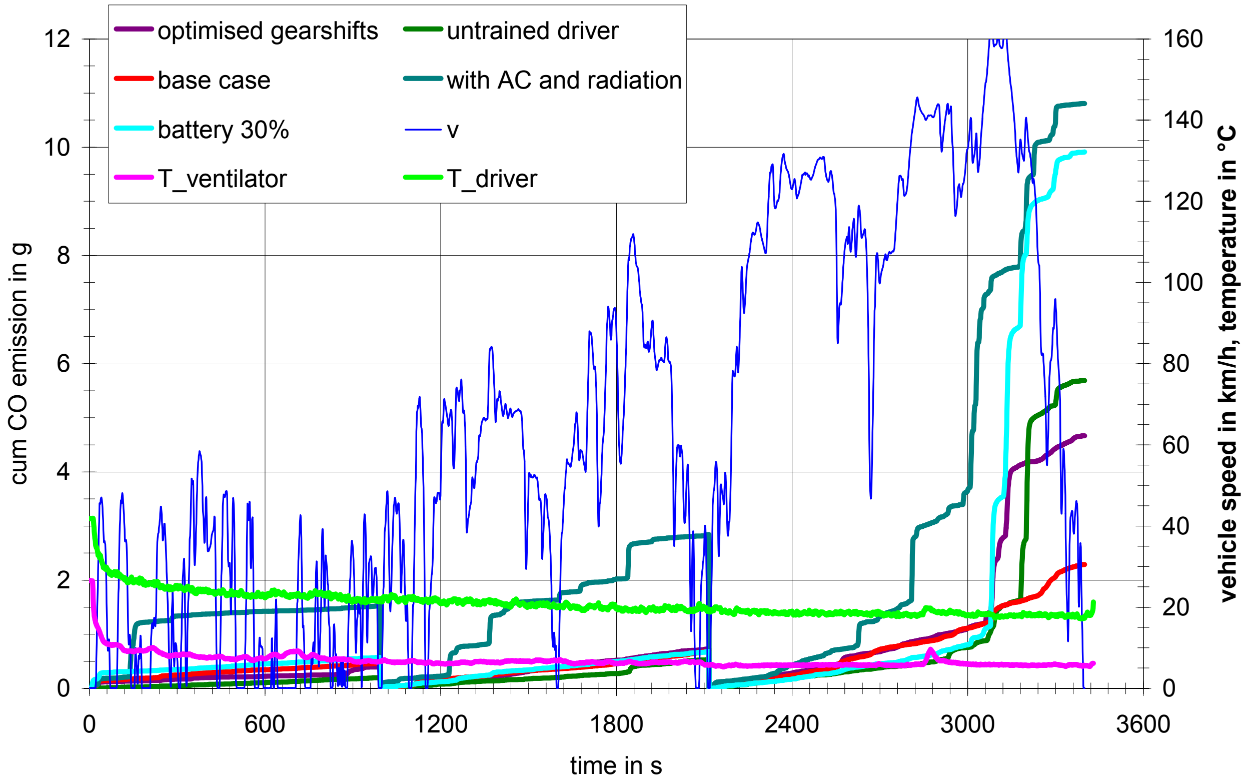


Figure 76: Cumulative CO emission for the different CADC parts, vehicle 4

9 Annex B – Proposal for realistic gearshift prescriptions

The existing gearshift prescriptions are vehicle speed based. This is not in line with practical use. For cars, light duty vehicles and motorcycles the driver normally shifts gears during acceleration phases at a fixed engine speed. This shift speed (normalised to the span between idling speed and rated speed) is a function of the power to mass ratio of the vehicle. Based on analyses of in-use driving behaviour data, carried out within previous projects (see [7] and [8]), upshift speed curves as functions of power to mass ratio were derived as shown in figure 77.

For average driving behaviour and acceleration phases manual transmissions shall be shifted from 1. to 2. gear when the engine speed reaches a value according to the following formula:

$$n\_\max\_acc(1) = (1.7444 \times pmr^{-0.3159} - 0.1) \times (s - n_{idle}) + n_{idle}$$

equation 9-1

where pmr is the rated power in kW multiplied by 1000 and divided by the vehicle mass in kg
n_{idle} – idling speed in min^{-1}
s - rated engine speed in min^{-1} at max. power

Upshifts for higher gears and average driving behaviour have to be carried out during acceleration phases when the engine speed reaches a value according to the following formula:

$$n\_\max\_acc(i) = (1.7444 \times pmr^{-0.3159}) \times (s - n_{idle}) + n_{idle}$$

equation 9-2

where pmr is the rated power in kW multiplied by 1000 and divided by the vehicle mass in kg
n_{idle} is idling speed in min^{-1}
s is rated engine speed in min^{-1} at max. power
i is the gear number (≥ 2)

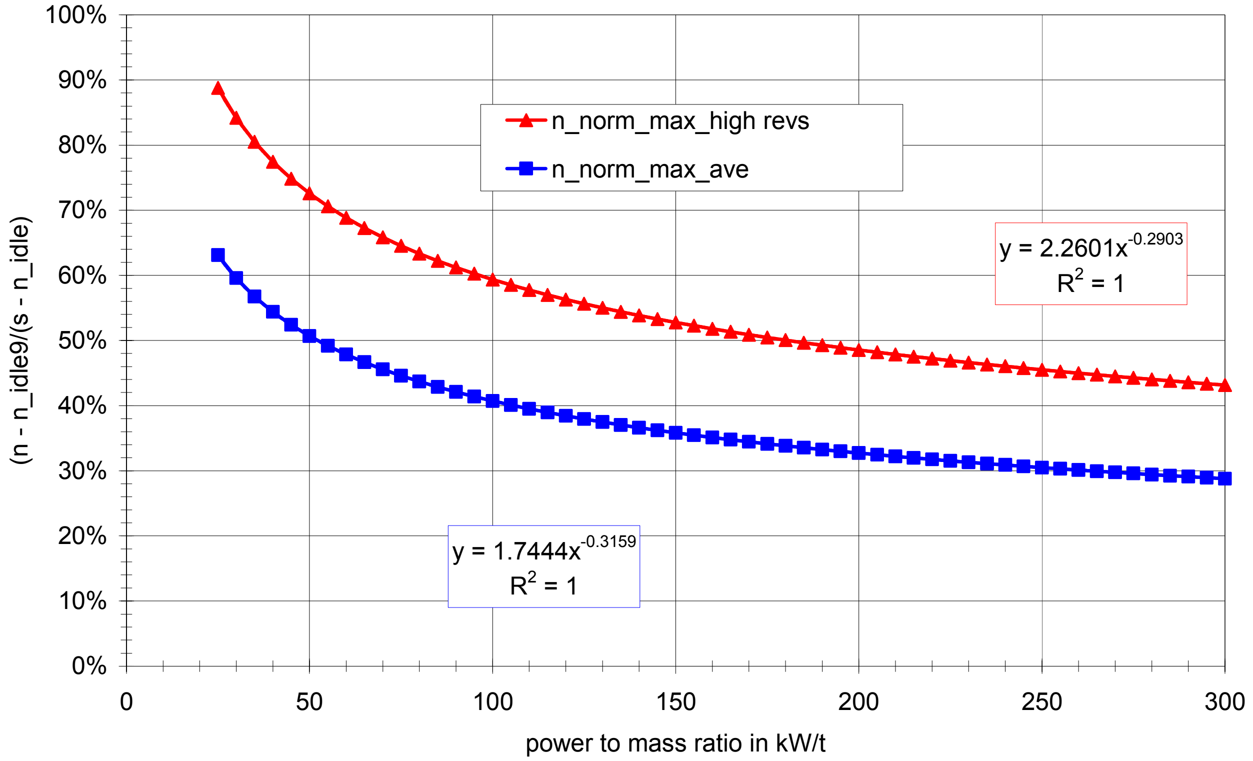


Figure 77: Normalised upshift speeds for cars (and light duty vehicles) in gears higher than first gear for average and high revs driving behaviour

The minimum engine speeds for acceleration phases in gear 2 or higher gears are accordingly defined by the following formula:

$$n\_\min\_acc(i) = n\_\max\_acc(i-1) \times \frac{r(i)}{r(i-1)}$$

equation 9-3

where *r(i)* – ratio of gear i

The minimum engine speeds for deceleration phases or cruising phases in gear 2 or higher gears are defined by the following formula:

$$n\_\min\_dec(i) = n\_\min\_acc(i-1) \times \frac{r(i)}{r(i-1)}$$

equation 9-4

where *r(i)* – ratio of gear i

When reaching these values during deceleration phases the manual transmission has to be shifted to the next lower gear.

Figure 78 shows an example for a gearshift sketch. The solid lines demonstrate the gear use for acceleration phases; the dotted lines show the downshift points for deceleration phases. During cruising phases the whole speed range between downshift speed and upshift speed may be used.

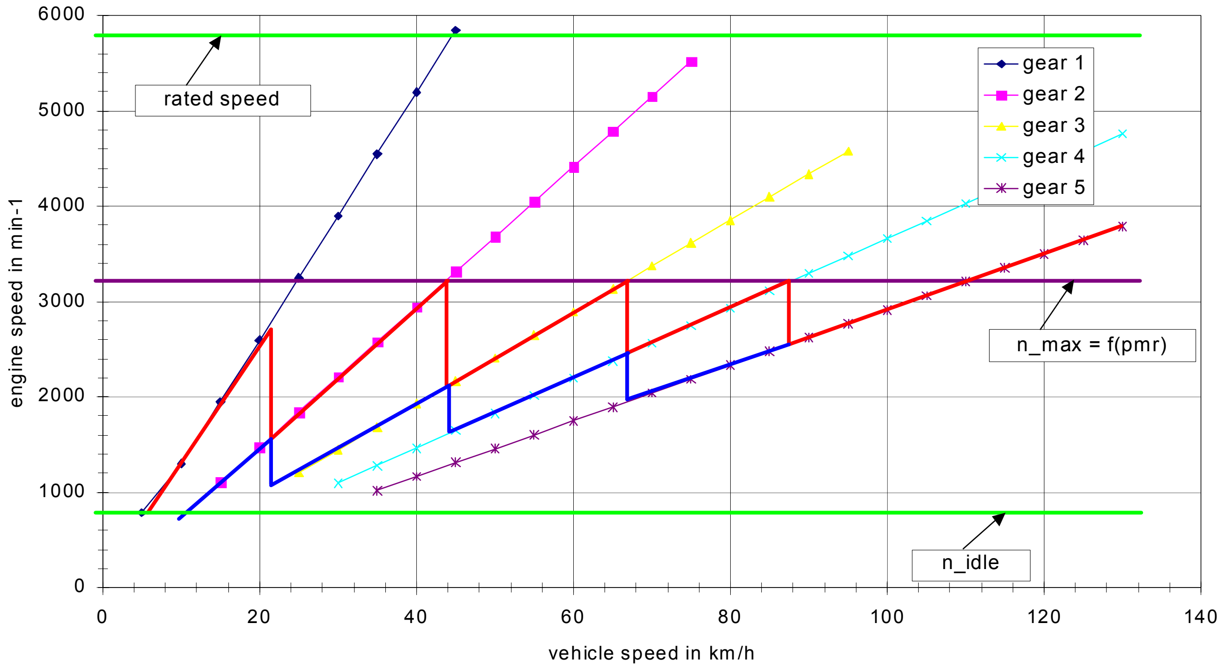


Figure 78: Example for a gearshift schema for a compact car. Upshifts and gear use during acceleration phases are coloured in red, downshifts and the additional gear use during constant speed or deceleration phases are coloured in blue.

Additional requirements

In order to avoid driveability problems these prescriptions have to be supplemented by the following **additional requirements**:

- No gearshift if a deceleration phase follows immediately after an acceleration phase.
- Downshifts to the 1. gear are prohibited for those modes, which require the vehicle to decelerate to zero.
- The 1. gear should only be used when starting from standstill.
- For those modes that require the vehicle to decelerate to zero, the engine speed is idling speed when the vehicle speed drops below 10 km/h or when the engine speed drops below $n_{idle} + 0.03 \times (s - n_{idle})$.
- The minimum time span for a gear sequence is 2 seconds.

Gear use calculation

Following the above prescriptions the gear use calculation is carried out in 3 steps:

Step 1: Calculation of shiftspeeds

Calculate upshift and downshift speeds for all gears according to the following formulas:

Upshift speeds in km/h during acceleration phases:

$$v_{1\to 2} = (n\_\max\_acc(1) \times (s - n_{idle}) + n_{idle}) \times \frac{1}{ndv_1}$$

equation 9-5

$$v_{i\to i+1} = (n\_\max\_acc(i) \times (s - n_{idle}) + n_{idle}) \times \frac{1}{ndv_i}$$ **, *i* = 2 to *ng*-1**

equation 9-6

Where i is the gear number (≥ 2)

ng is the total number of forward gears

n_{idle} is the idling speed in min^{-1}

s is the rated engine speed in min^{-1}

ndv_i is the ratio between engine speed in min^{-1} and vehicle speed in km/h in gear i

Downshift speeds in km/h during cruise or deceleration phases in gears 3 (3rd gear) to *ng* are calculated, using the following equation:

$$v_{i\to i-1} = (n\_\max\_acc(i) \times (s - n_{idle}) + n_{idle}) \times \frac{1}{ndv_{i-2}}$$, i = 3 to ng

equation 9-7

Where i is the gear number (≥ 2)

ng is the total number of forward gears

n_{idle} is the idling speed in min^{-1}

s is the rated engine speed in min^{-1}

ndv_{i-2} is the ratio between engine speed in min^{-1} and vehicle speed in km/h in gear i-2

Step 2 – Gear choice for each cycle sample

Engine speed = idling speed

The engine speed is set to idling speed and the gear to 0, if the following conditions are met:

- During stop phases
- During cruise or deceleration phases in second gear, if
  - the vehicle speed drops below 10 km/h or
  - the engine speed drops below $n_{idle} + 0.03 \times (s - n_{idle})$

Gear choice for acceleration phases

Gear = 6, if $v > v_{5 \rightarrow 6}$
Gear = 5, if $v > v_{4 \rightarrow 5}$
Gear = 4, if $v > v_{3 \rightarrow 4}$
Gear = 3, if $v > v_{2 \rightarrow 3}$
Gear = 2, if $v > v_{1 \rightarrow 2}$
Gear = 1, if $v \leq v_{1 \rightarrow 2}$

Gear choice for deceleration or cruise phases

Gear = 6, if $v > v_{4 \rightarrow 5}$
Gear = 5, if $v > v_{3 \rightarrow 4}$
Gear = 4, if $v > v_{2 \rightarrow 3}$
Gear = 3, if $v > v_{1 \rightarrow 2}$
Gear = 2, if $v \leq v_{1 \rightarrow 2}$

Step 3 – Corrections according to additional requirements

The gear choice is then modified according to the following requirements:

1. No 1. gear during deceleration phases.
2. No gearshift at a transitions from an acceleration phase to a deceleration phase: keep the gear that was used for the last second of the acceleration phase also for the following deceleration phase unless the speed drops below a downshift speed.
3. No upshifts during deceleration phases.
4. No gearshift in cruising phases.
5. If an acceleration phase is followed by a deceleration phase and gear is first gear, keep first gear.
6. If a gear is used for only one second, this gear shall also be assigned to the following second in case of acceleration or cruising phases and to the preceding second in case of deceleration phases. Since it could happen that the modifications according to this criterion create new phases where a gear is used for only one second, this modification step has to be applied several times.

Corresponding gearshift prescriptions are used, accepted and validated for the ECE global technical regulation for the exhaust emission measurements for motorcycles (WMTC, see [7]).

The gear use calculation for high revs driving behaviour is calculated accordingly but using the coefficients of the approximation function for this driving behaviour as shown in Figure 77.