Comparative analysis of different VIAQ test methodologies

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Analysis purpose and items

The purpose of this analysis is to compare different vehicle interior air test approaches to develop PM measurement test method.

The items

1. Vehicle Category
2. Criteria for excluding a vehicle from tests
3. Test Vehicle age/millage
4. Meteorological Conditions
5. Test Conditions
6. Sampling Points/Sampling Lines
7. Background air pollution level
8. Cabin air filter age
9. PM and gas components to be Measured
10. Measurement Methods
11. Test equipment requirements
12. Gas Analysers Calibration
13. Test Modes
14. HVAC Modes
15. Test Procedure
16. Test Protocol

Literature Cited

Index	Publication reference
CEN	CEN/WS 103 Real drive test method for collecting vehicle interior air quality data // Doc. CEN/WS 103 N. 23, 2021 Pham, L., **Molden, N.,** Boyle, S., Johnson, K., & **Jung, H.** (2019). Development of a Standard Testing Method for Vehicle Cabin Air Quality Index. *SAE International Journal of Commercial Vehicles*, 12(2). http://dx.doi.org/10.4271/02-12-02-0012
CabinAir	**Cha Y.** Dynamic and stationary measurement of in-vehicle PM2.5 and the filtration. VIAQ-21-07
Wei	**Wei, D.**, Nielsen, F., Ekberg, L., **Löfvendahl, A.**, Bernander, M., Dalenbäck, J-O. PM2.5 and ultrafine particles in passenger car cabins in Sweden and northern China—the influence of filter age and pre-ionization. Environ Sci Pollut Res 27, 30815–30830 (2020). https://doi.org/10.1007/s11356-020-09214-0
Abi-Esber	Abi-Esber L, El-FadelM (2013) Indoor to outdoor air quality associations with self-pollution implications inside passenger car cabins. Atmos Environ 81:450–463. https://doi.org/10.1016/j.atmosenv.2013.09.040
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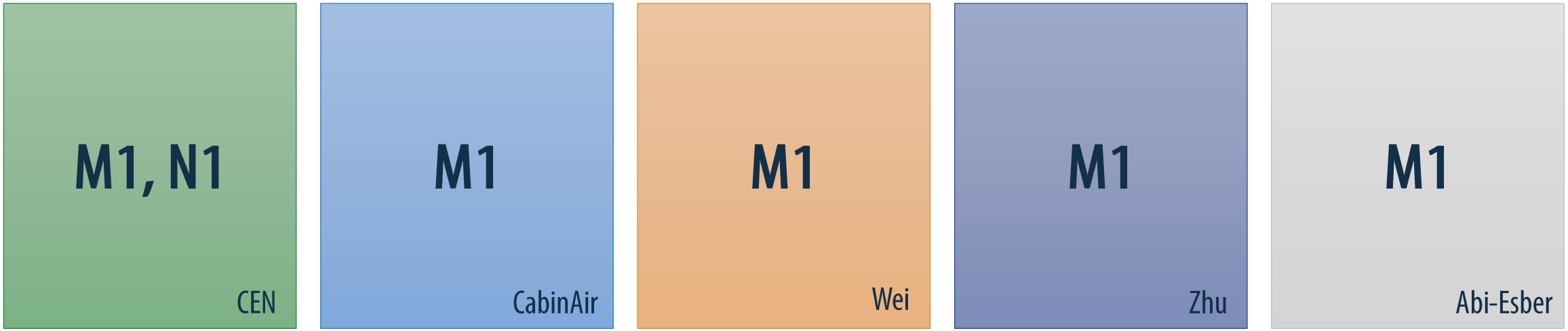
1.Vehicle Category



2.Criteria for excluding a vehicle from tests

The following checklist should be applied to all vehicles. Exclusion shall be based on a positive answer to any of the criteria below:

- ✓ Does the vehicle not have a full service history?
- ✓ Is there a Malfunction Indication Light showing on the vehicle instrument panel?
- ✓ Has the vehicle had unauthorised vehicle repairs?
- ✓ Has any part of the vehicle's heating and ventilation system replaced with non-original parts?
- ✓ Through visual inspection of the vehicle, are there any damaged ventilation system relevant components?
- ✓ Are there any obstructions to the vehicle air intake path?
- ✓ Is the vehicle not in overall safe operating condition?
- ✓ Is there any damage to the body of the vehicle, including but not limited to doors, windows and the rear?

CEN

3.Test Vehicle age/mileage

3 000…15 000 km

CEN

8 000…289 000 km

Abi-Esber

4. Meteorological Conditions

Temperature	10…20°C
Relative Humidity	40…80%
Atmospheric pressure	85…110 kPa
Weather condition:	no rain, fog, snow or standing water on the carriageway

CEN

Temperature	-6…29°C
Relative Humidity	30…65%

CabinAir

Relative Humidity	<70%
Rain free days	

Wei

5.Test Conditions

A valid test shall conform to the requirements indicated below:

- Driving time Monday to Sunday, 06:00 to 20:00
- Road condition Paved streets with no standing water, snow or ice

It is recommended to **avoid long tunnels, high altitudes and construction areas**. In addition, the test must be primarily conducted **on city roads and urban locations**. A test may be split up into multiple trips, each of which must meet the trip conditions. A trip shall start from a point at which the vehicle is stationary, with stationary defined as less than or equal to 0.5 km/h. There shall be no overlaps between the trips. A single trip shall be made up of continuous driving. Multiple trips from the same test can, in-between those trips, allow driving that does not meet the boundary conditions of this CWA. Each trip shall meet the conditions below:

- **Instantaneous vehicle speed ≤60 km/h**
- **Minimum distance 10 km**
- **Minimum duration 30 min**

A normal driving style shall be adopted. An involuntary stall invalidates the test, but a short period of deliberate engine-off – for example due to a stop/start system – is permitted. For a trip to be valid, all the conditions below shall be fulfilled:

- **Average speed 40…60 km/h**
- **Average altitude 0…700 m**

Windows, doors, sunroof or convertible soft top must be closed at all times. Heated or cooled seats should not be used.

There should **the driver and one passenger present in the vehicle for the duration of the test**. All **outer clothing of the driver should be made of [polyester] to minimise particle generation** from the driver. Clothing should cover both arms and legs. The occupants should avoid applying any fragrances prior to or during the test.

CEN

5.Test Conditions

City-road driving

Windows and doors are closed during the whole test
No interior PM sources, e.g. smoking

CabinAir

1. **City driving** with congested stop and go traffic at speeds of up to 40 km/h.
2. **Highway driving** slow moving traffic in its Northern part (average speed of 60 km/h) and faster traffic (average speed of 80 km/h) in the remaining Southern part.

During all tests, vehicle occupants refrained from smoking to preclude non-traffic sources of $PM_{2.5}$ and CO inside the vehicle.

Abi-Esber

1. **Stationary test**: The test vehicle was standing inside the tunnel with engine and HVAC system on, at an uphill emergency parking spot.
2. **Driving test**: driving on freeways and highways, with speeds ranging within 50–120 km/h, along the relatively polluted 760 km route.

Smoking was forbidden. 2–3 persons sat in the vehicle.

Wei

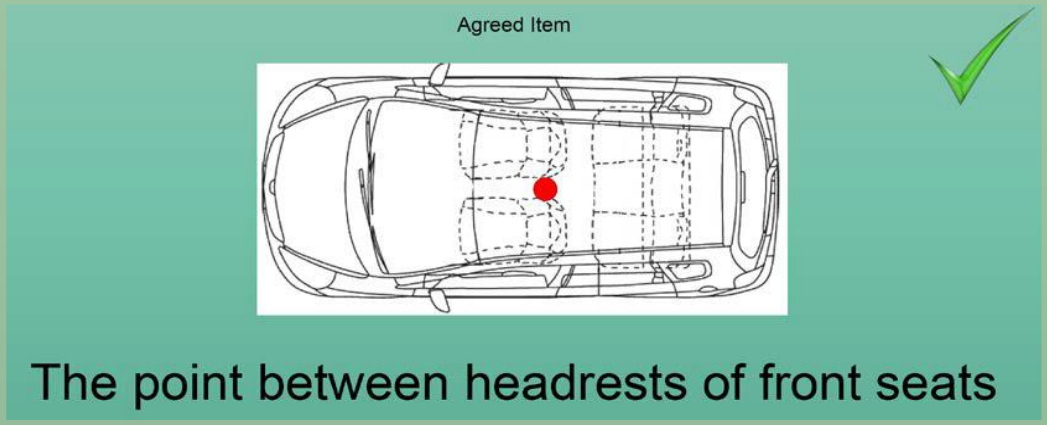
The test vehicles were in the traffic stream with an average speed of 50-60 mph for all **freeways**. Measurements usually took place on freeways between 10 am and 4 pm when on-shore sea breeze was dominant.

Windows were closed for all the runs.

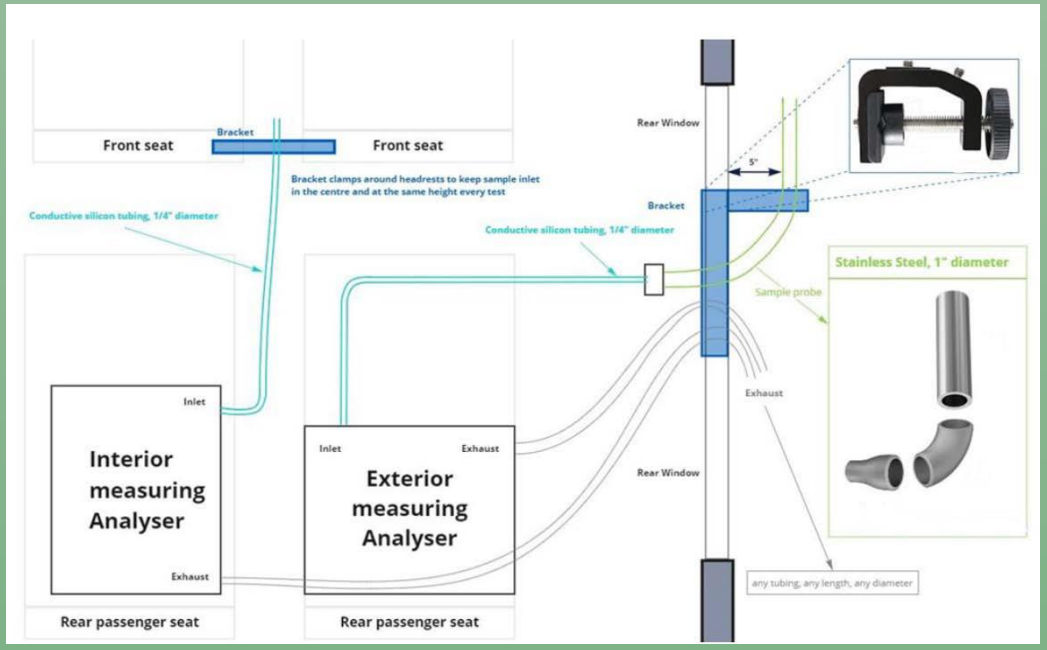
Zhu

6. Sampling Points/Sampling Lines

1. Following the UNECE VIAQ group, the interior sampling point should be a **head-height between the front headrests**



2. The external sampling point should be **as close as reasonably possible to the ventilation air intake**. Sampling should be isokinetic.



The sample lines should be made of a near-zero-loss material such as PTFE for gas and anti-static material for particulates.

CEN

6.Sampling Points/Sampling Lines

1. **Indoor** inlet fixed in the **mid between two front seats**
2. **Outdoor** inlet placed **close to the air intake area under the hood**

CabinAir

1. **In-vehicle** location which is the **passenger's breathing zone**
2. **Out-vehicle** sampling was conducted at **four locations** surrounding the test vehicle:

rear left of the car as observed by a seated driver (location 1), front left (location 2), rear right (location 3) and front right (location 4)

The tubes are 1.5 m long with an inner diameter of 5.7 mm. The sampling flow rate inside the tubes were 6 L/min

Abi-Esber

1. **Inside** sampling tube was **placed above the middle armrest between the front seats**
2. **Outside** sampling tube was placed **immediately outside of the HVAC air intake below the wind shield**, which measured exactly the air at HVAC upstream.

Wei

Outdoor particles were sampled through a 3 mm isokinetic probe **mounted on the car window** to ensure a representative UFP sample entered the inlet. For 300 nm particles (the largest particle size studied), with a fixed sampling flow rate of 1.0 L/min.

A similar probe was used for **in-cabin** air sampling to compensate for any diffusion loss in the sampling lines.

Zhu

7.Background air pollution level

PN concentration 5000…100,000 #/cm^3

$PM_{2.5}$ concentration, 5…100 µg/m^3

CEN

$PM_{2.5}$ about 40…300 µg/m^3

CabinAir

Air quality guideline values

Pollutant	Air in populated areas								
	Russian Federation		WHO		EU		USA		Korea	
PM_{10}, µg/m^3	300	60	50	20	50	40	150		100	50
$PM_{2.5}$, µg/m^3	160	35	25	10	25		35	12	50	25
Exposure time	30 minutes		24 hours		1 year					

8.Cabin air filter age

HVAC filter age: **New, OEM-approved.**

If a vehicle is not installed with a filter by the OEM, the vehicle is within the scope of this methodology, to be tested with no filter present.

CEN

Cabin filter slightly aged (road air pollution aged - real driving **aged used for 3 months** about 2 hours driving every day).

CabinAir

1. **New filter.**
2. **500-h-aged filter.**

Wei

Vehicles, all equipped with a **standard manufacture-installed particulate filter with activated carbon.**

Zhu

9.PM and gas components to be Measured

PN (10 nm to 10 µm), #/cm^3
PM_{10}, µg/cm^3
CO_2 , ppm
NO_2 , ppb

CEN

PM_1 , $PM_{2.5}$, PM_{10}
CO_2

tVOC

CabinAir

UFP (10 nm to 100 nm), #/cm^3
$PM_{2.5}$, µg/cm^3

Wei

$PM_{2.5}$

CO

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PN, #/cm^3
Particle size distributions (7.9…217 nm)
CO_2
CO

Zhu

10.Measurement Methods

PN concentration	Condensation particle counter (10 nm to 10 µm)
PM concentration (<10 µm)	Mini Wide Range Aerosol Spectrometer or Aethalometer
CO_2 concentration	Non-dispersive infra-red
NO_2 concentration	Non-dispersive ultra-violet or chemiluminescent detector

CEN

PN concentration and PM concentration	Mini Wide Range Aerosol Spectrometer (diameter from 10 nm to 35 µm, distributed into 41 channels)

Wei

$PM_{2.5}$	Optical backscatter technology
CO	Electrochemical technology

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PN	Water-based condensation particle counters (WCPC).
Particle size distributions	Scanning mobility particle sizer
CO_2	Non-Dispersive Infrared (NDIR)
CO	Electrochemical

Zhu

11.Test equipment requirements

PN concentration (10 nm to 10µm)	0 to 1,000,000 #/cm3
PM concentration (<10 µm)	0 to 1 mg/m3
CO_2 concentration	0 to 5,000 ppm
NO_2 concentration	0 to 0.5 ppm

CEN

PM concentration	0.001…150 mg/m3 accuracy of 0.1% of reading or 0.001 mg/m3, whichever is greater
CO	1…200 ppm, resolution of 0.1 ppm response time (t90%) of 40 s.

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12.Gas Analysers Calibration

For in-field calibration of the gas analysers, a **zero and span calibration shall take place at the start of the test and a zero and span check shall be made at the end of each test** that is under two hours in length. For tests longer than two hours, mid-test checks of zero or zero and span may be made (such that the time between checks does not exceed two hours); the analyser may be adjusted to the calibration gases if necessary.

CEN

1. **Annual calibration.**
2. **Automatic self-test done by instrument at each startup.**

Wei

$PM_{2.5}$ - They are **factory calibrated** to the respirable fraction of the ISO 12103-1, A1 Arizona test dust. **A zero calibration was applied prior to every use.**
CO - **Calibration with zero and span gas (50 ppm) was undertaken at the beginning of each testing round** (every two weeks).
The accuracy of the analyzer was tested in the range 0…3 ppm

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13.Test Modes

1. Urban driving

CEN

1. Stationary test
2. Dynamic test

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1. Stationary test
2. Driving test

Wei

1. Freeway driving

Zhu

1. Mobile test
2. Stationary test
3. Fume leakage test

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14.HVAC Modes

During each individual trip, the HVAC system should be in **automatic mode with 21°C temperature setting**, with ventilation flaps fully open and directed straight ahead.
If the vehicle does not have an automatic mode, the HVAC system should be set to **fresh air mode, with air conditioning switched on at 50%/medium temperature, fan speed 50%/medium**, and ventilation flaps fully open and directed straight ahead.

CEN

HVAC **ventilation**: **totally fresh air**
HVAC **fan speed**: **low or medium**
A/C: **ON**

CabinAir

Three ventilation modes:
1) **Driver window ½-opened**, air conditioning (**AC**) **off**, vents closed
2) Windows closed, **AC on fresh air intake**, **fan setting 'medium' or '2'**
3) windows closed, **AC on recirculation, fan setting 'medium' or '2'**

Abi-Esber

14.HVAC Modes

A/C ON
desired temperature 22°C,
ventilation airflow levels (extra low, low, medium, high)
Recirculation degree 0, 30, 50, 70%
Ionisation ON/OFF
windows closed

a) Extra low ventilation, medium ventilation and high ventilation are only used in combination with 0 recirculation
b) Thirty percent, 50% and 70% recirculation degrees are only used in combination with low airflow
c) Ionization off test cases means the baseline cases

Wei

Ventilation settings tested were as follows:
(i) circulation fan off and recirculation (RC) off
(ii) fan on and RC off
(iii) fan on and RC on
The supply air to the in-cabin environment was from outside under conditions (i) and (ii) and from inside under condition (iii). **Fan speed was kept from low to medium** for most of the tests. Under condition (i), outside air came into the in-cabin environment through leaks in windows and doors. Under condition (ii), outside air came into the in-cabin environment through a manufacture installed filter.
AC always ON.

Zhu

15.Test Procedure

1. Cold start operation shall be excluded. To ensure this, the first 10 minutes or the first 2 km of driving under internal combustion engine operation shall be excluded from any test, whichever comes later. This restriction does not apply to vehicles with no internal combustion engine.
2. A test is a continuous stretch of driving that can contain multiple trips.
3. A test may be split up into multiple trips, each of which must meet the trip conditions. A trip shall start from a point at which the vehicle is stationary, with stationary defined as less than or equal to 0.5 km/h. There shall be no overlaps between the trips. A single trip shall be made up of continuous driving. Multiple trips from the same test can, in-between those trips, allow driving that does not meet the boundary conditions of CWA.
4. For test results to be deemed adequate for use in comparing interior air quality performance between models within the scope of this CWA, it shall be required to collect:
   - at least 3 valid trips in total
   - in the required fan speed/ventilation modes
   - on 1 vehicle of its type.

CEN

15.Test Procedure

Test duration:
- parking - 30 min
- Driving (for one trip) > 60 min

Test Procedure:

i) Make a test plan and test matrix, determine test mode (stationary test or dynamic test), test location and test time

ii) Set up instruments, sampling inlets inside and outside the car

iii) Check the vehicle settings (Cabin air filter, HVAC fan speed, HVAC ventilation mode, A/C) and register the info on notebook

iv) Check environmental condition (temperature and humidity) and register the info

v) Test according to the test plan and register test related info during test

vi) Data collection and data post analysis

CabinAir

1. All the instruments were turned on at least 30 min in advance for warming up and stabilization.
2. The ventilation parameters were varied firstly
3. When a stable in-cabin air quality was achieved, a data collection interval of around 5…10 min started.

Wei

Each vehicle was tested at least 20 h on freeways. Same ventilation parameters were usually maintained constant for 20 min before switching to different settings.

Zhu

15.Test Procedure

Three types of tests (fume leakage, stationary, and mobile) were conducted at a duration of 30. . .45 min each test.
1. In fume leakage tests, engine fume leakage prior to exiting the tailpipe is examined by extracting tailpipe fumes using a customized exhaust extraction system. The exhaust fumes are collected into a well-fitted hose that is connected to the tailpipe through a sealed system that releases 15 m away downwind from the test location. Tests simulating idle mode were conducted at a controlled garage located on campus of AUB whereas those simulating engine combustion during car movement were conducted on a chassis dynamometer with both locations free from background $PM_{2.5}$ and CO sources. Chassis dynamometer testing is used to simulate engine combustion during vehicle movement at speeds of 40, 60 and 80 km/h. It cannot however simulate wind and associated vibration which constitutes a limitation to the current work. The engine was running during these tests at average speeds of 800, 1500, 1600 and 2150 RPM for speeds of 0, 40, 60 and 80 km/h, respectively. The exhaust pipes of the vehicles were inspected prior to field testing to ensure the absence of cracks or holes and to avoid the possibility of fume leakage to the immediate surroundings of the vehicle. $PM_{2.5}$ and CO concentrations are measured concomitantly inside and in the immediate vicinity of the vehicle. In the event of $PM_{2.5}$ or CO detection inside the cabin, the contamination would be attributed to engine fume leakage prior to reaching the tailpipe.
2. In stationary tests, the cars are parked at AUB campus in front of a playground, which constitutes a relatively open area where the influence of nearby cars and roadway emissions are precluded. Exhaust fumes are allowed to flow freely from the car tailpipe to its surrounding area. Idle tests were conducted whereby $PM_{2.5}$ and CO concentrations are measured inside the cabin as well as in the outdoor air in the immediate vicinity of the car.
3. In mobile tests, the cars are driven with a driver and a passenger at average speeds of 40 km/h on commercial/residential areas and 60 or 80 km/h on highways, respectively. Exhaust fumes are allowed to flow freely from the car tailpipe to its surrounding area. $PM_{2.5}$ and CO concentrations were measured inside the cabin as well as in the outdoor air in the immediate vicinity of the car.

16.Test Protocol

1. Vehicle information

Parameter	Description	Unit
Vehicle type	Type approval code	[code]
Vehicle variant	Type approval variant – optional for historical tests	[code]
Vehicle version	Type approval version – optional for historical tests	[code]
Manufacturer		[name]
Model		[name]
Model Year		[year]
Date of first registration		[day/month/year]
Country of current registration		[country]
Software code	If available	[code]
Vehicle ID	VIN	[code]
Vehicle category	European classification	[category]
Emissions certification norm	Regulatory stage	[Euro X]
Engine type		[compression ignition; s
Engine rated power		kW
Engine displacement		cc
Transmission		[automatic; manual]
Number of forward gears		#
Seat material		[material]
Cabin air volume		litres
Fuel type		[diesel; gasoline; LPG; CNG]
Type approval cycle	NEDC; WLTC	[norm]
Type approval CO_2 emissions	Combined	g/km
Odometer at start of test	Cumulative distance travelled by vehicle at start of test	Km
HVAC filter part	Manufacturer/part number	[name, code]
HVAC filter type	Generic type of material	[material]
Date of filter installation		[date]

2. Test condition information

Parameter	Description	Unit
Test ID	Unique identifier of test	[code]
Test date		[date]
Organisation conducting test		[name]
Test location		[city, country]
Start time of pre-test procedure	Pre-conditioning prior to trip	[time]
Start time of trip		[time]
End time of trip		[time]
Test time		S
Predominant mode	Start-stop mode active	[yes; no]

The cabin air quality index for PN is the "PN Filtration Rate" and is the ratio of the integrated interior PN concentrations and integrated exterior PN concentrations, thus:

$$CAQI_i = \frac{\int_0^t C_{i,\text{cabin}}\,dt}{\int_0^t C_{i,\text{outside}}\,dt}$$

The 1 Hertz transient test data to be reported

3. Reporting of trip results

Parameter	Description	Unit
Exterior PN concentration	Mean concentration	#/cm³
Interior PN concentration	Mean concentration	#/cm³
PN Cabin Air Quality Index*	Ratio of mean interior to exterior PN concentrations	[dimensionless]
Exterior PM concentration	Mean concentration	µg/cm³
Interior PM concentration	Mean concentration	µg/cm³
PM Cabin Air Quality Index*	Ratio of mean interior to exterior PM concentrations	[dimensionless]
Exterior CO_2 concentration	Mean concentration	ppm
Interior CO_2 concentration	Mean concentration	ppm
Exterior NO_2 concentration	Mean concentration	ppb
Interior NO_2 concentration	Mean concentration	ppb
NO_2 Cabin Air Quality Index*	Ratio of mean interior to exterior NO_2 concentrations	[dimensionless]
Ventilation mode	Automatic/Manual	[automatic/manual]
Fan speed setting	Automatic/Level	[automatic/level]
Temperature setting	Temperature/Level	[°C/level]
Vehicle speed	Mean	km/h
Trip distance		km
Ambient humidity	Mean	%
Ambient temperature	Mean	°C
Ambient pressure	Mean	kPa
Vehicle altitude	Mean	m
Trip validity	Does trip meet all boundary conditions in clause 8.5	yes/no

CEN

Test Protocol

PM_1
$PM_{2.5}$
PM_{10}
total PNC
41 size separated PNC and mass concentration

$PM_{2.5}$ removal efficiency is calculated as the fraction of $PM_{2.5}$ reduced comparing outdoor $PM_{2.5}$ concentration and indoor $PM_{2.5}$ concentration

CabinAir

Average inside and outside $PM_{2.5}$ concentrations and UFP counts were calculated for each data collection interval firstly by averaging the 1-min data, and then the general average was calculated for each test case (based on all data collection repetitions).
The indoor to outdoor ratio (I/O ratio) of $PM_{2.5}$ mass concentration and UFP counts were analysed afterwards, to evaluate the filtration performance regardless of ambient pollution level.

Wei

16.Test Protocol

Trip average in- and out-vehicle $PM_{2.5}$ and CO concentrations were calculated for each mobile trip by averaging the 1-min $PM_{2.5}$ and CO measurements. A general average in-vehicle air pollutant level was calculated afterward for each ventilation mode and car, and was compared to the 24- and 8-h World Health Organization (WHO) permissible exposure guidelines for $PM_{2.5}$ and CO (25 mg m3 and 9 ppm respectively). Also, one-way ANOVA and linear regression analysis were used to assess the statistical significance of the influence of ventilation mode and car age on in-cabin exposure. In addition, trip average in/out (IO) ratios were used to establish the relationship between average concentration measured inside the vehicle and that measured in its vicinity. They were calculated using 1-min IO ratios corresponding sequentially to the four tested out-vehicle locations and a single in-vehicle location which is the passenger's breathing zone.

Abi-Esber

Conclusions

1. The analytical review of published papers describing VIAQ research showed a wide range of approaches, measured substances and particle dimensions, different test modes and conditions, different HVAC settings etc. Most works are research or pilot study.
2. Only some publications contain of relatively detailed description of test methodology and test conditions and they were analysed in this document.
3. Most comprehensive test methodology description is in the document CEN/WS 103 N. 23.
4. Our informal working group could use this information for developing our own harmonized methodology taking into account researchers experience worldwide.
5. Most important criterions for our methodology will be: to find worse case scenario; to minimize cost and test time; to ensure accuracy and repeatability of tests in different laboratories; to harmonize test conditions and test procedure worldwide.

Your opinion

Comments? Suggestions? Proposals? Questions? Please fill Excel form: document VIAQ-22-08

	VIAQ-22-08
Name	
Organization	
Items	**Comments, suggestions**
Criteria for excluding a vehicle from tests	
Test Vehicle age/millage	
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Thank you for your attention!

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