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Test methodology development and repeatability assessment

1. Test methodology and equipment

Investigation purpose

This investigation is a part of work in the frame of stage 3 of Vehicle Interior Air Quality informal working group activity, regarding working items (see the task list in VIAQ-25-09):

5. Test Conditions
7. Background air pollution level
13. Test Modes
15. Test Procedure

The tasks of this investigation are

- to develop on road test methodology
- to check repeatability of test results in relatively stable test conditions, except background $PM_{2.5}$ concentration changing in wide range

Test equipment

Dusttrak DRX Aerosol Monitor 8533

The DRX Aerosol Monitor can measure both mass and size fraction at the same time and provides a gravimetric sample.

Technical Specification

Sensor Type
90° light scattering
Particle Size Range
0.1 to 15 µm
Aerosol Concentration Range
8533EP Desktop with External Pump 0.001 to 150 mg/m3
Display
Size Segregated Mass Fractions for PM1, PM2.5, Respirable, PM10 and Total. All displayed
Resolution
±0.1% of reading or 0.001 mg/m3, whichever is greater
Zero Stability
±0.002 mg/m3 per 24 hours at 10 sec time constant
Flow Rate
3.0 L/min
Flow Accuracy
±5% of factory set point, internal flow controlled
Temperature Coefficient
+0.001 mg/m3 per °C
Operational Temp
0 to 50°C

Detailed data on tsi.com

Test equipment

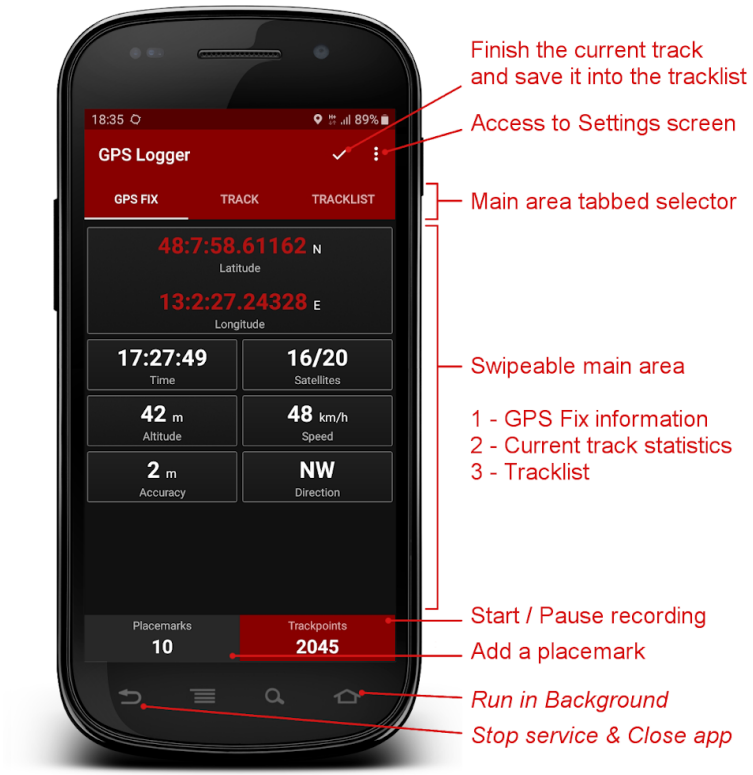
Thermo-hygrometer ADA ZHT 100-70

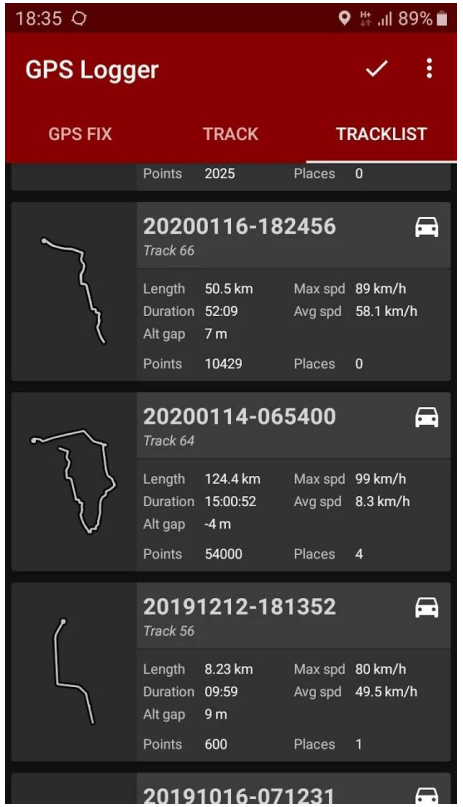
Technical Specification

Humidity range	0~100%
Resolution	0.1°C
Humidity accuracy	±3% (20 to 80%);±4.5% (0 to 20% and 80 to 100%)
Measuring range (temperature)	-20°C~70°C
Resolution	0.1°C
Temperature accuracy	±1.0ºC
Data update	0,5 s
Operating temperature	-20...+60°C, <10 - 90% relative humidity , non-condensing

Test equipment

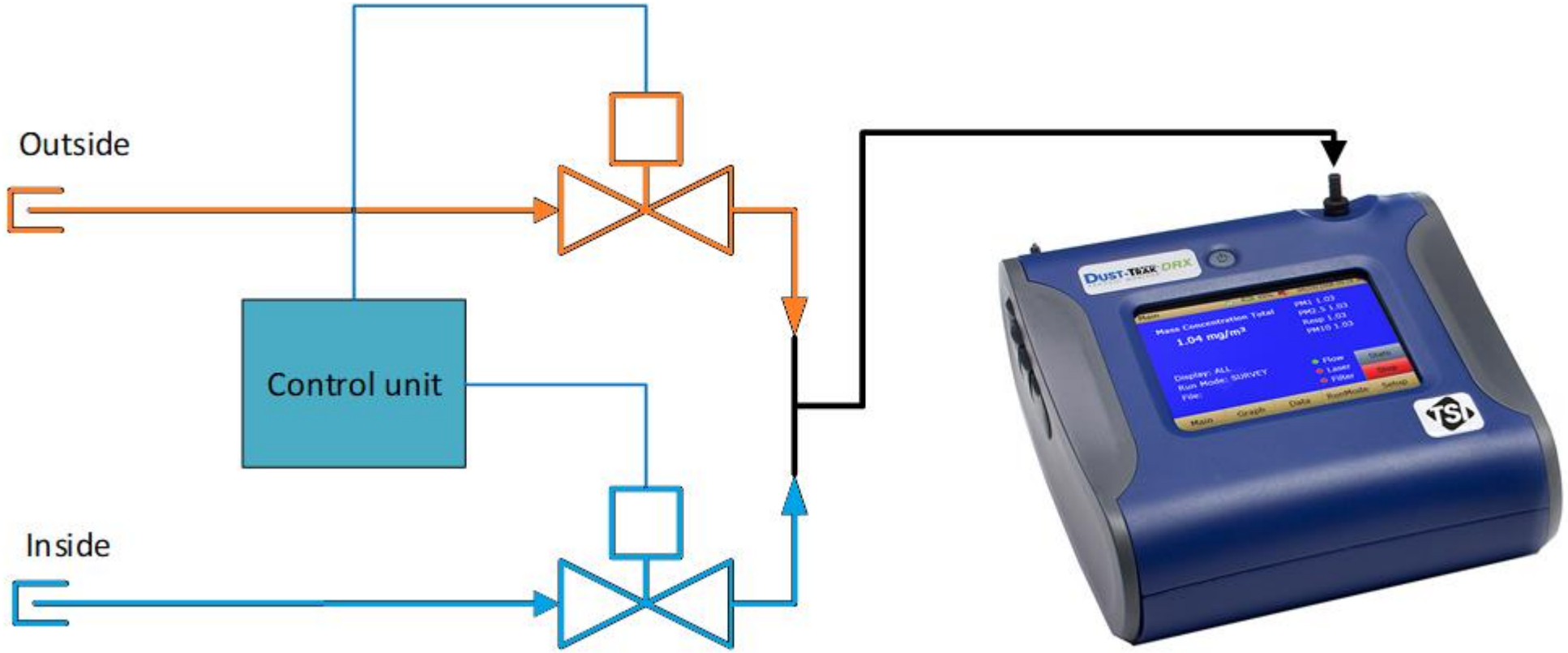
GPS Logger for Android





BasicAirData GPS Logger is an application for recording position and path. It also allows to determine trip duration, distance and average speed.

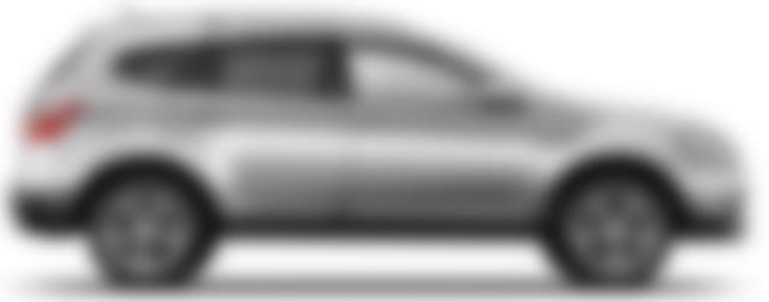
Test equipment – two valve sampling device



The length of sampling tubes for Outside and Inside channels are equal
All tubes are made of antistatic plastics

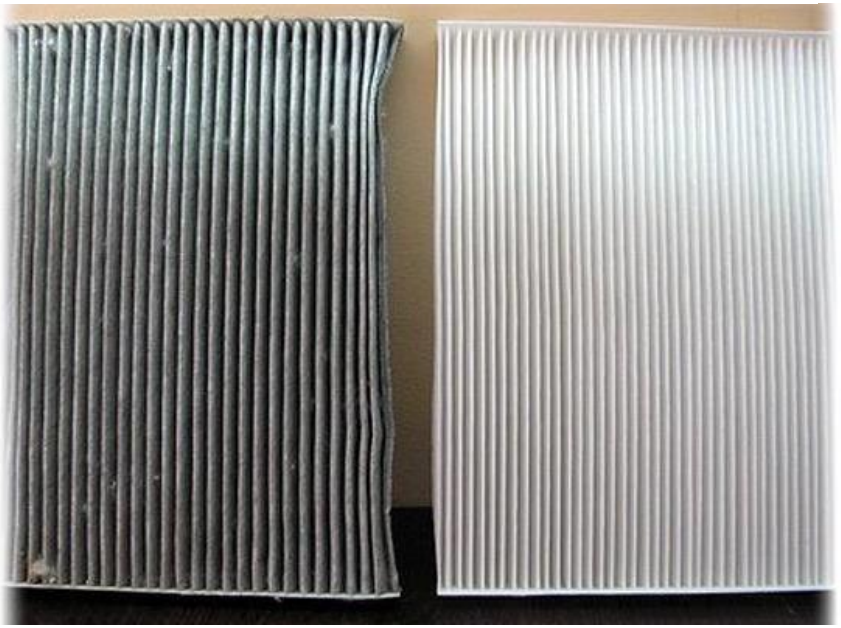
Test object

Vehicle: Compact crossover SUV (C-segment)

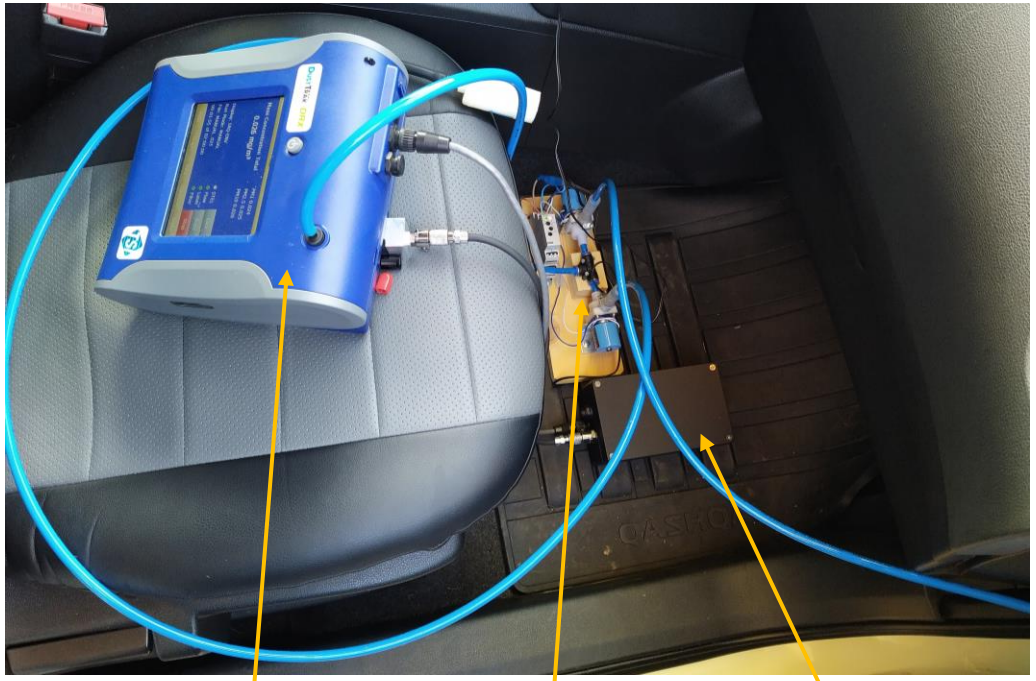


Cabin filter: OEM approved paper filter:

- new (>100 km)
- old (about 15 000 km)



Test equipment installed inside the car



Outside Sampling Tube

Dusttrak DRX Aerosol Monitor

Two Valves Unit

External Pump

Inside Sampling Tube

Test conditions

Data: 4 of July – 24 of August 2022 (always morning tests)

Temperature: 18…24°C

Relative humidity: 35…60%

Background $PM_{2.5}$ concentration average during the test 0,024…0,125 mg/m³

Valves switching time 40 s

Before testing zero calibration of Aerosol Monitor was performed

HVAC Modes

HVAC system settings:

- Manual mode
- Temperature 22˚C
- Fan speed: medium
- Fresh air mode (recirculation OFF)
- Air conditioning switched OFF
- Ventilation flaps fully open and directed straight ahead

Test conditions

As a base for test conditions and procedure development the informal document GRPE-86-45 “Proposal for a new UN Regulation No. [XXX] on uniform provisions concerning the approval of light duty passenger and commercial vehicles with regards to real driving emissions (RDE)” was used.

Subsection 8.3.1.
The vehicle, including the emission related components, shall be in good mechanical condition and shall have been run in and driven at least 3,000 km before the test. The mileage and the age of the vehicle used for RDE testing shall be recorded.

Subsection 8.3.2.
Vehicle conditioning. Before RDE testing, the vehicle shall be preconditioned in the following way:
The vehicle shall be driven on public roads, preferably on the same route as the planned RDE testing or for at least 10 min per type of operation (e.g. urban, rural, motorway) or 30 minutes with a minimum average velocity of 30 km/h. The vehicle shall subsequently be parked with doors and bonnet closed and kept in engine-off status within moderate or extended altitude and temperatures, for between 6 and 72 hours. Exposure to extreme atmospheric conditions (such as heavy snowfall, storm, hail) and excessive amounts of dust or smoke should be avoided.
Before the test start, the vehicle and equipment shall be checked for damages and the presence of warning signals that may suggest malfunctioning. In the case of a malfunction the source of the malfunctioning shall be identified and corrected or the vehicle shall be rejected.

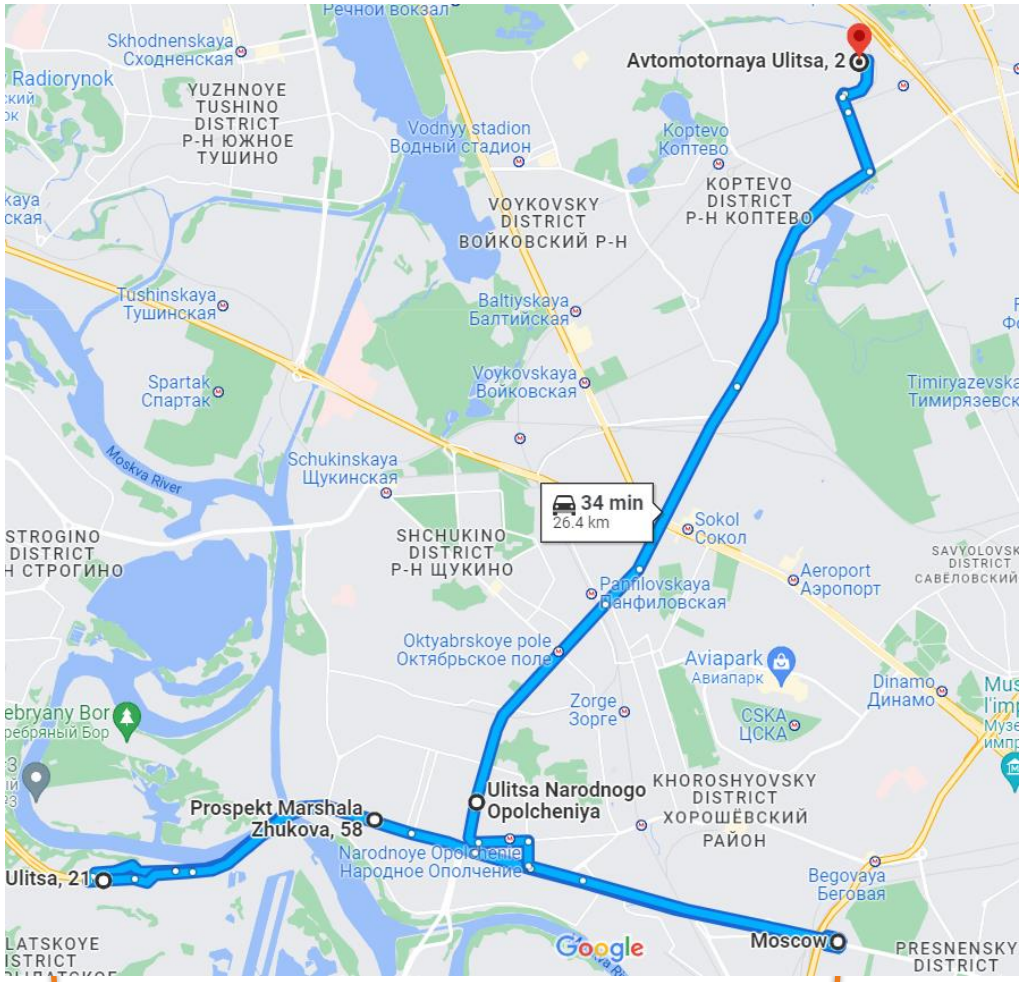
Test conditions

Subsection 9.1. (for 3 phase WLTC)
Urban speed bin is characterised by vehicle speeds lower than or equal to 60 km/h.
Expressway speed bin is characterised by speeds above 60 km/h and up to 100 km/h.

Subsection 9.2.
The trip shall consist of approximately 55 per cent urban and 45 per cent expressway speed bins. ‘Approximately’ shall mean the interval of ±10 per cent points around the stated percentages. The urban speed bin however can be lower than 45 per cent but never be less than 40 per cent of the total trip distance.

Subsection 9.3.
The RDE performance shall be demonstrated by testing vehicles on the road, operated over their normal driving patterns, conditions and payloads. RDE tests shall be conducted on paved roads (e.g. off-road operation is not permitted).
Local speed limits remain in force during a test, notwithstanding other legal consequences.
Stop periods, defined by vehicle speed of less than 1 km/h, shall account for 6-30 per cent of the time duration of urban operation. Urban operation may contain several stop periods of 10 s or longer.
The trip duration shall be between 90 and 120 minutes (suggested 30 and 60 minutes for VIAQ test purpose).
The start and the end points of a trip shall not differ in their elevation above sea level by more than 100 m. In addition, the proportional cumulative positive altitude gain over the entire trip and over the urban operation shall be less than 1,200 m/100 km.

Test route



urban part
V ≤ 60 km/h

expressway (urban motorway) part
V ≤ 80 km/h

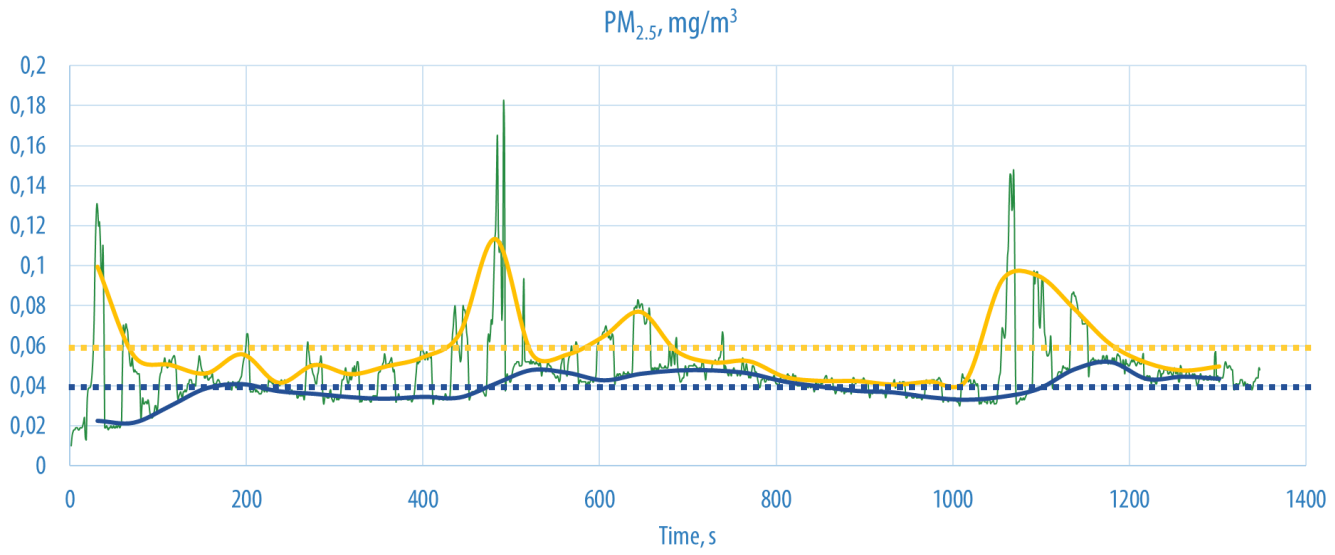
Test procedure

1. Setup sampling system and measuring devices inside the car.
2. Measure ambient air temperature and relative humidity.
3. Start the engine, adjust HVAC operation mode, switch on the PM analyzer and drive for at least 10 min.
4. Drive to the beginning of the test rote, start valves switching, PM analyzer, GPS logger.
5. Drive on the rote urban and expressway parts.
6. Park the car, stop the PM measurement, GPS logger and valves switching.
7. Switch off PM analyzer and the engine.
8. Save measurement protocol from PM analyzer and GPS track from logger to the computer

Procedure of test results analysis

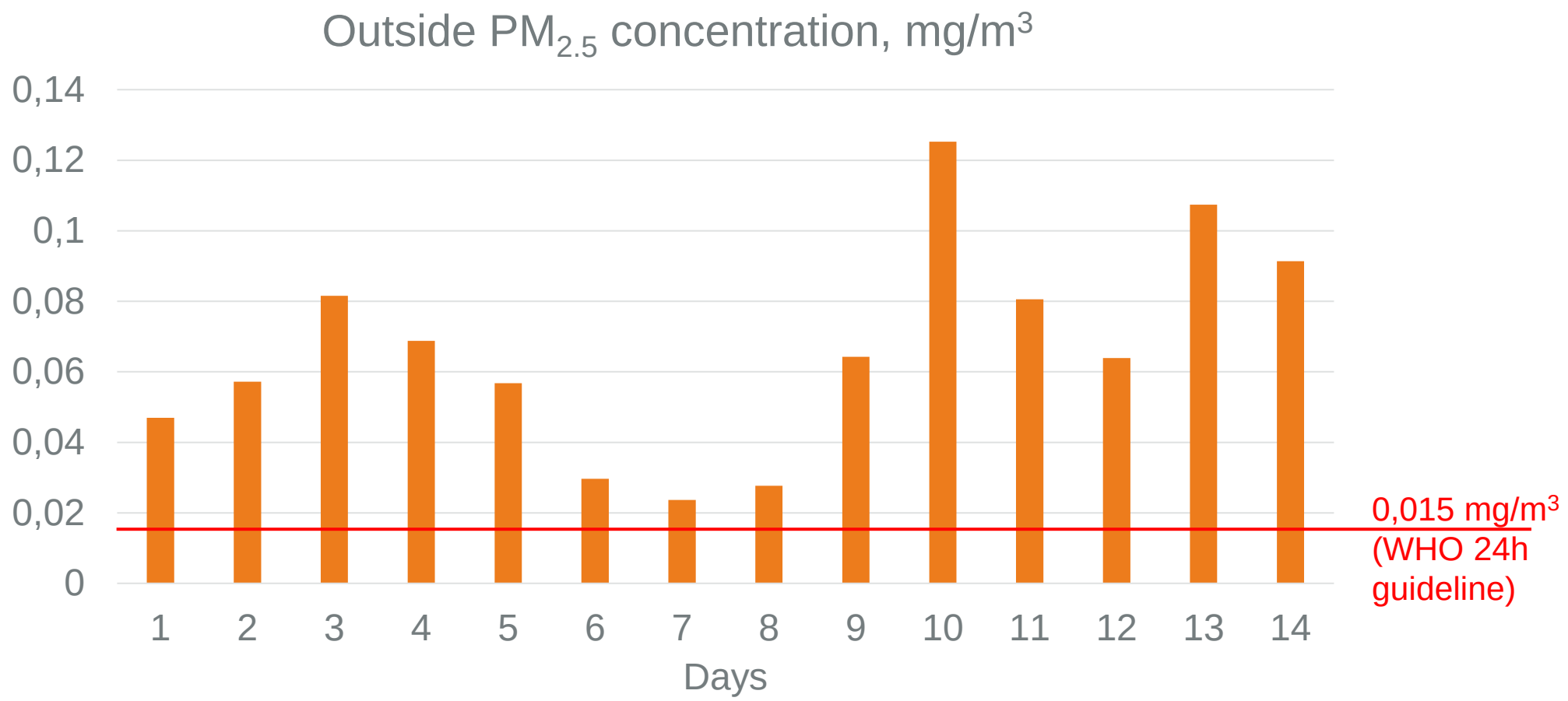
1. Analyze GPS track and calculate urban and expressway bins. Check for compliance with RDE requirements. If yes, than test is valid.
2. Analyze PM protocol and divide the measured data to inside and outside concentrations.
3. Calculate the average inside C_{in} and outside C_{out} concentrations.
4. Calculate the cleaning efficiency by formula:

$$\eta = \left(1 - \frac{C_{in}}{C_{out}}\right) \cdot 100\%$$

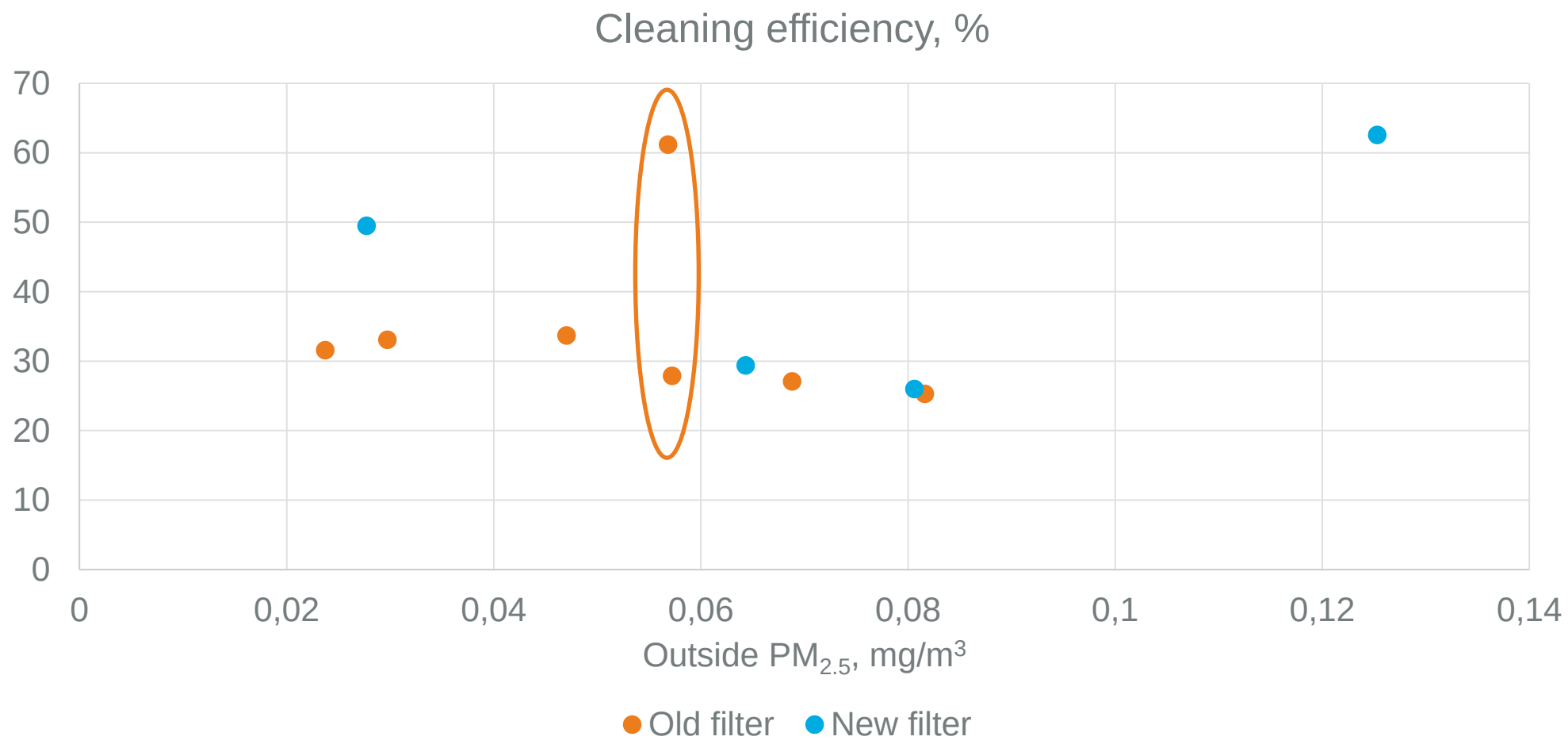


2. Test results and analysis

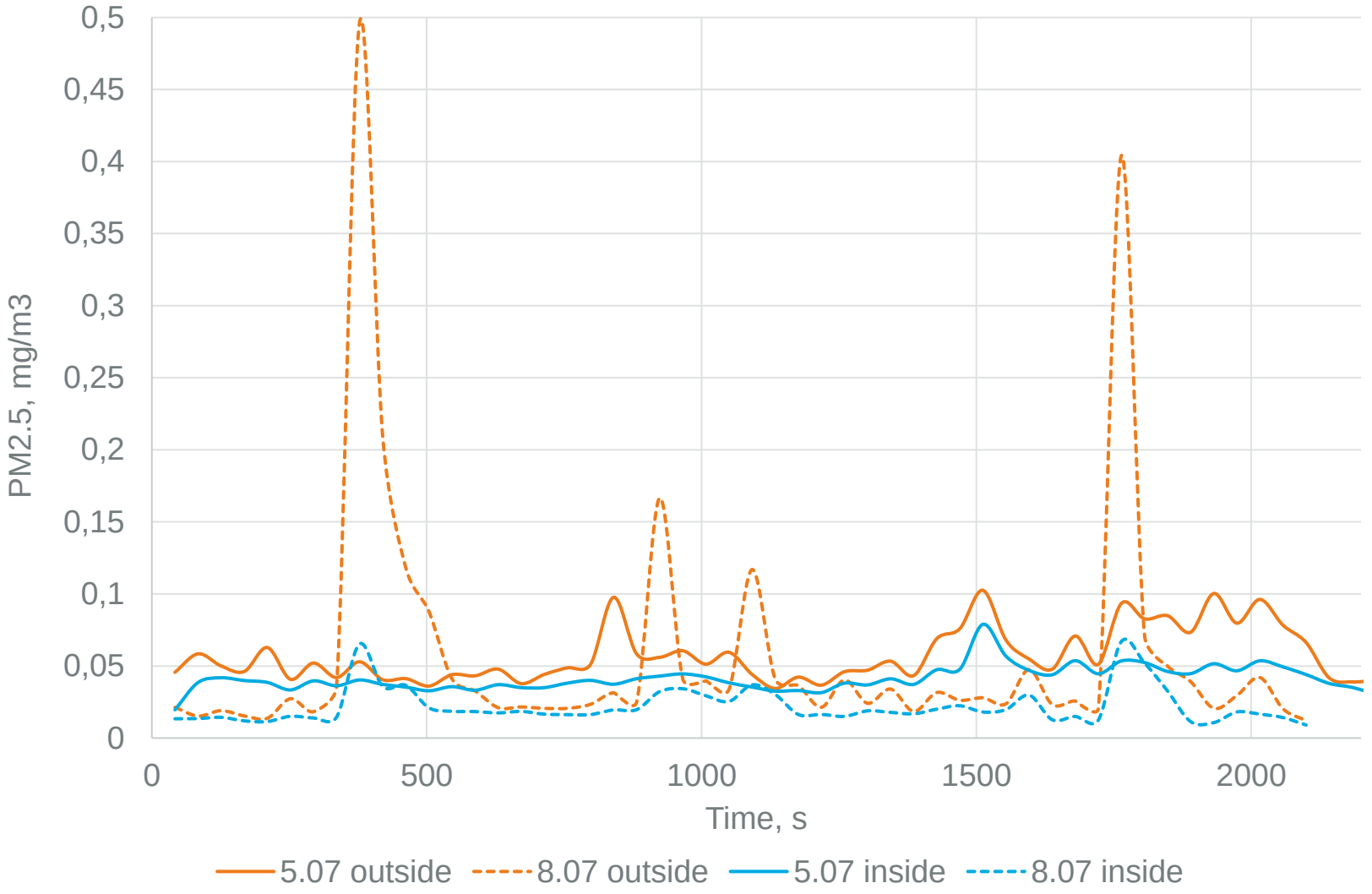
Background air pollution level



Test results



Analysis of test results

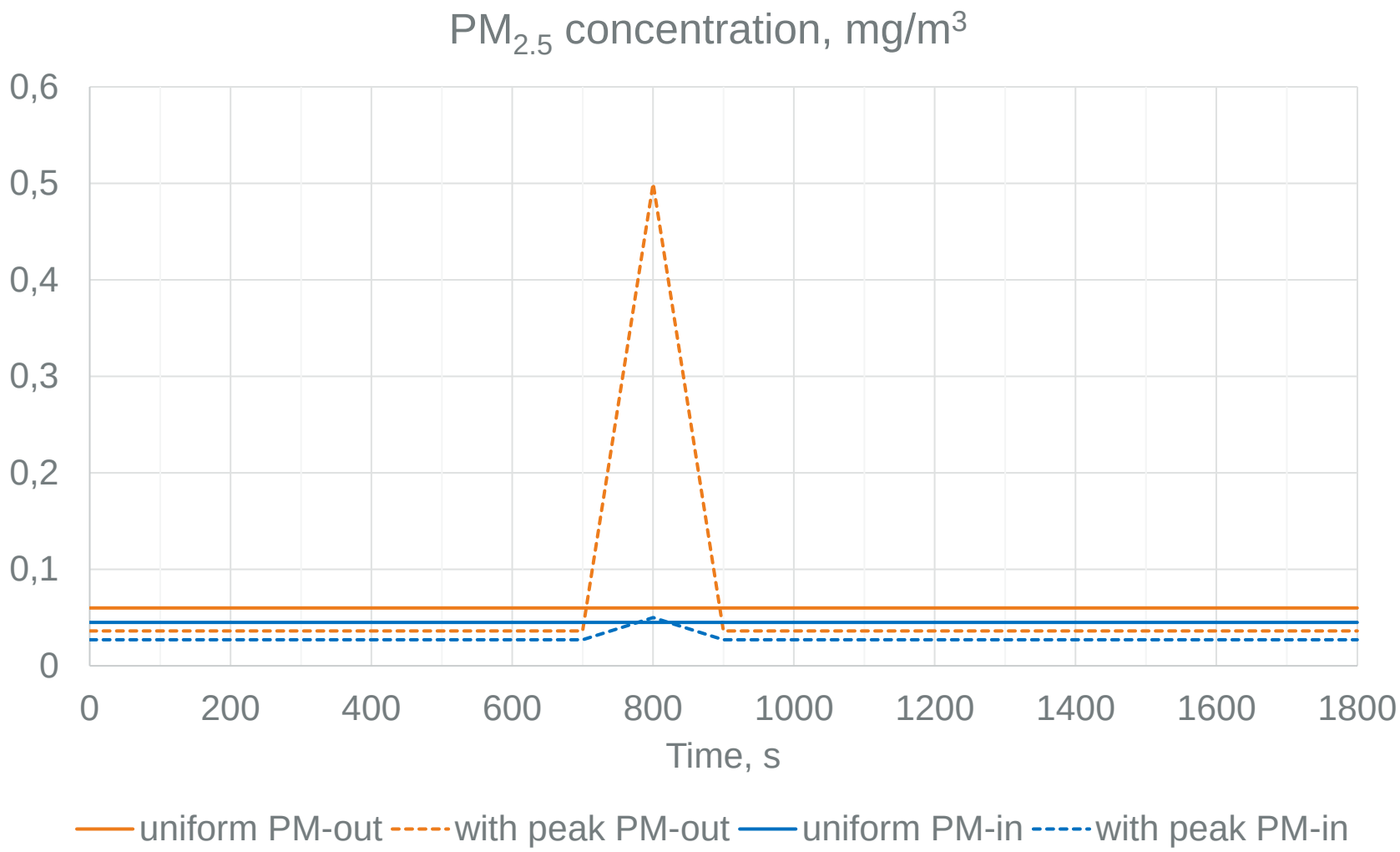


Two tests comparison:

Parameter/Data	5 July	8 July
Cabin filter	old	old
Temperature, C	24,7	18,8
RH, %	47	65
Trip distance, km	26,9	26,2
Trip time, min:sec	37:10	35:23
Urban bin, %	51,3	58,4
Expressway bin,%	48,7	41,6
Mean outside $PM_{2.5}$, mg/m^3	0,0572	0,0568
Mean inside $PM_{2.5}$, mg/m^3	0,0413	0,022
Cleaning efficiency, %	**27,9**	**61,2**

3. Discussion and conclusions

Analysis of test results – theoretical case

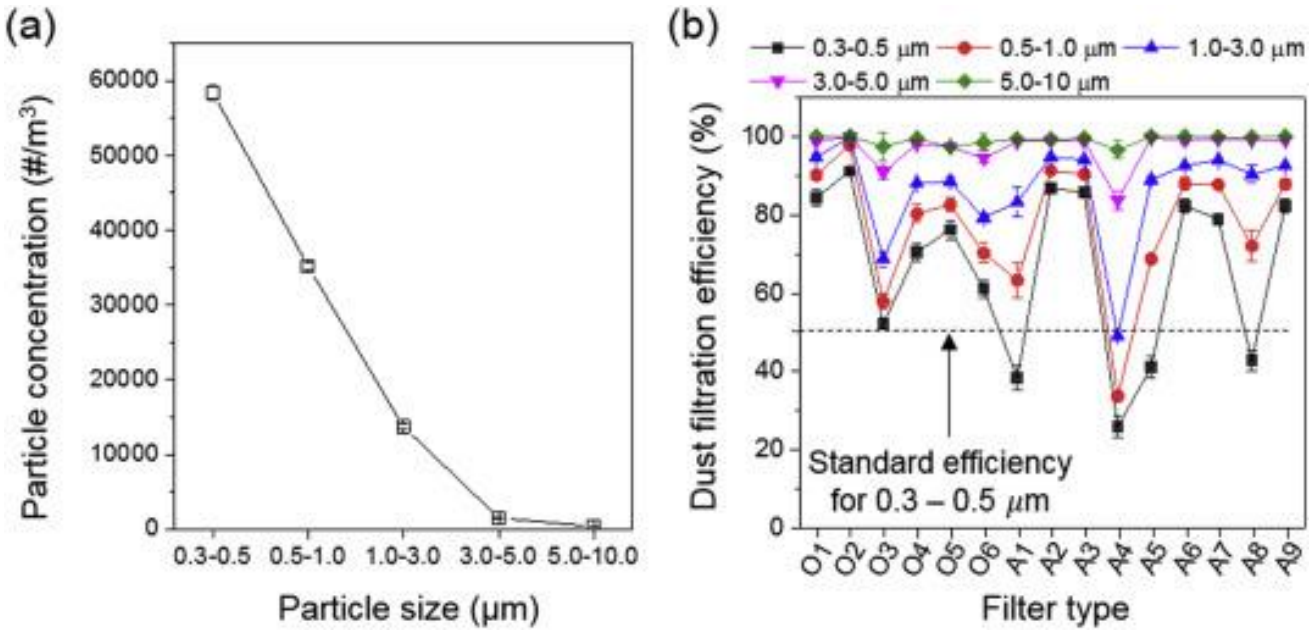


Two tests comparison:

Parameter	uniform	peak
Mean outside $PM_{2.5}$, mg/m³	0,06	0,06
Mean inside $PM_{2.5}$, mg/m³	0,045	0,028
Cleaning efficiency, %	**25**	**53,3**

Filter efficiency vs. particle size and vs. particle concentration (analysis of non reproducibility reasons)

Filtration performance of automotive cabin air filters. (a) Number particle concentration of generated ISO A2 dust particle. (b) Filtration efficiency of filters by particle size. Black dash line indicates standard for 0.3–0.5 μm filtration performance (>50%) defined by Korea Air Cleaning Association (SPS-KACA014-0144).



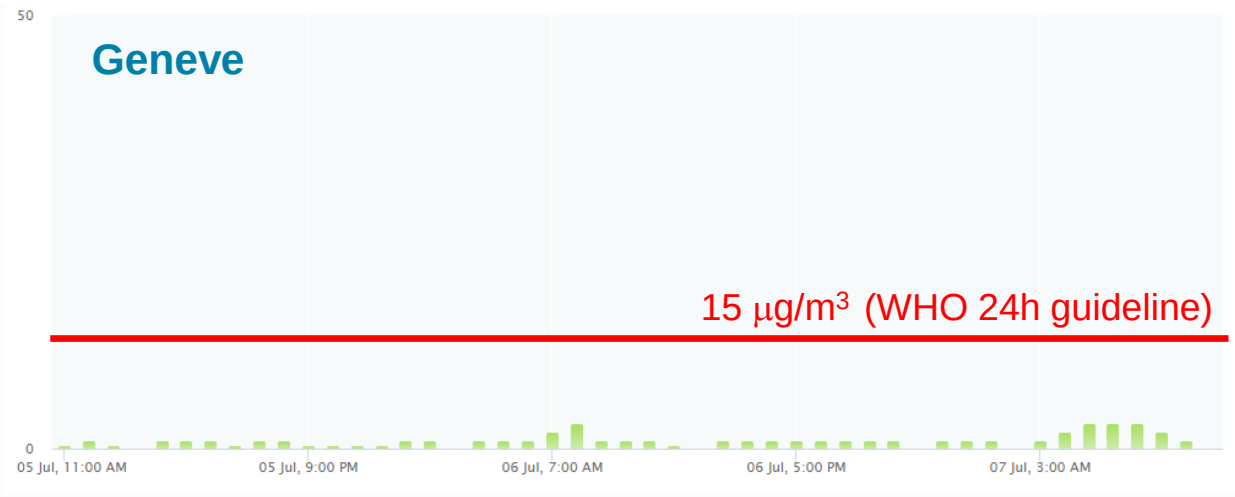
Ki Joon Heo, Jung Woo Noh, Byung Uk Lee, Yeonsang Kim, Jae Hee Jung, Comparison of filtration performance of commercially available automotive cabin air filters against various airborne pollutants, Building and Environment, Volume 161, 2019, https://doi.org/10.1016/j.buildenv.2019.106272

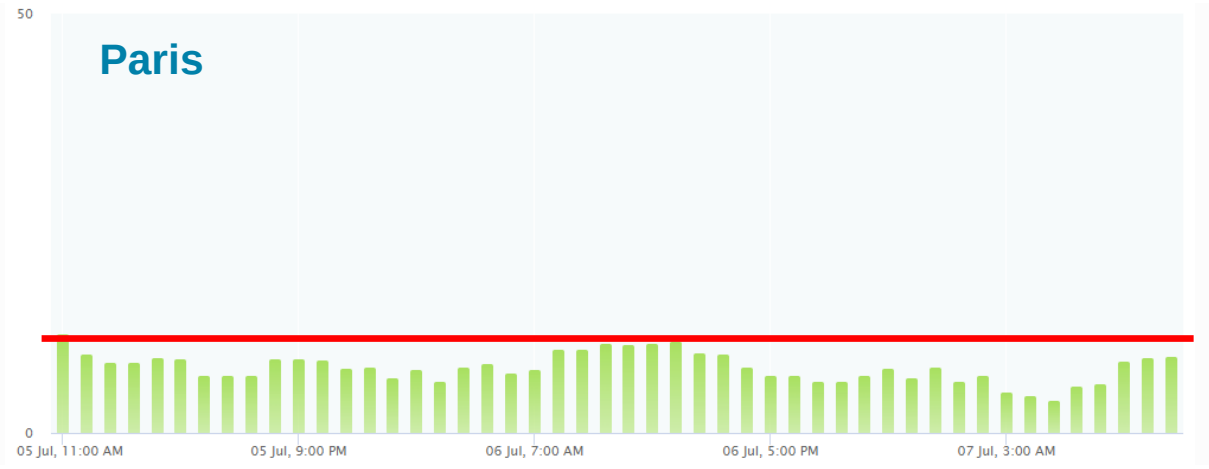
Cabin filters cleaning efficiency in percent (medium fan speed, recirculation OFF)

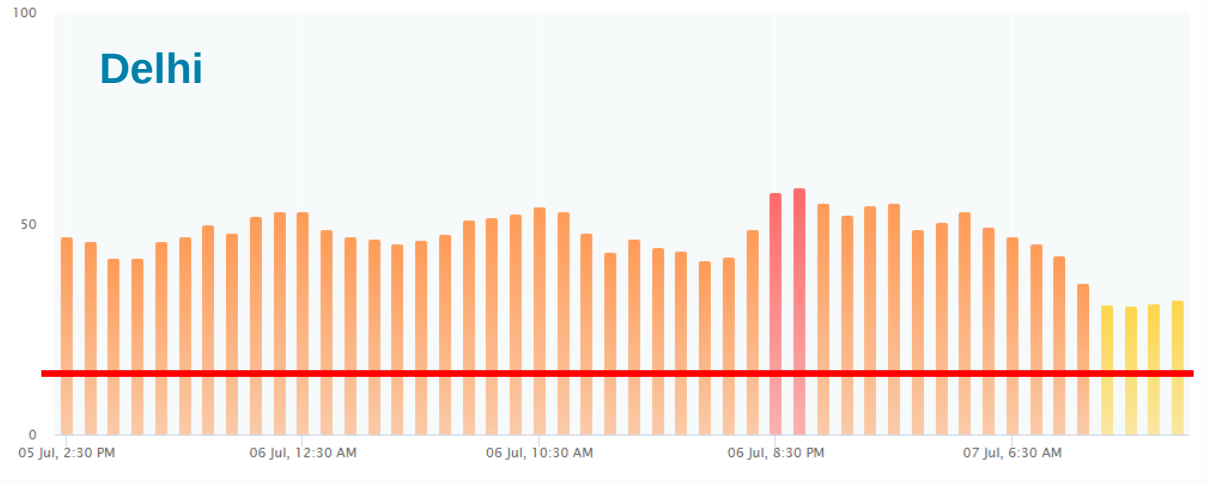
Filter	City	Highway
Purolator ONE	80,6	44,8
Fram Fresh Breeze	90,4	76,7
Beck/Arnley Paper	74,4	48,4
Purolator Premium	87,0	80,5
Bosch HEPA Premium	90,6	84,6

Fahad Alqahtani, Performance Study of Fiv formance Study of Five Different Cabin Air Filters in The ent Cabin Air Filters in The Laboratory and On-Road Drive, Graduate Theses, Dissertations, and Problem Reports. 2020, https://doi.org/10.33915/etd.7950

Analysis of $PM_{2.5}$ in different cities (5-7.07.2022), µg/m³







Conclusions

1. Test of car interior air cleaning efficiency with new and old cabin filters was carried out in relatively stable ambient conditions on the route incorporates urban and expressway (urban motorway) parts.
2. Outside $PM_{2.5}$ concentration variated from 1,6 to 8,3 times of WHO guideline level (15 $\mu g/m^3$)
3. Test results (air cleaning efficiency) were in wide range from 25 to 63 percent (for both new and old cabin filters).
4. The test results are strongly depend on background $PM_{2.5}$ concentration on the road.
5. The test conditions, modes and procedure need to be clarified to obtain more repeatable results in wide range of different ambient conditions and background $PM_{2.5}$ concentrations.
6. As an alternative or as an additional test could be consider laboratory test.

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Thank you
for your attention

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