

# Investigation of interior PM concentration in real driving conditions

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## 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:

I.4. Test Conditions

I.6. Background air pollution level

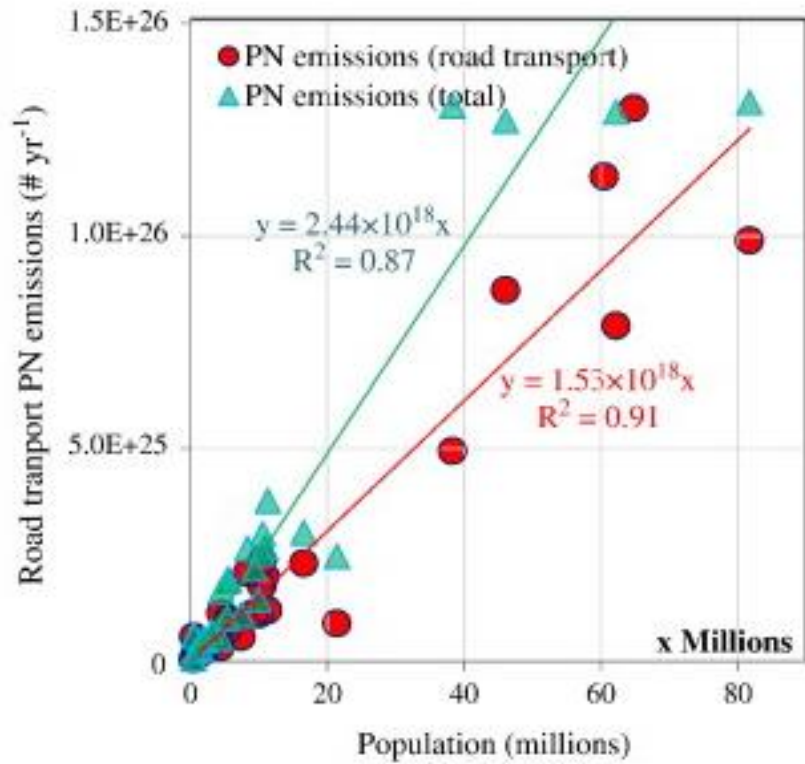
II.2. Test Modes

II.4. Test Procedure

**The purpose** of this investigation is to collect real data about particle matter concentration in the car cabin and obtain experience in measurement procedure, impact of different ambient, road and test conditions to measurement results.

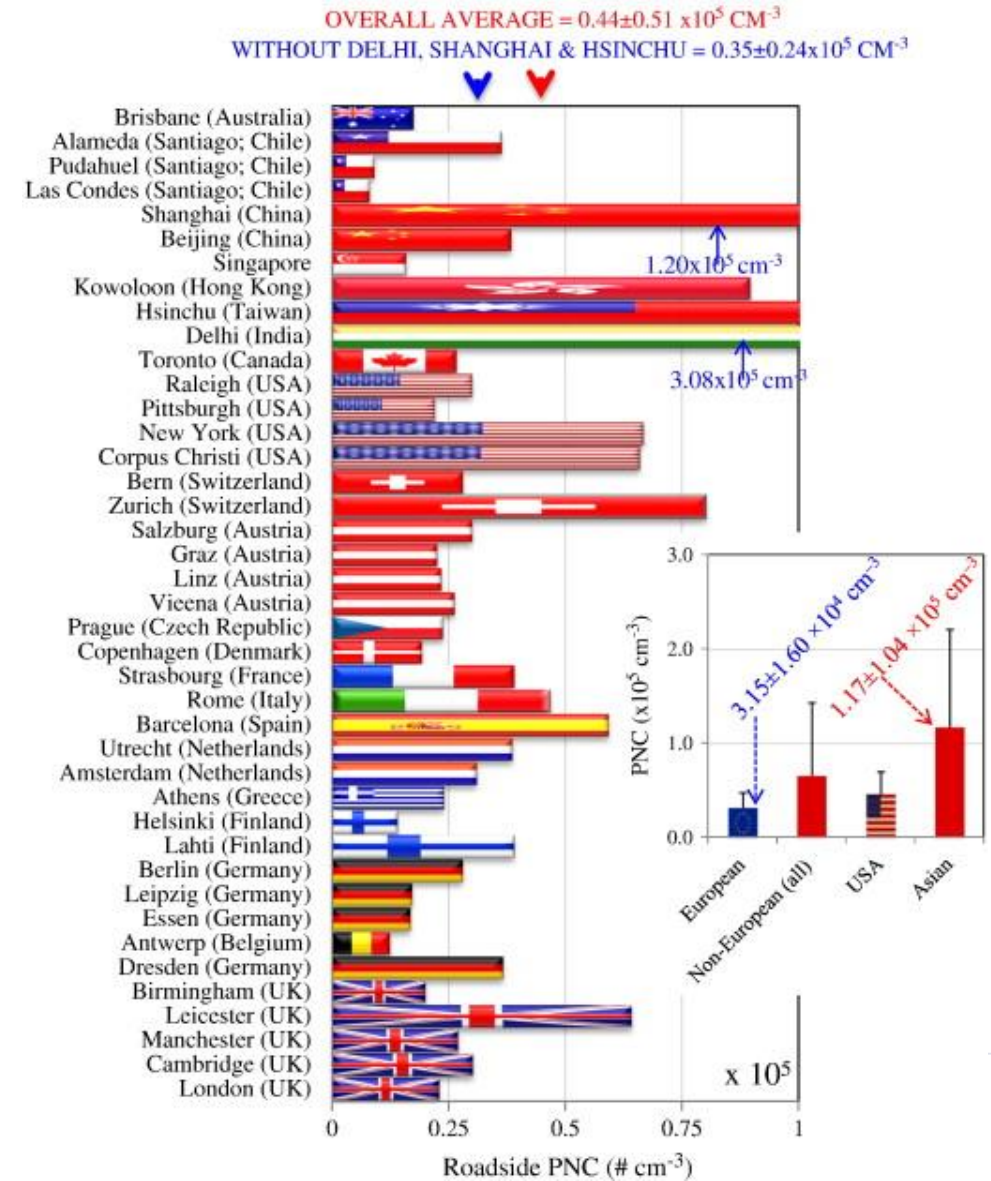
# Introduction

In Europe, the contribution from road traffic varied from ~ 32% of total PN emissions in Greece to ~ 97% in Luxemburg. France, Spain, Germany, Italy, UK and Poland



Prashant Kumar, Lidia Morawska, Wolfram Birmili, Pauli Paasonen, Min Hu, Markku Kulmala, Roy M. Harrison, Leslie Norford, Rex Britter. Ultrafine particles in cities, Environment International, Volume 66, 2014, Pages 1-10  
[doi.org/10.1016/j.envint.2014.01.013](https://doi.org/10.1016/j.envint.2014.01.013).

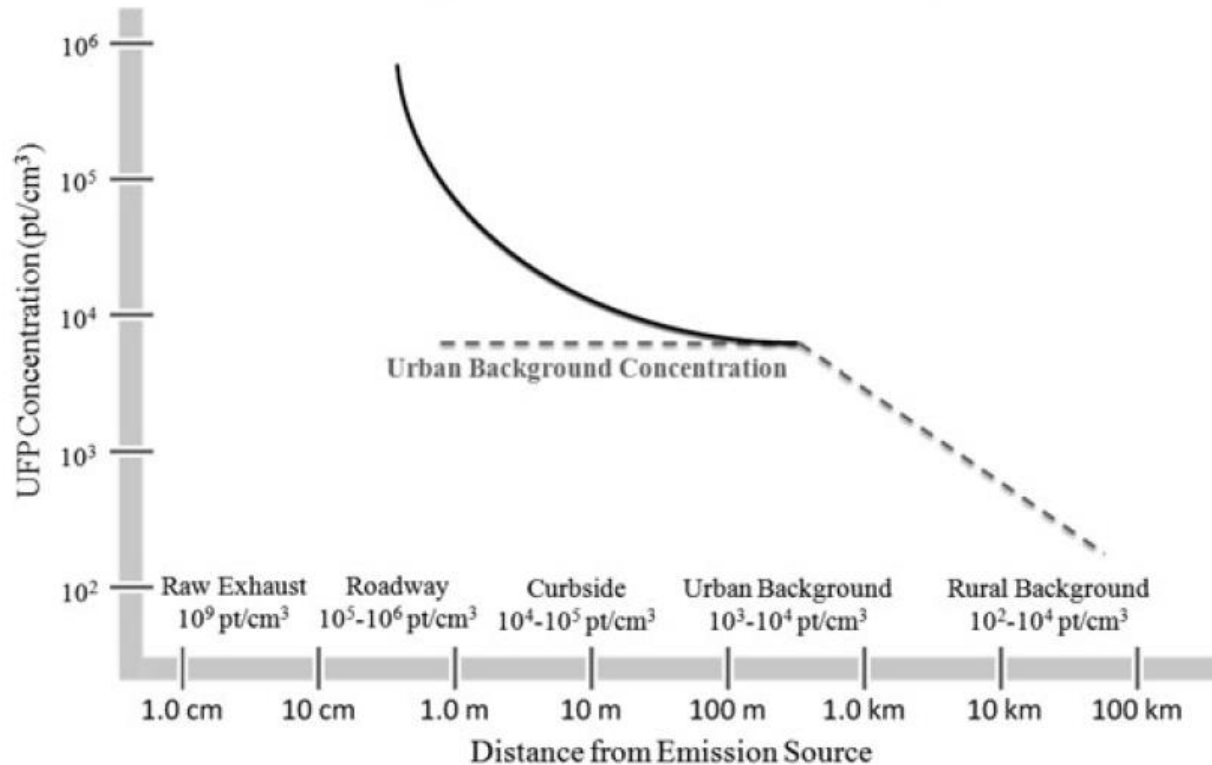
Typical measured PNC levels at the roadside in 42 different cities



# Introduction

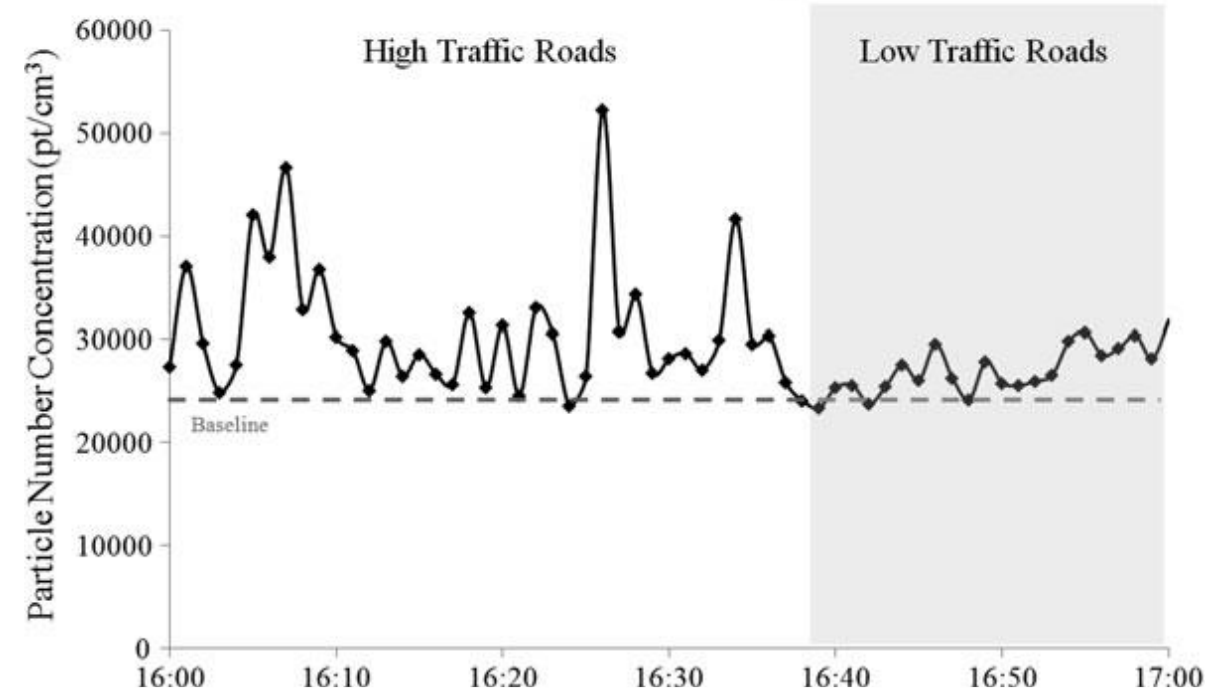
The range of ultrafine particles (UFP)\* concentrations reported in the literature for each spatial scale

UFP Concentrations Ranges in Urban and Rural Settings



The variation of UFP number concentration while walking along high and low traffic roads in Toronto, Canada

Variation of UFP Number Concentration on High and Low Traffic Roads



\*Ultrafine particles (UFP) are the smallest particles, with diameters less than 100 nm

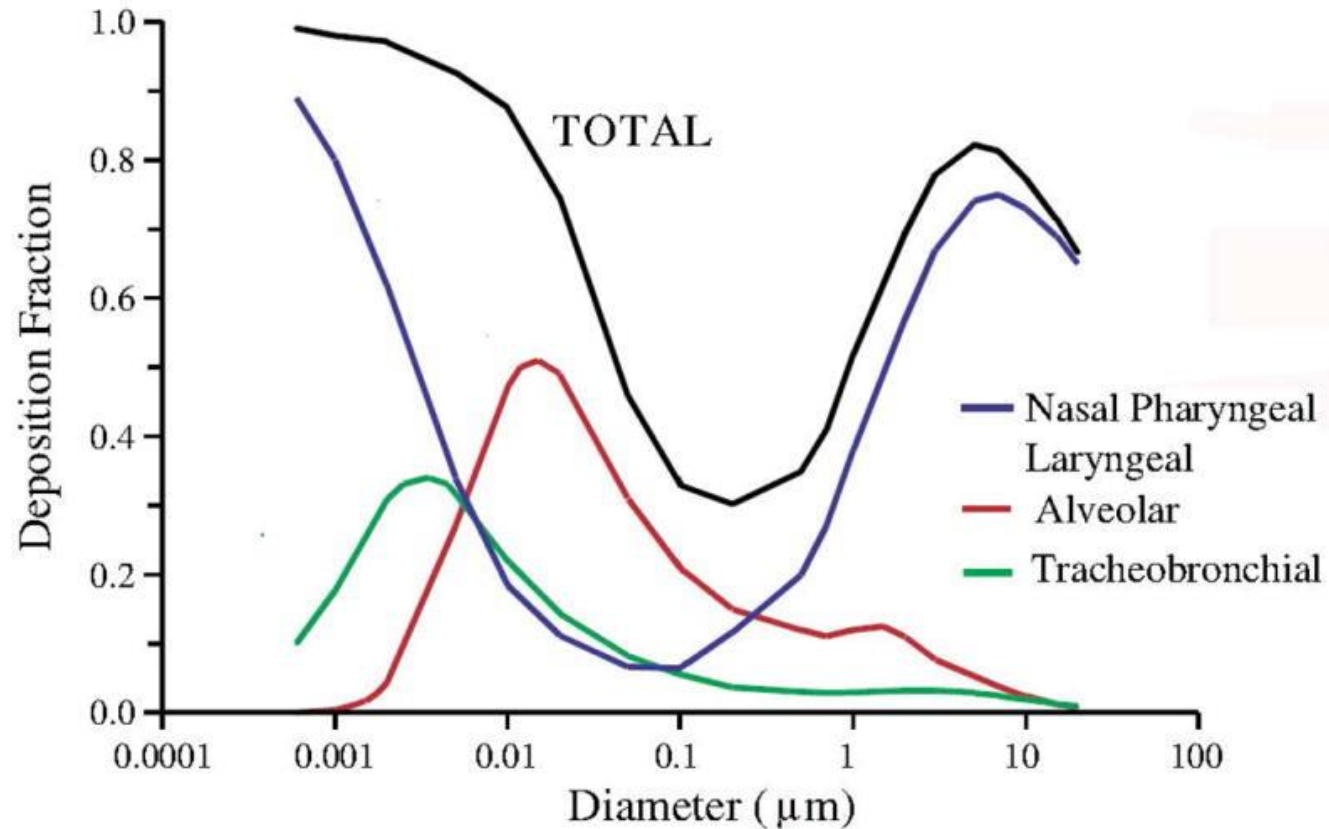
Zereini, Fathi & Wiseman, Clare. (2011). Urban Airborne Particulate Matter: Origin, Chemistry, Fate and Health Impacts. 2011, 663 p.

DOI: [10.1007/978-3-642-12278-1](https://doi.org/10.1007/978-3-642-12278-1)



# Introduction

Total particle deposition in the human respiratory tract and corresponding fractions in the extra thoracic, bronchial, and alveolar region according to ICRP Publication. For instance, total deposition is high at both ends of the size spectrum; above  $\sim 1 \mu\text{m}$ , gravitational sedimentation and inertial impaction are effective; below  $\sim 0.1 \mu\text{m}$ , diffusional deposition becomes the major mechanism for deposition.



Tsuda, A., Henry, F.S. and Butler, J.P. Particle Transport and Deposition: Basic Physics of Particle Kinetics. In Comprehensive Physiology, R. Terjung (Ed.). 2013, p. 1437-1471

[DOI:10.1002/cphy.c100085](https://doi.org/10.1002/cphy.c100085)



# Introduction

## Air quality guideline values

Pollutant	Air in populated areas									
	Russian Federation		WHO		EU		USA		Korea	
PM <sub>10</sub> , µg/m <sup>3</sup>	300	60	50	20	50	40	150		100	50
PM <sub>2,5</sub> , µg/m <sup>3</sup>	160	35	25	10	25		35	12	50	25

Exposure time

30 minutes

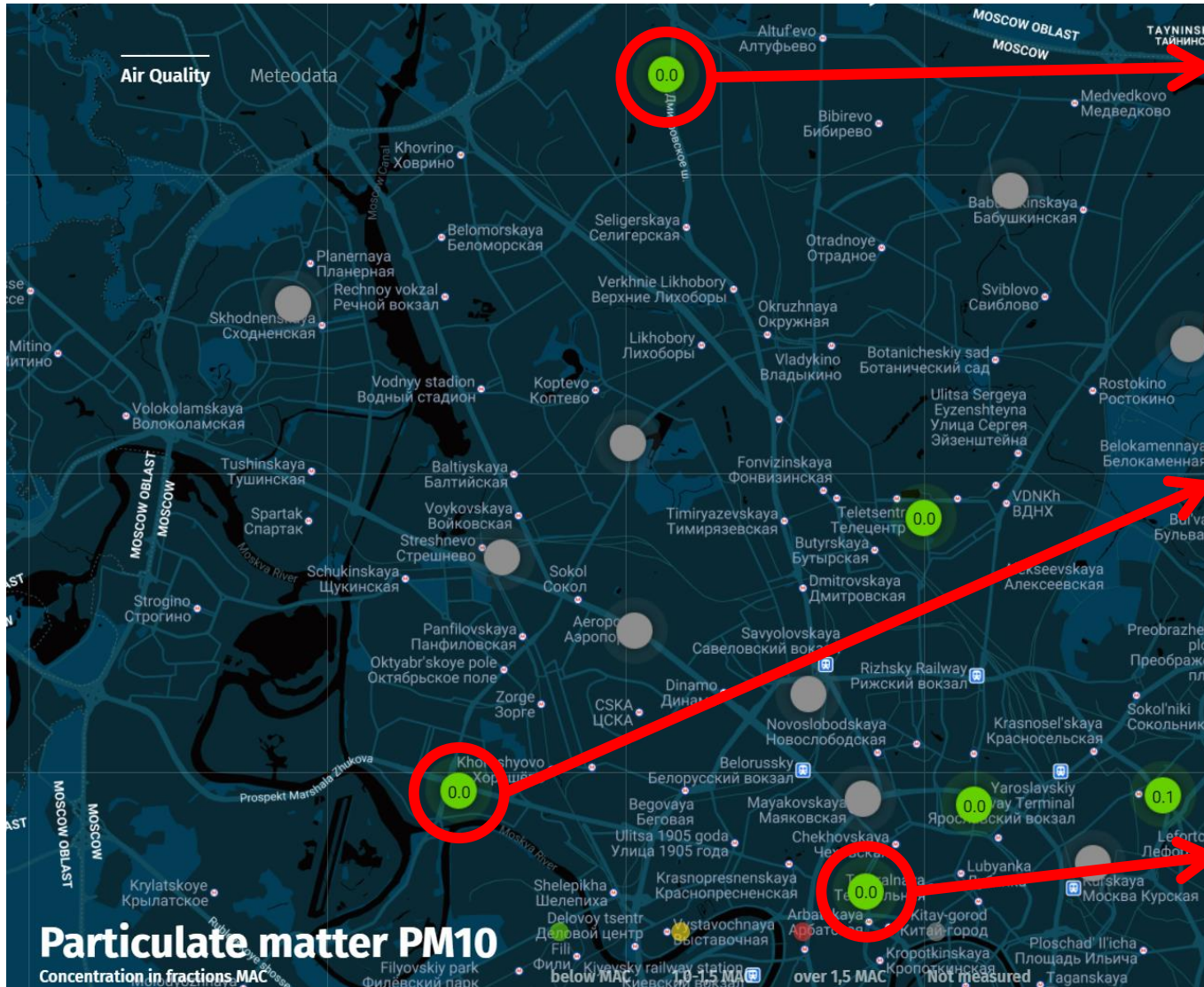
24 hours

1 year

# Introduction

## Mosecomonitoring Air Quality Stations for PM concentration measurement

Measurement data 2020



# Test procedure

1. Install the equipment into the car. Install the sampler between the front seat headrests
2. Measure humidity and temperature of ambient air
3. Start the engine. Set ventilation mode:
  - Recirculation OFF/ON
  - Air conditioner ON
  - Interior temperature setting 22 °C
  - Fan speed - 3 (or middle position)
4. Switch on the measurement of the concentration of particles in the cabin. Start GPS track recording. Start (Digital Video Recorder) DVR recording
5. Start and continue movement along the route.
6. 15 minutes after the start of the movement, measure the humidity and air temperature in the car.
7. After reaching the final point of the route, park the car and turn off the engine. Switch off the measurement of the particle concentration in the cabin. Turn off GPS track recording. Turn off DVR recording.
8. Measure the humidity and temperature of the ambient air.
9. Save all received data (recording of particle concentrations, GPS track, files from the video recorder) on a computer for further processing.



# 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.

Detailed data on [tsi.com](http://tsi.com)

## 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/m<sup>3</sup>

### Display

Size Segregated Mass Fractions for PM1, PM2.5, Respirable, PM10 and Total.  
All displayed

### Resolution

±0.1% of reading or 0.001 mg/m<sup>3</sup>, whichever is greater

### Zero Stability

±0.002 mg/m<sup>3</sup> 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/m<sup>3</sup> per °C

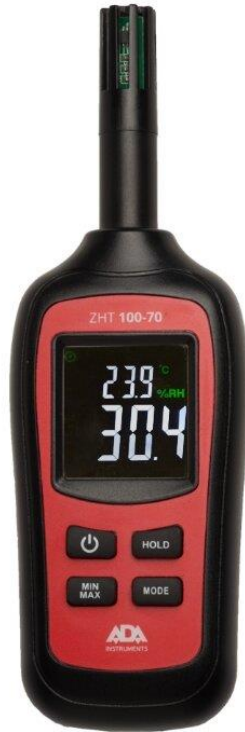
### Operational Temp

0 to 50°C



# Test equipment

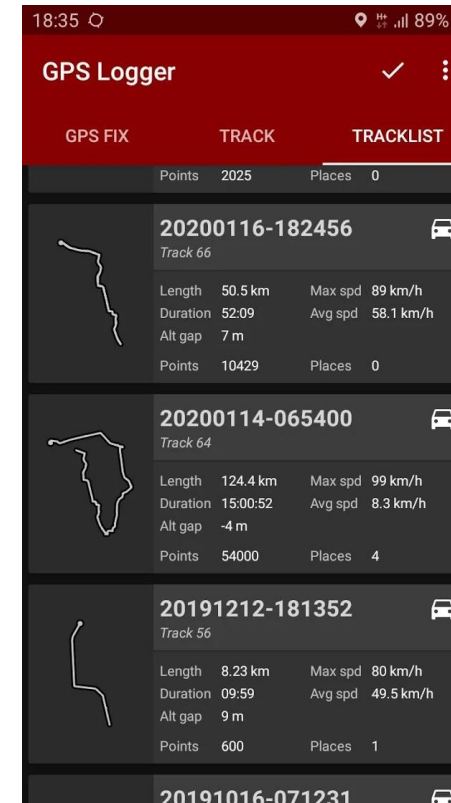
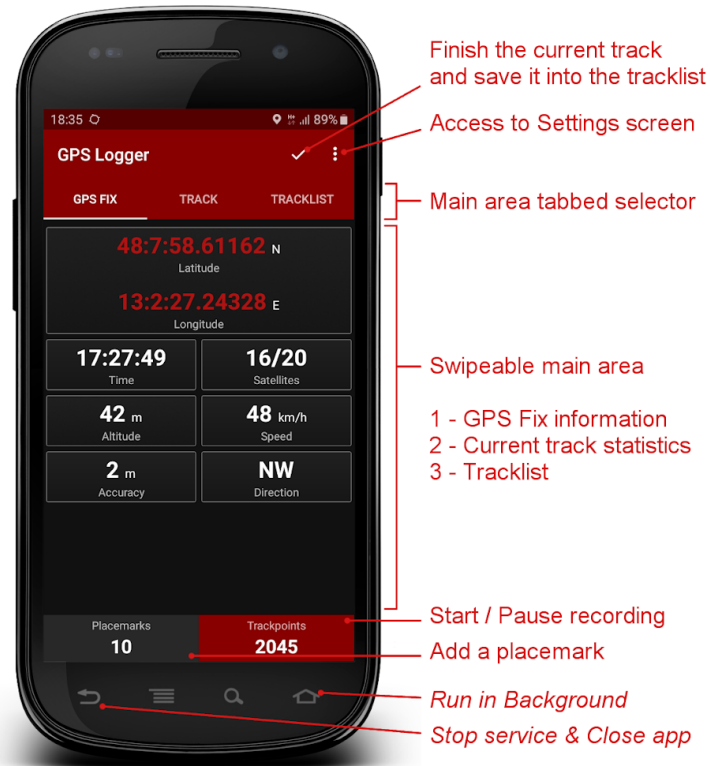
## Thermo-hygrometer ADA ZHT 100-70



## 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	±1.0°C
Data update	0,5 cek
Operating temperature	-20...+60°C, <10 - 90% relative humidity , non-condensing

## 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 installed inside the car



Dustrak DRX Aerosol Monitor

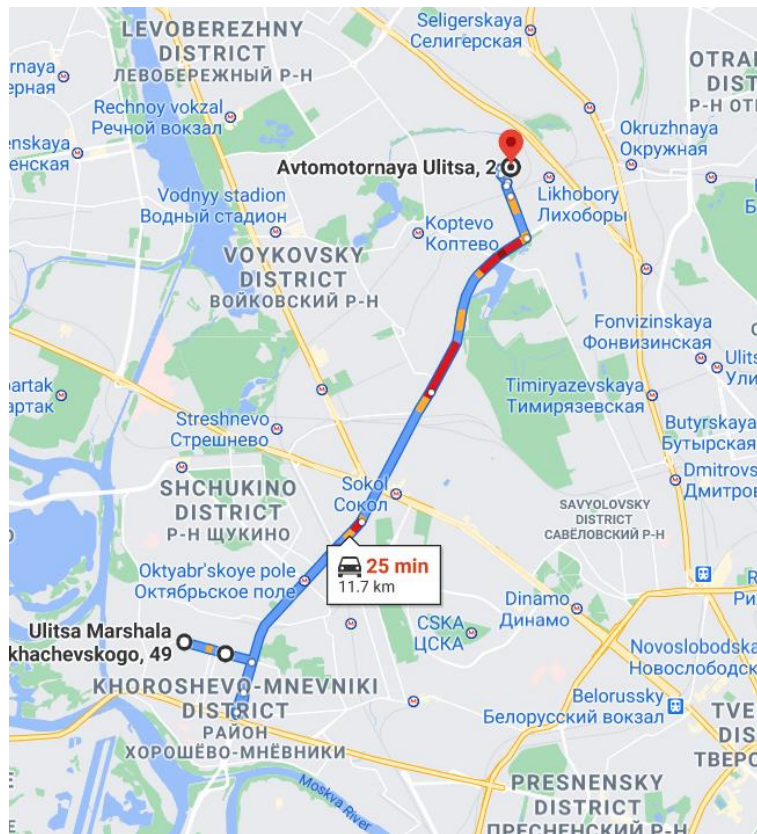


External Pump

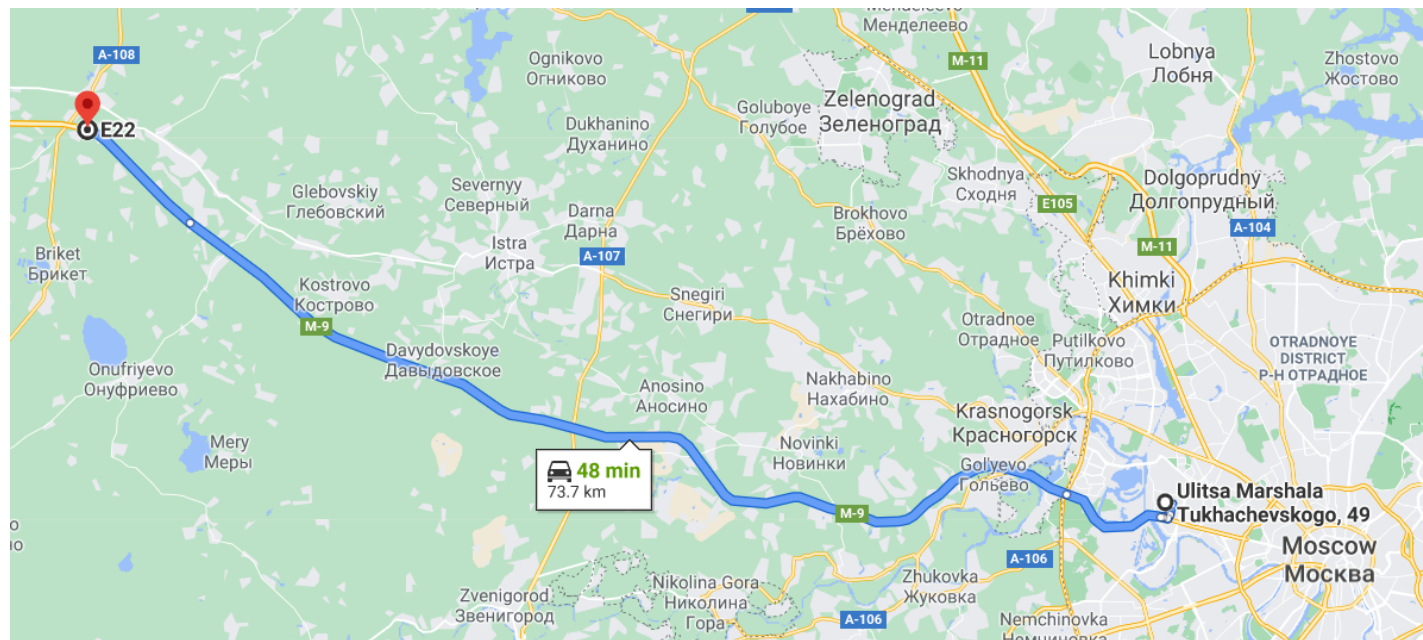
Sampling Tube

# Test routes

## City route



## Highway route



# Test modes

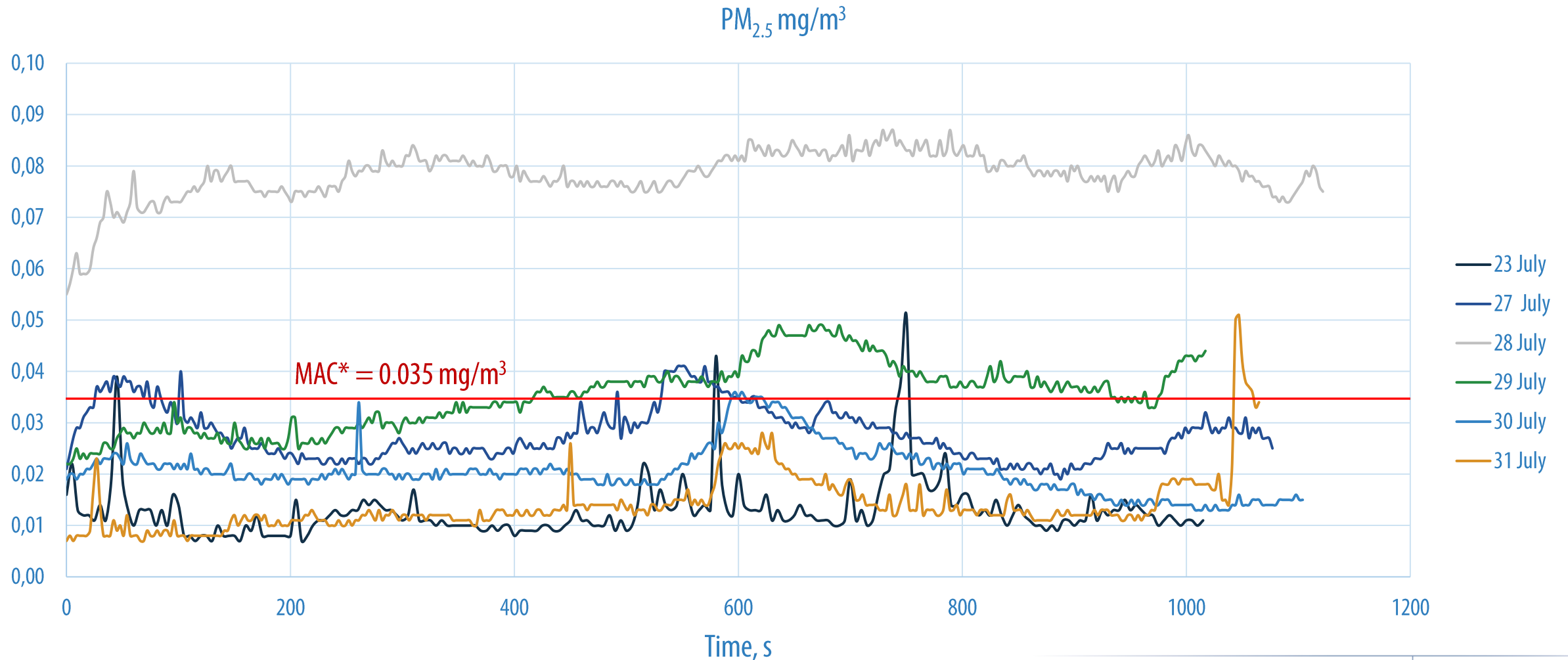
1. City test with windows **closed**
  - Recirculation **OFF**
  - Air conditioner ON
  - Interior temperature setting 22 °C
  - Fan speed - 3 (middle)
2. City test with windows **closed**
  - Recirculation **ON**
  - Air conditioner ON
  - Interior temperature setting 22 °C
  - Fan speed - 3 (middle)
3. City test with front passenger window **opened**
  - Ventilation OFF
4. Highway test
  - Recirculation OFF
  - Air conditioner ON
  - Interior temperature setting 22 °C
  - Fan speed - 3 (middle)

The tests were carried out in period from 20 of July till 14 of August 2020 in Moscow



# Test results

City test with windows **closed** / Recirculation **OFF** / morning

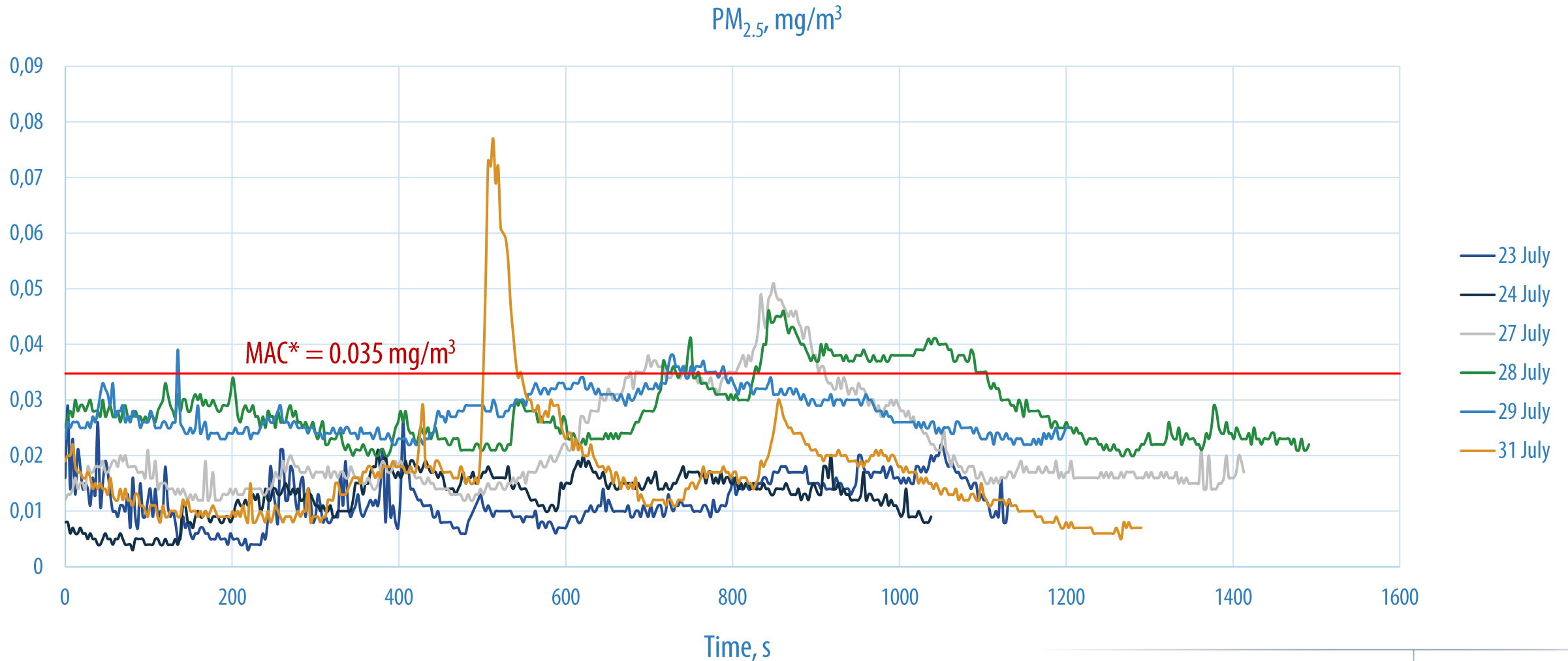


\* Maximum acceptable concentration (MAC) in Russia (MAC = 0.025 mg/m<sup>3</sup> - WHO limit)



# Test results

City test with windows **closed** / Recirculation **OFF** / evening



\* Maximum acceptable concentration (MAC) in Russia (MAC = 0.025 mg/m<sup>3</sup> - WHO limit)

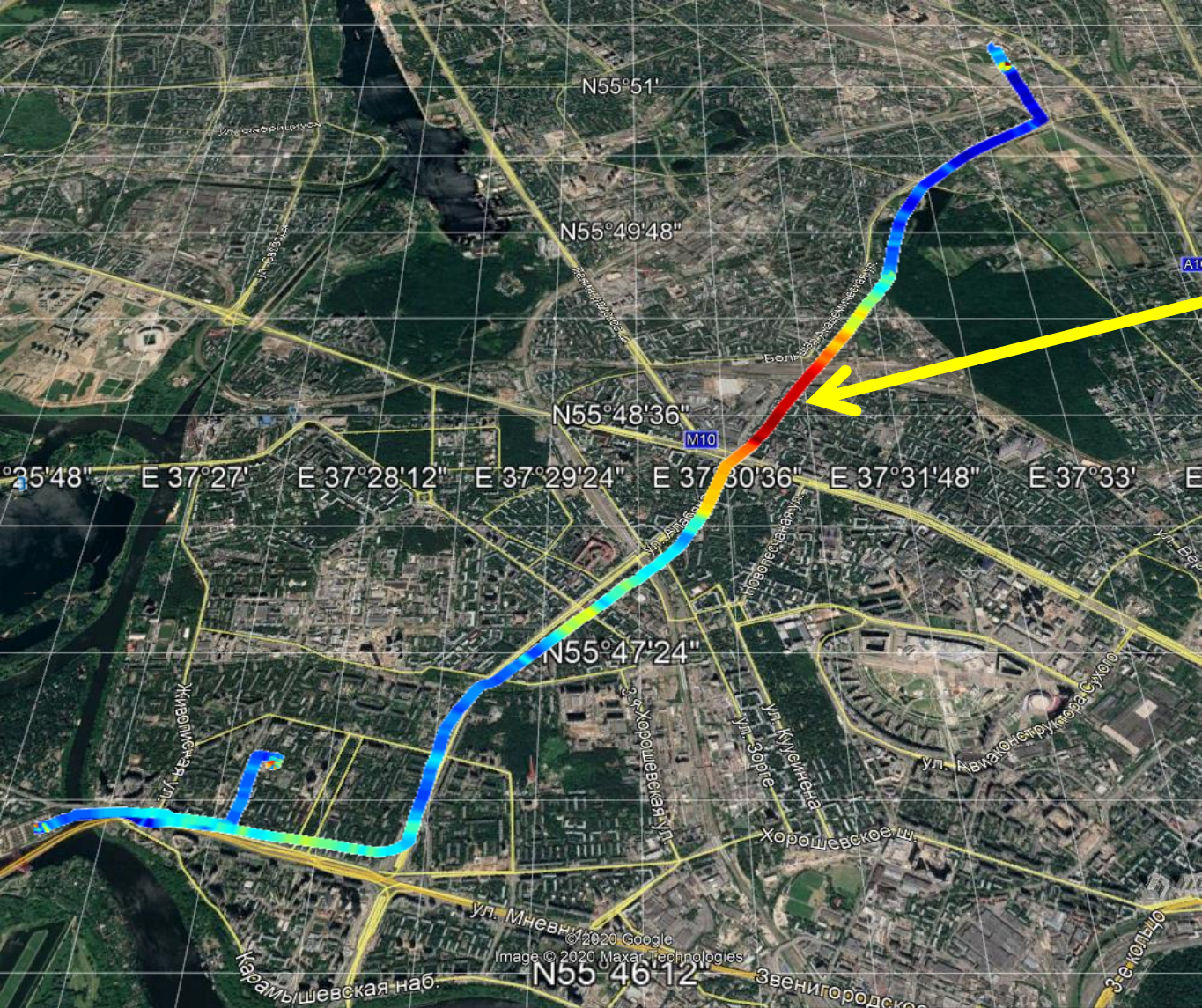




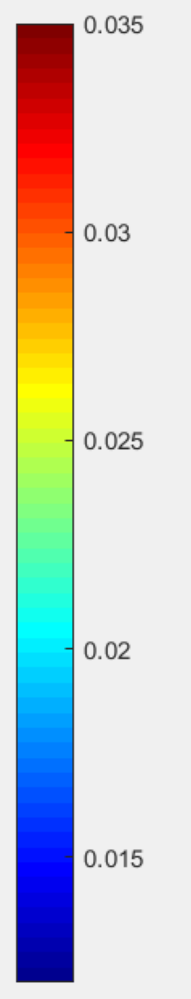
# Test results

City test with windows **closed** / Recirculation **OFF** / 24.07.20 morning

PM2.5, mg/m<sup>3</sup>



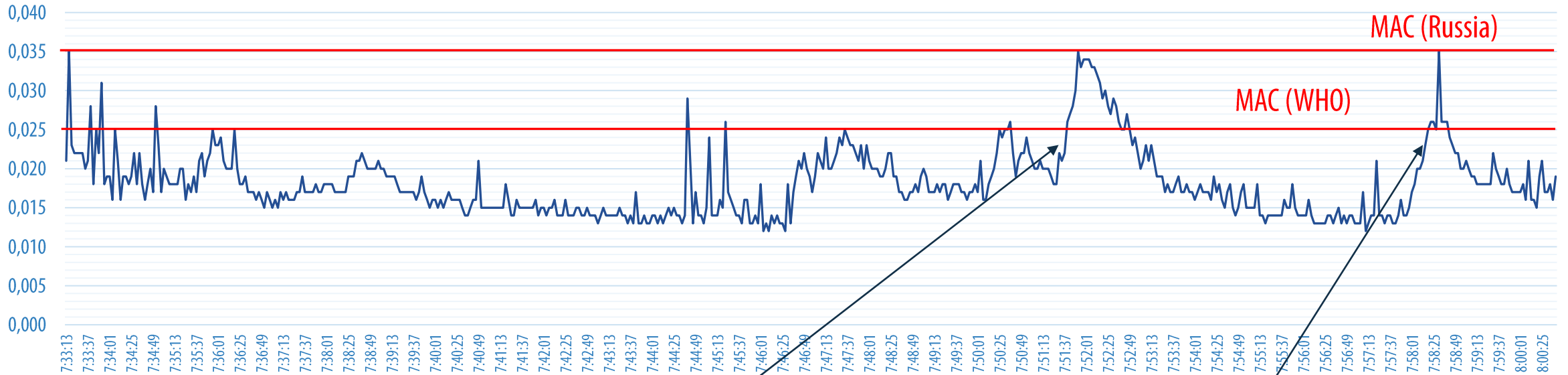
Tunnel (1.7 km)



# Test results

City test with windows **closed** / Recirculation **OFF** / 24.07.20 morning

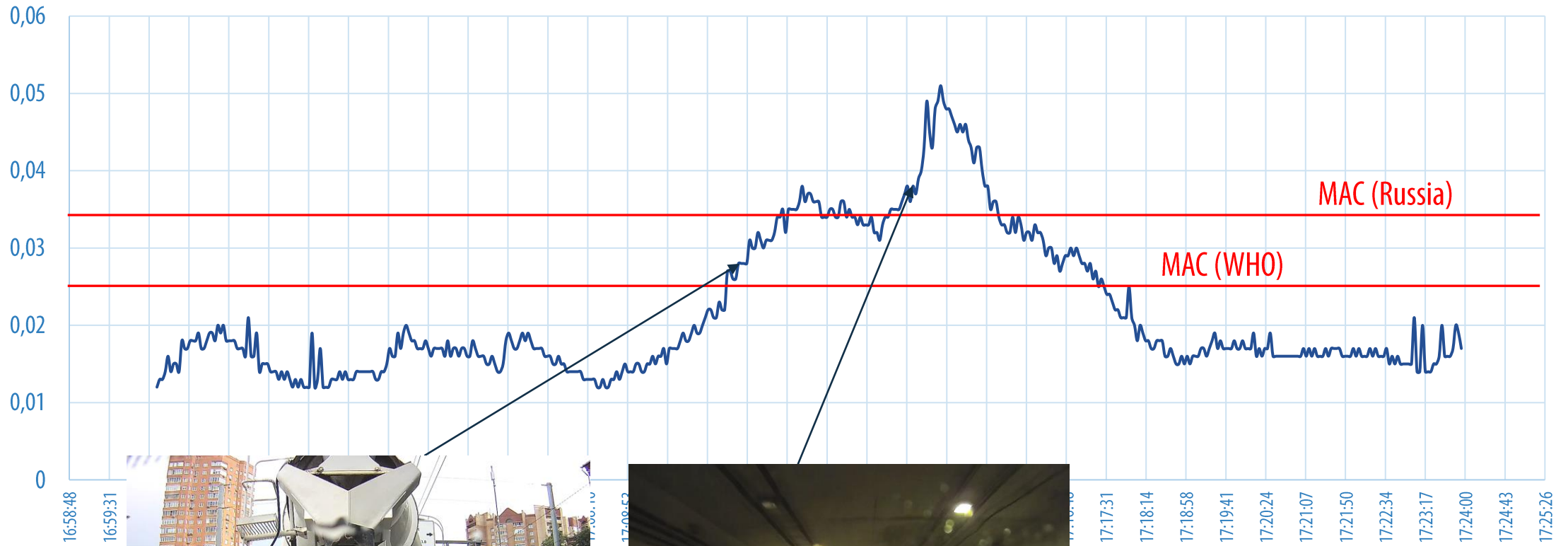
PM<sub>2.5</sub>, mg/m<sup>3</sup>



# Test results

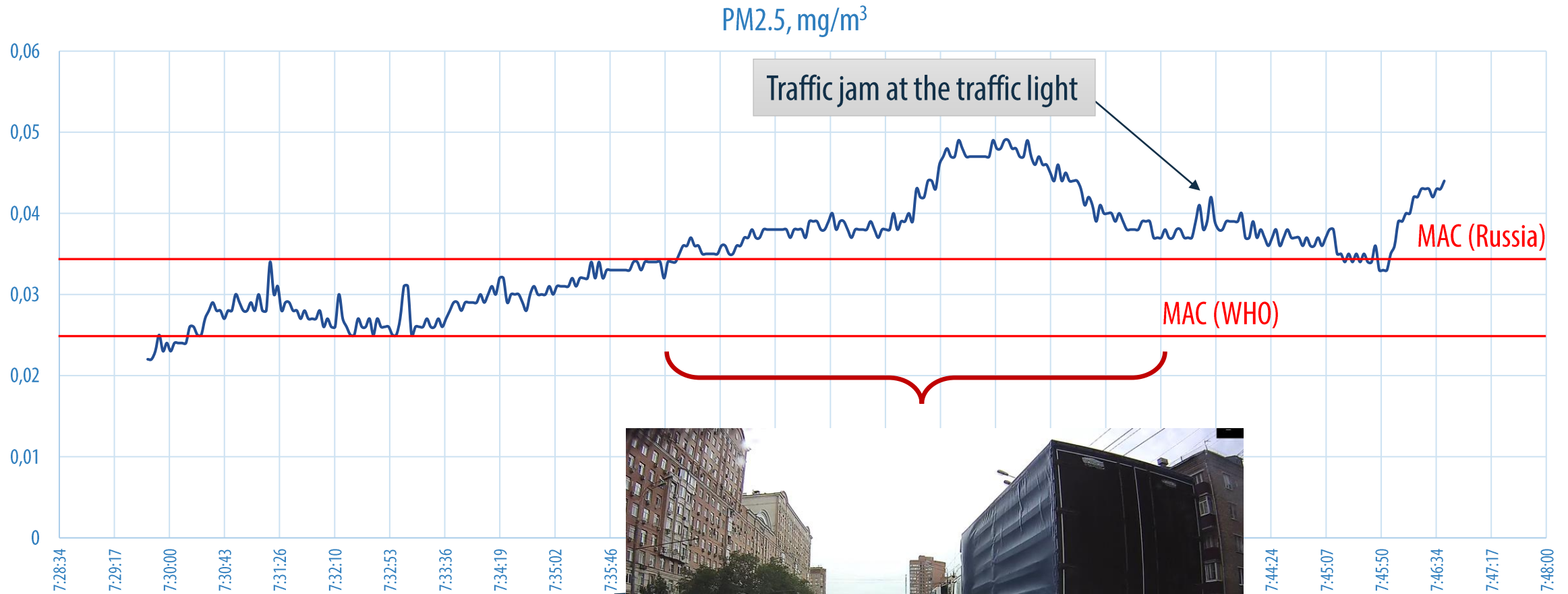
City test with windows **closed** / Recirculation **OFF** / 27.07.20 evening

PM2.5, mg/m<sup>3</sup>



# Test results

City test with windows **closed** / Recirculation **OFF** / 29.07.20 morning



Traffic jam at the traffic light

MAC (Russia)

MAC (WHO)

Following a heavy-duty vehicle



# Analysis of test results

City test with windows **closed** / Recirculation **OFF** / morning

Average trip distance – 11 km

Data	PM2.5, mg/m <sup>3</sup>	PM10, mg/m <sup>3</sup>	Average speed, km/h	Maximal speed, km/h	Trip duration, min:sec	Ambient temperature, °C	Relative humidity, %
23.07.2020	0.013	0.021	39.7	73	17:00	15	67.95
24.07.2020	0.018	0.019	30.7	76	27:00	17.05	56.35
27.07.2020	0.028	0.031	28.9	79	17:59	20.9	58.15
28.07.2020	0.079	0.08	36.4	73	18:43	19.6	82.8
29.07.2020	0.035	0.037	39.5	74	17:02	20	82.35
30.07.2020	0.021	0.022	36.6	80	18:27	20.7	69.35
31.07.2020	0.012	0.015	27.2	73	29:00	15.05	71.55

# Analysis of test results

City test with windows **closed** / Recirculation **OFF** / evening

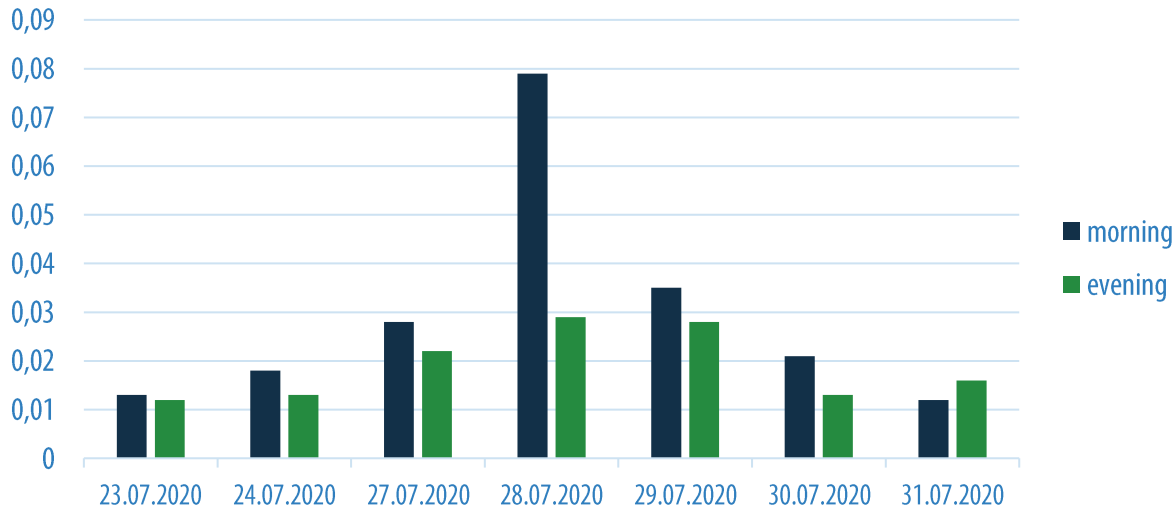
Average trip distance – 11 km

Data	PM2.5, mg/m <sup>3</sup>	PM10, mg/m <sup>3</sup>	Average speed, km/h	Maximal speed, km/h	Trip duration, min:sec	Ambient temperature, °C	Relative humidity, %
23.07.2020	0.012	0.019	30.1	78	18:53	21.55	37
24.07.2020	0.013	0.014	32.3	73	17:00	21.15	48.65
27.07.2020	0.022	0.023	26.3	72	23:31	19	79.35
28.07.2020	0.029	0.03	25	71	24:00	28.65	44.35
29.07.2020	0.028	0.029	30.9	72	20:00	29.05	46.5
30.07.2020	0.013	0.014	26.9	74	32:00	22.35	44.25
31.07.2020	0.016	0.018	26.4	72	21:39	21.3	51

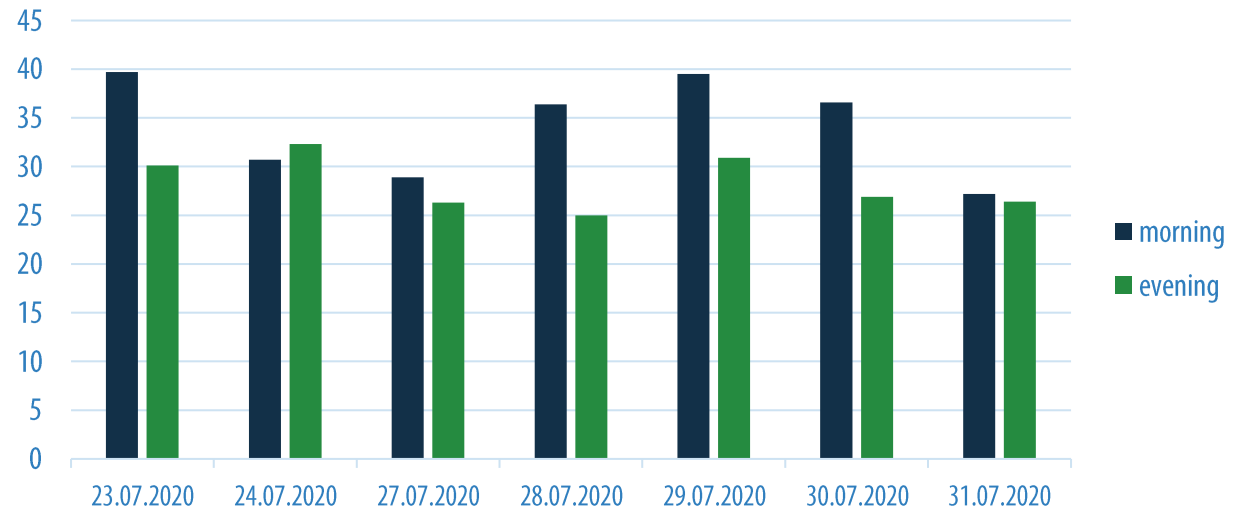
# Analysis of test results

## City test with windows **closed** / Recirculation **OFF**

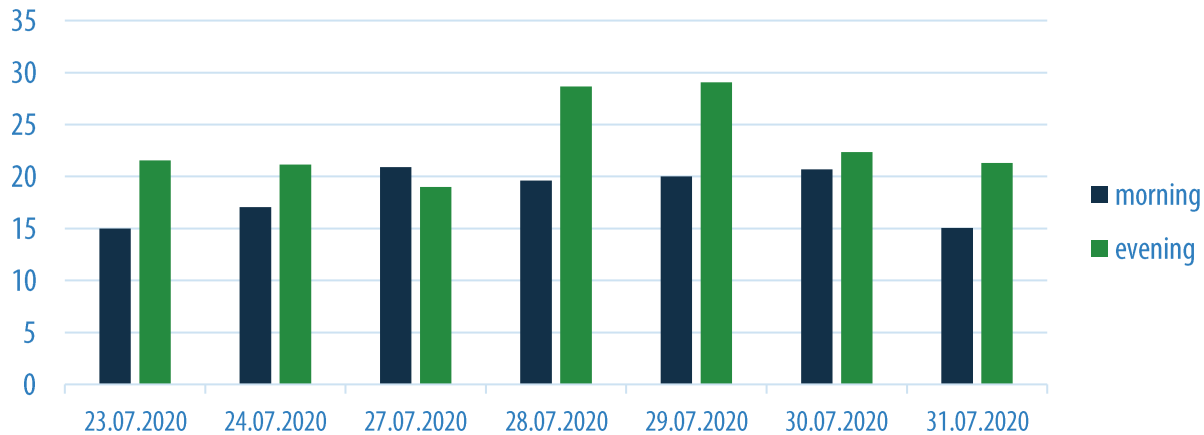
PM2.5, mg/m<sup>3</sup>



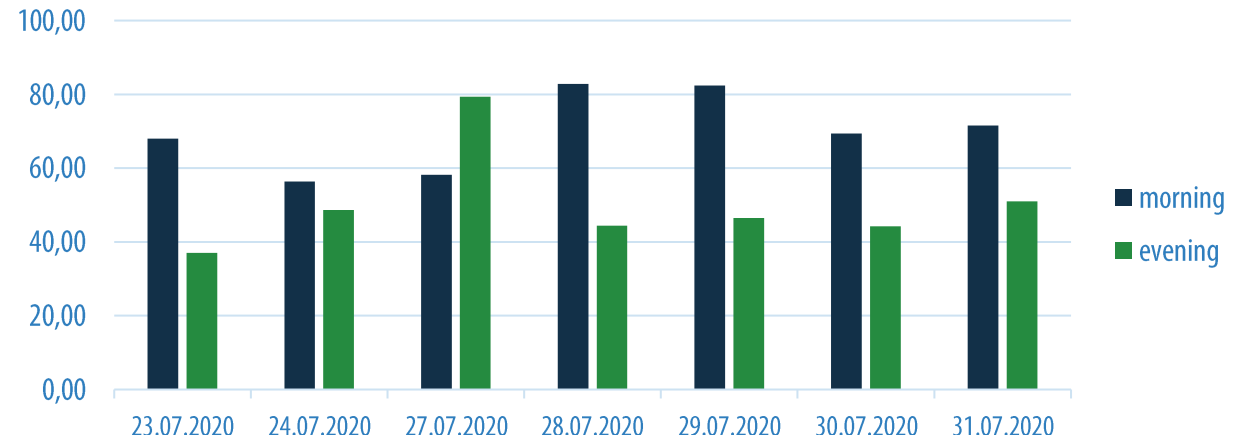
Average Speed, km/h



Ambient Temperature, C

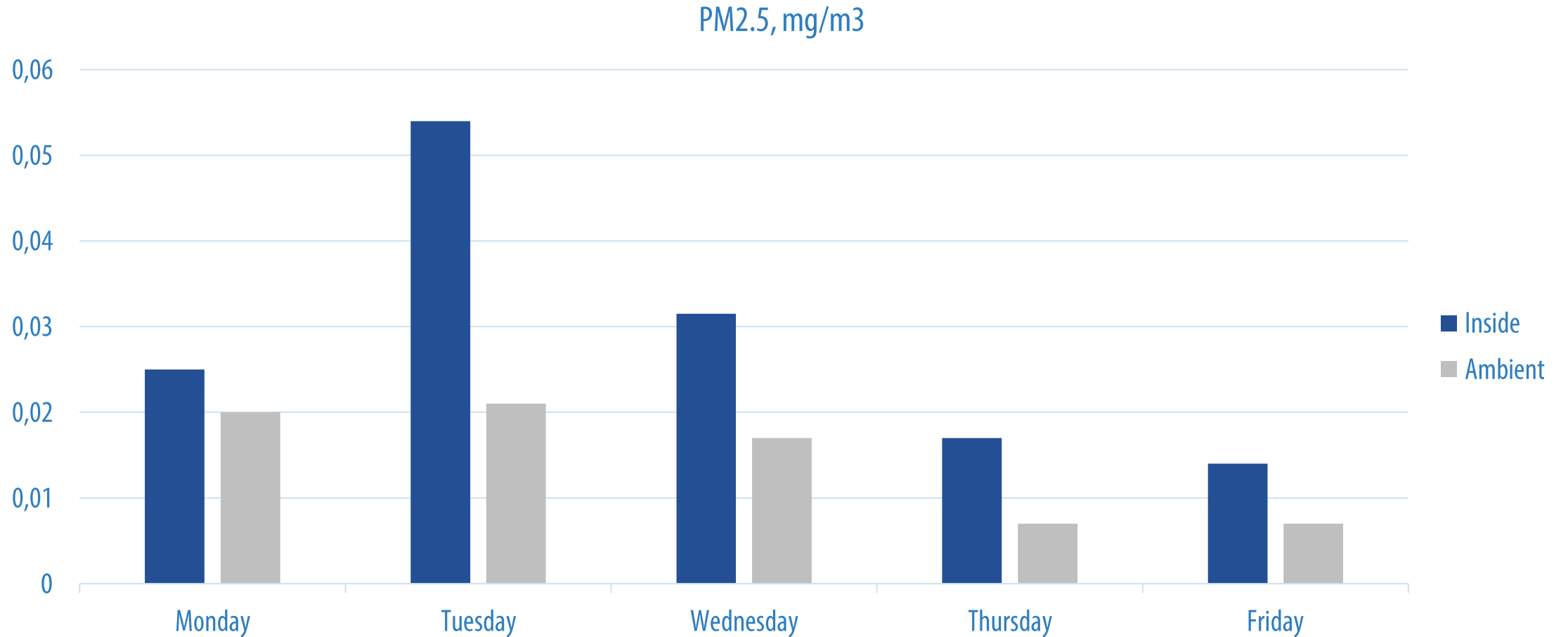


Relative humidity, %



# Analysis of test results

## City test with windows **closed** / Recirculation **OFF**



Inside PM concentration was calculated as average from morning and evening measurements for each particular day  
Ambient PM concentration from Mosecomonitoring data





# Analysis of test results

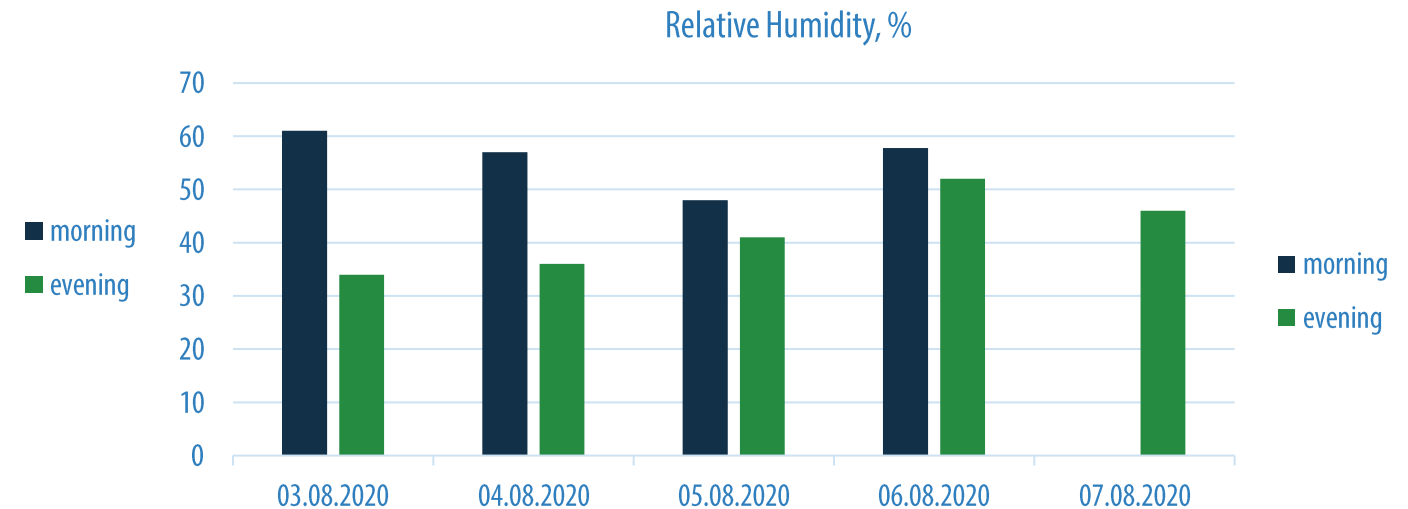
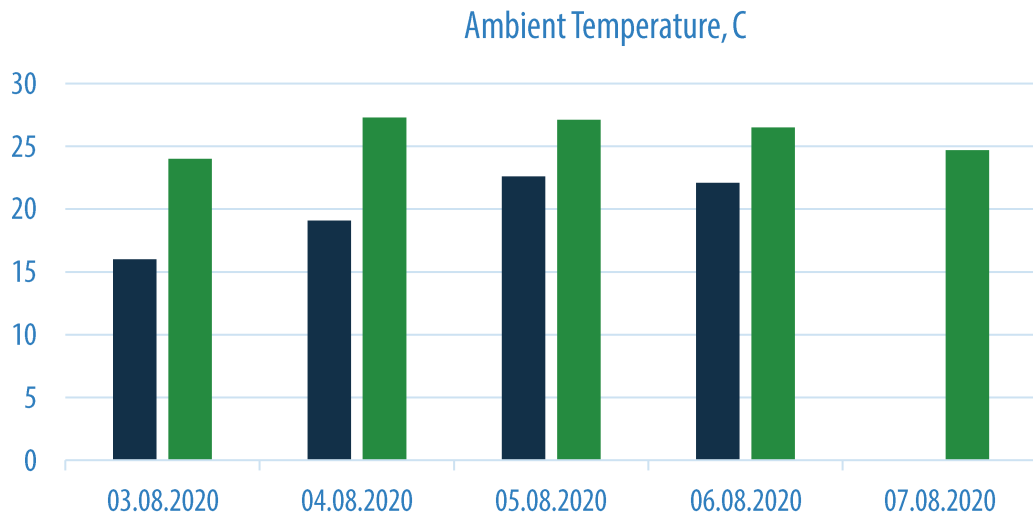
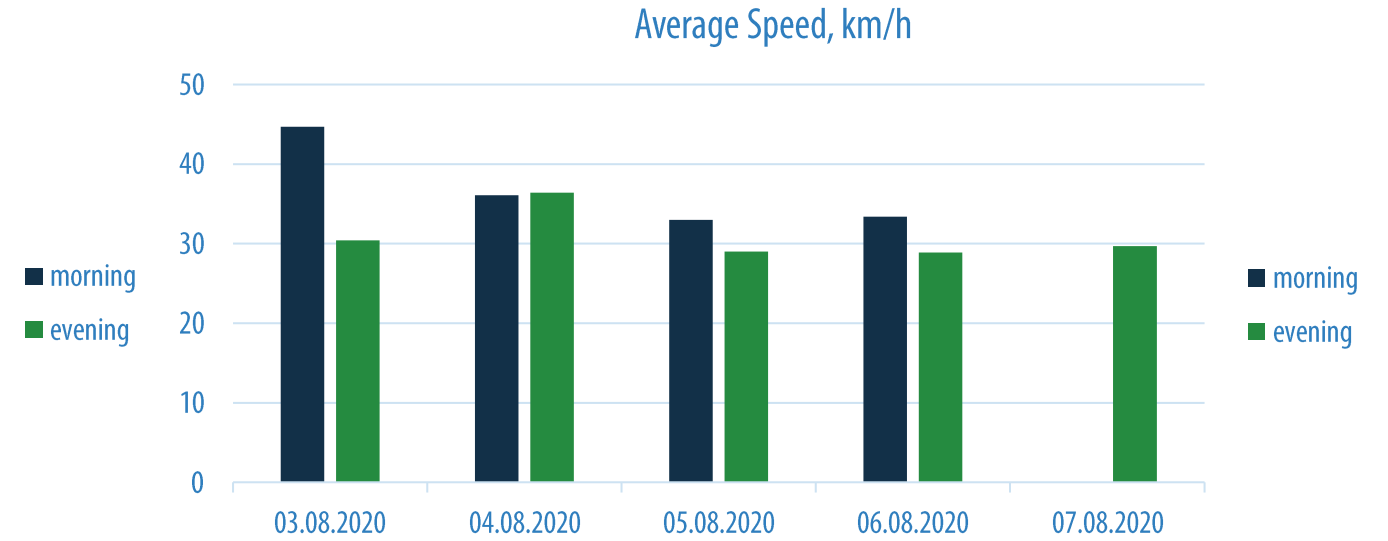
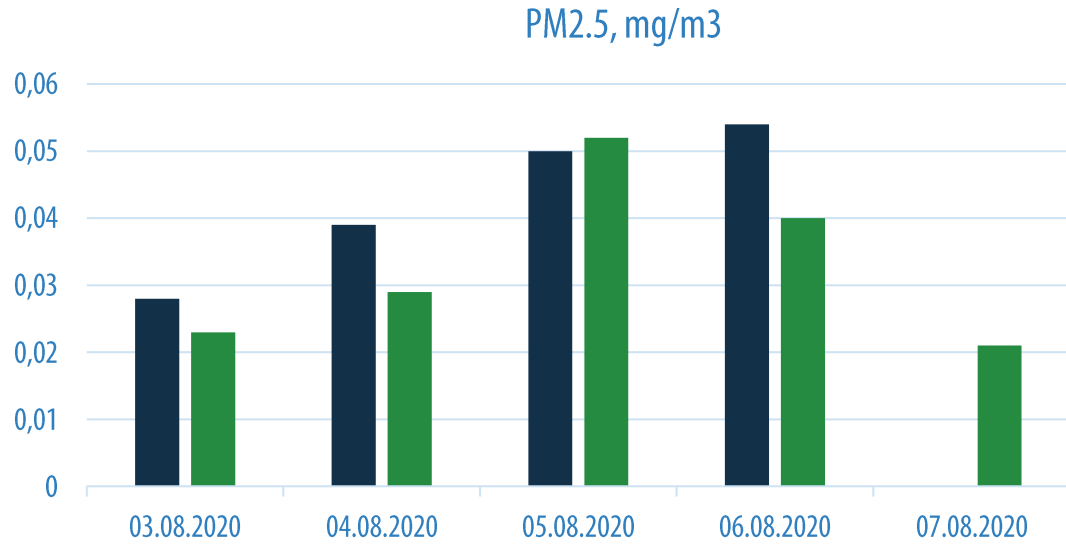
## City test with window **opened** / Ventilation **OFF**

Average trip distance – 11 km

Data	Time of day	PM2.5, mg/m <sup>3</sup>	PM10, mg/m <sup>3</sup>	Average speed, km/h	Maximal speed, km/h	Trip duration, min:sec	Ambient temperature, °C	Relative humidity, %
03.08.2020	Morning	0.028	0.03	44.7	72	20:18	17	53.2
	Evening	0.023	0.026	30.4	76	19:47	23.7	40
04.08.2020	Morning	0.039	0.042	36.1	71	19:31	20.5	53
	Evening	0.029	0.032	36.4	75	15:21	27.6	36
05.08.2020	Morning	0.05	0.054	33	76	21:44	24.7	42
	Evening	0.052	0.056	29	79	21:23	26.8	44
06.08.2020	Morning	0.054	0.057	33.4	70	20:56	23.2	53.6
	Evening	0.04	0.042	28.9	73	15:29	26.4	52
07.08.2020	Morning	0.021	0.026	29.7	78	19:37	24.7	46

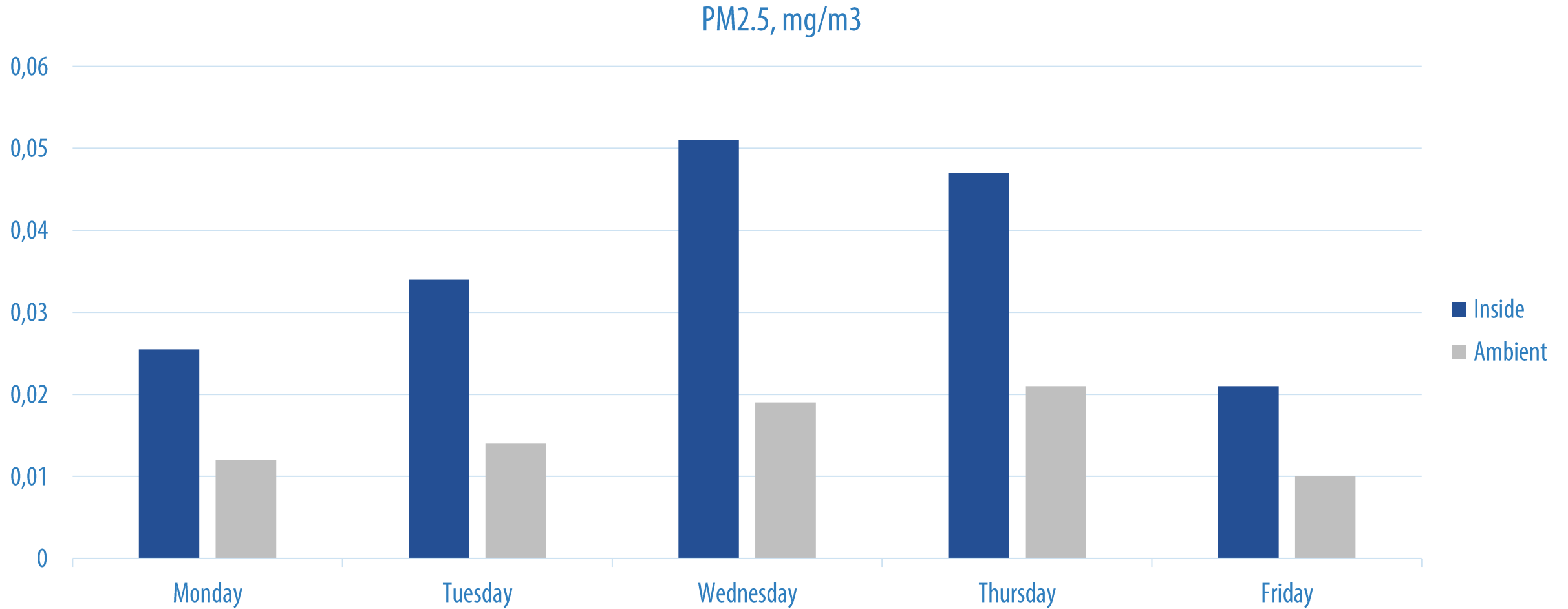
# Analysis of test results

## City test with window **opened** / Ventilation **OFF**



# Analysis of test results

## City test with window **opened** / Ventilation **OFF**

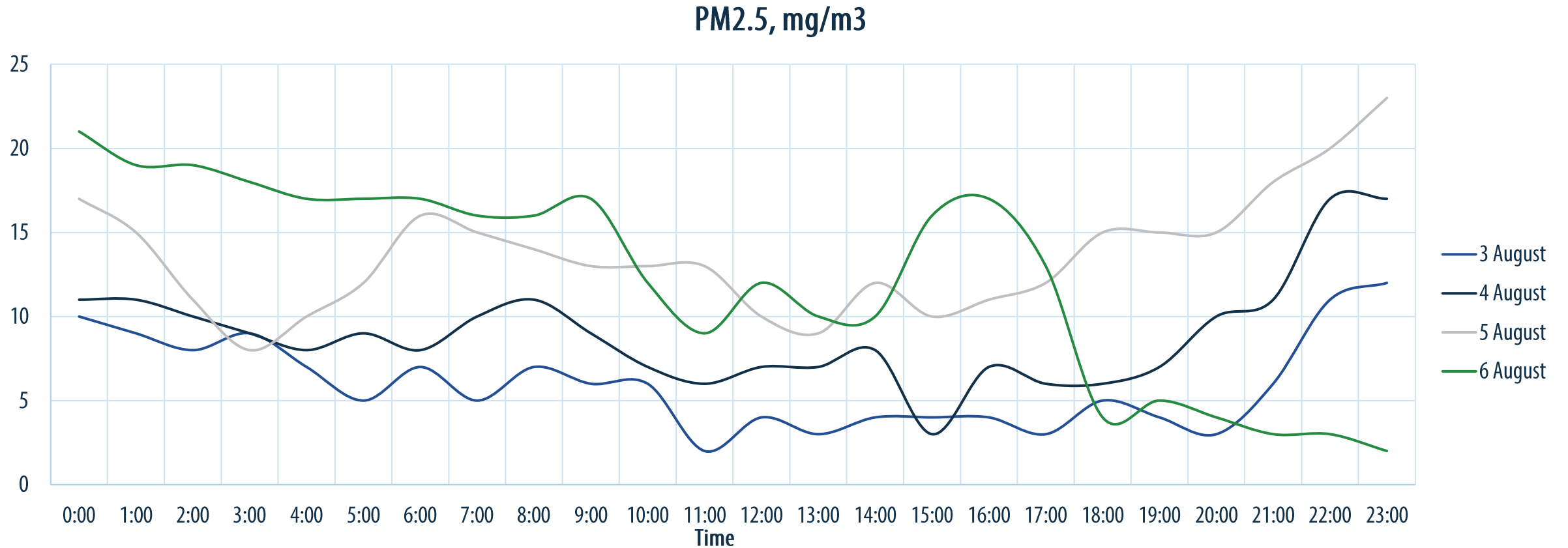


Inside PM concentration was calculated as average from morning and evening measurements for each particular day  
Ambient PM concentration from Mosecomonitoring data



# Analysis of test results

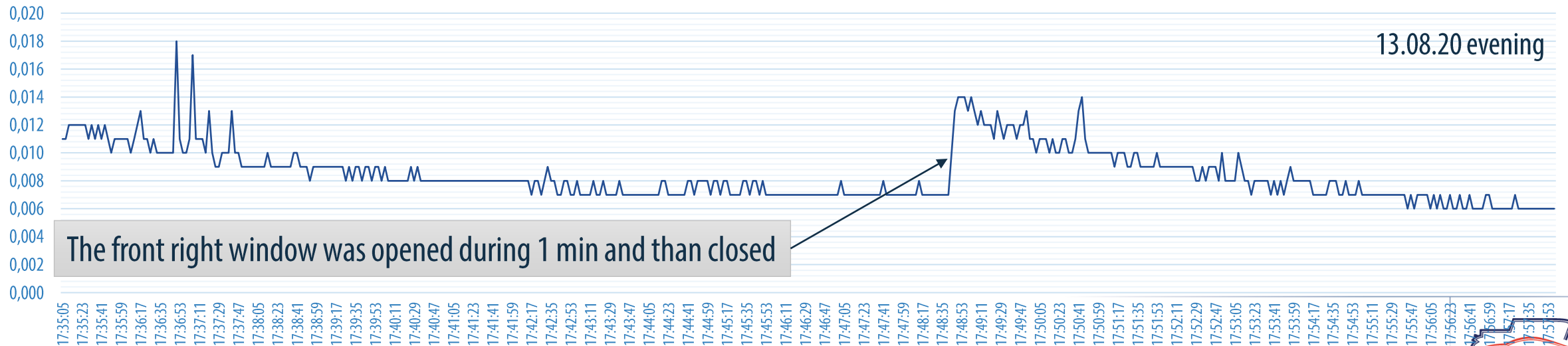
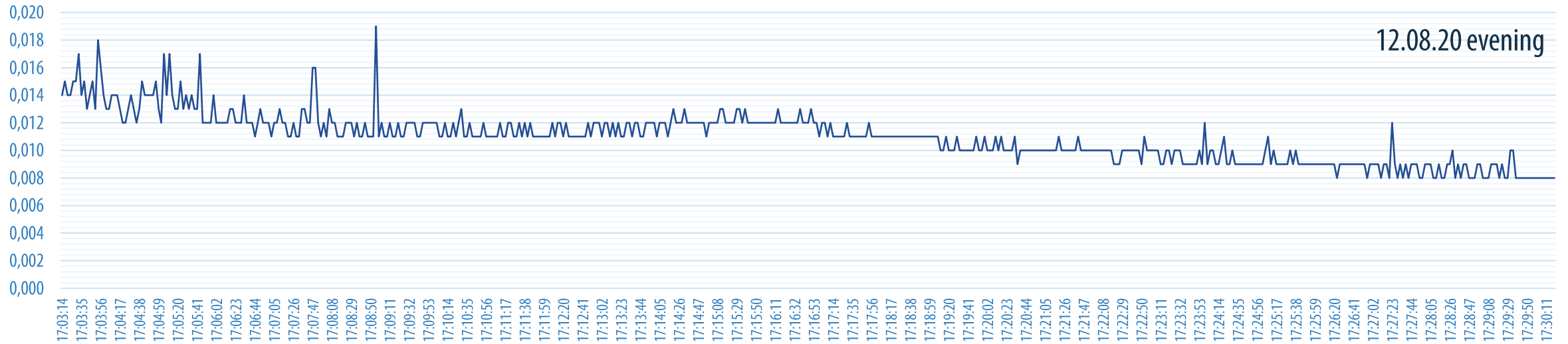
## Background PM concentration at Mosecomonitoring measuring station (Narodnogo Opolcheniya st., 21 build.1)



# Test results

## City test with windows **closed** / Recirculation **ON**

PM<sub>2.5</sub>, mg/m<sup>3</sup>



# Analysis of test results

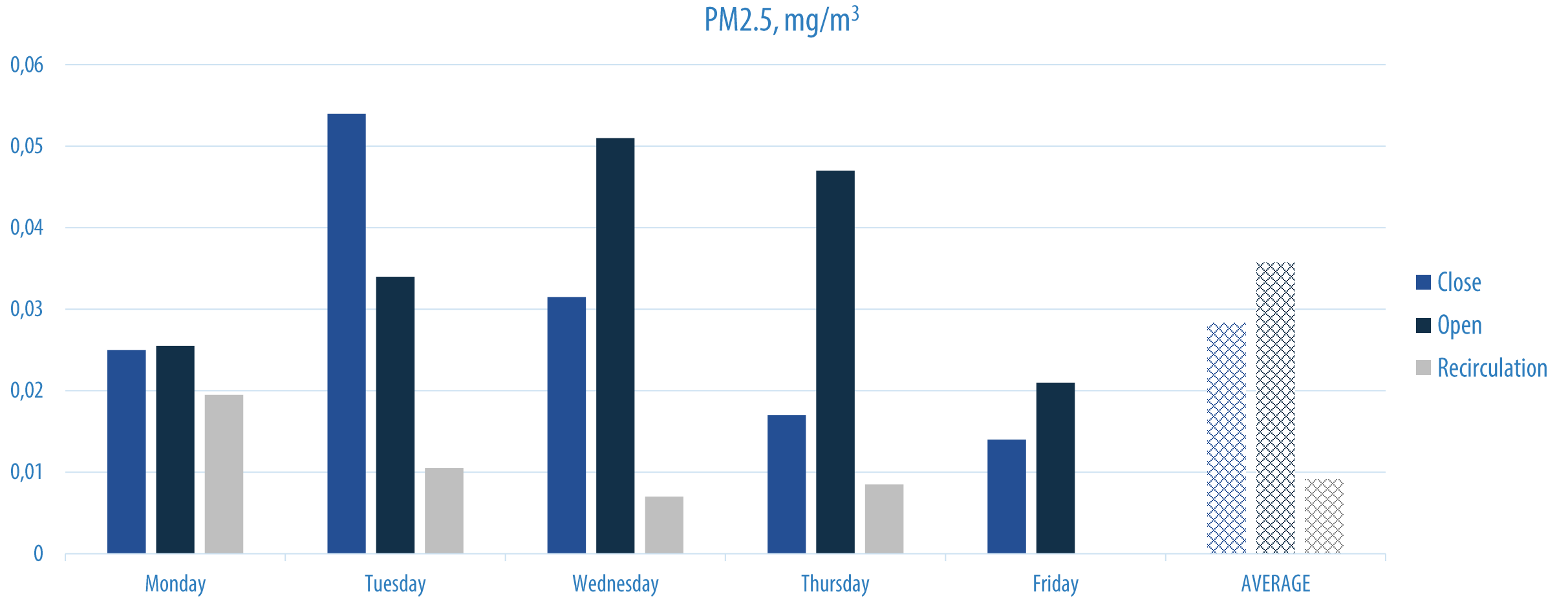
## City test with window **closed** / Recirculation **ON**

Average trip distance – 11 km

Data	Time of day	PM2.5, mg/m <sup>3</sup>	PM10, mg/m <sup>3</sup>	Average speed, km/h	Maximal speed, km/h	Trip duration, min:sec	Ambient temperature, °C	Relative humidity, %
10.08.2020	Morning	0.028	0.029	36.9	80	19:02	19.4	60
	Evening	0.011	0.011	19.5	73	27:19	28.5	36.4
11.08.2020	Morning	0.014	0.015	26	73	22:57	22.8	45
	Evening	0.007	0.007	23.3	74	23:38	20	45
12.08.2020	Morning	0.008	0.009	29.5	73	23:57	16.7	64.3
	Evening	0.006	0.006	-	-	-	18.9	62.3
13.08.2020	Morning	0.009	0.009	35.3	70	20:04	14.7	87
	Evening	0.008	0.008	28.8	79	22:50	16	71

# Analysis of test results

## City tests comparison

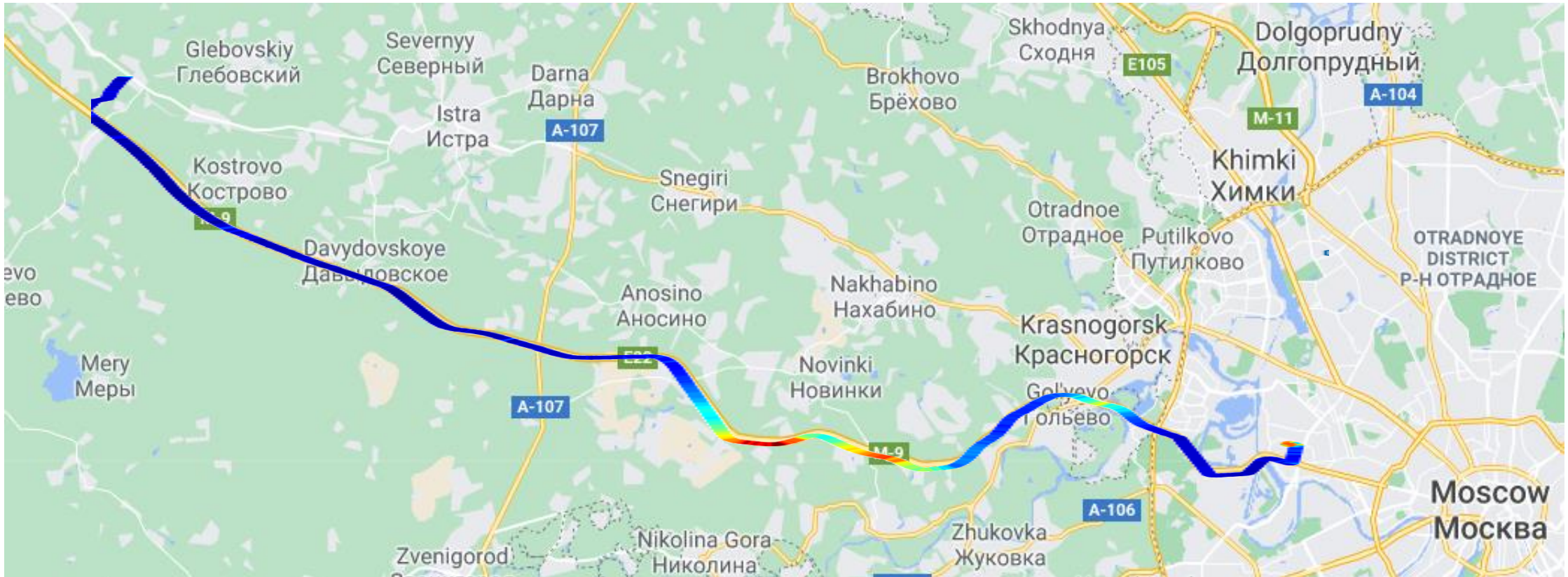


The measurements were carried out in different Mondays, Tuesdays...

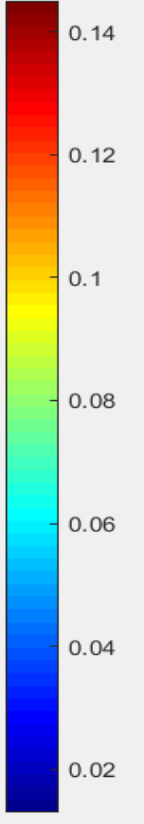


# Test results

Highway test with windows **closed** / Recirculation **OFF** / 26.07.2020



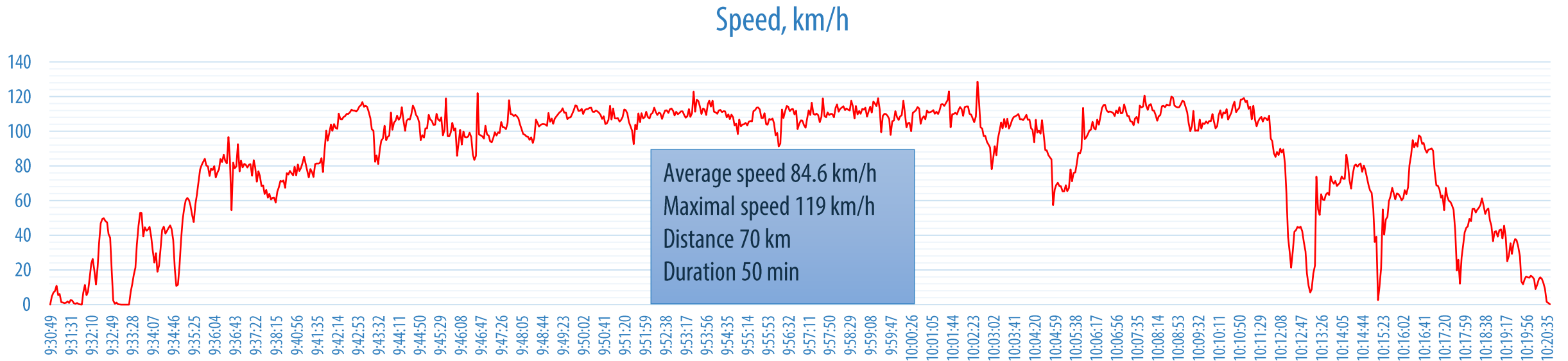
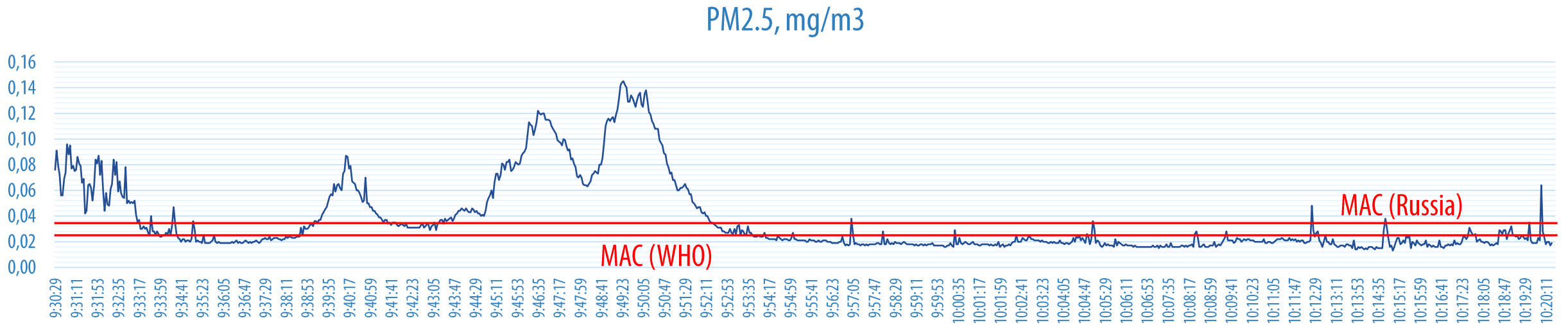
PM2.5,  
mg/m<sup>3</sup>





# Test results

Highway test with windows **closed** / Recirculation **OFF** / 26.07.2020



# Test results

Highway test with windows **closed** / Recirculation **OFF** / 8.08.2020

PM<sub>2.5</sub>, mg/m<sup>3</sup>



# Conclusions

1. Particles are very toxic substances, which may deposit inside the human body. Concentration of particles in the cities could be very high and depend on wind velocity, relative humidity and emissions from stationary and mobile sources. The concentration is significantly vary from day to day and during the day.
2. Test procedure was developed to collect some statistical data about particles concentration inside the vehicle cabin in different driving conditions and ventilation modes.
3. The tests were carried out to measure particle concentrations in vehicle interior air in real driving conditions. The measurements indicate the strong influence of outer sources and conditions to inside concentrations (heavy duty vehicles, tunnels, road reconstruction etc.) and exciding of maximum acceptable concentration in some cases.
4. The measurement results showed strong correlation between background particles concentration and interior concentration.
5. The collected data will help to develop real driving test procedure for vehicle interior air quality assessment.

# Next steps

1. Tests at different driving conditions city (centre, jams, rings), suburban, highway.
2. Tests at different ventilation system settings
  - Air blower speed
  - Air conditioner ON/OFF
  - Temperature settings
3. Tests at different sampling points.
4. Tests with different cabin filters (supplier, filter age).
5. Development of real driving vehicle interior air quality assessment test procedure.

**Thank you for your attention!**

