Report on Measurements of Air Pollution with Ultrafine Particles from Traffic

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January 2025

Preface

The submitted report was created as a part of the LIFE IP project – Improving Air Quality (populair), the full name of the project: "*Enhancing the implementation of Air Quality Management Plans in Slovakia by strengthening capacities and competencies of regional and local authorities and promoting air quality measures*", project number: **LIFE18 IPE/SK/000010**.

The report was prepared by the Centre for Sustainable Alternatives (CEPTA) as an associated beneficiary (partner) of the project.

The primary objective was to measure air pollution (concentration of ultrafine PM particles) resulting from traffic in selected cities and parts of Slovakia.

The measurements were taken **from 7 November to 12 November 2024**. To highlight air quality issues, we also used the results of measurements conducted prior to the start of the implementation of this project. It is indicated in the text.

This project could not have been carried out without the financial support of the European Union, for which we are grateful.

Kaare Press-Kristensen & Miloš Veverka, January 2025

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Title photo: Measurement of ultrafine particles pollution next to a busy mountain pass Čertovica, 8 November 2024.

Co-funded by the European Union. Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

The project is co-funded by the state budget of the Slovak Republic through the Ministry of Environment.

Content

1. Introduction and methodology

The aim of the ultrafine particles measurements was to determine the extent to which road transport contributes to air pollution with ultrafine particles in inhabited areas of Slovakia. We carried out measurements from 7 November to 12 November 2024 in the following cities and towns in Slovakia:

- Sereď (7 November - 8 November 2024) – primary school
- Čertovica (8 November 2024) – mountain pass, busy road
- Prešov (8 November – 9 November 2024) – busy crossroads, pedestrian zone, background
- Banská Bystrica (10 November – 11 November 2024) – busy crossroads, busy road, bus stop, primary school, pedestrian zone, background

In addition, the pollution to which the car passengers are exposed inside the cabin of the car was measured:

- on the way from Podbrezová to Banská Štiavnica (9 November 2024 in the evening)
- on the way from Banská Štiavnica to Rovinka near Bratislava (12 November 2024 in the morning)

We also compared the ultrafine particles emissions from the exhaust of an older diesel car (Euro 4 emission standard) with a new diesel car (Euro 6) and also with a car with a petrol engine and LPG drive.

The measurements were carried out using the P-Trak Ultrafine Particle Counter from TSI, model 8525 (Fig. 1), which measures ultrafine dust particles with diameters ranging from 0.02 to 1 μm as the number of particles per 1 cm^3 of air. The device is compact and easily portable, with the primary advantage being real-time measurement, which enables the identification of pollution sources.

The time of measurement in cases of large fluctuations in values, e.g. at crossroads or busy roads, is approximately 30 minutes, while for steady values (background) it is at least 5 minutes.

The device measures in second intervals. Minute averages are used in the graphs.

In some localities, parallel measurements were carried out using two identical P-Trak instruments (at different sites within the same locality, simultaneously). At some sites, concentrations of fine $PM_{2.5}$ particles were also measured simultaneously with the Aeroqual device in $\mu g/m^3$.

Fig. 1: Portable measuring instrument P-Trak, model 8525.

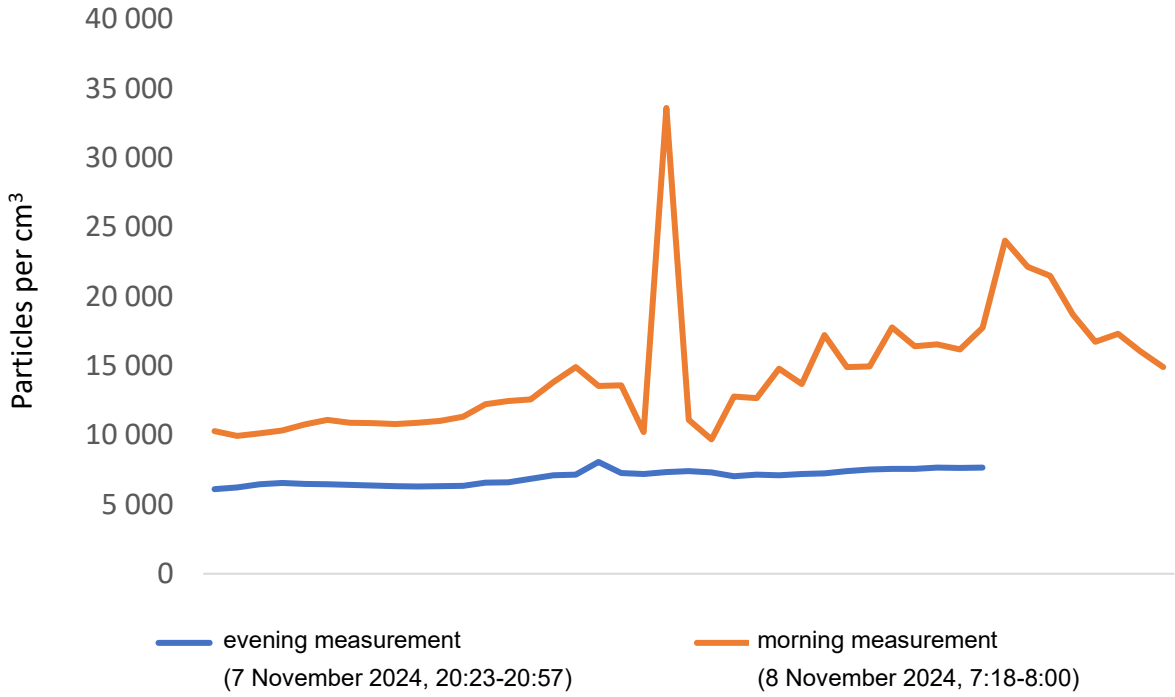
2. Primary schools – Sereď and Banská Bystrica

We measured air pollution with ultrafine particles at the entrance to the primary school campus, where parents bring their children to school by car every morning. We always took measurements in the afternoon or evening, when there is almost no traffic in front of the school, and then the next morning between 7:00 and 8:00, when parents bring their children by car before the start of classes, and the traffic intensity is at its highest.

We took measurements in front of the primary school J. A. Komenského in Sereď (7 November – 8 November 2024, Figs. 2-6) and the primary school Golianova in Banská Bystrica (10 November -11 November 2024, Figs. 7-8).

Fig. 2: Primary school J. A. Komenského in Sereď.

Fig. 3: Measurement of ultrafine particles pollution in front of the primary school J. A. Komenského in Sereď.



During the evening and morning measurements, there was weather inversion, no wind or only light wind.

As can be seen from the graph in Fig. 3 and from the average values of measurements below, pollution in the morning on Friday, 8 November 2024, is higher than in the evening on Thursday, 7 November 2024, due to the high traffic density during the morning rush hour, when many parents bring their children to the school by car. If parents allowed their children to walk or cycle to school, traffic density would be lower, the journey to school would be safer, and the air would be cleaner.

Primary school J. A. Komenského, Thursday evening – average: 6,960 particles per cm^3

Primary school J. A. Komenského, Friday morning – average: 14,480 particles per cm^3

Fig. 4: Evening measurement in front of the primary school in Sered'.

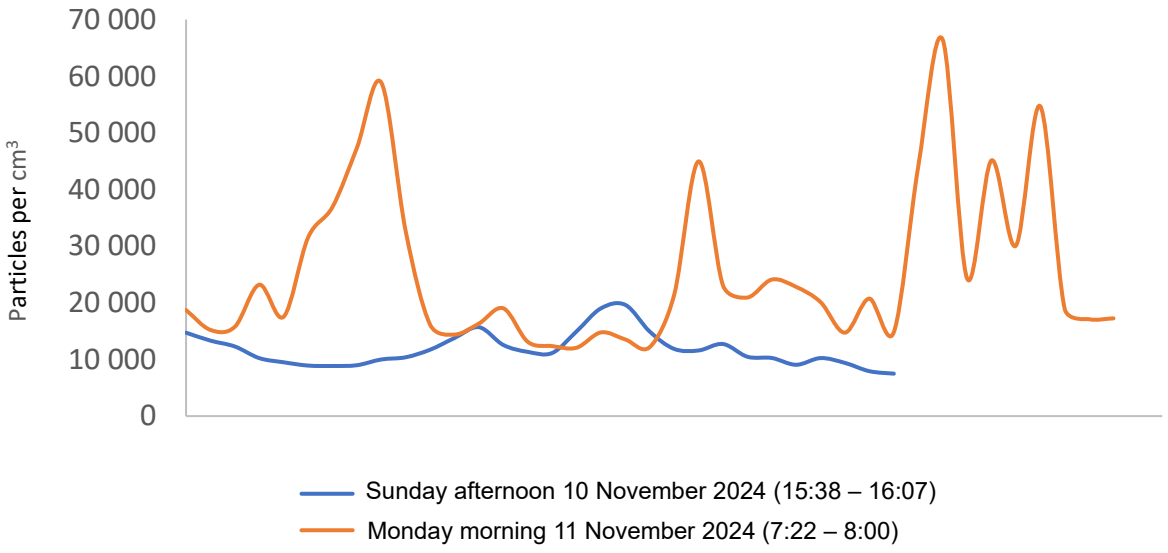
Fig. 5: Morning measurement in front of the primary school in Sered'. Measured values exceeded 100,000 particles per cm³.

Fig. 6: The school headmaster came to school by bike – a good example for everyone.

In front of the primary school Golianova in Banská Bystrica, we took measurements on Sunday, 10 November 2024, in the afternoon, when the traffic intensity was minimal. We repeated the measurements on Monday, 11 November 2024, in the morning, when parents bring their children to the school by car.

During the afternoon and morning measurements, a weather inversion occurred, characterised by clear sky and light wind.

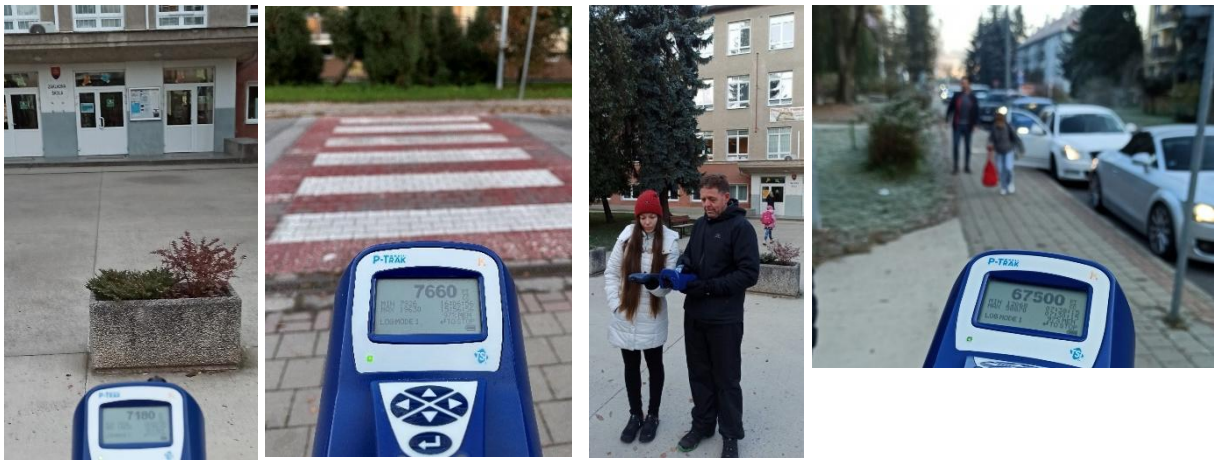
Fig. 7: Measurement of ultrafine particles pollution in front of the primary school Golianova in Banská Bystrica.



It follows from the graph in Fig. 7 and from the average values of the measurements below that the pollution on Monday morning is significantly higher than on Sunday afternoon due to the high traffic density during the morning rush hour, when a lot of children are brought to school by their parents' cars. If children could walk or cycle to school, traffic density would be lower, the journey to school would be safer, and the air would be cleaner.

Primary school Golianova, Sunday afternoon – average:	12,170 particles per cm³
Primary school Golianova, Monday morning – average:	25,990 particles per cm³

Fig. 8: Measurements in front of the primary school Golianova in Banská Bystrica on Sunday, 10 November 2024, in the afternoon (2 photos on the left) and on Monday, 11 November 2024, in the morning (2 photos on the right).



3. Mountain pass Čertovica

Mountain pass Čertovica is located at an altitude of 1,232 m above sea level in the Low Tatras mountains. A busy road No. 72, classified as a first-class road, leads through it, connecting Horné Pohronie with Liptov.

Measurements of air pollution with ultrafine particles from traffic were carried out on 8 November 2024 around lunchtime. The weather was clear and sunny, with a weak southwest wind of 1 – 2 m/s blowing. We measured with two P-Trak instruments simultaneously at two different sites (Fig. 9).

Initially, we measured on the south side of the road, at sites 1 and 2. Site 1 was 20 m from the edge of the road (perpendicular to the road, Fig. 11) and site 2 was right at the edge of the road. Consequently, we moved to the northern edge of the road, specifically to sites 3 and 4. Site 3 was right at the edge of the road, and site 4 was on a slope about 3 m above site 3 and about 10 m from the edge of the road.

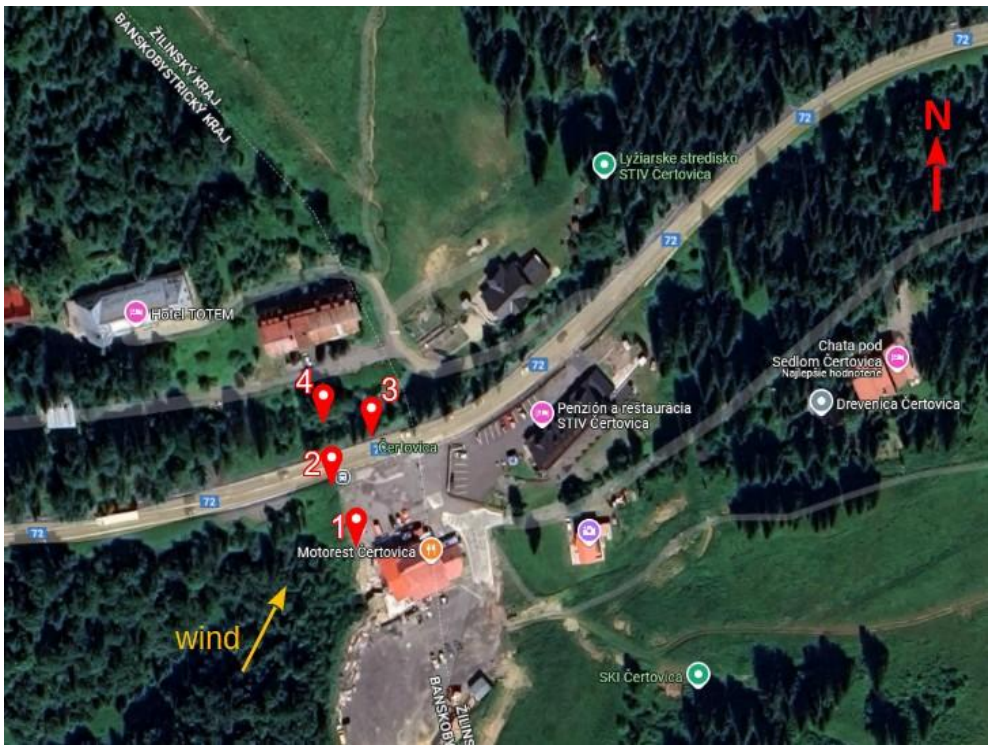
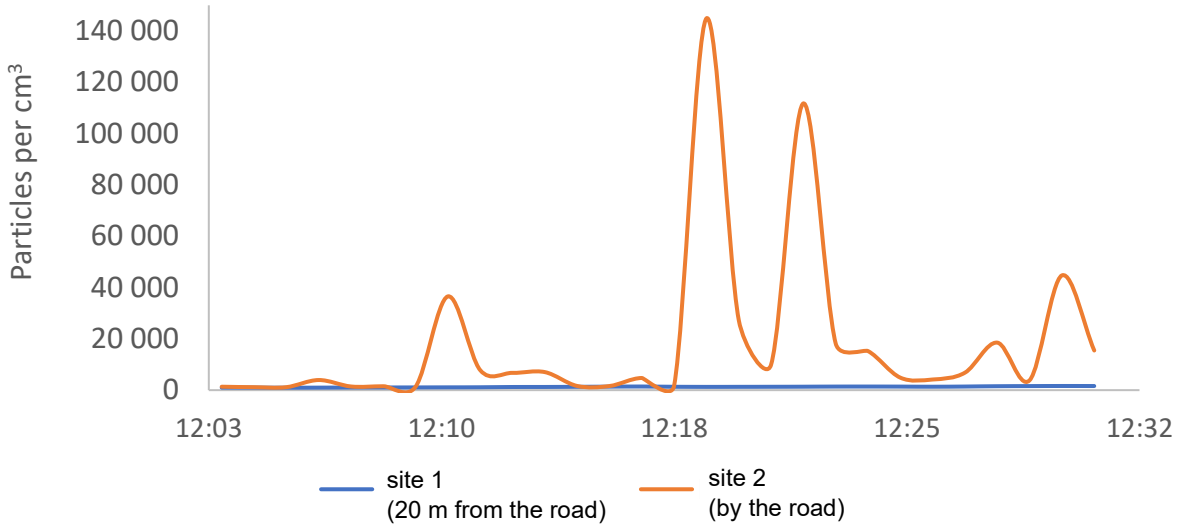


Fig. 9: Measurement of pollution with ultrafine particles in the mountain pass Čertovica. At the same time, sites 1 and 2 were measured, followed by sites 3 and 4.

Fig. 10: Čertovica – measured values at site 1 (20 m from the road) and site 2 (by the road).



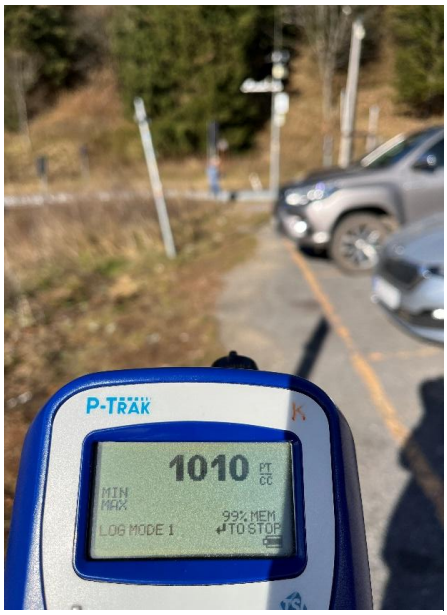


Fig. 11: Čertovica – site 1 (20 m from the road): clan air was indicated. The road is in the background.

Fig. 12: View from site 2 (by the road) on site 1 (20 m from the road).

Fig. 13: Site 2 (by the road). Pollution was significantly higher than at site 1.

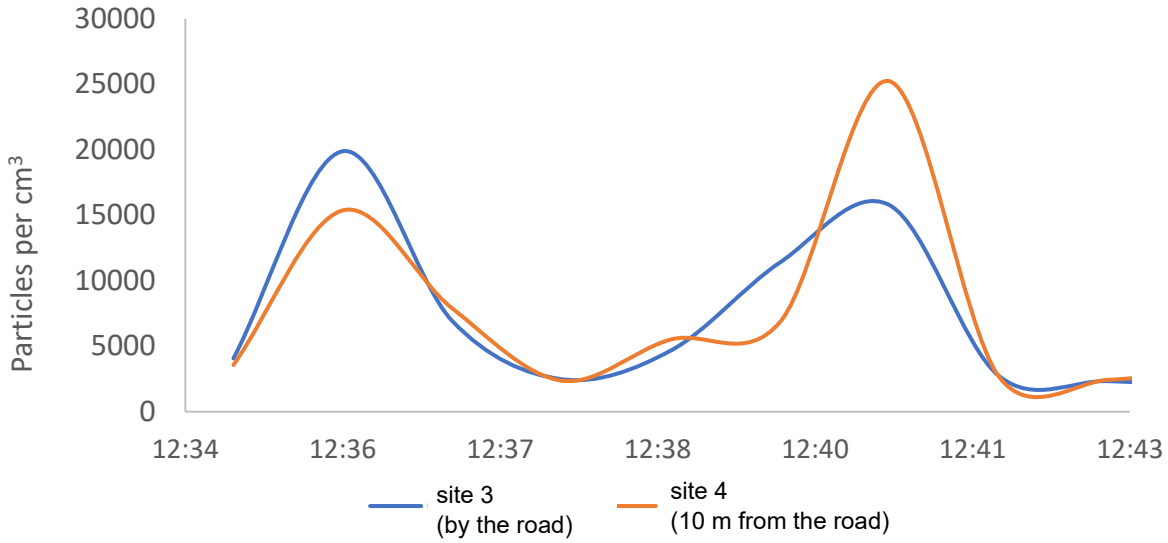
It is evident from the graph of the measured values (Fig. 10) that site 1, located 20 m from the road, exhibited stable and very low pollution levels. It means that it is clean mountain air, unaffected by traffic pollution. This is because the south-east wind was blowing (Fig. 9) and the pollution from traffic did not reach site 1, although it was only 20 m from the road.

Site 2, located immediately adjacent to the road, exhibited significantly higher levels of ultrafine particle pollution, depending on the traffic intensity. If a convoy of cars passed on the road, pollution increased significantly (as indicated by the peak on the graph), and during periods without traffic, the values dropped to the level of site 1, indicating clean mountain air.

site 1 (20 m from the road) – average: 1,270 particles per cm^3

site 2 (by the road) – average: 18,040 particles per cm^3

Fig. 14: Čertovica – measured values at site 3 (by the road) and site 4 (10 m from the road).



The measured values of pollution on the opposite side of the road at sites 3 and 4 are very similar, although site 4 was about 10 m from the road (graph in Fig. 14). This is due to the fact that both sites are in the direction of the wind, almost the same pollution from the road comes to both of them. Higher pollution at site 4 at a minute 12:40 – 12:41 can be explained by the fact that the hot exhaust gases rise upwards and are also driven up the slope by a slight wind.

site 3 (by the road) – average: 7,540 particles per cm^3

site 4 (10 m from the road, on a slope) – average: 7,240 particles per cm^3

Fig. 15: Čertovica – site 3 (by the road).

Fig. 16: View from site 3 on site 4.

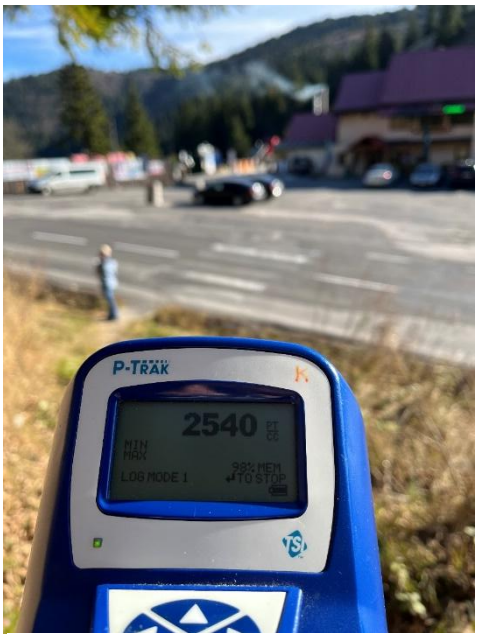


Fig. 17: View from site 4 (10 m from the road, on a slope) on site 3.

All sites (1 to 4) were not affected by emissions of ultrafine particles from local heating and cooking in the surrounding cottages and restaurants, as the wind carried emissions of this type away from the measuring sites (Fig. 9).

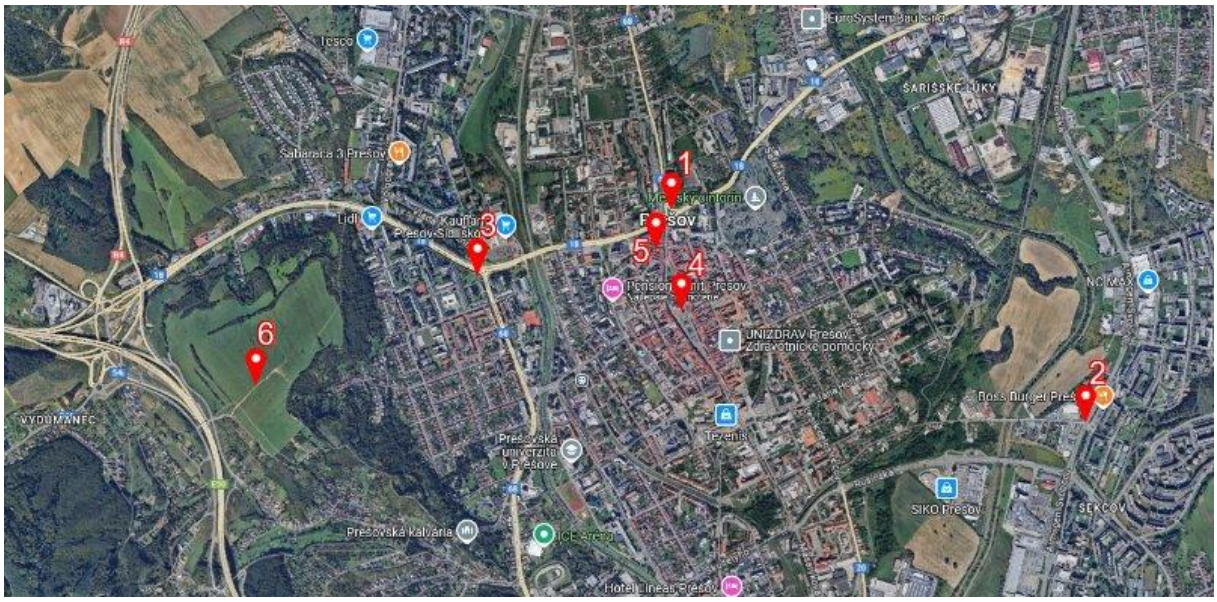
4. Prešov

From 8 November to 9 November 2024, we carried out measurements of air pollution with ultrafine particles in Prešov at the localities listed in Table 1 and Figure 18. These were busy crossroads and urban background, both in the central pedestrian zone and on the outskirts of the city.

Tab. 1: Localities of measurements of air pollution with ultrafine particles in Prešov.

No.	Locality	Location
1	Crossroad 1 - Námestie mieru	49°00'06.8"N 21°14'21.5"E
2	Crossroad 2 - Arm. gen. Svobodu/Pod Táborom	48°59'34.8"N 21°16'00.9"E
3	Crossroad 3 - Obrancov mieru/Levočská	48°59'59.0"N 21°13'37.5"E
4	City centre – Hlavná street (evening measurement)	48°59'50.2"N 21°14'26.6"E
5	City centre – Penzión Hradby (morning measurement)	49°00'01.0"N 21°14'19.6"E
6	City background - outskirts (evening measurement)	48°59'40.0"N 21°12'44.1"E

Fig. 18: Localities of measurements of air pollution with ultrafine particles in Prešov.



At a busy crossroads, parallel measurements were taken simultaneously with two P-Trak instruments at different sites. At some sites, concentrations of fine $PM_{2.5}$ particles were also measured simultaneously with the Aeroqual device in $\mu g/m^3$.

During the measurements, there was weather inversion, it was sunny, no wind or only light wind.

Crossroad 1 - Námestie mieru

We took measurements at a busy crossroads in Námestie mieru in Prešov during the afternoon rush hour (15:15 – 15:45) on Friday, 8 November 2024.

Directly at the crossroad, we measured simultaneously ultrafine particles with the P-Trak instrument and fine $PM_{2.5}$ particles with the Aeroqual device at site 1 (Fig. 19). At the same time, we measured ultrafine particles on the opposite side of the crossroad (site 2) with the second P-Trak instrument. Then we measured ultrafine particles in the open window of the office on the 3rd floor in the building of the Prešov Self-Governing Region (site 3).

Fig. 19: Measurement sites at Námestie mieru square in Prešov:
1 – parallel measurement of ultrafine particles (P-Trak) and $PM_{2.5}$ (Aeroqual)
2 – parallel measurement of ultrafine particles with the second P-Trak
3 – measurement of ultrafine particles in the open window of the office on the 3rd floor.

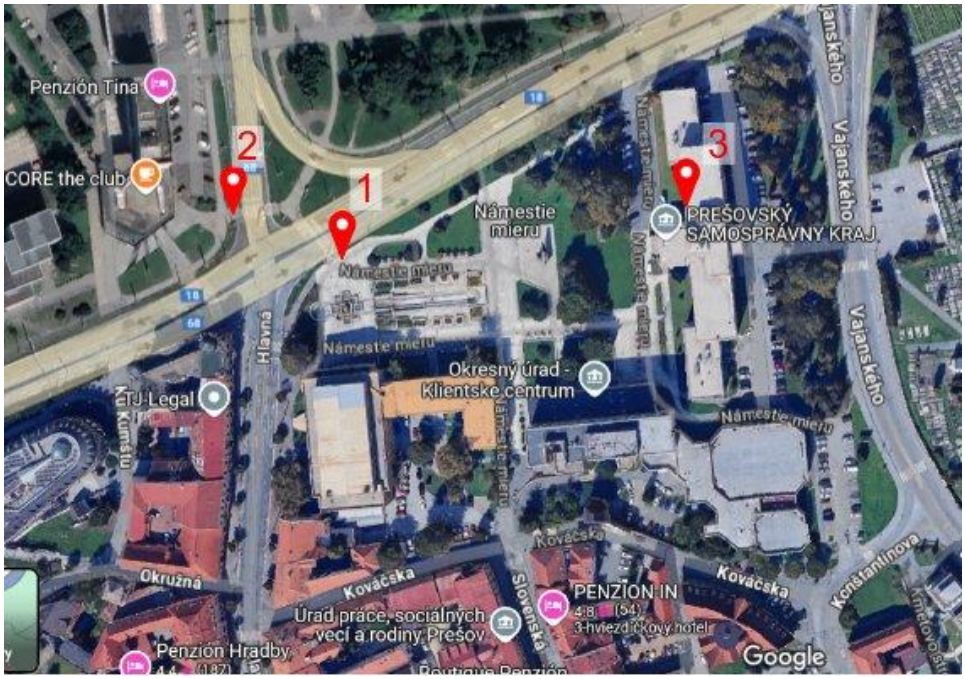
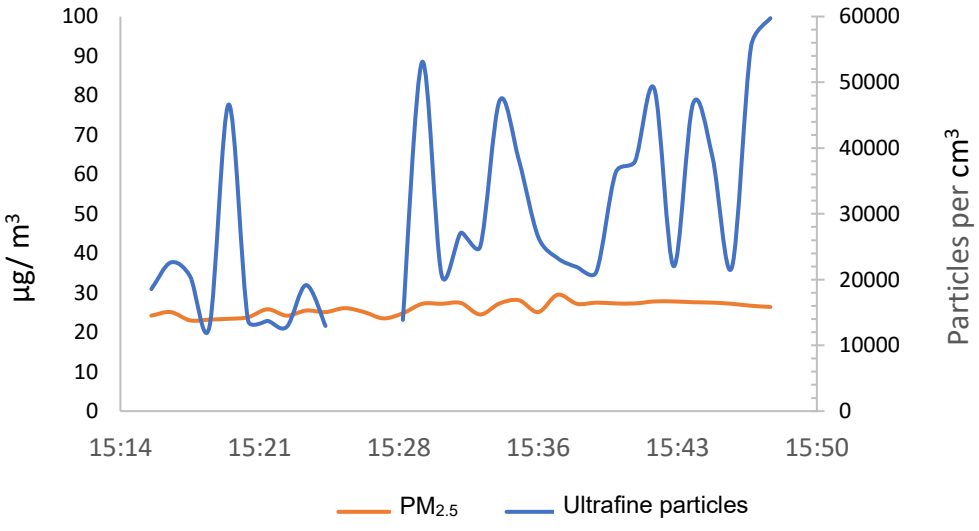
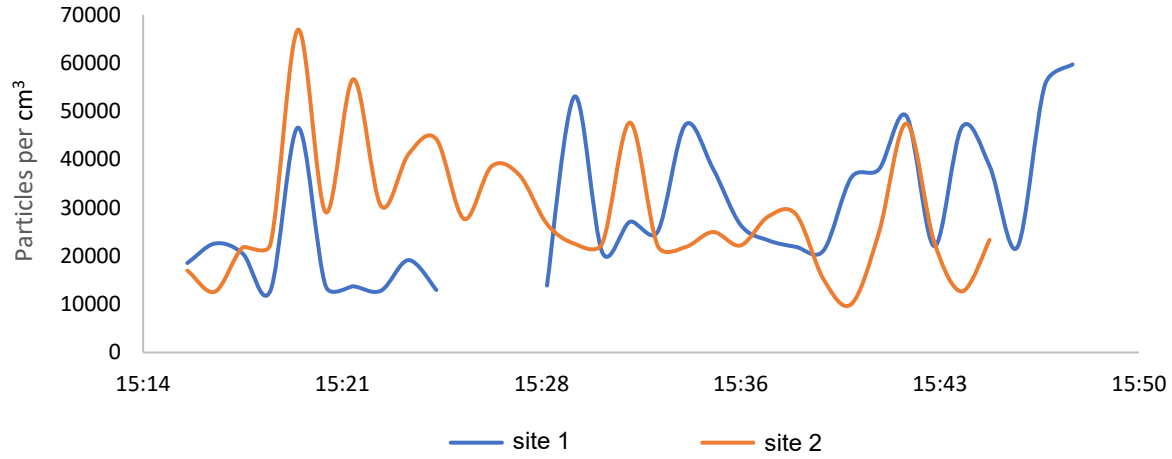


Fig. 20: Comparison of measurements of $PM_{2.5}$ with Aeroqual (µg/m³) and of ultrafine particles with P-Trak (number of particles per cm³) at the same place at site 1, at the busy crossroad in the square of Námestie mieru.



As can be seen from the graph in Fig. 20, ultrafine particles exhibit significant fluctuations due to changes in traffic volumes and different sources of pollution – diesel vehicles without filters are a significant source of ultrafine particles, while $PM_{2.5}$ pollution shows no major fluctuations, remaining at the level of background pollution. This means that ultrafine particles are a more effective indicator than $PM_{2.5}$ for monitoring traffic pollution.

Fig. 21: Parallel measurements of ultrafine particles at sites 1 and 2 near the busy crossroad, Námestie mieru square.



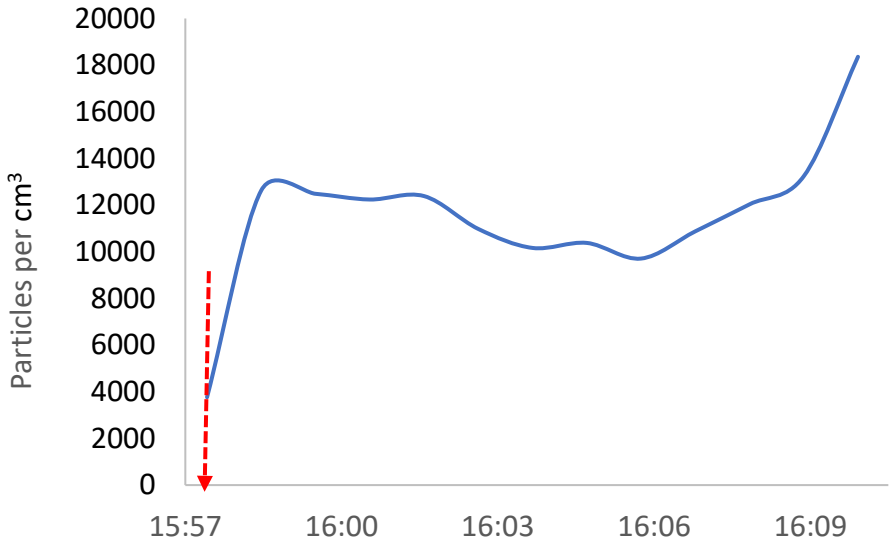
It follows from the graph in Fig. 21 that there are significant differences in pollution fluctuations when comparing one side of the crossroad (site 1) with the other (site 2, Fig. 22) simultaneously. This was expected; however, the level of average pollution for 30 minutes was very similar at both sites:

site 1 (Nám. mieru) – average: 29,310 particles per cm^3

site 2 (Nám. mieru) – average: 28,980 particles per cm^3

Fig. 22: Crossroad Námestie mieru in Prešov. Parallel measurement at site 2, exactly in front of site 1. In the short term, pollution exceeded 200,000 particles per cm^3.

Fig. 23: Measurement of ultrafine particles at site 3 – in the open window of the office on the 3rd floor. The red arrow indicates the time when the window was opened.



In the office (Fig. 23), before the window was opened, the pollution with ultrafine particles was below 4,000 particles per cm^3. After opening the window at 15:57 (red arrow), the pollution increased considerably, due to polluted air from the outside. The measuring device was directly in the window (Fig. 24). The outside air contained 10,000-18,000 particles per cm^3.

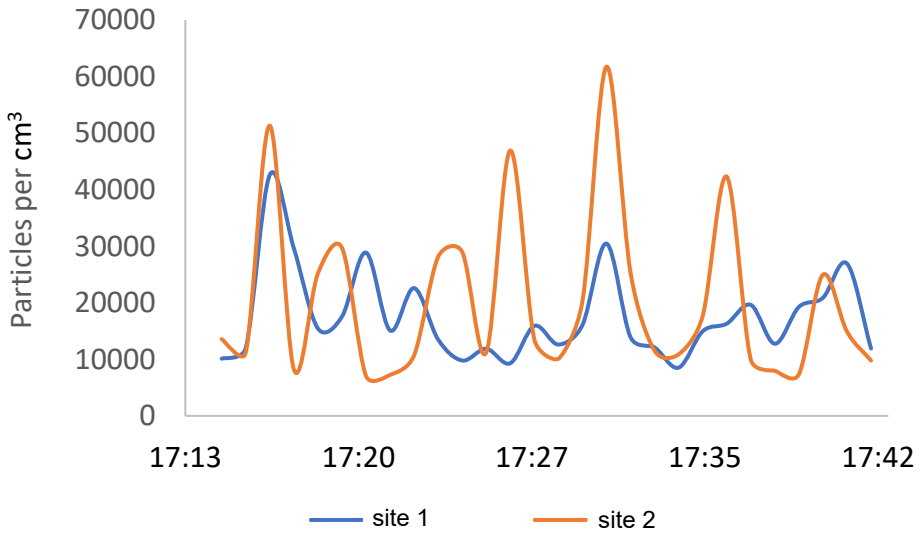
Fig. 24: Measurement of ultrafine particles at site 3 – in the open window of the office on the 3rd floor.

Crossroad 2 - Arm. gen. Svobodu/Pod Táborom

We carried out the measurements during rush hour on Friday evening (17:13 – 17:42), 8 November 2024, near the busy street of Arm. gen. Svobodu, at the crossroad with the street of Pod Táborom. Near the crossroad, there is a monitoring station of the Slovak Hydrometeorological Institute (SHMI). The measurements were taken simultaneously with two P-Trak devices at two different sites (Fig. 25).

Fig. 25: Parallel measurement of ultrafine particles at a crossroad of streets of Arm. gen. Svobodu and of Pod Táborom in Prešov.
Sites:
1 – next to the monitoring station of SHMI
2 – on the other side of the crossroad

Obr. 26: Parallel measurements of ultrafine particles near the crossroad of the street of Arm. gen. Svobodu and the street of Pod Táborom.



It follows from the graph in Fig. 26 that there are significant differences in pollution fluctuations when comparing one side of the crossroad (site 1) to another simultaneously, as expected. However, the average pollution level for 30 minutes was similar at both sites:

site 1 (Arm. gen. Svobodu) – average: 17,520 particles per cm^3

site 2 (Arm. gen. Svobodu) – average: 20,270 particles per cm^3

Fig. 27: Measurement at the crossroad of the streets of Arm. gen. Svobodu and Pod Táborom in Prešov, site 1 - next to the monitoring station of SHMI.

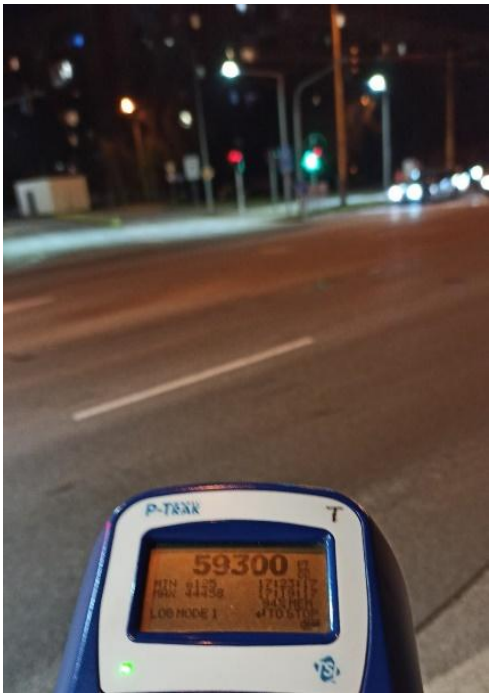


Fig. 28: Measurement at the crossroad of the streets of Arm. gen. Svobodu and Pod Táborom in Prešov, site 2 – on the other side of the crossroad.

Crossroad 3 - Obrancov mieru/Levočská

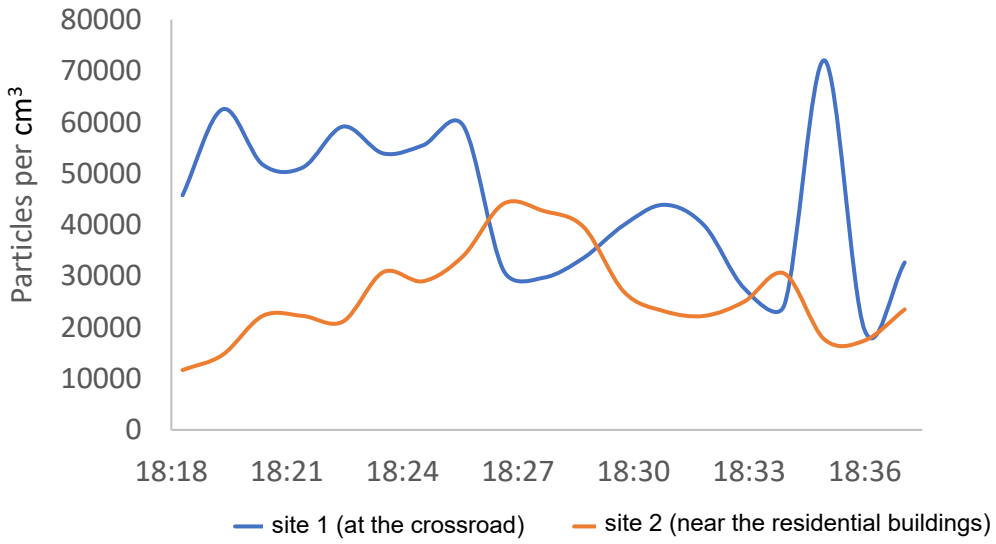
The crossroad of the streets of Obrancov mieru and Levočská belongs to the crossroads of heavy traffic in Prešov, as it relies main roads of the city. Although we took the measurements on Friday evening (8 November 2024, from 18:18 to 18:38), and the traffic intensity was lower, the ultrafine particle pollution was substantial.

At this crossroad, we also carried out parallel measurements at two different sites – one directly at the crossroad and the another approximately 70 m from the crossroad near residential buildings (Fig. 29, 30).

Fig. 29: Parallel measurement of ultrafine particles at the crossroad of the streets of Obrancov mieru and Levočská in Prešov.
Sites:
1 – directly at the crossroad
2 – near the residential buildings

Fig. 30: Measurement at the crossroad of the streets of Obrancov mieru and Levočská, site 2 – near the residential buildings. Site 1 is opposite to site 2, directly at the crossroad.

Fig. 31: Parallel measurements of ultrafine particles at the crossroad of the streets of Obrancov mieru and Levočská.



As expected, pollution from traffic directly at the crossroad (site 1) is significantly higher and more variable than the pollution approximately 70 m from the crossroad near residential

buildings (site 2) – Fig. 31. The increased values at site 2 at 6:27 p.m. were also caused by passers-by who were smoking cigarettes.

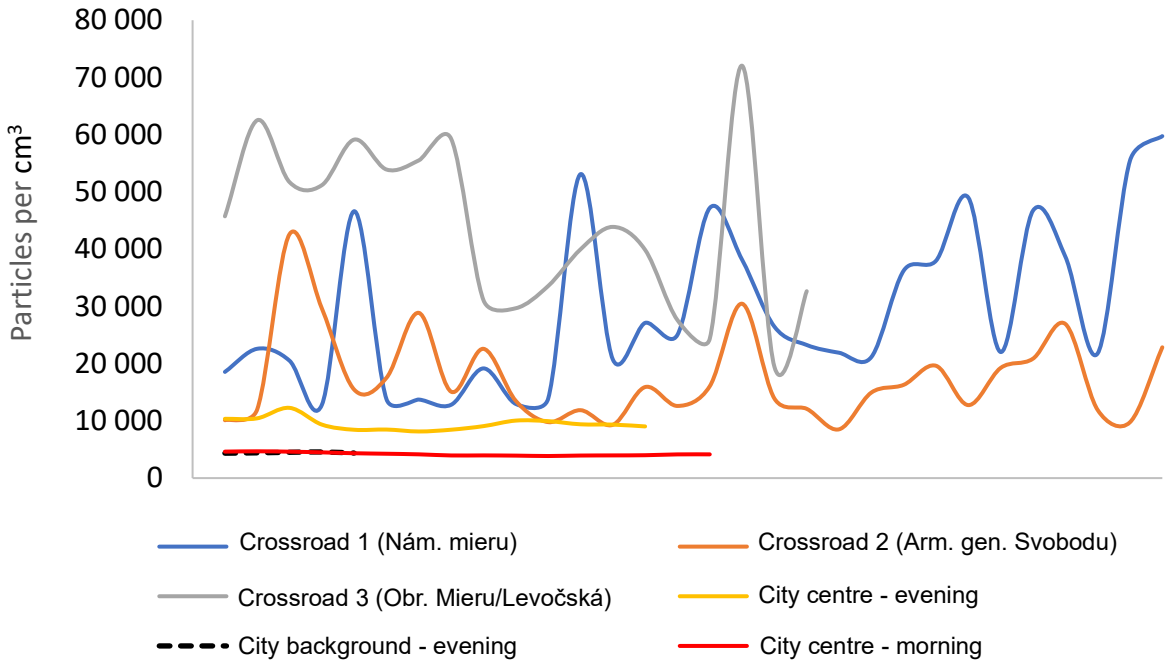
site 1 (near the crossroad) – average: 43,850 particles per cm^3

site 2 (near the residential buildings) – average: 26,230 particles per cm^3

Prešov – mutual comparison of measurements with the city background

There is a comparison of measured values of ultrafine particle concentrations from all six localities in Prešov in the graph in Fig. 32. Average values are in Table 2.

Fig. 32: Mutual comparison of measured results of ultrafine particles from all 6 localities in Prešov.



Tab. 2: Average measured values of air pollution with ultrafine particles in individual localities in Prešov.

No.	Locality	Date of measurement	Average pollution
1	Crossroad 1 - Námestie mieru	8 November 2024	**29,310** particles per cm^3
2	Crossroad 2 - Arm. gen. Svobodu/Pod Táborom	8 November 2024	**17,520** particles per cm^3
3	Crossroad 3 - Obrancov mieru/Levočská	8 November 2024	**43,850** particles per cm^3
4	City centre – Hlavná street (evening measurement)	8 November 2024	**9,490** particles per cm^3
5	City centre – Penzión Hradby (morning measurement)	9 November 2024	**4,200** particles per cm^3
6	City background – outskirts (evening measurement)	8 November 2024	**4,450** particles per cm^3

Fig. 33: Measurement of city background at site 6 in Prešov, on the outskirts of the city - meadow, evening of 8 November 2024.

As can be seen from the graph in Figure 32 and Table 2, all three crossroads show significant fluctuations and a significantly higher level of pollution than localities with no traffic – the city centre (pedestrian zone), city background on the meadow above the city (site 6, Figs. 18 and 33). The values in the city centre measured in the morning of 9 November 2024 (site 5) were very similar to the values measured in the evening of 8 November 2024 in the meadow above the city (city background, site 6, Fig. 33).

According to the WHO, a safe long-term level of ultrafine particle pollution is up to 1,000 particles per cm^3.

It is clearly evident from the measurements that traffic is a significant source of air pollution with ultrafine particles in the city. With increasing distance from busy roads and crossroads, pollution decreases substantially.

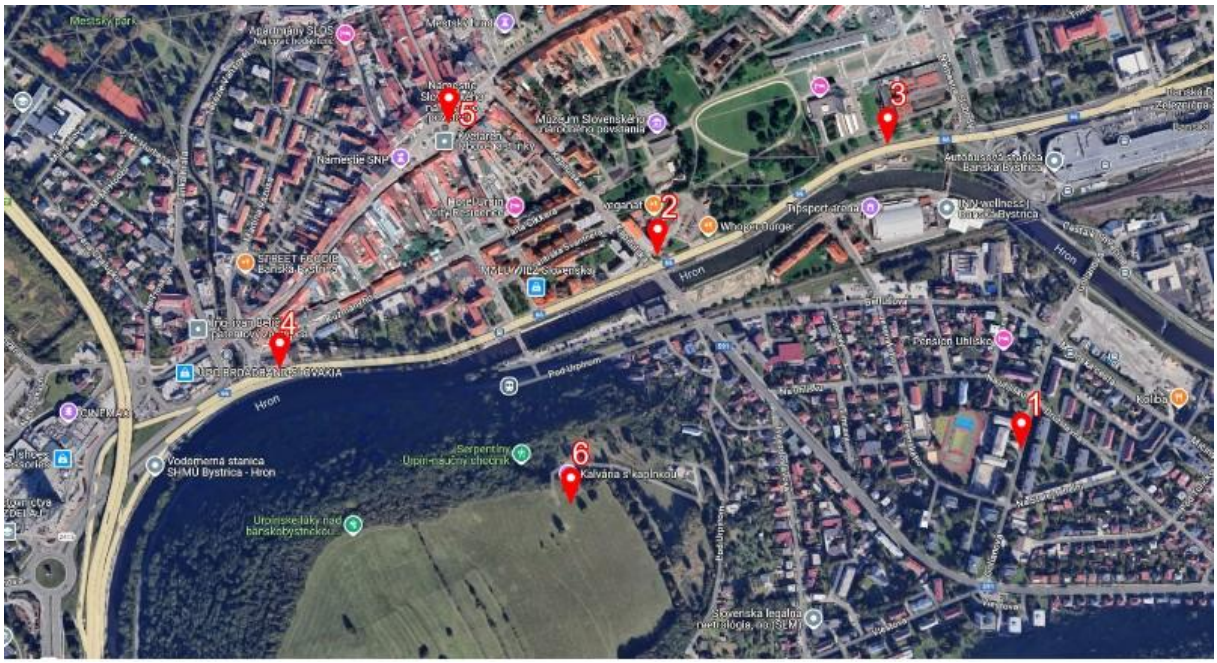
5. Banská Bystrica

From 10 November 2024 to 11 November 2024, we carried out measurements of air pollution with ultrafine particles in Banská Bystrica in the localities listed in Tab. 3 and Fig. 34. We measured pollution in front of the primary school Golianova (the results of measurements are in Chapter 2), at a busy crossroads and by a busy road, at a bus stop. We also measured the urban background both in the central pedestrian zone and on the outskirts of the city.

Tab. 3: Localities of measurement of air pollution with ultrafine particles $PM_{0.1}$ in Banská Bystrica.

No.	Locality	Location
1	Primary school ZŠ Golianova	48°43'50.0"N 19°09'28.8"E
2	Crossroad – Štefánikovo nábrežie/Kapitulská	48°44'00.4"N 19°08'59.5"E
3	Busy street - Štefánikovo nábrežie, AMS	48°44'06.4"N 19°09'18.0"E
4	Bus stop – Štadlerovo nábrežie	48°43'53.7"N 19°08'26.3"E
5	City centre – Nám. SNP (pedestrian zone)	48°44'07.2"N 19°08'42.7"E
6	City background – outskirts (evening measurement)	48°43'47.5"N 19°08'52.4"E

Fig. 34: Localities of measurement of air pollution with ultrafine particles $PM_{0.1}$ in Banská Bystrica.



At the crossroad (2) and at the bus stop (4), parallel measurements were taken simultaneously with two P-Trak instruments at two different heights – at the height of the nose of an adult (at approximately 160 cm tall above the ground) and of a child (at a height of 55 cm above the ground) in order to find out whether the children are exposed to higher concentrations of ultrafine particles than adults, as the child's nose is closer to the exhausts of cars. In some localities, concentrations of fine particles $PM_{2.5}$ were also measured with the Aeroqual device in $\mu g/m^3$.

During the measurements, stable weather inversion prevailed, characterised by clear sky, no wind, or only light wind.

Evening measurement in Banská Bystrica

On Sunday evening, 10 November 2024, we conducted measurements at the busy crossroads of Štefánikovo nábrežie and Kapitulská Street (Fig. 34 - site 2), located in the city centre - Nám. SNP (pedestrian zone, Fig. 34 - site 5, Fig. 36 on the right) and the city background on the outskirts of the city near the Calvary with the chapel (Pod Urpínom Street, Fig. 34 - site 6, Fig. 36 on the left). At the busy crossroads of Štefánikove nábrežie / Kapitulská, parallel measurements were made simultaneously with two P-Trak instruments at two different heights – at the height of the nose of an adult and a child (Fig. 36, in the middle).

Fig. 35: Measurements in Banská Bystrica, Sunday evening (10 November 2024).

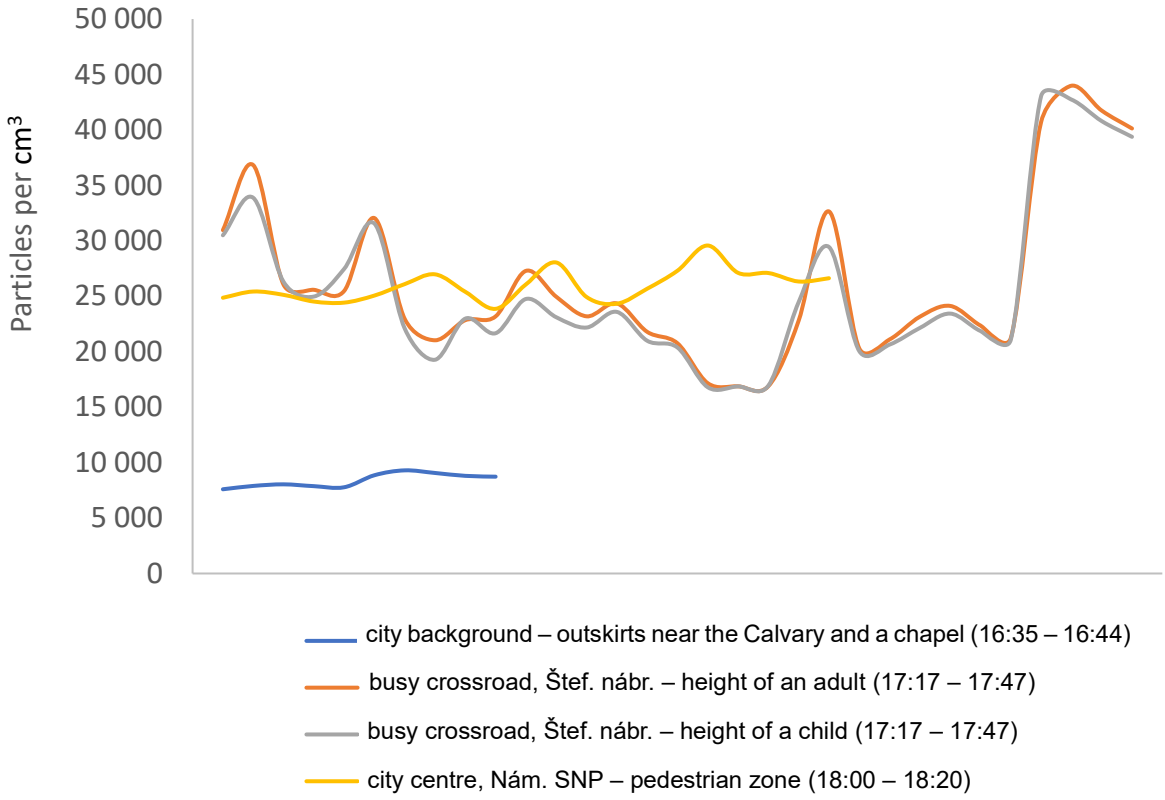
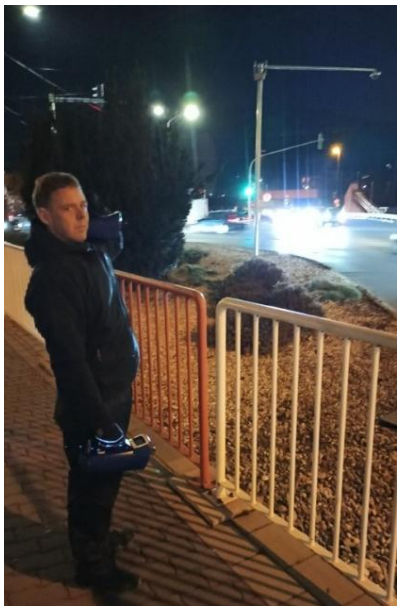
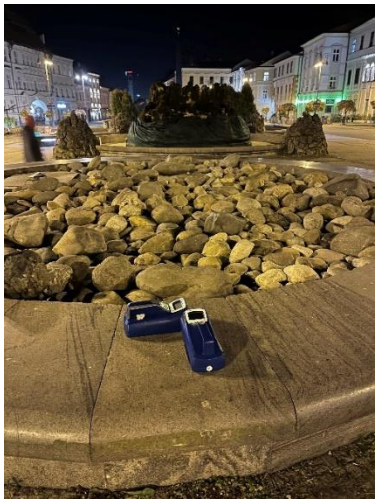


Fig. 36: Measurements in Banská Bystrica on Sunday evening (10 Nov. 2024), from left to right: city background on the outskirts near the Calvary and chapel; busy crossroads of Štefánikovo nábrežie/Kapitulská – devices simultaneously at the height of an adult and the height of a child; city centre (pedestrian zone).





It is obvious from the graph in Fig. 35, that the pollution with ultrafine particles at a busy crossroad at the level of inhalation of a child at 55 cm above the ground (grey curve) and at the level of inhalation of an adult, 160 cm above the ground (red curve) are almost the same, as the pollution is quickly dispersed throughout the nearby street space. The values showed relatively high fluctuations depending on the current traffic density at the crossroad.

The city background on the outskirts of the city near the chapel is significantly lower and the values are stable (blue curve) than the pollution at the crossroad, because there were no sources of pollution nearby (traffic or local fireplaces).

In the city centre, in the pedestrian zone of Námestie SNP square, we measured significantly higher values (yellow curve) than on the outskirts of the city, comparable to those at a busy crossroads with Sunday evening traffic intensity. We assume that this is due to emissions from nearby restaurants, of which there are many in the square. There was a weather inversion, with no wind or only light wind, which prevented the pollution from dispersing.

The average values from measurements are presented in Table 4. The safe level of pollution according to WHO recommendations is up to 1,000 particles per cm^3. Such values can be found in Slovakia in the mountains or further from sources of pollution (combustion processes, such as traffic and heating with solid fuels) when it is windy.

Tab. 4: Average pollution values of the measurements in Banská Bystrica on Sunday evening (10 Nov. 2024).

No.	Locality	Time of measurement	Average pollution
2	Crossroad – Štefánikovo nábrežie/Kapitulská – height of child's inhalation	17:17 – 17:47	25,680 particles/cm^3
2	Crossroad – Štefánikovo nábrežie/Kapitulská – height of adults' inhalation	17:17 – 17:47	26,280 particles/cm^3
5	City centre – Nám. SNP (pedestrian zone)	18:00 – 18:20	25,950 particles/cm^3
6	City background – outskirts near the Calvary and a chapel	16:35 – 16:44	8,390 particles/cm^3
WHO recommendations – safe level of pollution			up to 1,000 particles/cm^3

Morning measurements in Banská Bystrica

On Monday morning, 11 November 2024, after the measurements near the primary school ZŠ Golianova, (Chapter 2), the following measurements were taken near the busy road of Štefánikovo nábrežie, near the automatic monitoring station (AMS) for the air quality monitoring by SHMI (Fig. 34 - site 3, Fig. 38), at the busy crossroad of Štefánikovo nábrežie with Kapitulská street (Fig. 34 - site 2, Fig. 37) during highly intensive morning traffic, and in the city centre – Nám. SNP (pedestrian zone, Fig. 34 - site 5, Fig. 39).

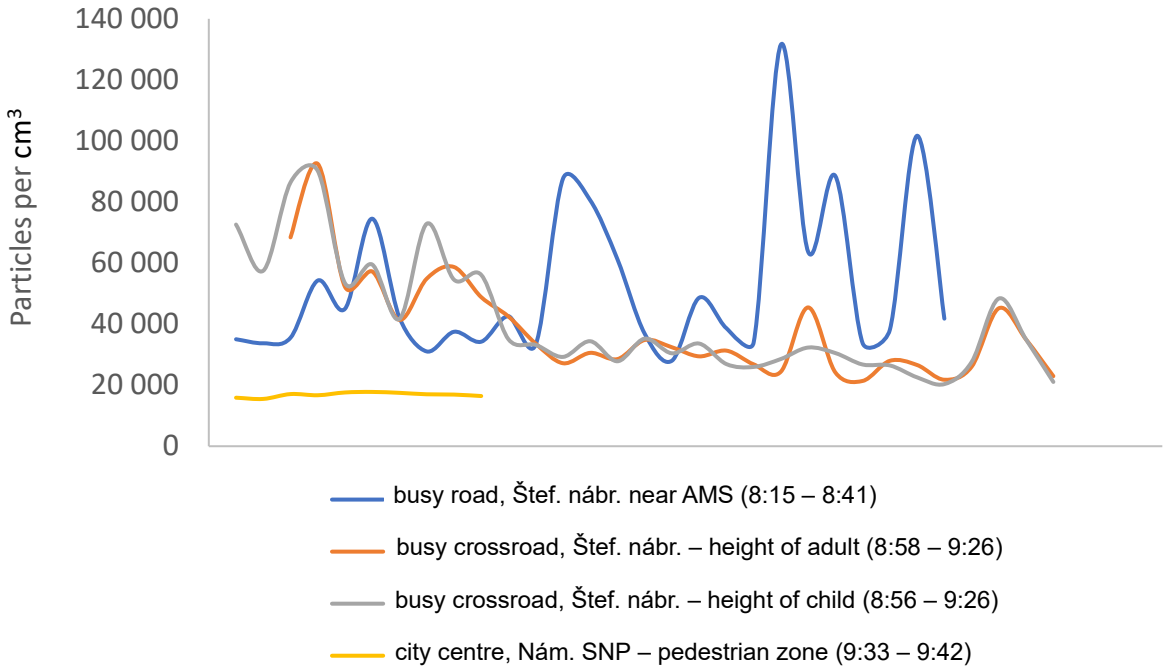
At the busy crossroad of Štefánikovo nábrežie/Kapitulská (Fig. 37), parallel measurements with two P-Trak devices were again conducted simultaneously at two different heights – at a height of the nose of an adult (160 cm) and of a child (55 cm).

Fig. 37: Busy crossroad of Štefánikovo nábrežie/Kapitulská, Monday morning, 11 Nov. 2024. Parallel measurements – device on the shoulder (height of inhalation of an adult) and lower (height of inhalation of a child).

Fig. 38: Ultrafine particles measurement near the busy road of Štefánikovo nábrežie, next to AMS, on Monday morning, 11 November 2024. We were measuring simultaneously with Aeroqual as well.

Fig. 39: Ultrafine particles measurement in the city centre (pedestrian zone) on Monday morning, 11 November 2024. We were also measuring simultaneously with Aeroqual.

Fig. 40: Measurements in Banská Bystrica on Monday morning, 11 November 2024.



Tab. 5: Average values of pollution from measurements in Banská Bystrica, on Monday morning, 11 November 2024.

No.	**Locality**	**Time of measurement**	**Average pollution** (number of particles per cm^3)
2	Crossroad – Štefánikovo nábrežie/Kapitulská st. – height of a child's inhalation	8:56 – 9:26	41,170 particles/cm^3
2	Crossroad – Štefánikovo nábrežie/Kapitulská st. – height of an adult's inhalation	8:58 – 9:26	38,350 particles/cm^3
3	Busy road - Štefánikovo nábrežie near AMS	8:15 – 8:41	52,350 particles/cm^3
5	City centre – Nám. SNP (pedestrian zone)	9:33 – 9:42	16,840 particles/cm^3
WHO recommendations – hourly average, high level of pollution, to be avoided			over 20,000 particles/cm^3

From the graph in Fig. 40 and the average values in Table 5, it can be seen, as we expected, that the pollution with ultrafine particles at a busy crossroad at the height of inhalation of a child at 55 cm above the ground (grey curve) and at the level of inhalation of an adult of 160 cm above the ground (red curve) are almost the same, as the pollution quickly disperses to the nearby street. The values showed relatively large fluctuations depending on the current traffic at the crossroad.

Pollution on the busy road on Štefánikovo nábrežie, near the automatic monitoring station (AMS), exhibited high fluctuations, with minute averages reaching over 80,000 and a peak of more than 120,000 ultrafine particles per cm^3 of air. The average value of the entire measurement also points to high pollution from traffic – above 50,000 particles per cm^3.

In the city centre, in the pedestrian zone of Námestie SNP square (Fig. 39), we measured significantly lower values (yellow curve) than on Sunday evening at the same place (Fig. 35). We assume that this is due to the fact that significantly fewer restaurants are open on Monday mornings.

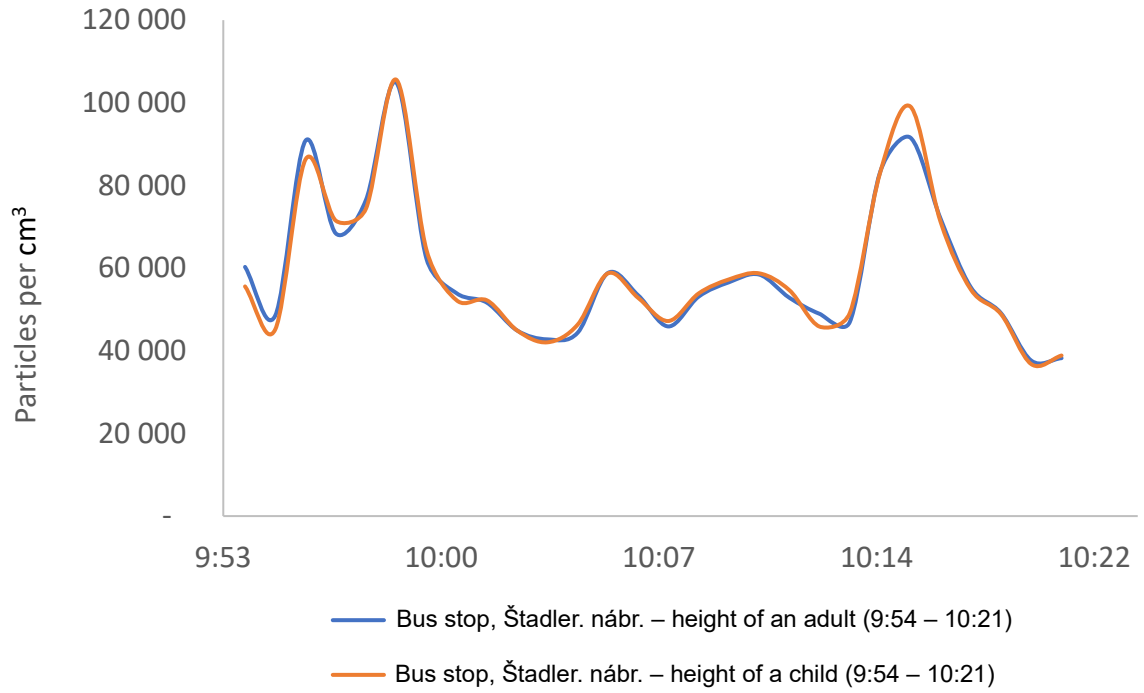
According to WHO recommendations, pollution level of above 20,000 particles per cm^3 (hourly average) is harmful to health and should be avoided by people. Traffic pollution measured at

localities near a busy road (Fig. 34 - sites 2 and 3, Table 5) significantly exceeds this value, although these are only half-hour averages.

Morning measurement at the bus stop

On Monday morning, 11 November 2024, we also measured traffic pollution at the bus stop on Štadlerovo nábrežie (Fig. 34 - site 4), which is on the same busy road as sites 2 and 3 on Štefánikovo nábrežie. The measurements were made in parallel with two P-Trak devices at the same time, at two different levels – at the level of the nose of an adult (160 cm) and a child (55 cm).

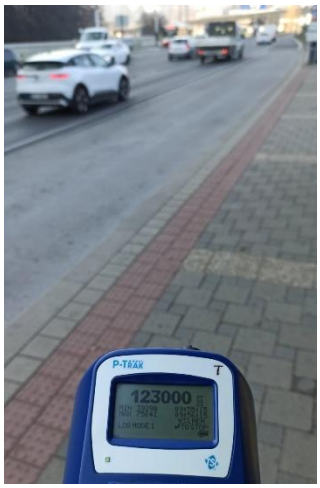
Fig. 41: Parallel measurements at the bus stop on Štadlerovo nábrežie in Banská Bystrica on Monday morning, 11 November 2024.



It follows from the graph in Fig. 41 and from the average values below, as we expected, that the pollution with ultrafine particles at the bus stop on a busy road at the level of inhalation of a child at 55 cm above the ground (red curve) and at the level of inhalation of an adult of 160 cm above the ground (blue curve) are practically exactly the same, as the pollution quickly disperses to the entire nearby area of the street. The values showed relatively large fluctuations depending on the current traffic of the busy road.

bus stop, at the height of a child – average:	58,975 particles per cm^3
bus stop, at the height of an adult – average:	58,982 particles per cm^3

Fig. 42: Measurements at the bus stop, Štadlerovo nábrežie in Banská Bystrica, on Monday morning, 11 Nov. 2024.



The WHO recommends avoiding pollution of above 20,000 particles per cm^3 (hourly average). The values at the stop were almost three times higher, although it was only a half-hour measurement. Passengers waiting at the bus stop are exposed to significant air pollution with ultrafine particles generated by traffic, especially on days with temperature inversions and deteriorated dispersion conditions, as was the case during the measurement.

6. Ultrafine particle emissions from diesel, petrol and LPG cars

We measured the concentration of ultrafine particles in the exhaust fumes of the diesel, petrol, and petrol/LPG passenger cars.

We placed the inlet of the P-Trak within 10 cm of the car exhaust, ensuring that the device captures only the undiluted exhaust fumes of the car and not the surrounding air.

The measurements were carried out for a short time only to make photo documentation, as prolonged exposure to high concentrations of ultrafine particles, close to the instrument's detection limit of 500,000 particles/cm^3, can clog the instrument. Consequently, it must be cleaned.

The measurements were taken in Veľká Ida on 9 November 2024 and also in Zvolen on 11 November 2024.

Comparison of a new diesel car with an older diesel and with a petrol car

We measured the exhaust gases of a new diesel car equipped with a functional diesel particulate filter (DPF) as part of a combustion products cleaning system that meets the Euro 6 emission standard – Škoda Rapid (Fig. 43). We also measured an older diesel car without a DPF (Euro 4 emission standard – Toyota Avensis, Fig. 44) and an older petrol car – Toyota Corolla (Fig. 45). Measurements were carried out in June 2015.

Fig. 43: Measurement of ultrafine particle emissions in exhaust gases of a new diesel car Škoda Rapid with a functional DPF (Euro 6 emission standard), the measured value was 3,330 particles/cm³. Photo on the left, the measurement further from the exhaust - background, approximately 5,000 particles/cm³.

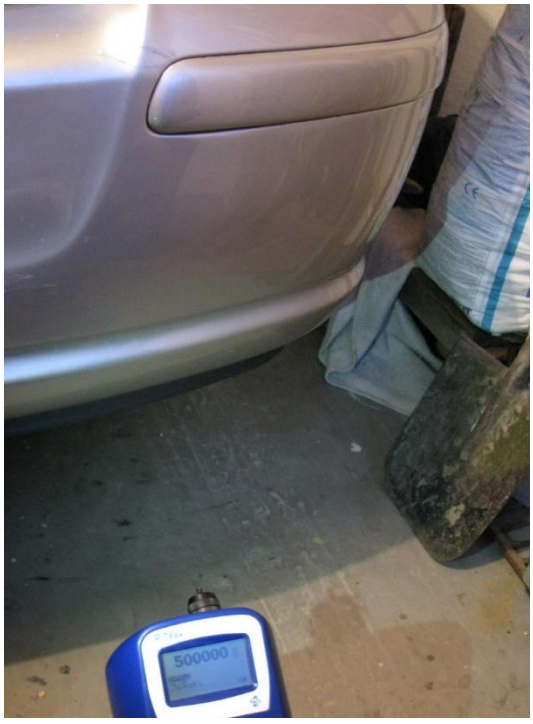


Fig. 44: Older diesel cars with no DPF – Toyota Avensis (Euro 4 emission standard). The instrument displayed an upper limit of detection of 500,000 particles per cm³.

Fig. 45: Older petrol car - Toyota Corolla (Euro 4 emission standard). The instrument displayed a value of 43,100 particles per cm³.

From the measurements in Figs. 43-45, it is clear that new diesel vehicles equipped with a functional DPF meeting the strict Euro 6 emission standards practically do not emit ultrafine particles, and the concentrations measured behind the exhaust are even lower than the background concentrations.

On the other hand, older diesel vehicles (Euro 4 and older emission standards) are an essential source of ultrafine particles, emitting exhaust gases at a concentration of over 500,000 ultrafine particles per cm^3.

Interestingly, older petrol vehicles are a source of ultrafine particles in traffic, but significantly less than older diesel cars.

Comparison of an older diesel car with a newer petrol/LPG car

We measured the exhaust fumes of an older Mazda 6 GH diesel car (Euro 4 emission standard) and a newer Škoda Octavia II petrol car (Euro 5 emission standard), which was retrofitted with LPG and can therefore run on both petrol and LPG. The measurements were taken in Veľká Ida on 09 November 2024 (diesel and LPG, Figs. 46, 47) and in Zvolen on 11 November 2024 (petrol and LPG, Fig. 48).

Fig. 46: Older diesel car Mazda 6 GH (Euro 4 emission standard). Measured values are approaching the upper detection limit of the instrument of 500,000 particles per cm^3. Measured in Veľká Ida on 09 Nov. 2024.

Fig. 47: Newer petrol car Škoda Octavia II retrofitted with LPG. After switching to LPG, the instrument displayed values of approximately 10,000 particles per cm^3, which is consistent with the background (see photo on the right). Measured in Veľká Ida on 09 Nov. 2024.

Fig. 48: Newer petrol car Škoda Octavia II retrofitted with LPG. Photo on the left – motor running on petrol (15,400 particles per cm^3), photo in the middle – motor running on LPG (15,300 particles per cm^3), photo on the right – background (16,000 particles per cm^3). Measured in Zvolen, 11 November 2024.

Measurements in Veľká Ida (Fig. 46) confirmed our previous findings (Fig. 44) that older diesel vehicles with the Euro 4 emission standard and older are a serious source of ultrafine particles. By contrast, newer petrol vehicles (Fig. 48 on the left) are not a relevant source of ultrafine particles, as the concentrations were practically the same as the background (Fig. 48 on the right).

Similarly, measurements in Veľká Ida and Zvolen confirmed that the LPG vehicle is not a source of ultrafine particles, as the concentrations measured behind the exhaust were identical to the background concentrations (Figs. 47, 48).

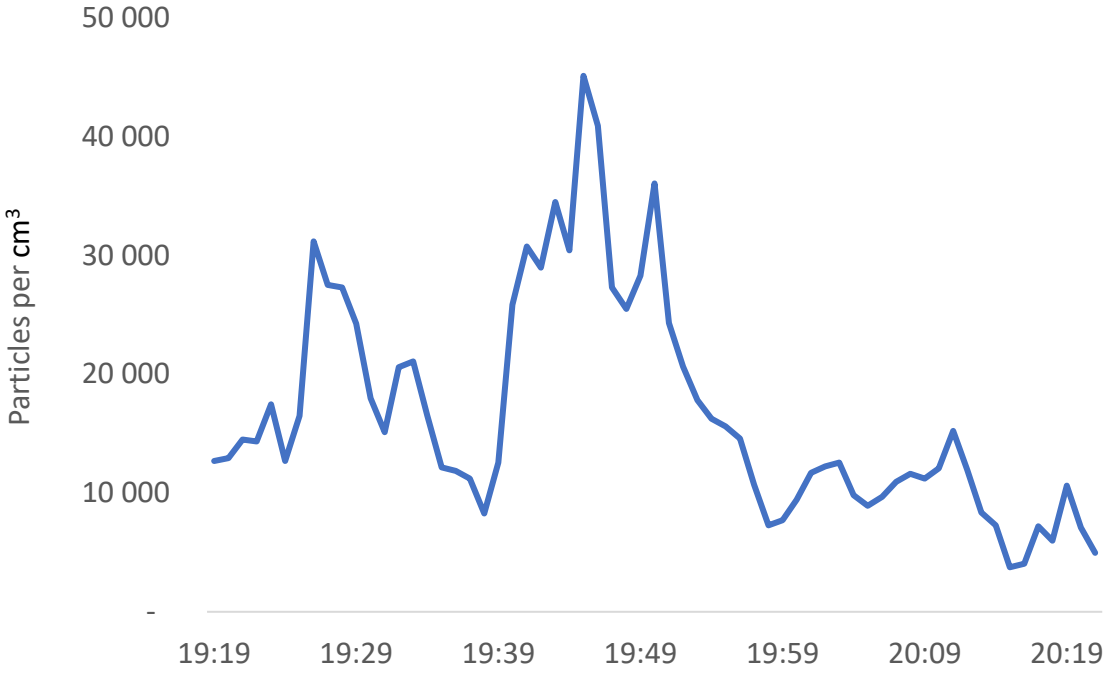
7. Concentration of ultrafine particles in a car interior

The passengers in a car are exposed to increased concentrations of ultrafine particles from the outside if this environment is polluted, the car ventilation is switched on, and the outside air is drawn into the car interior. This is because ultrafine particles are too small to be removed by the car's pollen or dust filters.

The aim of the measurements was to reiterate this fact, which is evident from several previous measurements (e.g. in September 2022), and to document it.

We measured ultrafine particle pollution on the road from Podbrezová to Banská Štiavnica on Saturday, 09 November 2024, in the evening (19:20 – 20:20) in the car interior with the ventilation constantly on, which draws air from the space in front of the car, at ventilation intensity at level 2 out of 4. We were driving from Podbrezová to Banská Bystrica on the first-class road No. 66, then on the R1 and from Hronská Breznica to Banská Štiavnica on the first-class road No. 51. The measured values are in the graph in Fig. 49. The weather was stable, and weather inversion occurred, as during all the measurements from 7 November to 12 November 2024.

Fig. 49: Pollution with ultrafine particles in a car interior, travelling from Podbrezová to Banská Štiavnica, on Saturday evening, 9 November 2024.



The graph in Fig. 49 confirms that the passengers in the car are exposed to high concentrations of ultrafine particles when the surrounding air is polluted. In this case, it is a mixture of the two most important sources of pollution. On the one hand, these are old diesel vehicles that are part of the traffic, especially if the diesel vehicle is equipped with a non-functional DPF filter directly in front of the car. The second significant source of pollution is local fireplaces and solid fuel heating, as it was Saturday evening, people were at home and using their heating. Additionally, the inversion and cold weather conditions made it impossible to disperse the emissions, and smoke accumulated in the valley. The first-class road No. 66 from Podbrezová to Banská Bystrica passes through several smaller villages, or next to them, where the main source of heating is the combustion of wood and solid fuels. On Saturday evening, the traffic intensity was lower, and the pollution from the heating was also evidenced by the characteristic smell in the interior of the car, which is also detected by the first major peak on the graph between 19:20 and 19:39.

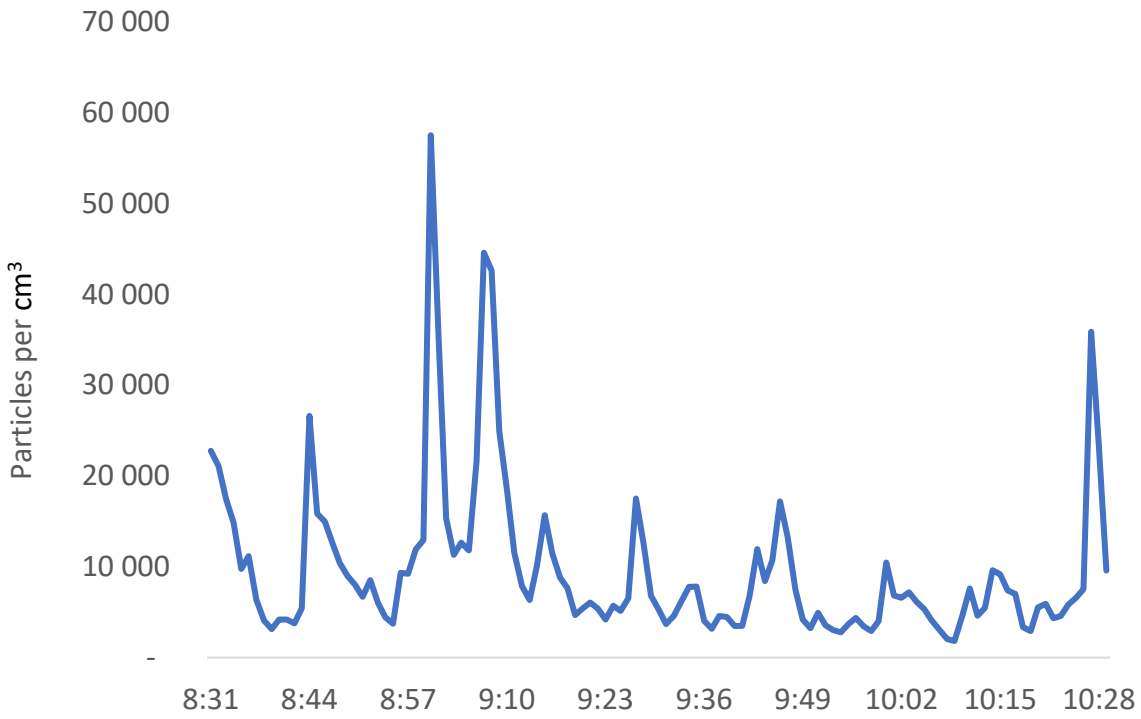
The big peak between 19:39 and 19:59 represents driving on the R1 through Banská Bystrica to Hronská Breznica. Here, a significant factor of pollution is the higher traffic density on the highway, but emissions from local heating in municipalities along the road also play a role.

The pollution measured while driving on the first-class road No. 51 from Hronská Breznica to Banská Štiavnica was not affected by traffic, but by local heating in the villages of Kozelník and Banská Belá. It is represented by smaller peaks from 19:59 to 20:19.

We took another measurement on the way from Banská Štiavnica to the village of Rovinka (near Bratislava) in the morning of 12 November 2024. We began measuring inside the car after leaving the town of Banská Štiavnica (part of Šobov) on the way to Žarnovica. The measurement took place with the ventilation constantly on, drawing air from the area in front of the car, with the ventilation intensity of 2 out of 4. Firstly, we were driving on the second-class road No. 2530 to Žarnovica, then along the R1, where we joined the D1 near Trnava. At the Triblavina exit, we turned from the D1 onto the first-class road No. 61, next to Ivanka pri Dunaji. We then proceeded to the D4, which took us to the village of Rovinka.

The measured values from the entire, almost two-hour journey are displayed in the graph in Fig. 50. The weather was stable, similar to that during previous measurements.

Fig. 50: Pollution with ultrafine particles in a car interior, travelling from Banská Štiavnica to Rovinka (near Bratislava) on Tuesday morning, 12 November 2024.



From the graph in Fig. 50, it is evident that the pollution with ultrafine particles in the car interior fluctuated considerably during driving, reaching relatively high values occasionally, depending on the surrounding air pollution.

The initial high values above 20,000 particles per cm^3 are caused by emissions from local fireplaces in the part of Šobov (outskirts of Banská Štiavnica). This was followed by a forest area extending as far as the village of Hodruša – Hámre, which lacked any sources of pollution (Fig. 51), resulting in a significant improvement of air quality in the car to a background level of approximately 3,000 particles per cm^3.

The peak between 8:44 and 8:57 represents the passage through the village of Hodruša – Hámre and is caused by the heating of houses in the village. Due to the weather inversion, the

smoke was kept in a relatively narrow and unventilated valley, as evidenced by the characteristic smell of smoke in the car.

Other peaks from 8:57 are exclusively caused by traffic on the R1 highway, D1 motorway, first-class road No. 61 and D4 motorway, as these roads lead relatively far from settlements and the impact of solid fuel heating is minimal. As can be seen from the graph, pollution from traffic exceeded 40,000 particles per cm^3 for a few minutes. Minute averages are used in the graph, so the second-by-second measurements were certainly even higher. Figures 52 and 53 demonstrate that the type of car in front of the measured car is crucial. If it is an older diesel car without a diesel particulate filter, the values in the car interior are high (Fig. 52), if it is a newer diesel car, the pollution is at the background level (Fig. 53).

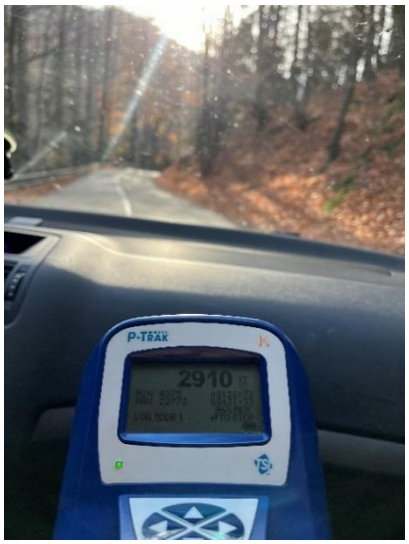


Fig. 51: Road through the forests, ahead of Hodruša. The instrument displays 2,910 particles per cm^3.

Fig. 52: Highway R1, there is an older diesel car in front of us. The instrument displays 15,900 particles per cm^3.

Fig. 53: Road Nr. 61, there is a truck equipped with DPF in front of us. The value is 2,940 particles per cm^3.

8. Conclusion

Our measurements revealed that increased traffic intensity leads to increased air pollution with harmful ultrafine particles. However, not every car contributes equally to traffic pollution.

New cars that meet the Euro 5 emission standard, as well as those equipped with a fully functional exhaust gas cleaning system, especially a DPF, do not pose a major problem for air pollution.

Air quality is fundamentally deteriorated by cars with the Euro 4 emission standard and older. Especially old diesel vehicles that are not equipped with a functional DPF are a significant source of harmful ultrafine particles.

According to WHO recommendations, a safe level of pollution is up to 1,000 ultrafine particles/cm^3 of air. During our measurements, from 7 November to 12 November 2024, we did not reach this average value anywhere, and we only came close to it at Čertovica mountain pass (at site 1), which was not affected by emissions from traffic or from local heating with solid fuels (Chapter 3, pp. 7 – 8). During the inversion weather that persisted during the measurements, the background values in the cities were also high above the safe level of pollution.

On the contrary, the level of pollution of above 20,000 ultrafine particles/cm^3 of air, which the WHO considers harmful to health as an hourly average and is recommended to be avoided, was exceeded for a short time in several locations affected by intensive traffic (Prešov, Banská

Bystrica, pollution in the car interior). In Banská Bystrica, the half-hour averages at the bus stop were almost three times higher (Chapter 5, p. 24-25).

If older diesel vehicles (Euro 4 emission standard and older) and vehicles with malfunctioning DPF could be removed from traffic, the air in our cities, along busy roads and in car interiors would be much cleaner and healthier.