Assessing the Impact of Emissions from Zürich Airport on Ultrafine Particles and Volatile Organic Compounds in a nearby Residential Area

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Civil aviation and airports are major urban sources of Ultrafine Particles (UFPs) and Volatile Organic Compounds (VOCs)[1]. UFPs are a concern because their small size (<100 nm) allows deep lung penetration and associated health risks. The aviation emission profile from the USA's Environmental Protection Agency includes 15 hazardous VOCs of which many are carcinogenic Polycyclic Aromatic Hydrocarbons (PAHs)[2]. VOCs can act as precursors to secondary organic aerosols and low-volatility VOCs can condense on particles, altering their properties. To characterize UFPs and VOCs emissions from aviation, two intensive one-month measurement campaigns of gaseous and particulate matter were performed in November 2022 and August 2024, 1 km downwind of Zürich Airport. The results indicate that high UFP number concentrations up to 300 000 cm^{-3} originate solely from aircraft operations, as shown by the similar diurnal profiles between air traffic movements and UFPs concentrations in Fig. 1a. These emissions are either advected downwind of the airport or mixed downward during aircraft landing overpasses. Using Positive Matrix Factorisation (PMF) on the VOCUS Proton Transfer Reaction Mass Spectrometer (PTR-MS) data, a factor containing naphthalene species and several alkanes with m/z > 100 (Fig. 1 c) has been attributed to VOCs aviation-related emissions. This is further supported by the co-increase of its time series with UFPs temporal evolution (Fig 1.b). However, when the site is not downwind and under the influence of landing overpasses, only UFPs concentrations increased, rather than the VOCs aviation-related factor (Fig. 1a), highlighting landing overpasses as a major source of UFPs but not of VOCs. This contrast likely results from lower engine thrust during taxiing at the airport than during landing overpass, which produces more VOCs due to reduced combustion efficiency[3]. At this stage, we cannot exclude a contribution of VOC emissions from engine refuelling. Future work will investigate the formation and evolution of VOCs in aviation plumes and their potential role in UFPs formation and growth. The widespread presence of UFPs and the co-emission of VOCs poses health concerns for communities near airports that should be addressed.

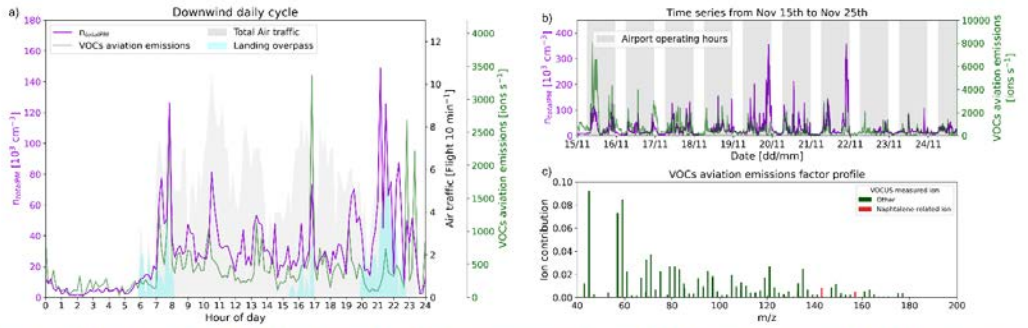

Figure 1: a) Diurnal cycle of air traffic at Zürich airport, UFPs number concentration $n_{totalPM}$, and VOCs aviation emissions when the measurement site was downwind of the airport during the fall 2022 measurement campaign and b) 10-days time series of the same variables. c) Factor profile of the VOCs aviation emissions determined by a source apportionment of PTR-MS data.

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Ultrafine particle characterization in the near-road environment: association with traffic composition using high time-resolution traffic counts

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Traffic related air pollution (TRAP) is a dominant source of ultra fine particles (UFP) and Black Carbon (BC), especially in densely populated urban areas. Due to the rapid introduction of low- and zero-exhaust emission vehicles around the world, the aerosol particles in the near-road environment are evolving rapidly. The city of Bogotá, in Colombia, which still faces serious air pollution levels, has recently adopted cleaner public policies aiming at improving air quality. Among these efforts, the city has included over 1400 battery electric public transport buses (about 11% of the total), as well as a similar number of CNG public transport buses that had replaced older pre-EURO diesel-power buses. In this work, we report on the characterization of the near-road aerosol particles in a 22 km stretch of a main road where many older buses have been replaced by EV and CNG public transport buses. The main objective is to quantify observable transformation of the near-road exposure to UFP and BC under the recent investments in cleaner transport alternatives. The measurements were carried out from August to November of 2023, both at static sites (on 9 bus stops along the study road) as well as by pedestrians carrying portable monitoring devices. The instrumentation deployed at the bus-stops included devices for determining aerosol size distribution and particle number concentrations (from 10 nm to 10 μm), as well as BC and $PM_{2.5}$. Size distributions were measured with a radial DMA (TSI model 3910) and an optical particle sizer for larger particles (TSI model 3330). Mobile measurements of UFP were carried out with hand-held condensation particle counters (TSI model 3007) and portable aethalometers for BC (AethLabs, model AE51). Overall, we collected personal exposure measurements for pedestrians and cyclists over hundreds of kilometers traveling along the main road. During the sampling period, we also registered traffic counts at 10-second resolution, by analyzing video recordings collocated with real-time particle measurements. Categories for motorcycles, light-duty vehicles, SUVs, and different types of public transport buses (either CNG, EV, or diesel-powered) were also recorded. The geometry of the road was carefully determined to establish an "urban canyon" index. The results of this observational study demonstrated high concentrations at bus-stops, with mean BC concentration of 15.6 $\mu g/m^3$ and UFP number concentration of 64,800 part/cm^3 throughout the campaign. For individual days, UFP reached mean values of over 106,000 part/cm^3. Similarly high values were observed for pedestrians walking with portable instruments, for whom the average personal exposure concentration was 19.8 $\mu g/m^3$ of BC and 60,400 part /cm^3 for UFP. For the analysis, the concentration time-series were decomposed in a slow- and a rapid-varying component. We found a strong association between the fast-varying aerosol field and traffic volume, while the slow-varying part was closely associated with background concentrations and street geometry. Furthermore, our data suggests that the frequency of high BC concentration events can be fully explained by the prevalence of high-emitting diesel vehicles of all types. These events, however, only explain a minor fraction of the observed BC concentration, suggesting that motorcycles and light-duty vehicles are significant sources of BC and UFP in this road. Our measurements clearly show that the efforts to modernize the public transport fleet are still far from enough to achieve an effective reduction in UFP and BC concentrations, particularly in the near road environment. Future studies should analyze the contribution from motorcycles to the near-road aerosol fields, as their use has increased dramatically in the city, which can negate the potential benefits of investing in cleaner public transport alternatives.

Measuring Urban Aerosol Volatility Fractions with a Catalytic Stripper at anACTRIS Aerosol Observatory: Characterization and Implementation

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Aerosol particles play a central role in atmospheric processes, influencing air quality, human health, and climate. To fully understand these impacts, it is essential to quantify not only the physical properties such as concentration or size but also their chemical composition. Offline chemical analysis of aerosol samples or online mass spectrometry are generally complicated or expensive. Another efficient method is to determine the partitioning between the volatile and non-volatile fractions. This information provides insight into the chemical composition of an air mass and allows to infer information about aerosol sources, chemical aging, and transformation processes in the atmosphere [e.g. 1, 2, 3, 4].

A catalytic stripper (CS) is commonly used to separate the volatile and semi-volatile fraction from the solid aerosol particles, which allows for precise measurement of the non-volatile fraction and the total aerosol load [5]. Compared to a thermal denuder, it has the advantage that volatile substances undergo catalytic transformation and cannot recondense into particles after treatment. The CS has successfully been used in many automotive applications such as Particle Measurement Program (PMP) compliant studies [5, 6]. However, not many atmospheric aerosol studies apply this simple distinction between volatile and solid particles, which plays an important factor for the investigation of air quality, human health and climate impact of aerosols.

Here we present the application of a CS for measurements of non-volatile aerosol particles at the Aerosol Observatory of the University of Vienna which is on track to become a National Facility for aerosol in-situ observations within the pan-European Aerosol, Clouds, and Trace Gas Research Infrastructure ACTRIS. This study includes the characterization of the CS with respect to particle penetration and removal efficiency of volatile and semi-volatile components. For particle penetration silver particles were generated with the Silver Particle Generator (SPG) and treated by the Sintering Stage S8000 to obtain thermally stable silver spheres in the size range between 2 nm and 100 nm. The characterization of the removal efficiency of volatile and semi-volatile particles is done with tetracontane, which is a well-established method in many regulations for the testing of volatile particle removal (VPR) systems in the automotive section (e.g. Euro-7).

The aim of this study is to present initial results from continuous measurements of the non-volatile aerosol fraction over several weeks at the Aerosol Observatory in Vienna, demonstrating their potential for source identification and chemical characterization, and highlighting the importance of non-volatile particle measurements.

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A comprehensive characterization of particles emitted by Internal Combustion Engines using different sampling and analytical techniques.

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Internal Combustion Engines (ICEs) emit micrometric and nanometric particulate matter, which contributes to air pollution and global warming and poses a threat to human health. Technological advances in the combustion process and the introduction of suited particulate filters have considerably reduced, in the last couple of decades, the amount of such particles released in the environment. These advances are certainly encouraging and reassuring. However, a deeper comprehension of the particulate physics and chemistry, at both micrometric and nanometric scales, would greatly help understanding its behaviour both inside the vehicles after-treatment systems (ATSs) and once released in the atmosphere. The present work is aimed at such extensive knowledge of the ICE-emitted particulate behaviour, exploiting several sampling techniques and analytical methodologies such as Transmission Electron Microscopy (TEM), Energy-Dispersive X-Ray (EDX) analysis, Single-Particle Extinction and Scattering (SPES) and Raman micro-spectroscopy to investigate the properties of particles collected at various stages of ICE and ATSs.

Samples were obtained following the guidelines outlined in the European Commission Regulation 1151 (2017) during chassis-dyno driving tests performed under standardized type-approval conditions on various modern diesel- and gasoline-fuelled vehicles. The particulate samples were collected from the engine out, raw and diluted tailpipe exhaust.

A TEM sampler was used to collect samples on carbon-coated copper grids dedicated to TEM and EDX analyses. A MICRO-PSS (Portable Particulate Sampling System) and the PSS on the dilution tunnel of a Constant Volume Sampler (CVS) system were employed for the collection of particles on Quartz-fibre and PTFE-coated glass-fibre filters, to be later investigated by means of Raman micro-spectroscopy. Aliquots extracted from selected filter samples were analysed with SPES. An innovative approach was also explored: single particles identified with Raman were isolated and extracted from the filters, then deposited on TEM grids to perform a correlative TEM analysis.

The results obtained at this stage of analysis show that soot and particulate emitted at the engine-out stage essentially consist of black carbon. However, other types of particles can be detected downstream the ATS, and at different stages of the emission analysis system. For instance, the formation of elongated carbon structures similar to agglomerates of nanorods has been observed by TEM at the vehicle raw tailpipe (after the particulate filter and before the CVS dilution system). CVS-diluted samples, instead, contained, as expected, much fewer particles, essentially consisting of black carbon again. The presented methodology highlights the advantages of combining several techniques to understand the dynamics and reactions of the ICE exhaust in the vehicle and sampling systems. In addition, it paves the way to extensive correlative analyses to be performed with multiple methods (e.g. TEM and Raman) on the same sample to obtain a comprehensive particulate characterization that could be extended to the study of non-exhaust particles such as those from tyre and brake wear.

Field Study On The Abatement Effect Of Particles In Engine Exhaust Of Excavator Equipped With DOC And DPF

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This study investigated the particulate control efficiency in the engine exhaust of a diesel-powered excavator equipped with a DOC+DPF filtration system under operating modes at a construction site. The excavator has an engine displacement of 5,860 cm3 with a rated power of 110 kW, which has been in service for 15 years. A DOC+DPF aftertreatment system for engine exhaust was employed for 4 years, with both components utilizing cordierite ceramic substrates. The catalytic coating materials include platinum and palladium. The porosity of DOC and DPF are 57% and 37 %, and the mean size of pores is 10~12um and 5~7um, respectively. The filtration system has a cumulative operating time of 220 hours. The diesel fuel used had a sulfur content of 1.4 mg/kg, polycyclic aromatic hydrocarbons (PAHs) at 1.4%, and a cetane number of 53.0. Particle number (PN) concentrations were measured using an optical particle counter paired with a calibration system, which could make real-time measurements through direct exhaust sampling and a dilution device. Particle number concentrations were measured by a TSI DustTrak 8533 monitor. Gaseous pollutants, including CO, NO, and NO2, were detected by using an electrochemical analyzer. Mass concentration of particles was derived by filter samples, which were collected by manual operation following an isokinetic sampling protocol and analyzed in the laboratory. All measurements were conducted under both idling and operating modes of the excavator. The results of the idle mode test indicate that the average PM2.5 concentration in the engine exhaust without control by DOC+DPF was 5.98 mg/m³. The average concentration decreased to 0.68 mg/m³ with control devices. The control efficiency of PM2.5 was approximately 89%. The average PN concentration was 1.96 × 106 #/cm³ and 2.38× 102#/cm³, with and without control by DOC+DPF, respectively. CO concentrations were 212ppm and 94ppm. The results under excavator operating conditions indicated that the concentration in engine exhaust without DOC+DPF treatment was 190 ppm for CO, 7.53 × 106 #/cm³ for PN, and 22.7 mg/m3 for PM. The concentration in engine exhaust with DOC+DPF treatment was 6 ppm for CO, 9.36 × 102 #/cm3 for PN, and 0.03 mg/m3 for PM, respectively. Overall, the field measurement results demonstrate that installing a DOC+DPF system on a diesel-powered excavator could significantly reduce emissions of particles and CO in the engine exhaust, respectively.

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Roadside Optical Vehicle Emissions Reporter (ROVER) III Project: Evidence of exhaust tampering in Alberta, Canada

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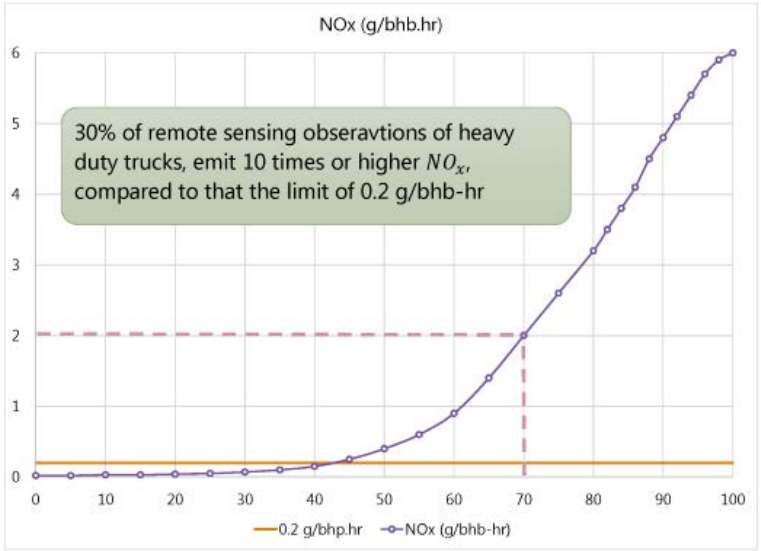
The ROVER III project (2020–2022) used the on-road remote sensing technology to characterize real-world emissions from light-duty gasoline vehicles (LDGVs) and heavy-duty diesel vehicles (HDDVs) across multiple urban centres in Alberta, Canada. Motivated by evidence that a small fraction of vehicles disproportionately contributes to fleet-wide emissions, ROVER III evaluated emission skewness, the prevalence of high emitters, and the in-use performance of modern emission control systems. For LDGVs, vehicles less than 10 years old accounted for more than half of excess HC emissions, suggesting premature deterioration of emission control systems and/or delayed maintenance responses. Light-duty gasoline trucks, particularly pickup trucks, were identified as dominant contributors to HC and NO emissions, with pronounced spatial variability across cities.

For HDDVs, emissions distributions were less skewed but showed widespread exceedances of NOx and particulate matter benchmarks. Approximately 30% of model year 2010 and newer HDDVs exhibited persistently elevated NOx emissions, consistent with malfunctioning or tampered selective catalytic reduction and particulate filtration systems. Among tractor trucks, 38% of model year 2010 -2015 vehicles showed evidence of malfunction or tampering and, despite representing less than one quarter of the fleet, accounted for nearly half of total tractor-truck NOx emissions. Projections indicate that by 2035, such vehicles could increase total NOx emissions by 145% relative to a fully compliant fleet, up to 2.75 times higher than previously forecast. The associated public health burden is estimated at CA$5.4 billion in damages between 2024 and 2035.



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Particle number emissions from a Turbulent Jet Ignition engine fueled with hydrogen and ammonia

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Objective of the study was analysis of H_2, NO_x, and particle number emissions using a TJI system under passive and active pre-chamber conditions. Static operating conditions (AVL 5804, 1-cyl; n = 1400 rpm; IMEP = 3.77 bar) were applied for the analysis, covering both passive and active pre-chamber operation (Fig. 1a) with respect to gaseous components and particulate emissions. Hydrogen combustion and combustion of its mixture with a small ammonia fraction result in different concentrations of gaseous species. Combustion of pure hydrogen (Fig. 1b) produces low NO concentrations, ranging from about 30 ppm to over 300 ppm at higher λ values, associated with lean charge combustion. In contrast, a small ammonia share (5%) leads to more than a tenfold increase in NO_x emissions, resulting from the fuel-NO formation mechanism described by the Zeldovich model. Analysis of unburned hydrogen (Fig. 1b) indicates higher values under significantly leaner combustion conditions. In this case, the use of hydrogen or ammonia does not result in significant differences.

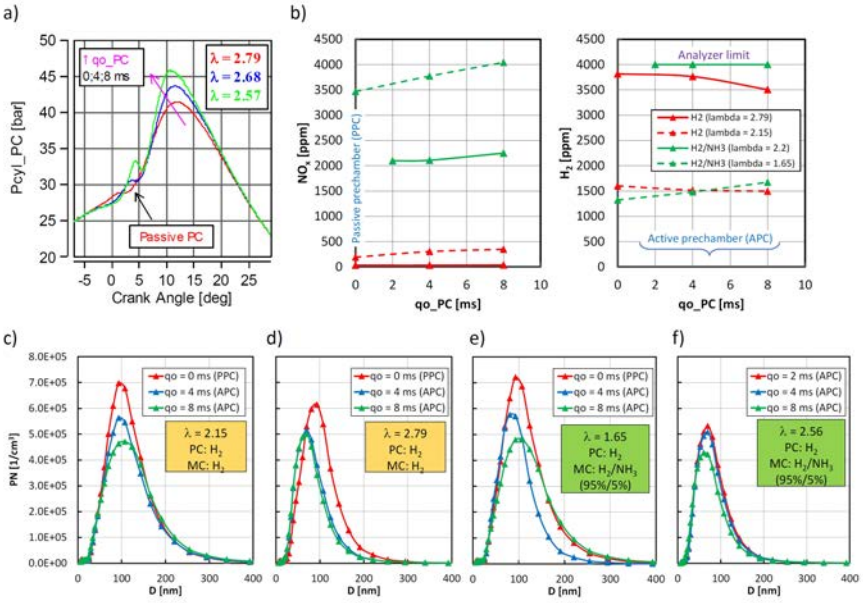

Fig. 1. Engine test results: a) indicator measurements (point: H_2; λ = 2.79); b) exhaust gas concentrations; and particle number distributions (n = 1400 rpm): c) λ = 2.15, H_2; b) λ = 2.79, H_2; c) λ = 1.65, H_2+NH_3; d) λ = 2.56, H_2+NH_3

Analysis of particle number distributions (Fig. 1c-f) indicates that combustion of different carbon-free fuels has a limited effect on particle number characteristics. Under very lean combustion conditions, particle number decreases from 7E+05 1/cm³ at a diameter of 100 nm to 6E+05 1/cm³. Similar trends were observed for combustion of the hydrogen–ammonia mixture. Each increase in pre-chamber fuel dose reduces the maximum particle number. An increase in excess air ratio shifts particle number distribution curves toward smaller particle diameters.

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Cost-benefit: Electrostatic precipitators for residential stoves

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Background: Residential heating with wood (and coal) in small stoves is a significant pollution source in many countries. The smoke contains same toxic particles and carcinogenic PAHs as tobacco smoke and increases the risk of cancer, blood clots, cardiovascular diseases, serious lung diseases, etc. Thereby contributing significantly to mortality and morbidity, i.e. imposing a very expensive health burden on society. However, the expensive health burden could make requirements for electrostatic precipitators for new residential stoves a positive investment for society. **Purpose:** The purpose of this study was to perform a cost-benefit screening of the following scenario: the ongoing revision of the EU Ecodesign regulation for stoves leads to an outcome where electrostatic precipitators (or similar technology) will be a mandatory requirement for new wood stoves. Furthermore, externalities due to air pollution (health costs only) and climate pollution have been calculated per Gigajoule (GJ) of house heating for new wood stoves (with/without precipitators) in comparison to heat pumps. **Methods**: Calculations were conducted for densely populated urban areas, smaller towns, and rural areas, as the latter typically have more intense use of biomass than the former, in Denmark and Slovakia, two EU countries that have same size but quite different per-capita average income to illustrate the consequences in both wealthier and less wealthy countries in the EU. Costs of precipitators in case of mass production were estimated to be 1,000 euro. Specific fuel use and health externalities for densely populated urban areas, smaller towns, and rural areas in Denmark and Slovakia were used. General air pollution health externalities in Denmark and global warming per GJ of heating for existing Ecodesign wood stoves (with/without precipitators) and heat pumps were calculated including four air pollutants: $PM_{2.5}$, NOx, NH_3, and SO_2, and four climate pollutants: CO_2, CH_4, N_2O, and BC. **Results:** Annual cost of electrostatic precipitators represents only 0.2-0.5% of the incomes in Denmark and Slovakia. As a result, making electrostatic precipitators mandatory for new wood stoves would not pose a general financial burden but some families might need financial support to install precipitators. The benefits to cost ratio of requiring electrostatic precipitators for residential stoves is 2.7-19.4 making it a beneficial investment for society if the revised Ecodesign regulation mandates the use of electrostatic precipitators for stoves. Even though the externalities are highest per kg $PM_{2.5}$ in densely populated urban areas, the benefits to cost ratios are highest in rural areas because of significantly higher fuel use per stove and because $PM_{2.5}$ spread far from the source causing exposure on a regional level. The general health costs of air pollution from a new wood stove meeting current Ecodesign regulations in Denmark are approximately 180 times higher per GJ of household heating than those from even a coal-powered electric heat pump. If electrostatic precipitators are made mandatory in the Ecodesign regulation, new wood stoves would still result in about 70 times higher health costs per GJ of heating compared to a coal-powered heat pump. Climate pollution from a wood stove complying with current Ecodesign regulations causes significantly more global warming per GJ of household heating than a heat pump powered by coal-based electricity. This remains true even when assuming that CO□ emissions from wood stoves are entirely carbon neutral. Electrostatic precipitators reduce the BC emission from wood stoves, thereby substantially lowering their climate impact. **Acknowledgement:** This study was funded by the Clean Air Fund and the European Climate Foundation.

Field investigations of particle pollution from residential heating in Slovakia

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Background: Residential heating with wood and coal in small stoves and boilers is the dominating source of particle and PAH emissions in Slovakia and contributes significantly to the local pollution in small villages and towns. This increases the risk of cancer, blood clots, cardiovascular diseases, lung diseases, etc. Thus, contributing significantly to mortality and morbidity, placing a heavy and expensive health burden on society. Burning wood and coal in stoves can also pollute indoor air due to emissions inside the home causing high particle pollution during the cold seasons when people spend most of their time indoors and ventilation is limited. The health damage associated with indoor air pollution is usually not included when calculating the health burden of air pollution. **Purpose:** The purpose was to conduct field investigations in Slovakia, measuring particle number concentrations in Slovak nature with no local pollution sources, in village areas (e.g. parks) with no smell of wood/coal smoke, and while walking in residential areas heating with wood and coal. **Methods:** Particle number was measured with calibrated P-Traks from TSI in 31 Slovak villages in the winter 2020, 2023, 2024, and 2025. No other significant local pollution sources were active during measurements (pollution from passing diesel cars was noted and removed from result). **Results:** Background pollution in Slovak nature typically ranged from 500-1,000 particles per cm^3 depending on weather conditions, i.e. people in Slovakia would inhale what the WHO considers as a low pollution level if national pollution sources were eliminated. In village areas (e.g. parks) with no smell of wood/coal smoke were typically 2,000-6,000 particles per cm^3. However, during inversion periods in valleys, the concentration exceeds 10,000 particles per cm^3 in village areas with no smell. While walking on streets in residential village areas, particle concentrations (minute averages) could locally exceed 40,000 particles per cm^3 which WHO considers to be a high pollution level. Supplementary indoor measurements in a few homes (without other active pollution sources) revealed concentrations above 50,000 particles per cm^3. **Conclusion:** This field study confirms that local heating with wood and coal in villages in Slovakia generally contributes significantly to local pollution with increased particle number and that stoves can contribute to high indoor air pollution. **Acknowledgement:** This work is funded by the EU LIFE program: Project LIFE-IP SK AQ Improvement.

Reducing the uncertainty of condensation particle counter calibrations at low particle number concentrations by reducing electrical noise in the Faraday cup aerosol electrometer

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The latest version of the European Ambient Air Quality Directive [1] mandates the measurement of the number concentration and size distribution of ultrafine particles. The European standard EN 16976:2024 [2] sets out a method for the measurement of the particle number concentration of ambient air using condensation particle counters (CPCs). CPCs measure particles in the size range from 10 nm to a few micrometers. Measurements of particle number concentration are also required by vehicle legislation such as Periodic Technical Inspection legislation [3] and aerospace engines emissions legislation [4].

In 2026 NPL increased its ISO 17025 scope of CPC calibrations against a reference Faraday Cup Aerosol Electrometer (FCAE) in accordance with ISO 27891[5], reducing the lower end of the concentration range from 1000 cm^{-3} (1.5 fC cm^{-3}) to 100 cm^{-3} (0.15 fC cm^{-3}). At these ultra-low currents, the zero noise and zero offset of the reference Faraday cup electrometer start to become significant contributors to the overall uncertainty in the CPC calibration. Coupled with the difficulty to calibrate the reference FCAE at charge concentrations below 1.5 fC cm^{-3} this forms an important measurement challenge.

This work examines the process of driving down the measurement uncertainties at ultra-low currents. This was achieved by modifying the calibration procedures of both the CPC and primary FCAE. The primary FCAE calibration was modified to increase the measurement duration at the lowest currents to minimise the contribution of the electrical noise. The improvements in CPC calibrations, included physical adaptions such as vibration dampening, using fixed brick installations rather than standard laboratory benchtops and additional ambient background charge insulation external to the body of the FCAE. The sampling periods during the calibrations were adjusted to minimise the contribution of the fluctuations in the FCAE instrument noise with a focus on the crucial zero current measurments and a new approach was taken to dealing effectively with the FCAE zero offset, to minimise its contribution to the overall measurement uncertainty.

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Lowcost ambient UFP monitoring with diffusion chargers

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Over the past years, there has been increased interest in measuring ultrafine particles (UFP) in ambient air to complement existing particle mass metrics (PM10, PM2.5). The renewed interest stems from the new WHO recommendations to measure UFP, and the new EU air quality directive which mandates UFP measurements.

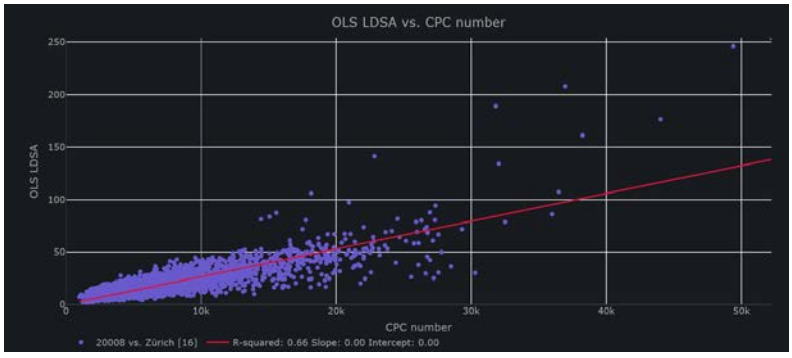
Due to the complexity and cost of traditional UFP measurements (with condensation particle counters (CPC) for particle number, and the mobility particle size spectrometer (MPSS) for particle size distributions), there will always be insufficient coverage of UFP metrics, in particular as it is well known that UFP concentrations vary more spatially than the traditional PM2.5/PM10 measurements.

To address the issue of low spatial coverage, we have developed a low-cost diffusion-charging based device that can be deployed anywhere, i.e. outside of traditional measurement stations with complex inlet systems and climate-controlled interiors, as long as power (~4 Watt) is provided. The sensor measures the charge transfer to the aerosol, which is roughly proportional to the lung-deposited surface area (LDSA), a metric which has the potential to be interesting for health effects. The full instrument consists of the LDSA sensor (OLS) coupled with a data transmission/control unit enclosed in a weather-proof box. Measurement data and instrument status information is transmitted to a cloud backend, from where the data can always be visualized online in any browser.

The new instruments have been deployed on a larger scale in early 2025 within the EU project “net4cities” (33 devices in 11 partner cities in Europe), as well as another 9 instruments measuring in and around Zürich. These ~40 instruments have been running nearly one year in 24/7 operation with no onsite intervention necessary so far, only minor over-the-air-updates of the software were performed until now. The data availability is roughly 99%. Some of the instruments are co-located with traditional devices; and in two locations, multiple instruments have been deployed to the same location, which allows to assess how well the instruments agree over longer times.

The measured LDSA values correlate reasonably well with CPC number concentration measurements, e.g. for the location Zürich-Kaserne, we observe an R2 of 0.68 for hourly values of the fourth quarter of 2025 (see figure below). This shows the similarity of LDSA and particle number measurements, and means LDSA could well serve as UFP complement to existing PM measurements.

In conclusion, the observed high reliability, high data quality, low maintenance combined with ease of deployment and operation and low cost of this new instrument appear to allow UFP measurements on far larger scale than was possible with traditional instruments.



Uncertainty of the dilution factor of diluters with internal mixing gas preparation

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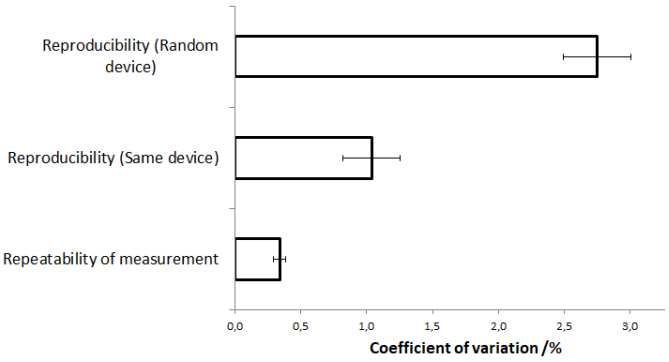
Dilution systems are widely used to adjust the concentration of aerosols, either during the generation or quantification of aerosols. Dilution systems with internal mixing gas preparation are often used for this purpose [1, 2]. They are based on the passive passage of a defined total flow rate of the aerosol to be diluted. This flow is divided into two partial flows. A small partial volume flow flows through a capillary, whereby its particle concentration remains constant, if losses within the capillary can be neglected. The majority of the total flow passes through a bypass consisting of a valve and an absolute filter for particle separation and then mixes again with the capillary flow. The valve adjusts the ratio of the two volume flows and thus the dilution ratio of the system.
The dilution rate is not a measurand as defined by GUM [3], because it is not measured during the application. Nevertheless, the concept of quantifying its uncertainty can be applied. To quantify the uncertainty of the dilution rate, the dilution rate of a diluter (DIL 554, Topas GmbH) was measured independently from the calibration process, according to type A evaluation of standard uncertainty of GUM.
The dilution rate was measured by two CPCs upstream and downstream the diluter employing a DMA-classified DEHS test aerosol. With a sample duration of 115 s the standard deviation of the downstream sample is 3.9 %, which is dominated by the counting process of the CPC. The standard deviation of the mean is estimated according to GUM to 0.36 %, which is confirmed by the measurement of the repeatability (repeated measurement of dilution factor without any user intervention) in figure 1. This indicates that only random errors dominate the measurement uncertainty. The measurement of the dilution rate was repeated 30 times with the same device and 90 times with 10 randomly selected devices to quantify the reproducibility (figure 1).



The contribution discusses the applied method to quantify the uncertainty of the dilution rate and aims on developing a common method to evaluate the uncertainty of dilution systems to enable the comparison of results.

[1] Fuchs, N.A., Sutugin, A.G. (1965) Journal of Colloid Science, Volume 20, Issue 6, 492-500, doi.org/10.1016/0095-8522(65)90031-0.
[2] Göhler D., Hillemann L., Große S., Peters C., Stintz M. and Rudolph A. 25th European Aerosol Conference (EAC 2020), Aachen, Germany (virtual conference). dx.doi.org/10.13140/RG.2.2.14092.33923
[3] JCGM 100 (2008) Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM)

Testing and Calibration of bcMeter, an Open-Source, Low-Cost Black Carbon Monitor

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Black carbon (BC) is a major short-lived climate forcer and air pollutant, yet significant gaps remain in global data collection, partly due to the high cost of reference-grade instruments. The open-source bcMeter offers a low-cost alternative for monitoring BC; however its performance has not been sufficiently evaluated.

This paper investigates the bcMeter's accuracy in measuring BC, the factors influencing its performance, and its suitability for deployment in resource-limited environments. A six-test co-location campaign involving three bcMeter units (BCM A–C) and an AE33 reference aethalometer was conducted at two Swiss sites (Dübendorf and Zürich) over a total duration of 30 days. The study assessed performance at a ten-minute temporal resolution, higher than previously reported, and examined the effects of filter loading, tube material, and temperature fluctuations. Data were pretreated, and two post-processing approaches were applied: centered moving average (CMA) smoothing and multiple linear regression (MLR) prediction incorporating environmental predictors.

Results show that, despite inherent noise, the bcMeter reliably captures temporal BC trends under suitable conditions or with appropriate data treatment. When comparing the collocation data of AE33 and bcMeter, R^2 values were 0.59–0.74 for pretreated data, improving to 0.65–0.78 with MLR and 0.74–0.85 with CMA calibration. Filter loading caused a reduction in R^2 of more than 30 percent and led to systematic underestimation, while instrument temperature fluctuations were identified as the main driver of large residual spikes. Polyurethane tubing outperformed conductive PVC in short-term stability. CMA reduced noise at the expense of fine temporal detail, whereas MLR preserved more detail but was more sensitive to large deviations from AE33 readings.

With a hardware cost below 300 CHF, the bcMeter demonstrates strong potential for low-cost BC monitoring. However, careful evaluation of the intended application and available infrastructure is essential to ensure proper calibration and reliable operation, especially in resource-constrained settings. Future efforts should focus on automated filter tape advancement and methods to compensate for environmental effects, thereby supporting robust, scalable field deployment and enhancing performance.

Continuous Monitoring of UFP Across 11 European Cities: First Results from the Net4Cities Project

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Ultrafine particles (UFPs; <100 nm) represent a significant environmental health challenge, particularly within the transport sector. Traditional mass-based metrics used to monitor particulate matter emissions (PM10, PM2.5) poorly capture the impact of UFPs, which contribute only negligibly to mass but dominate in number and need to be addressed. Recent updates to the EU air quality directive (Directive (EU) 2024/2881) have placed an emphasis on ultrafine particle (UFP) measurements, particularly within the newly defined supersites. These supersites are mandated to perform total UFP particle number concentration (PNC) measurements using condensation particle counters (CPC). While PNC has long been the primary metric for quantifying UFP exposure, Lung Deposited Surface Area (LDSA) has emerged as a valuable complementary for a more nuanced health risk assessment. LDSA specifically quantifies the total active surface area of particles that deposit in the alveolar regions of the lung[1]. In the Horizon Europe Net4Cities project, a major aim is to enhance air and noise pollution monitoring infrastructure across 11 European cities to support Zero Pollution Action Plans and the EU Green Deal objectives, including through the measurement of UFPs. To address this new legislative requirement for the monitoring of UFPs, the Net4Cities project has adopted a dual-approach through the measurement of PNC using Airmodus CPCs and the measurement of LDSA using naneos diffusion-charging LDSA monitors. In the 11 partner cities, new UFP monitoring networks have been established at traffic, airport, and port monitoring sites, leading to the installation of 24 CPCs and 33 LDSA monitors. In this work we present preliminary results of these extensive measurements of PNC and LDSA across Europe. We also perform initial comparisons of the two metrics and identify linkages with local meteorology and transport emissions sources. Our preliminary results confirm a high degree of spatiotemporal heterogeneity in concentrations, a characteristic previously identified in smaller-scale studies, and demonstrate that these fluctuations are strongly coupled with local human activity across all site types.

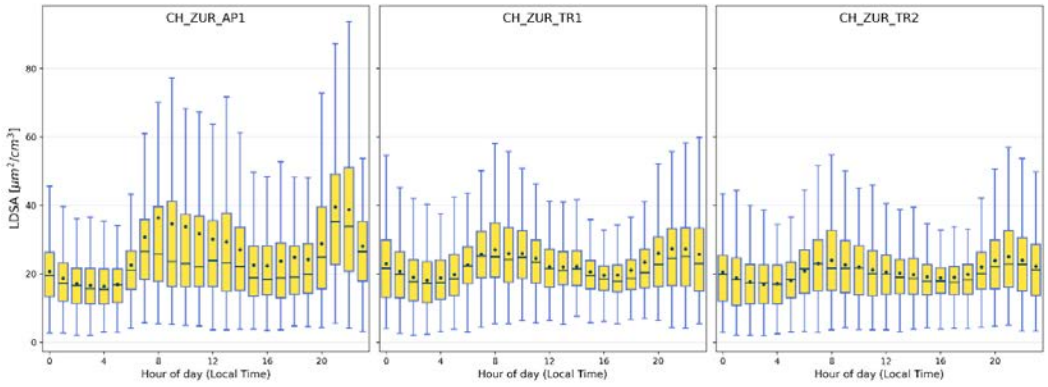

Figure 1: Box-and-whisker plots of hourly mean LDSA concentrations at three selected sites (one airport, two traffic hubs) in a representative partner city, measured from March 28th to November 20th, 2025.

[1]Yuan, J.; Zhang, W.; Hu, J.; Rupakheti, M.; Rupakheti, D. Studies on Lung-Deposited Surface Area (LDSA) of Particulate Matter during 2005–2024. Air Qual. Atmosphere Health 2025, 18, 2431–2446.

Experimental evaluation of nucleation phenomena in an oxidation flow reactor (DOFR™)

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Oxidation flow reactors (OFR), such as Dekati® Oxidation Flow Reactor (DOFR™) are aerosol conditioning units designed to simulate atmospheric aging and especially used in studying secondary aerosol formation. DOFR design is similar to previously published OFR TSAR (Tampere University Secondary Aerosol Reactor, Simonen et al. [1]). Utilizing high concentrations of OH-radicals and UVC (254 nm) radiation, days-long oxidation processes can be achieved within minutes. The oxidation of volatile vapors, present in the measured aerosol, can make them condensable within the OFR chamber, leading to growth of existing particles or to nucleation of new particles. Whether nucleation takes place depends on the overall process parameters, but more interestingly here, on the ratio between condensable vapor and seed particles of the measured aerosol. So, at the output of the OFR, the condensed particulate mass can end up in its own distribution mode and/or growing the existing seed particle mode. Similar phenomena in which background aerosol influences new particle formation may also happen in real ambient conditions affecting, e.g., pollution formation processes.

In our experiments we varied the ratio between condensable vapor and seed particles around the point where nucleation takes place. Soot seed particles were generated using a Miniature Inverted Soot Generator (MISG). An eDiluter™ Pro along with a catalytic stripper were used to condition and to adjust the concentration of the soot seed particles. As a condensable vapor precursor, toluene, α-pinene, and mixture of their vapor was introduced from a temperature-controlled flow saturator continuously and in pulses with a syringe. The prepared aerosol was then atmospherically aged with a DOFR™ using stable humidity and ozone concentration. The aged aerosol from the DOFR™ was measured with an ELPI®+ and an SMPS. The oxidation age was estimated by using a CO gas tracer, and the aging controlled by varying the UVC radiation intensity in the oxidation chamber.

The point where nucleation occurs was found for both stable and pulsed vapor cases. Results for the pulsed vapor case with four different injection intervals are shown in Figure 1. Measurements were performed to cover cases where practically only nucleation or coated soot particles were present, as well as the case where both modes are present. Clear differences were observed between ELPI®+ and SMPS distributions as the soot seed particles started to grow from the condensing vapor, indicating the change in effective density of the measured particles. Additionally, the DOFR™ response time for a pulsed vapor source was determined by comparing an input of a near point source of vapor to an output of a broadened particle size distribution.

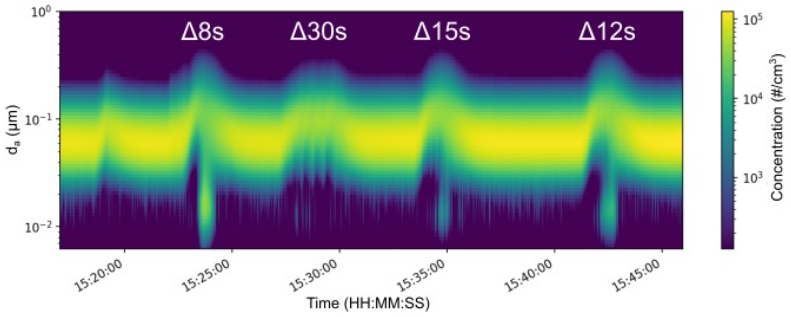

Figure 1: Vapor injection series with varying injection interval

[1] P. Simonen, E. Saukko, P. Karjalainen, H. Timonen, M. Bloss, P. Aakko-Saksa, T. Rönkkö, J. Keskinen, M. Dal Maso, Atmos. Meas. Tech., 2017, 10, 1519–1537.