

# Directly measuring droplet dispersion in an indoor environment with a high-sensitivity Aerosol Flame Photometer

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## 1 Introduction

Awareness of pollution and its effects on human health has traditionally focused on industrial and combustion sources, but indoor air quality has been attracting increasing attention, both in the light of high exposure time and in the wake of the COVID-19 pandemic. Proper ventilation is key to improving air quality in enclosed spaces (Persily, 2015), and facilitates the removal of particles generated indoors by activities such as cooking, burning hydrocarbons, and human presence.

Gas monitors for CO<sub>2</sub> are increasingly adopted as a low-cost indication of indoor air quality, but their effectiveness is limited to CO<sub>2</sub>-producing activities and cannot for example detect poor air quality resulting from cooking on an electric hob or from activities generating dust.

It is therefore of interest to develop instruments allowing experimental measurements of the dispersion of particles, which can be used to validate numerical models and to test the correlation between the diffusion of particles and of gases such as CO<sub>2</sub>. Aerosol flame photometry is a promising technique in this regard.

Here we present a new high-sensitivity and high-frequency Aerosol Flame Photometer (AFP; Cambustion Ltd, UK) and use it to directly measure the temporal dispersion of aerosol particles in a room with natural mixing. Measurements from the AFP are compared to (i) those of a Rapid Response Ambient CO<sub>2</sub> Analyser (Cambustion Ltd, UK) to evaluate the suitability of CO<sub>2</sub> measurements as a surrogate for particle dispersion, and (ii) to number concentration measurements from a Condensation Particle Counter (CPC).

## 3 Results

The measurements from the three detectors correlate well overall, showing the same general trends. However, significant differences can be noted depending on the phase of the experiment (Fig. 2).

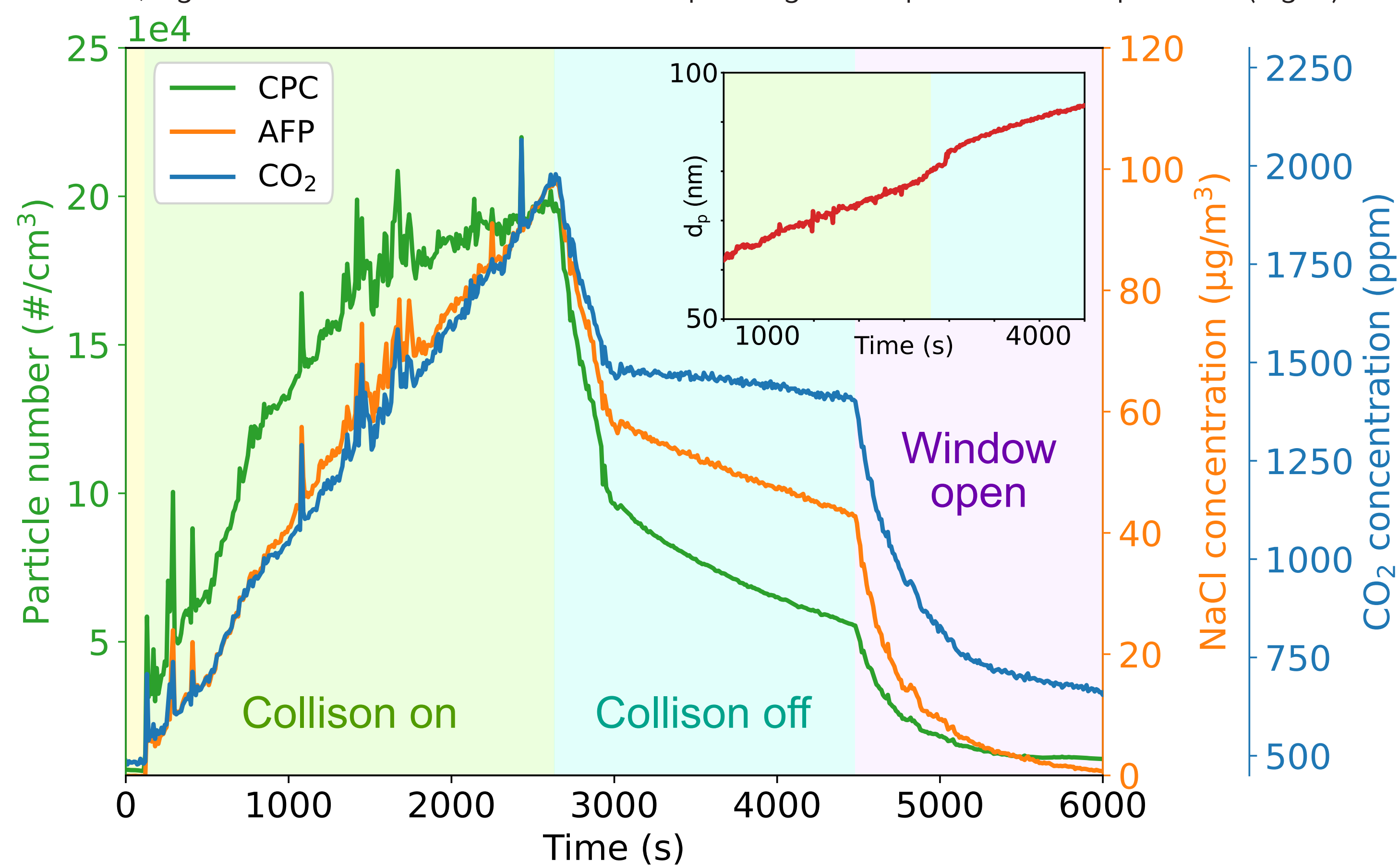


Figure 2. Concentration of particles, sodium chloride, and CO<sub>2</sub> as measured by the CPC, AFP, and gas analyser respectively; data is presented averaged to 0.1 Hz; the background colours represent different phases of the experiment. The inset shows the average NaCl particle diameter ( $d_p$ ) as calculated from the AFP and CPC signals.

While the Collision nebulizer is turned on, the measurements from the CO<sub>2</sub> and AFP are extremely well correlated and the recorded concentrations increase in an almost linear fashion, other than for a few spikes. For the CPC instead, the rate of concentration increase drops with time. The steady increase in sodium and CO<sub>2</sub> confirms that the generator is still operating correctly and that the number concentration levels off due to particle agglomeration, with a self-preserving distribution forming. This is highlighted by the increase in the average equivalent NaCl particle diameter calculated from the AFP and CPC signals (see Fig. 2 inset).

As soon as the nebulizer is turned off, a sharp decrease is observed in all the concentrations, and the short term variations in the measurements settle down due to flow homogenization within the room. The large difference between the concentration at the sample point and the room average shows that personal exposure can be difficult to predict without direct measurement.

The CO<sub>2</sub> concentration then stabilises as there is very little air exchange in the room, but the particle number and sodium mass drop steadily due to particle deposition. Again due to agglomeration, the CPC reading decays at the fastest rate, as is highlighted by the half-lives of the monitored quantities when the window is opened (see Table 2).

Table 2. Half-life of the particle number and concentration of sodium chloride and CO<sub>2</sub> calculated from an exponential fit to the experimental data.

	Particle number	NaCl concentration	CO <sub>2</sub> concentration
Half-life after opening window	190 s	206 s	232 s

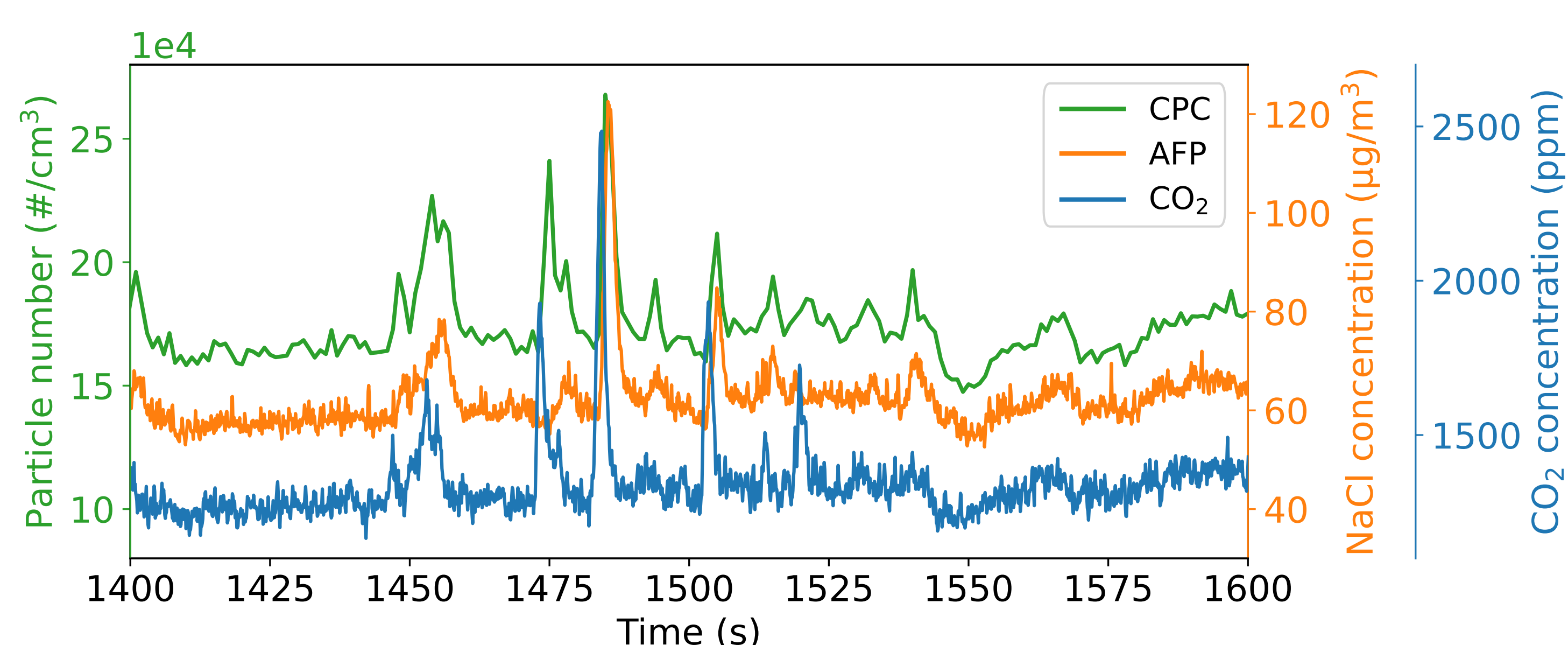


Figure 3. High-frequency detail (10 Hz for AFP, CO<sub>2</sub>; 1 Hz for CPC) of the data from Figure 2, highlighting the significant short-term variations in concentration. The gas sensor has a slightly faster response time than the other detectors.

## 2 Experimental setup

### Aerosol Flame Photometer

Flame photometry was originally established as a technique to detect trace concentrations of metallic ions in aqueous solutions (Barnes *et al.*, 1945). Aerosol flame photometry allows detection of metallic ions both in droplet form and as solid particles, and has been adopted as part of the ISO standard EN149:2001+A1:2009 for testing of respiratory masks.

The Aerosol Flame Photometer (AFP) used in this work is a new instrument developed by Cambustion Ltd (Cambridge, UK) and allows high-frequency measurements over a wide dynamic range. The sub-second response time ( $T_{10-90\%}$ ) allows temporal variations of ambient aerosols to be accurately resolved.

### Rapid Response Ambient CO<sub>2</sub> Analyser

A Rapid Response Ambient CO<sub>2</sub> Analyser (Cambustion Ltd, UK) based on Non-Dispersive Infra-Red (NDIR) detection is used to measure concentrations from a few parts per million (ppm) up to 10%, suitable for the typical ambient concentration of 420 ppm.

### Aerosol generation and measurement

A Collision nebulizer containing a solution of 0.9% sodium chloride (NaCl) in distilled water is supplied with about 3 lpm of 20% CO<sub>2</sub> in N<sub>2</sub>. The atomizer is placed on a table in a meeting room of about 24 m<sup>3</sup>, producing droplets well-mixed in the CO<sub>2</sub> tracer for about 40 minutes; the total output from the nebulizer is recorded in Table 1. The dispersion of the aerosol and gas is studied using the AFP and Rapid CO<sub>2</sub> detector described above, and a CPC, all sampling at nose-height across the table from the nebulizer (Fig. 1). The room is ventilated before the experiment by opening the windows, and no active ventilation is present during the measurements.

Table 1. Integral output from the Collision nebulizer over the 40 minutes of particle generation.

Collision output (gas)	Collision output (solution)	CO <sub>2</sub> released	NaCl released
0.12 m <sup>3</sup> (0.5% of room)	10 – 15 ml	1000 ppm	~ 5 mg/m <sup>3</sup>

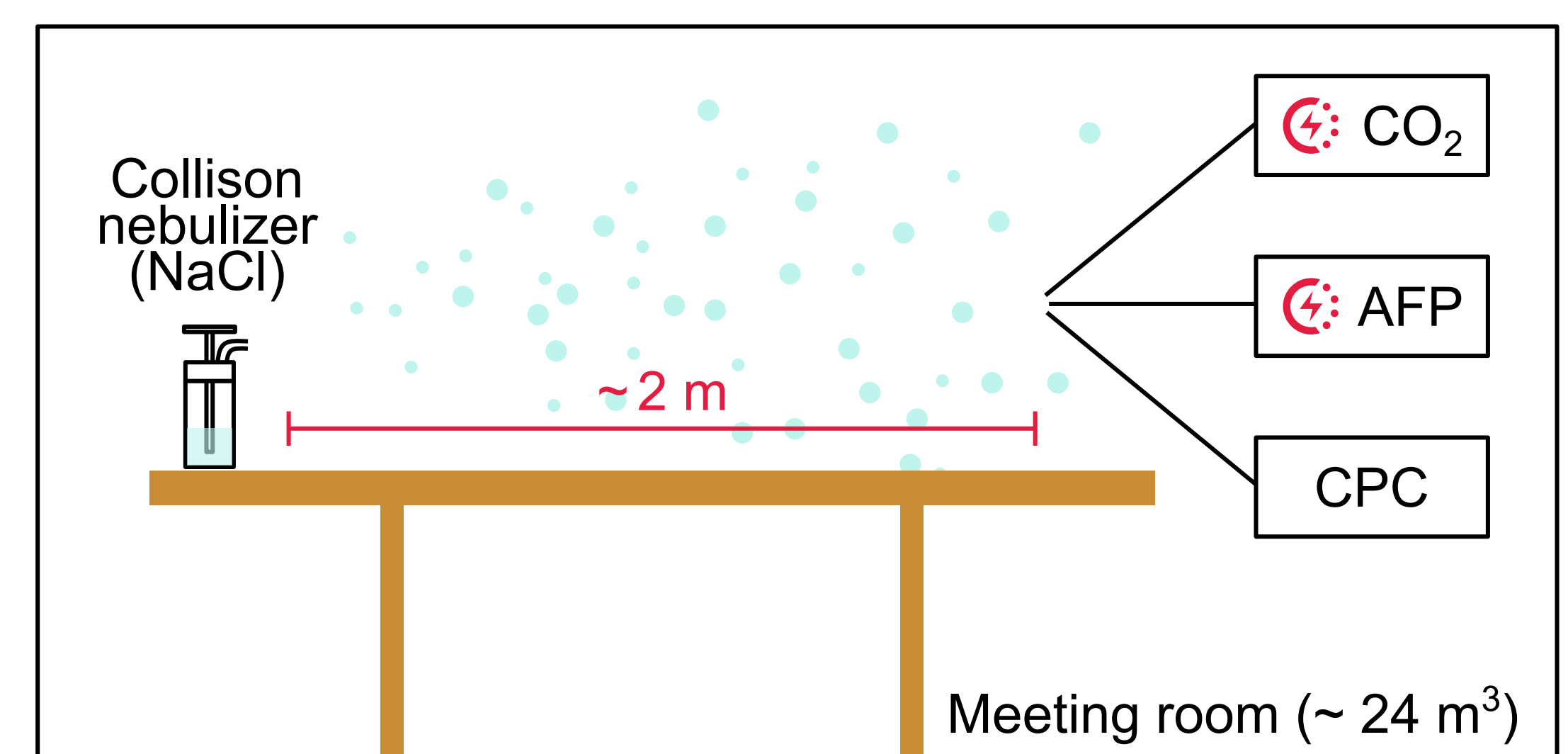


Figure 1. Experimental setup in the room.

## 4 Calibration of the AFP

The Aerosol Flame Photometer was calibrated for sodium chloride using the setup in Figure 4.

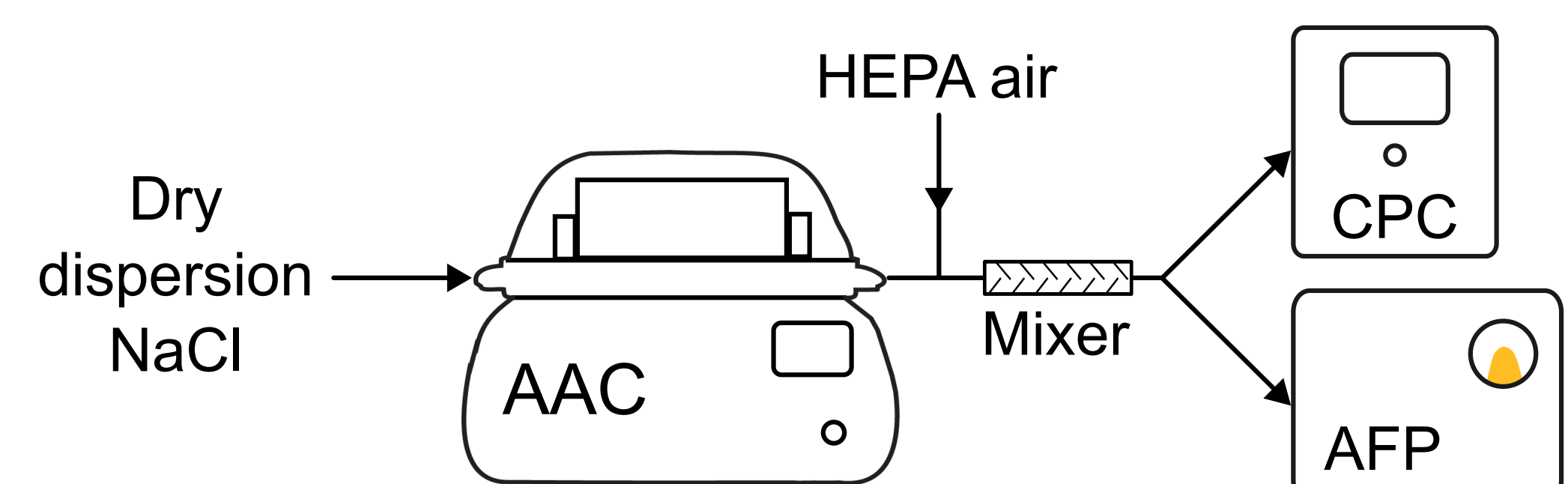


Figure 4. Experimental setup used in the calibration of the AFP.

Particles measuring between 100 – 200 nm in aerodynamic diameter were generated in mass concentrations spanning over two orders of magnitude (0.2 to 100 µg/m<sup>3</sup>) as shown in Figure 5. A calibration factor of 19.6 (µg/m<sup>3</sup>)/V was calculated from the best fit to all the point, resulting in a detection limit of ~ 15 ng/m<sup>3</sup> of NaCl.

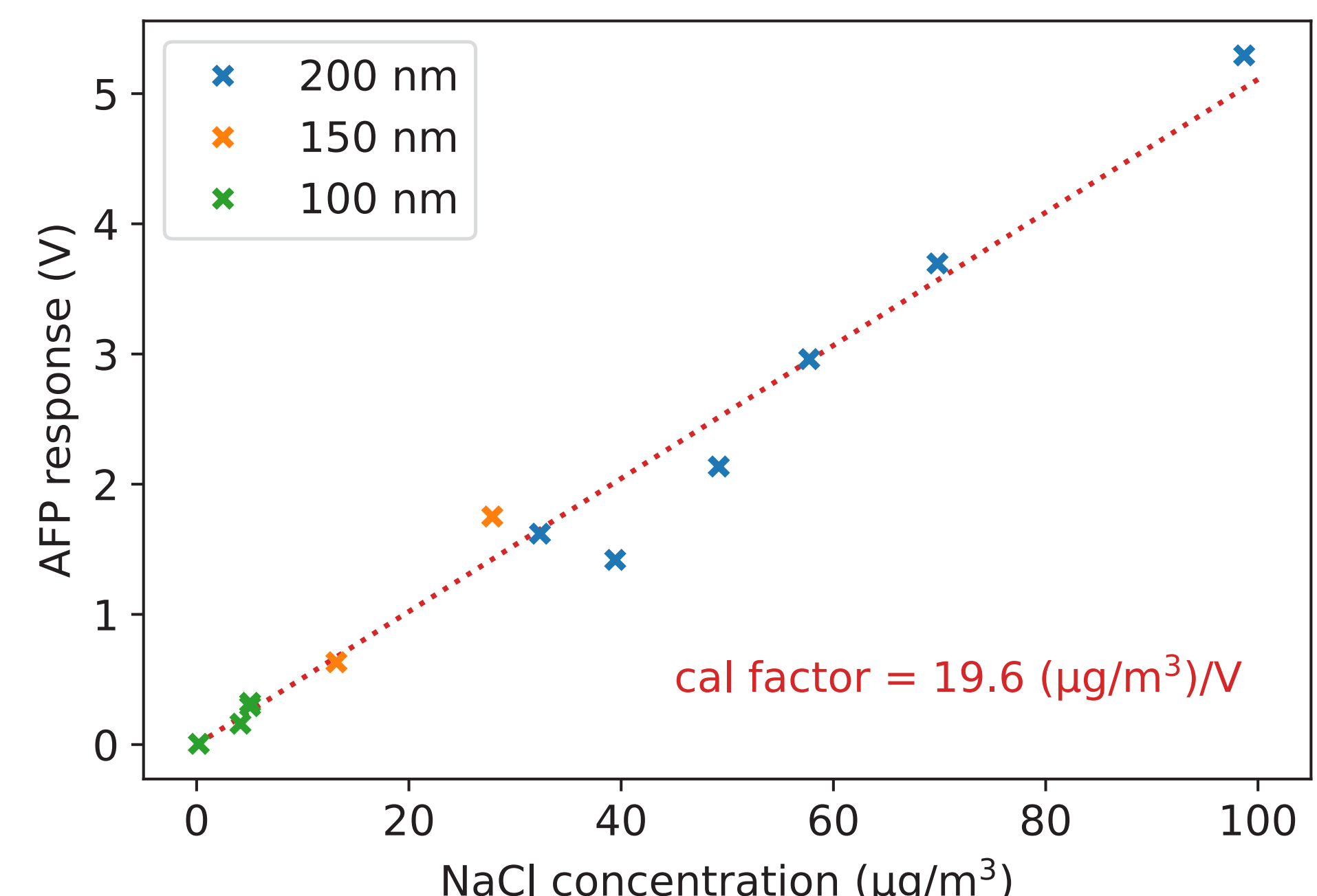


Figure 5. Calibration curve obtained for NaCl particles.

## 5 Conclusion

The new Aerosol Flame Photometer presented in this work can detect a wide dynamic range of concentrations with high temporal resolution and can be used to study the dispersion of particles in real environments with high sensitivity and specificity. Since the mass of sodium in each droplet remains constant during the evaporation, the response of the AFP only depends on the initial droplet diameter and is not affected by the state of the particles (liquid or solid) upon detection, making this technique particularly relevant to studies on viral load and on the transmission of respiratory diseases.