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PARTICLE SIZE COMPARISON BETWEEN SCANNING MOBILITY PARTICLE SIZER TSI 3936L75 AND NEW TSI 3938W50-CEN-7 CONDUCTED AT NPL AND LONDON MARYLEBONE ROAD MONITORING SITES

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Particle size comparison between scanning mobility particle sizer TSI 3936L75 and new TSI 3938W50-CEN conducted at NPL and London Marylebone Road monitoring sites

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ABSTRACT

A new TSI 3938W50-CEN-7 scanning mobility particle sizer (SMPS) system was purchased and trialled in 2022 for use across the Particle Concentrations and Numbers Network in 2023. This new model of SMPS 3938 had a larger size scan range (nominally 10 - 800 nm) than the older model TSI 3936 SMPS (nominally 16 - 600 nm). In July and August 2022, a validation campaign took place at NPL (Teddington) and London Marylebone Road for the new TSI 3938W50-CEN-7 SMPS, consisting of two parts.

Firstly, laboratory tests were performed at NPL using ambient air to: (a) confirm that the new SMPS instruments could operate continuously when installed at site and, (b) co-locate the old TSI 3936L75 SMPS and new TSI 3938W50-CEN-7 SMPS models to challenge the instruments with “urban background” ambient air to check for any differences in the particle size distributions between the two instruments. Secondly, tests at London Marylebone Road, an “urban traffic” site, to: (a) confirm that the new SMPS instruments could operate continuously when installed at a roadside site and (b) co-locate the old and new SMPS models to challenge the instruments with roadside air and check for any differences in the particle size distributions between the two instruments.

The TSI 3938W50-CEN-7 SMPS was shown to operate successfully over a month at both NPL and London Marylebone Road sites. The size distribution comparison at NPL showed a good correlation between the two SMPS systems meeting the ± 10 % bounds above a particle diameter of 50 nm and the ± 20 % bounds at particle diameters between 20 nm and 50 nm. The size distribution comparison at the London Marylebone Road site indicated a reasonable correlation (± 20 %) between the two SMPS systems for particle diameters of 20 nm and 50 nm. At both sites the two SMPS size distributions deviated by more than 20 % below a particle diameter of 20 nm, but this was to be expected due to the different D_{50}, the condensation particle counter size cut offs and the different scan range of the two SMPS instruments (16-600 nm versus 10-800 nm).

Above a particle diameter of 50 nm at London Marylebone Road, a higher particle number concentration was measured by the TSI 3938W50-CEN-7 SMPS compared to the TSI 3936L75 SMPS. There is not a simple explanation for this difference, indeed the measurement of different particle number concentrations by different models of SMPS is being discussed by CEN TC264 WG32[1]. As this short study demonstrated that the two SMPS systems behaved differently when challenged with roadside aerosol composition, this shows that additional care must be taken when comparing results from different SMPS systems at roadside sites such as London Marylebone Road.

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CONTENTS

1 INTRODUCTION

In 2022, the three TSI model 3936L75 scanning mobility particle sizers (SMPSs), on the Particle Concentrations and Numbers (PCN) network at London Marylebone Road (LMR, UKAIR[2] ID UKA00315), London Honor Oak Park (HOP, UKA00656), and Chilbolton Observatory (CO, UKA00614), were 15 years old and most parts were no longer supported by their manufacturer, TSI.

In October 2021, the Environment Agency ordered three new SMPS systems (TSI model 3938W50-CEN-7 SMPS) which were delivered in August 2022. The new instruments were supplied with calibration certificates from TSI and the Leibniz Institute for Tropospheric Research (TROPOS), which is linked with the World Meteorological Organization (WMO) through its role as the World Calibration Centre for Aerosol Physics (WCCAP) within the WMO's Global Atmosphere Watch (GAW) program.

Further to this, they also required a calibration and validation by NPL as part of NPL's contract with the Environment Agency. A comparison study was conducted to assess and quantify any step-change between the old and new systems.

A TSI 3938W50-CEN-7 SMPS system was purchased and trialled in 2022 for use across the Network in 2023. This new version had a larger size scan range (nominally 10 - 800 nm) than the older model TSI 3936L75 SMPS (nominally 16 - 600 nm). In July and August 2022, a validation campaign took place at NPL (Teddington) and LMR for the new TSI 3938W50-CEN-7 SMPS, consisting of two parts.

Firstly, laboratory tests were performed at NPL using ambient air to: (a) confirm that the new SMPS instruments could operate continuously when installed at site and, (b) co-locate the old TSI 3936L75 SMPS and new TSI 3938W50-CEN-7 SMPS models to challenge the instruments with "urban background" ambient air to check for any differences in the particle size distributions between the two instruments. Secondly, tests at London Marylebone Road, an "urban traffic" site, to: (a) confirm that the new SMPS instruments could operate continuously when installed at a roadside site and (b) co-locate the old and new SMPS models to challenge the instruments with roadside air and check for any differences in the particle size distributions between the two instruments.

2 EXPERIMENTAL SET UP AND TEST METHOD

2.1 TEST METHOD AND DATA ANALYSIS

Field tests at the NPL urban background site were conducted between 12 – 29 July 2022 and at the LMR urban traffic site between 25 August – 6 October 2022. The tests were conducted using the instrumentation shown in Figure 1 and Figure 2, and the set up in Figure 3.

In both cases, a TSI 3750200 sampling system was used with a 4-way flow splitter. The first arm went to the TSI 3936L75 SMPS, the second arm to the TSI 3938W50-CEN-7 SMPS, the third arm to a TSI 3772-CEN-7 stand-alone condensation particle counter (CPC), the data from which are out of the scope of this report, and the final arm was connected to a needle valve and pump to balance the flows through the splitter. Each arm had a compensated flow of 1 L min^{-1} for a total flow through the inlet dryer of the recommended 4 L min^{-1}. This ensures an identical split of the ambient aerosol for each instrument, avoid any sampling or transport bias. It should be noted that the sampling height of the inlet at NPL was at nominally 17 m high.

The data were recorded with TSI Aerosol Instruments Manager Software (AIM) as SMPS scans (2-3 min) and averaged over 5 min. The SMPS were operated with different versions of the AIM software: the old 3936 SMPS with AIM 9.0 and the new 3938 SMPS with AIM 11. The data were reviewed to remove any anomalous results and a subsection of the full data set was taken where both instruments had over 99 % data capture. These subsections of data (12 – 26 July at NPL and 25 August – 30 September 2024 at LMR) were then averaged for the number concentration at each size bin. The 3936 SPMS had a size resolution of 32 size bins per decade at NPL and 16 size bins per decade at LMR. The 3938 had a size resolution of 64 size bins per decade at both NPL and LMR. The averaged data was then plotted using the normalised particle number concentration ($dN/dlogD_p$) to allow a comparison of the two SMPS systems with different size bins across the measurement range (Figure 4 and Figure 5).

2.2 SMPS INSTRUMENTATION

Figure 1 - SMPS TSI 3936L75, consisting of an electrostatic classifier TSI 3080 and a long differential mobility analyser TSI 3081 (left), and condensation particle counter TSI 3775 (right).

Figure 2 - SMPS TSI 3938W50-CEN-7, consisting of an electrostatic classifier TSI 3082 and a wide-range differential mobility analyser TSI 3083 (bottom), and condensation particle counter TSI 3750-CEN-7 (top).

2.3 SITE SET UP

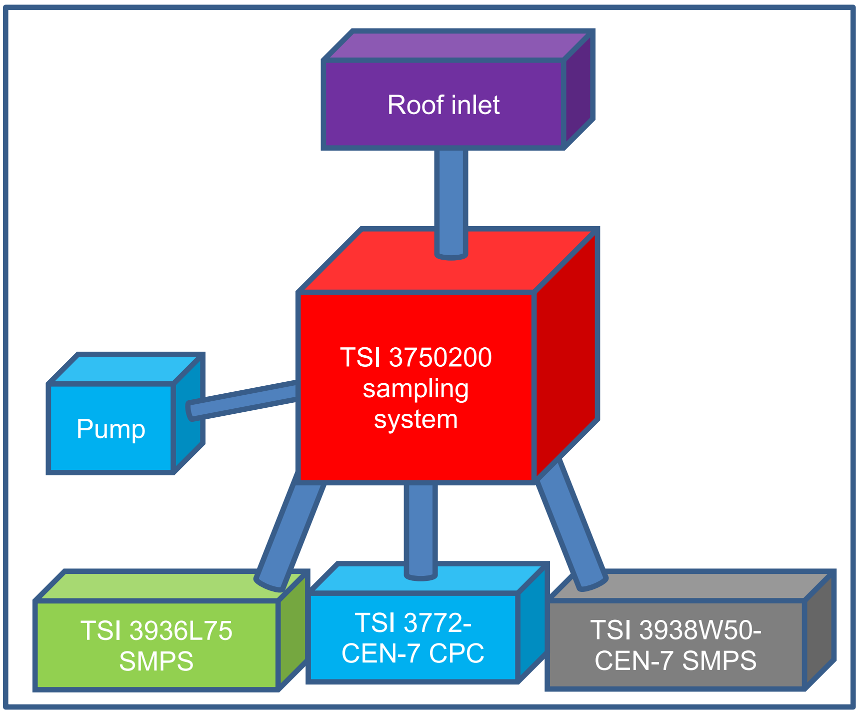

Figure 3 - Schematic set up at NPL and LMR.

3 RESULTS

The TSI 3938W50-CEN-7 SMPS had 100 % data capture over the measurement period at NPL between 12 and 29 July 2022.

The TSI 3938W50-CEN-7 SMPS had 99 % data capture over the measurement period at London Marylebone Road between 25 August and 6 October 2022.

Two figures were produced from the mean of a ratified subset of the data set at each site: Figure 4 for the comparison at NPL and Figure 5 for the comparison at LMR. Both figures follow the same format. The orange line is the particle size distribution for the old TSI 3936 SMPS which was the instrument to be replaced at the monitoring sites. The dashed blue lines represent the upper and lower bounds of a 10 % deviation from the TSI 3936 SMPS size distribution. The solid blue lines represent the upper and lower bounds of a 20 % deviation from the TSI 3936 SMPS size distribution. The green line is the particle size distribution for the TSI 3938 SMPS, which was the new instrument to be installed at the monitoring sites. The 10 % and 20 % bounds were chosen to align with a paper by Wiedensohler et al[3], which proposed a combination of these bounds for particle sizes from 20 nm – 800 nm. These also form the basis for the TROPOS SMPS calibration pass/fail criterion (against a reference SMPS) and the equivalent criterion in the European Technical Specification CEN/TS 17434:2020'[a,4]. It should be noted however, that only one of the instruments (TSI 3938W50-CEN-7 SMPS) is CEN compliant and therefore, a full comparison according to CEN/TS 17434:2020 cannot be performed.

Importantly, the y-axis of each plot is not simply particle number concentration but $dN/dlogD_p$ of the particle number concentration. This normalises for the different particle size bins used in the two SMPS systems, allowing a direct comparison of the size distributions.

Since these initial tests were carried out for this report, the TSI 3938 SMPS has been operating at LMR in 2023 and 2024. This data is displayed in Figure 6. The data for 2020, 2021 and 2022 are from the TSI 3936 SMPS. Figure 6 gives a much longer-term version of the comparison carried during this study, with the caveat that this data will be affected by year-to-year variability of the pollution environment at the LMR site, as this was not a collocated SMPS study.

NPL began reporting the total particle number concentration (TNC) for the SMPS at LMR with the 2024 data. Previously, only the TNC of the CPC at the LMR site had been reported. Figure 7 shows SMPS TCN and the CPC TNC for LMR. The reason for including this plot in this report, is to further investigate the apparent drop in TNC between the TSI 3936 and TSI 3938 SMPS instrument seen in Figure 5.

[a] CEN/TS 17434:2020 specifies a maximum deviation of ≤ 10 % for size channels between 20 nm and 200 nm compared to a size distribution reference SMPS, ≤ 50 % for 10 nm to 20 nm and ≤ 20 % for 200 nm to 800 nm

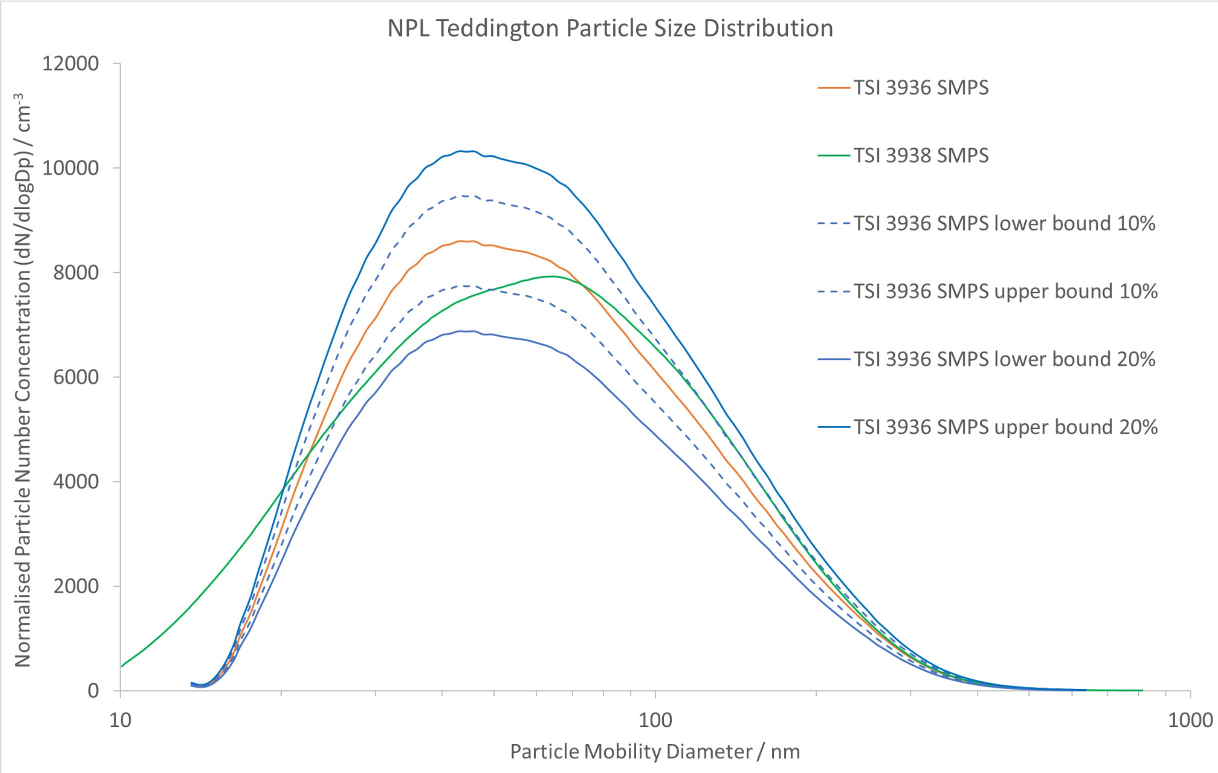

Figure 4 - SMPS comparison at NPL.

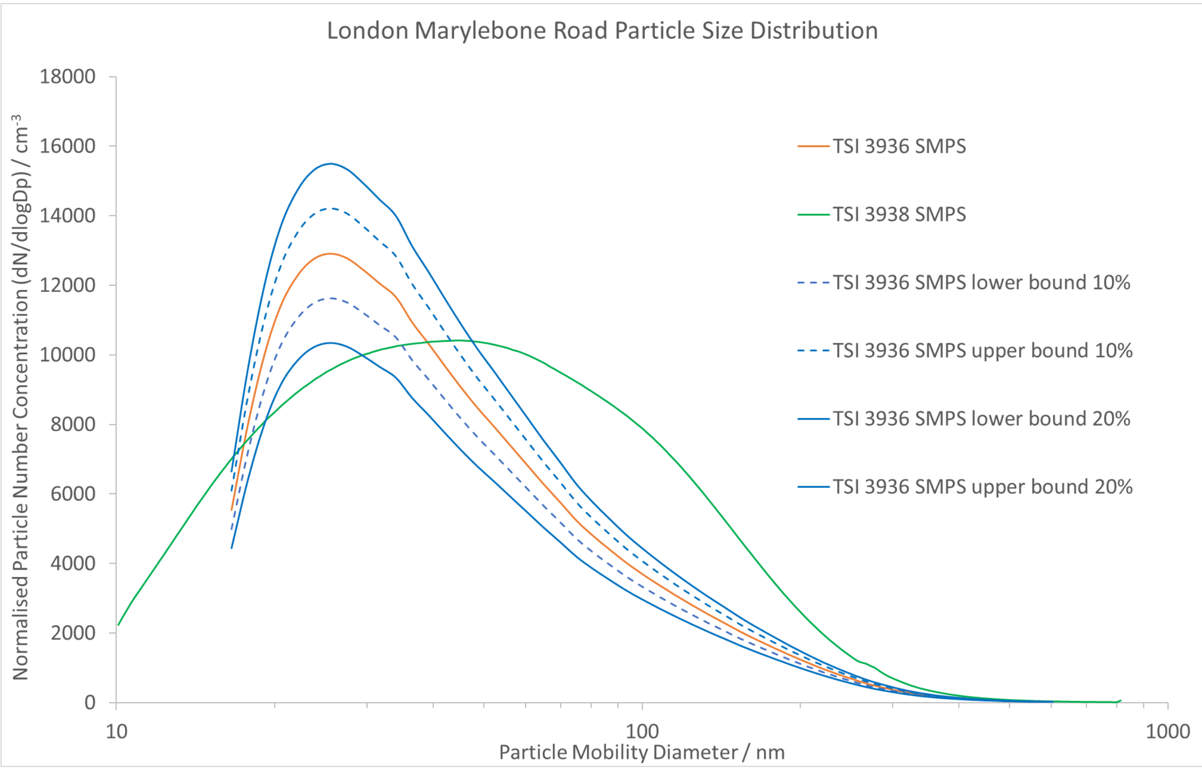

Figure 5 - SMPS comparison at London Marylebone Road.

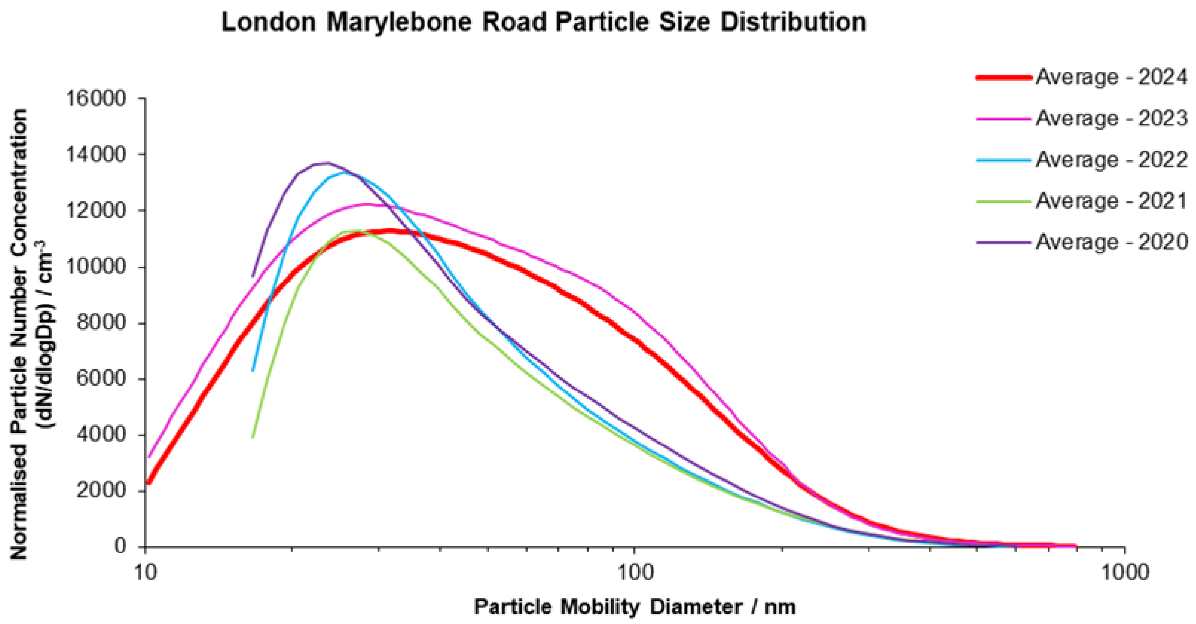

Figure 6 - Comparison of 2020 to 2024 annual average particle size distributions at London Marylebone Road[5]. Note that the 2020-2022 data were recorded using the 3936 SMPS and the 2022-2024 data using the 3938 SMPS.

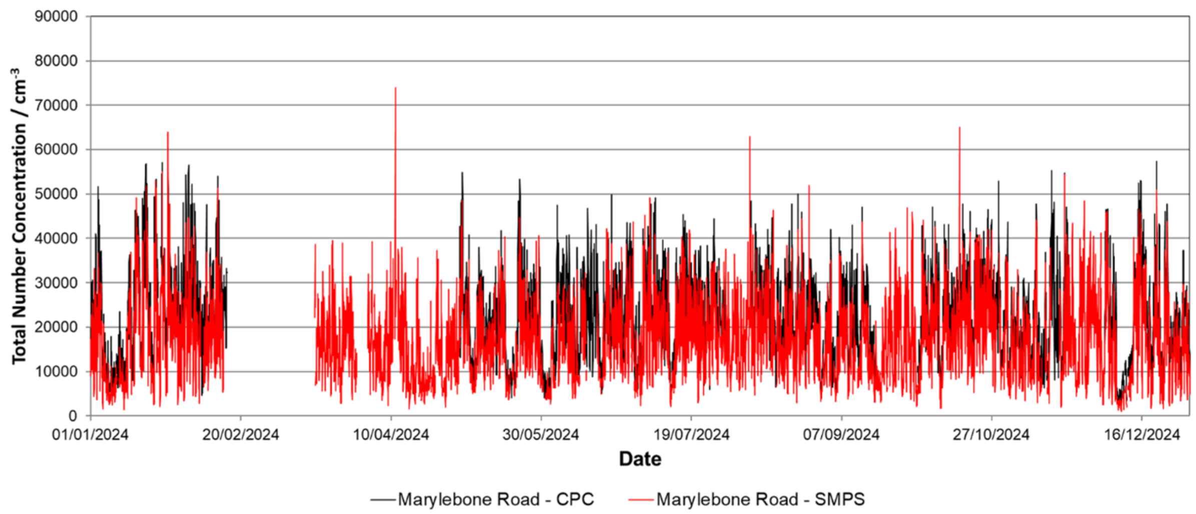

Figure 7 - Hourly total particle number concentrations from both CPC and SMPS instruments at London Marylebone Road in 2024[5]

4 DISCUSSION

The particle size distribution comparison at NPL shown in Figure 4 indicates a good correlation (± 10 %) between the two SMPS systems above a particle diameter of 50 nm. At particle diameters between 20 nm and 50 nm a correlation of ± 20 % is achieved. Below a particle diameter of 20 nm the two SMPS size distributions deviated from each other by more than 20 %. This is to be expected as the TSI 3938W50-CEN-7 SMPS has a lower scan size in the differential mobility analyser (DMA) of 10 nm compared to the nominally 16 nm lower scan size of the TSI 3936 SMPS DMA[5]. Additionally, the CPC behind the DMA in the TSI 3938W50-CEN-7 SMPS has a D_{50} of 7 nm, whereas the CPC behind the DMA in the TSI 3936L75 SMPS has a D_{50} of 4 nm[5]. These differences in the lower CPC size cut off (D_{50}) and the different scan range starting diameter between the two SMPS systems explain the increased deviation in particle number concentration below 20 nm.

The particle size distribution comparison at LMR shown in Figure 5 shows an agreement within the ± 20 % bounds of the two SMPS systems between a particle diameter of 20 nm and 50 nm (dipping slightly below the 20 % deviation line at 25 nm) although this falls outside of the ± 10 % bounds. Above a particle diameter of 50 nm a higher particle number concentration is measured by the TSI 3938W50-CEN-7 SMPS compared to the TSI 3936L75 SMPS. There is not a simple explanation for this difference, indeed the measurement of different particle number concentrations by different models of SMPS is being discussed under CEN TC264 WG32[1]. Below a particle diameter of 20 nm the two SMPS size distributions deviate from each other in the same way as in the comparison at NPL. Again, this is to be expected because of the different cut-off sizes described above.

It can also be seen that the peak height of the particle size distributions in both Figure 4 and Figure 5 is different between the two instruments, again there is not a simple explanation for this difference and it is being discussed under CEN TC264 WG32[1]. The TNC comparison plot between the SMPS and the CPC at LMR shown in Figure 7 displays a good agreement between the two instruments. Therefore, it is reasonable to conclude that the TNC measurement of the TSI 3938 SMPS is not in error. Figure 6 shows that although a similar shift in peak position is seen as in Figure 5, the decrease in peak height is not as prominent. As the results of Figures 6 and 7 are for a one-year period, it stands to reason that they will have a greater reliability than the initial 3-to-5-week tests carried out for this study, although it should be considered that there may be some changes in the pollution environment from year-to-year.

SMPS calibration plots carried out at NPL for the two instruments used in this study are included in Annex 1 (Figure 8 and Figure 9). Both instruments were working within acceptable parameters when used in this study.

5 CONCLUSION

The TSI 3938W50-CEN-7 SMPS was shown to operate successfully at both NPL and LMR sites (data capture 100 % and 99 % respectively). The size distribution comparison at NPL showed a good correlation within the between the two SMPS systems meeting the ± 10 % bounds above a particle diameter of 50 nm and the ± 20 % bounds at particle diameters between 20 nm and 50 nm. Below a particle diameter of 20 nm the two SMPS size distributions differed from each other by more than 20 %, but this was to be expected due to the different D_{50} of the CPCs and the difference in size scan ranges of the two SMPS instruments.

The size distribution comparison at LMR indicated a reasonable correlation (± 20 %) between the two SMPS systems between particle diameters of 20 nm and 50 nm. Again, below a particle diameter of 20 nm the two SMPS size distributions deviated from each other, but this was to be expected due to the different D_{50} of the CPC size cut offs and the lower scan range of the two SMPS instruments. Above a particle diameter of 50 nm at LMR a higher particle number concentration was measured by the TSI 3938W50-CEN-7 SMPS compared to the TSI 3936 SMPS. There is not a simple explanation for this difference, indeed such differences are being discussed under CEN TC264 WG32[1]. As this short study demonstrated that the two SMPS systems behaved differently when challenged with roadside aerosol composition, this shows that additional care must be taken when comparing results from different SMPS systems at roadside sites such as London Marylebone Road. The aerosol at the NPL site can be considered to be more urban background in nature than the LMR monitoring site. The ambient aerosol at LMR fluctuates more rapidly in size distribution and number concentration, due to being a roadside monitoring site, which might explain why there was not such a good agreement between the averaged size distributions. Different scan ranges and scan times in the different AIM software versions could also lead to differences. Recording additional parameters such as TNC or using a scan comparison or different averaging times could likely help to explain the complexity of the results but are beyond the scope of this report.

This report has shown that the change in SMPS instrumentation on the network will most likely result in a change in the shape of the particle size distribution at monitoring sites independent of any real changes in the aerosol size distribution. This was to be expected due to the difference in design, particle size range and D_{50} of the two instruments. We recommend the SMPS PCN data reported for 2023 and subsequent years has a note added to the UK-AIR website highlighting this change in instrumentation.

6 REFERENCES

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7 ANNEX 1 – NPL SMPS CALIBRATION PLOTS

The two SMPS instruments used in this study were calibrated at NPL using the NPL procedure TECHPRO0064. Polystyrene latex (PSL) spheres with NIST-traceable certified mean diameters were nebulised and dried to generate calibration aerosols to evaluate the accuracy of the size axis of the supplied differential mobility analyser (DMA). A stepwise method was used for each calibration, with each measurement point being held for 60 s. The stepwise operation was conducted in both directions. The method used is in accordance with ISO 15900:2020. The calibration data for both instruments passed the quality checks of the procedure.

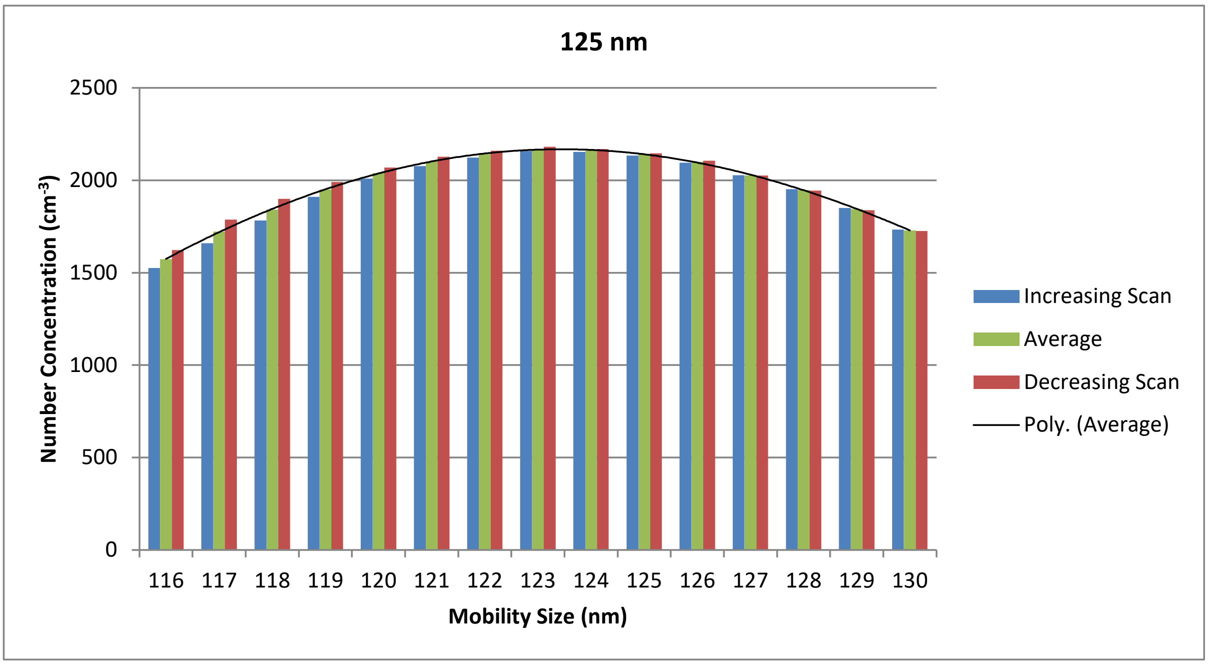

Figure 8: Plot of the ~125 nm stepwise calibration of the TSI 3938W50-CEN-7 SMPS taken from the NPL calibration certificate NPL_DMA_CAL_102

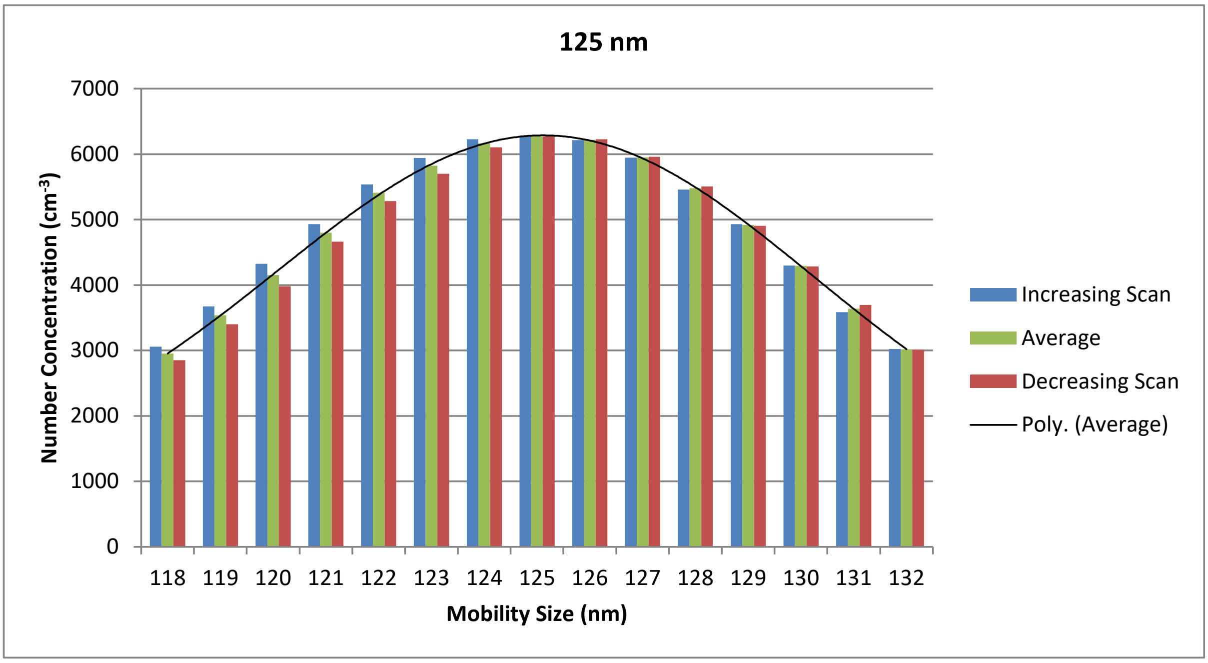

Figure 9: Plot of the ~125 nm stepwise calibration of the TSI 3936 SMPS taken from the NPL calibration certificate NPL_DMA_CAL_96