Sensorbee AB

Test of the Sensorbee Air Pro 2 Sensor System for use as an Indicative Monitor for PM_{10} and $PM_{2.5}$

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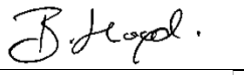
Prepared By	B. Lloyd	Consultant	
Approved By	D Harrison	Technical Director	

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EXECUTIVE SUMMARY

Two Sensorbee Air Pro 2 Sensor Systems, both of which monitor PM_{10} and $PM_{2.5}$, were operated alongside PM_{10} and $PM_{2.5}$ Fidas 200S. A comparison was made in line with the Performance Standards for Indicative Ambient Particulate Monitors, Version 4, dated August 2017[1]. In accordance with the criteria described therein, a summary of the performance of the instrument is given in the overleaf Table and summarised below.

The Sensorbee Air Pro 2 Sensor System passes all criteria set out in the Performance Standard for Indicative instruments for collecting PM_{10} and $PM_{2.5}$ data.

In order to be used for indicative purposes the Sensorbee Air Pro 2 Sensor System must be set up in the same configuration as which it was tested, namely the following must be installed:

- Sensor Type and Firmware Version: Tera NextPM Adjusted and 10.47. Modifications to the sensor firmware version would require verification by the certification committee. Modifications to the sensor itself may require repeating the field test or comparing systems operating different versions of the sensor to show that there are no differences to the measurements.

- Firmware and Algorithm Version of Sensor System: 3.36.2-pro2 and PMAlgo 1.0. Modifications to the algorithm will need approval by the certification committee and if modifications are made to the PM mass calculation, then this would potentially require the field test to be repeated.

Certification Range:

PM_{10}	To be decided by the certification committee
$PM_{2.5}$	To be decided by the certification committee

[1] Performance Standards for Indicative Ambient Particulate Monitors, Version 4, Environment Agency, August 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642895/LIT_7070.pdf

Test	Results	MCERTS Specification
Constancy of the sample volumetric flow	Prior permission was sought and received not to perform this test as the flow rate is too low to be accurately monitored.	Sample volumetric flow averaged over the sampling time to remain constant within ± 3% of the rated value. All instantaneous values to remain within ± 5% of the rated value.
Tightness of the sampling system	1.62%	Leakage not to exceed 2% of sampled volume.
Maintenance interval	Minimum of 2 years.	Greater than or equal to two weeks.

Performance characteristics when monitoring PM_{10}		
Test	**Results**	**MCERTS Specification**
Intra-instrument uncertainty for the reference method	Only one PM_{10} Fidas was used during the testing of the Sensorbee Air Pro 2. A default value of 0.67 µg m^{-3} was used.	≤ 2.5 µg m^{-3}. If only a single reference method instrument is available, then values from previous tests performed by the same laboratory/network using identical pattern of samplers can be used. If those are not available a default value of 0.67 µg m^{-3} can be assumed.
Intra-instrument uncertainty for the candidate method	0.23 µg m^{-3} (All data, n = 81) All data are less than 30 µg m^{-3}.	≤ 5 µg m^{-3} for all data as well as for the subsets: less than and greater than or equal to 30 µg m^{-3} for PM_{10}. The “greater than” data subset shall contain at least 8 data pairs. If 80 data pairs are produced still without generating the required 8 data pairs in the “greater than” subset then this is considered sufficient and the testing may be terminated.
Highest resulting uncertainty estimate comparison against data quality objective (measurement uncertainty)	All Data: W_{CM} = 31.3% (n = 81) All data are less than 30 µg m^{-3}.	W_{CM} ≤ 50%. The resultant expanded uncertainty is assessed for the full dataset, and the subset of data greater than or equal to 30 µg m^{-3}.

Performance characteristics when monitoring $PM_{2.5}$		
Test	**Results**	**MCERTS Specification**
Intra-instrument uncertainty for the reference or equivalent method	Only one $PM_{2.5}$ Fidas was used during the testing of the Sensorbee Air Pro 2. A default value of 0.67 µg m^{-3} was used.	≤ 2.5 µg m^{-3}. If only a single reference method instrument is available, then values from previous tests performed by the same laboratory/network using identical pattern of samplers can be used. If those are not available a default value of 0.67 µg m^{-3} can be assumed.
Intra-instrument uncertainty for the candidate method	0.16 µg m^{-3} (All data, n = 81) All data are less than 18 µg m^{-3}.	≤ 5 µg m^{-3} for all data as well as for the subset: less than and greater than or equal to 18 µg m^{-3} for $PM_{2.5}$. The “greater than” data subset shall contain at least 8 data pairs. If 80 data pairs are produced still without generating the required 8 data pairs in the “greater than” subset then this is considered sufficient and the testing may be terminated.
Highest resulting uncertainty estimate comparison against data quality objective (measurement uncertainty).	All Data: W_{CM} = 34.0% (n = 81) All data are less than 18 µg m^{-3}.	W_{CM} ≤ 50%. The resultant expanded uncertainty is assessed for the full dataset, and the subset of data greater than or equal to 18 µg m^{-3}.

1. Legislative Background

The European Commission (EC) Directive 2008/50/EC[2] was accepted into UK law in June 2010. Member States of the European Union (EU) are required to measure the mass of particulate matter (PM) below 10 microns diameter (PM_{10}) and below 2.5 microns diameter ($PM_{2.5}$). Concentrations are reported as 24-hour averages, and for PM_{10} it is a requirement that there are fewer than 35 exceedences of 50 µg m^{-3} per year, and that the annual average is below 40 µg m^{-3}. For $PM_{2.5}$ there is no daily limit, though there is an annual average target of 10 µg m^{-3}. The European reference methods for quantifying PM_{10} and $PM_{2.5}$ are set out in the standard EN12341[3]. The reference instruments sample one filter every 24 hours (as per the reporting requirements), and there is a potential delay of several weeks before the filters are weighed, and the concentrations calculated.

While there is no legal mandate, there is often a need to have real-time data at a frequency of at least hourly. In light of this, the EC allows Member States to use instruments that can be proven equivalent to the European Reference Methods[4]. Many instruments are available that use a variety of methods to quantify PM. Candidate instruments are tested in duplicate against the reference methods for a minimum of 40 days at each of a minimum of four tests that cover a range of test locations and seasons. A mathematical analysis is undertaken to show that the slope and intercept are not significantly different from 1 and 0 respectively, and that the expanded uncertainty at the limit value is less than 25%. It is possible for a slope and/or intercept correction factor to be introduced; however, it is a requirement that the same correction factors are used for all the datasets.

Within the United Kingdom (UK), the Environment Agency (in collaboration with CSA) runs a Monitoring Certification Scheme (MCERTS) for Continuous Ambient Mass Monitoring Systems (CAMS) and this has been used successfully for several years to certify instruments that are proven equivalent to the European Reference methods[5]. Such certified instruments tend to be relatively large and expensive and often require air-conditioned enclosures in which to operate effectively.

Within the UK, there is often a requirement to monitor PM using cost-effective weatherproof methods that provide real-time data at a high frequency of 15 minutes or lower. Such equipment needs to be able to accurately identify that there has been a significant spike in PM concentrations, but it is not necessarily a requirement to accurately know the magnitude of this spike. As such, these instruments could be described as giving an “indication” of PM but are not intended to be equivalent to the European Reference Methods, and therefore are not suitable for compliance reporting. Typically, “indicative” methods can be used as a first approximation to compliance and then followed with more accurate methods that conform to the European reference methods for compliance measurement purposes. Indicative instruments are often situated at industrial processes that are regulated by the EA or Local Authorities (LAs).

The EA have developed a certification scheme for indicative instruments[1]. As with the equivalent tests, candidate instruments are tested in duplicate against the reference or equivalent method for a minimum of 40 days; however, it is just a requirement that there is a single test rather than at least four. Further, the mathematical analysis requires that the expanded uncertainty at the limit value is less than 50%, rather than 25% as is required for equivalent instruments.

[2] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

[3] Standard EN12341:2014 Ambient air - Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter

[4] European Standard EN16450:2023 Ambient air - Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2,5}$)

[5] https://www.csagroup.org/en-gb/services/mcerts/mcerts-product-certification/mcerts-certified-products/mcertscertified-productscontinuous-ambient-air-monitoring-system-mcerts-for-uk-particulate-matter/

2. Methodology

From the 9th July 2024 to the 28th September 2025, two candidate Sensorbee Air Pro 2 sensor systems were collocated with a Fidas 200S measuring both PM_{10} and $PM_{2.5}$. The Fidas 200S has previously been shown to be equivalent to the European reference Method. The location of the tests was at the London Teddington Bushy Park monitoring station. The zero leak tests were carried out by the National Physical Laboratory (NPL) which has ISO17025 accreditation for these tasks.

The serial numbers for the two Sensorbee Air Pro 2 Sensor Systems tested were sb_jxje and sb_9jlz.

The Sensor Type and Firmware Version were Sensor Type Tera NextPM Adjusted, Firmware Version 10.47.

The Sensor System was Firmware Version 3.36.2-pro2, Algorithm Version PMAlgo 1.0.

The instruments produced hourly average concentrations which were averaged to 24 hour average concentrations. A 24 hour average was only valid when there was at least 75% data capture (18 hourly average concentration data values) for that day.

The Sensorbee Air Pro 2 sensor systems performed well throughout tests. Over the 81-day period, no hourly average data was missing, and therefore all 24 hour averages were valid. No days of data were lost due to data capture of the Fidas 200S, meaning that all 81 days had valid data for comparison.

The following Sections discuss the results in the order that they are discussed in the performance standard.

3. Certification Range

The instrument is designed to operate over a measurement range of 0 µg m^{-3} to 1000 µg m^{-3}.

As with all certification projects, it is not always possible to achieve these high concentrations over the course of the test. The highest concentrations observed during the Teddington tests were:

- Maximum Hourly PM_{10} 50.5 µg m^{-3};
- Maximum Hourly $PM_{2.5}$ 20.4 µg m^{-3};
- Maximum 24 hour PM_{10} 23.6 µg m^{-3};
- Maximum 24 hour $PM_{2.5}$ 13.1 µg m^{-3}.

The decision as to the appropriate certification range is left to the Certification Committee.

4. Constancy of Sample Volumetric Flow

Prior permission was sought and received not to perform this test as the flow rate is too low to be accurately monitored.

5. Tightness of the Sampling System

The performance standard states that “the tightness of the sampling system shall not exceed 2% of sampled volume”. These tests were performed on the same systems to those employed in the Teddington Bushy Park tests.

Leak tests were performed by placing a HEPA filter on the inlet to the instruments on 2nd October 2025 for sb_jxje and 6th October 2025 for sb_9jlz at the National Physical Laboratory (NPL), Teddington. The zero leak tests were undertaken by NPL which has ISO17025 accreditation for these tasks.

For sb_jxje, PM_{10} and $PM_{2.5}$ particle counts were 126.91 before the HEPA test, decreasing to 0.00 after application of the HEPA filters. This corresponds to a leak rate of 0.00% for PM_{10} and $PM_{2.5}$.

For sb_9jlz, PM_{10} and $PM_{2.5}$ particle counts were 70.06 before the HEPA test, decreasing to 1.13 after application of the HEPA filters. This corresponds to a leak rate of 1.62% for PM_{10} and $PM_{2.5}$.

All leak rates are below the required 2%, but the highest of these (1.62%) shall go on the certificate.

6. Intra Instrument Uncertainty of the Reference or Equivalent Method

As only a single Fidas 200S for PM_{10} and $PM_{2.5}$ were operated during the testing of the Sensorbee Air Pro 2, a default value of 0.67 µg m^{-3} was used as the 24 hour intra instrument uncertainty for both PM_{10} and $PM_{2.5}$. As such, the instrument meets the intra instrument uncertainty for the reference or equivalent method specification for both PM_{10} and $PM_{2.5}$.

For PM_{10}, the 24 hour intra instrument uncertainty was shown to be 0.23 µg m^{-3} and this value is used in the calculation of the Sensorbee Air Pro 2 PM_{10} expanded uncertainty. As such, the instrument meets the intra instrument uncertainty for the reference or equivalent method specification for PM_{10}.

For $PM_{2.5}$, the 24 hour intra instrument uncertainty was shown to be 0.16 µg m^{-3} and this value is used in the calculation of the Sensorbee Air Pro 2 $PM_{2.5}$ expanded uncertainty. As such, the instrument meets the intra instrument uncertainty for the reference or equivalent method specification for $PM_{2.5}$.

7. Intra Instrument Uncertainty of the Candidate Method

The performance standard states that the "Intra instrument uncertainty for the candidate method should be ≤5 µg m^{-3} for all data as well as for the subsets: less than and greater than or equal to 30 µg m^{-3} for PM_{10} and 18 µg m^{-3} for $PM_{2.5}$. Each "greater than" data subset shall contain at least 8 data pairs. If 80 data pairs are produced still without generating the required 8 data pairs in the "greater than" subset then this is considered sufficient and the testing may be terminated".

Calculations of the intra instrument uncertainty were undertaken using the methodology described in EN16450[4], and the results are shown for PM_{10} in Table 7.1. Calculations were performed using the 24 hour average data and the regression was forced through the origin.

For all three categories, the intra instrument uncertainty (u_{bs}) was lower than the required 5 µg m^{-3}, and as such, the instrument meets the intra instrument uncertainty for the candidate method specification for PM_{10}. Note that as after 81 days there were no days where PM_{10} was ≥ 30 µg m^{-3}, the decision was taken to stop the test in accordance with the requirements of the performance standard. All 81 days had valid data for comparison.

Table 7.1 - Intra instrument uncertainties for the Sensorbee Air Pro 2 for PM_{10}.

All Data		**< 30 µg m^{-3}**		**≥ 30 µg m^{-3}**	
n	**u_{bs} / µg m^{-3}**	**n**	**u_{bs} / µg m^{-3}**	**n**	**u_{bs} / µg m^{-3}**
81	0.23	81	0.23	0	NA

The results for $PM_{2.5}$ are shown in Table 7.2. Calculations were again performed on the 24 hour average data and the regression was forced through the origin as permitted by the performance standard. For all three categories, the intra instrument uncertainty (u_{bs}) was lower than the required 5 µg m^{-3}, and as such, the instrument meets the Intra instrument uncertainty for the candidate method specification for $PM_{2.5}$. Note that as after 81 days there were no days where $PM_{2.5}$ was ≥ 18 µg m^{-3}, the decision was taken to stop the test in accordance with the requirements of the performance standard. All 81 days had valid data for comparison.

Table 7.2 - Intra instrument uncertainties for the Sensorbee Air Pro 2 for $PM_{2.5}$.

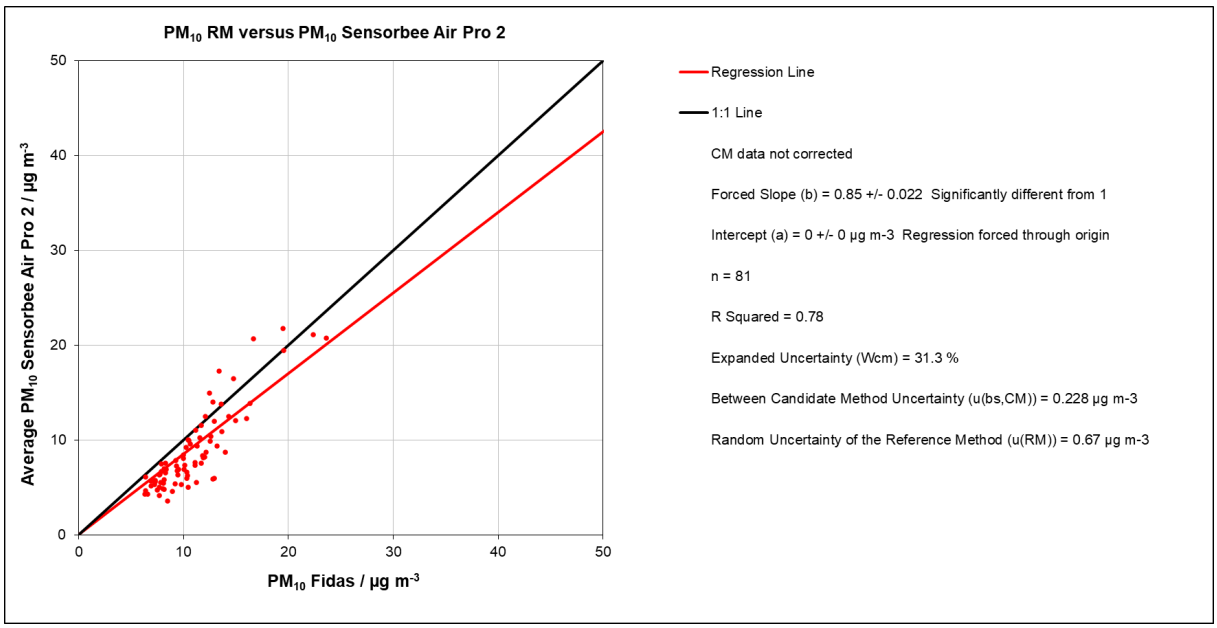
All Data		**< 18 µg m^{-3}**		**≥ 18 µg m^{-3}**	
n	**u_{bs} / µg m^{-3}**	**n**	**u_{bs} / µg m^{-3}**	**n**	**u_{bs} / µg m^{-3}**
81	0.16	81	0.16	0	NA

8. Expanded Uncertainty of the Candidate Method for PM_{10}

The performance standard states that the highest expanded uncertainty estimate (W_{CM}) should be below 50%. For PM_{10}, the expanded uncertainty is assessed for the full dataset, and the dataset split to be greater than 30 µg m^{-3}. Of the full dataset at least 8 pairs of the results obtained by employing the standard method must be greater than 30 µg m^{-3}. If 80 data pairs are produced still without generating the required 8 data pairs in the "greater than" subset then this is considered sufficient and the testing may be terminated. In accordance with the performance standard, the expanded uncertainties were calculated at 50 µg m^{-3} using the methodology described in EN16450[4].

The 24 hour average concentrations of PM_{10} were calculated from the hourly average data. The 24 hour averages of sensor systems sb_jxje and sb_9jlz were then averaged. These were plotted against the PM_{10} Fidas Equivalent Method data (Figure 8.1). It was decided to force the orthogonal regression through the origin, which is permitted according to the performance standard.

Figure 8.1 - Comparison of 24 hour averages of PM_{10} Sensorbee Air Pro 2 against the PM_{10} Fidas (All data).



The figure gives the slope (b); intercept (a); number of data points (n); R^2; the expanded uncertainty (W_{CM}); and the between candidate and reference method uncertainties discussed in the previous two sections. The expanded uncertainty is 31.3%, which is below the required 50%.

All 81 PM_{10} data points are less than 30 µg m^{-3}. Therefore, testing was terminated after 81 data pairs had been collected as permitted by the performance standard and the expanded uncertainty for the "greater than" subset was not calculated.

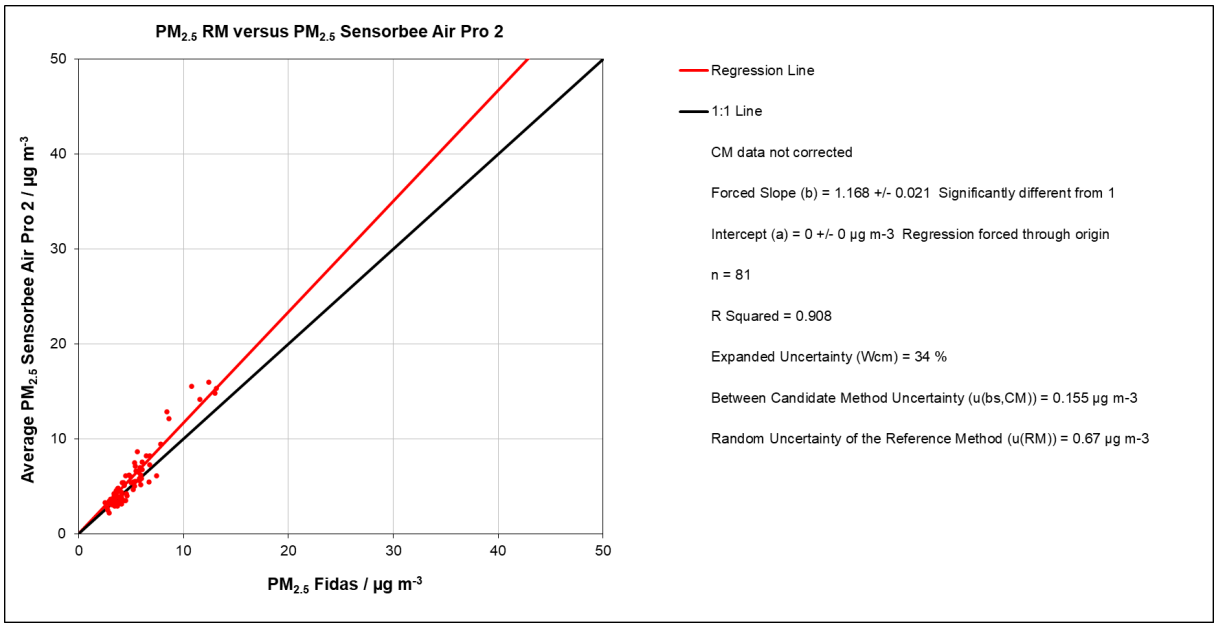
As the expanded uncertainty of the whole dataset was below 50%, the Sensorbee Air Pro 2 sensor system meets the performance standard for PM_{10}.

9. Expanded Uncertainty of the Candidate Method for $PM_{2.5}$

The performance standard states that the highest expanded uncertainty estimate (W_{CM}) should be below 50%. For $PM_{2.5}$, the expanded uncertainty is assessed for the full dataset, and the dataset split to be greater than 18 µg m^{-3}. Of the full dataset at least 8 pairs of the results obtained by employing the standard method must be greater than 18 µg m^{-3}. If 80 data pairs are produced still without generating the required 8 data pairs in the "greater than" subset then this is considered sufficient and the testing may be terminated. In accordance with the performance standard, the expanded uncertainties were calculated at 30 µg m^{-3} using the methodology described in EN16450[4].

The 24 hour average concentrations of $PM_{2.5}$ were calculated from the hourly average data. The 24 hour averages of sensor systems sb_jxje and sb_9jlz were then averaged. These were then plotted against the $PM_{2.5}$ Fidas Equivalent Method data. It was again decided to use orthogonal regression forced through the origin, which is permitted according to the performance standard. The plot is shown in Figure 9.1 and the expanded uncertainty is 34.0% which is below the required 50%.

Figure 9.1 - Comparison of 24 hour averages of $PM_{2.5}$ Sensorbee Air Pro 2 against the $PM_{2.5}$ Fidas (All data).



All 81 $PM_{2.5}$ data points are less than 18 µg m^{-3}. Therefore, testing was terminated after 81 data pairs had been collected as permitted by the performance standard and the expanded uncertainty for the "greater than" subset was not calculated.

As the expanded uncertainty of the whole dataset was below 50%, the Sensorbee Air Pro 2 sensor system meets the performance standard for $PM_{2.5}$.

10. Maintenance Interval

The performance standard states that the maintenance interval should be a minimum of 2 weeks. During the 11.5 weeks that the instruments were operational at Teddington Bushy Park, no maintenance was required. The manufacturer states that the maintenance interval is a minimum of two years and recommends that the PM sensors are replaced every 24 months.

As the maintenance service cycle is a minimum of two years, the instrument meets the criterion of a greater than or equal to 2 weeks maintenance interval.

11. Conclusions

The Sensorbee Air Pro 2 sensor systems pass all the criteria set out in the Performance Standard for indicative instruments Version 4 for collecting PM_{10} and $PM_{2.5}$ data when operated with Firmware Version 3.36.2-pro2 and Algorithm Version PMAlgo 1.0.

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