

TSI® Instrumentation for Measuring Atmospheric Particles



According to EN 16976:2024 and
CEN/TS 17434:2020

A Buyer's Guide to European Standard Compliance (A4)

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Introduction

While air quality varies significantly around the globe, there is also variation in how air quality is measured. Specifically, within atmospheric aerosol measurement, the two most widely-used quantification approaches are measuring particle mass (PM) and particle number (PN). While US and other regulations are based on particle mass, there is a growing movement towards also quantifying particle number.

While number-based measurements of atmospheric aerosol have been made for years in numerous countries often by scientific/research networks or measurement campaigns, it has been difficult to compare data gathered internationally. This difficulty is due to the fact that particle measuring sites were sometimes using different sampling, conditioning, and particle measurement instrumentation. “Harmonizing” these aspects is key to comparing data and drawing conclusions relevant to all the fields relevant to ambient aerosols, including public health, emissions regulations, and climate.

Basics of the CEN TS and EN Standards for Atmospheric Monitoring

The overall goal of the CEN¹ standards pertinent to atmospheric monitoring is to “harmonize” the measurements taken. The technical committee (CEN/TC 264) “Air quality” has a dedicated working group of experts. That means for atmospheric air quality monitoring data to be compliant with the relevant CEN standards, that data must be collected using compliant sampling, conditioning, and particle measurement instrumentation. These standards specify what instrumentation must be used, what features an instrument must have and/or criteria it must fulfill, as well as how data must be reported.

EN 16976:2024

EN 16976:2024 “Ambient air - Determination of the particle number concentration of atmospheric aerosol” pertains to measurements of particle number concentration and was published in 2024. This EN supersedes the previous CEN/TS 16976:2016.

CEN/TS 17434

While EN 16976:2024 pertains to particle number, CEN/TS 17434 “Ambient air - Determination of the particle number size distribution of atmospheric aerosol using a Mobility Particle Size Spectrometer (MPSS)” pertains to particle size distribution. The most recent finalized revision of the standard was released in 2020. There is currently work in progress to transfer this CEN/TS into a full EN standard in the same way as done for particle number. Changing the D50 requirement for the CPC from 7 nm to 10 nm is relevant since CEN/TS 17434 refers to the old CEN/TS 16976.

Relevance of these two CEN Standards

These two CEN standards are relevant to any governmental, private or academic institution which intends to measure ultrafine and fine particles in ambient air. While some may consider following those standards only partially, the comparability, traceability and acknowledgment of the results is established by these harmonized procedures. Adhering to the prescribed measurements secures the reputation of the air quality assessment.

Structure of this Buyer’s Guide to CEN Compliance

This Buyer’s Guide is divided into five sections. Each section is devoted to a main function within atmospheric aerosol monitoring: [sampling and drying](#), [dilution](#), [humidity measurement](#), [particle number concentration measurement](#), and [particle size distribution measurement](#).

Within each section, this Guide uses tables to detail the requirements that the two standards (EN 16976:2024 and CEN/TS 17434:2020) specify for instrumentation. When applicable, details pertaining to specific line items within a table may be found in the text following that table.

Following the requirements, a subsection titled “The TSI® Solution” is devoted to the relevant TSI® instrument to demonstrate how the instrument meets the listed requirements. At the end, a final section titled “[The Full TSI® Solution](#)” provides a complete overview and demonstrates compliance of all components.

¹ CEN stands for European Committee for Standardization. CEN is an association – officially recognized by the European Union (EU) and by the European Free Trade Association – that brings together the National Standardization Bodies of 33 European countries. CEN is committed to develop European Standards (EN) for various kinds of products, materials, services, and processes. TS stands for Technical Specification. A TS is a normative document that is established by an appropriate technical body within CEN. After some years a TS can, if the relevant stakeholders view it as worthwhile, be further developed into a European Standard (EN). All TS and EN are approved through a vote by CEN national members.

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Section 1: Sampling and Drying

Any measurement can only be as representative as the sample that has been taken for analysis. As is the case with any other scientific endeavor, care must be taken to ensure that the aerosol sample delivered to the particle instrument is representative of the aerosol one wishes to characterize. Specifically, the sampling and conditioning process should aim to preserve the size distribution and concentration of the sampled aerosol as much as possible. Condensation of water from the humid ambient air that is sampled is affecting the measurement results and can harm even the instruments.

A CEN-compliant sampling system includes several components: a PM10 sampling head, a sampling tube, a cyclone, and a dryer. Use of the cyclone is optional and depends upon the size distribution of the aerosol to be sampled. Design and performance requirements are covered in the following tables.

Dilution is optional; a diluter should only be used under certain conditions as specified by EN 16976:2024 Section 5.1.3 (see Table 4 line item #1). Design and performance requirements for the diluter are covered in "[Section 2: Dilution \(optional\)](#)" within this document.

(continued on next page)

Sampling: Design Requirements

Table 1: Design requirements for the sampling inlet (not including the dryer).

Line item	Design aspects		Section:		CEN requirement
			16976	17434	
1	Overall system		7.1	8.1	<ul style="list-style-type: none"> The sampling system must bring a sample of ambient air from the outdoors to the inside of the monitoring station while preserving the size distribution of the ultrafine particles in that air. The sampling system must condition the aerosol to defined relative humidity and temperature.
2	Sampling head	Design	5.1.1	6.1.1	<ul style="list-style-type: none"> The sampling system's design must permit that the sampling process results in representative sampling, even under a wide range of wind conditions.
3		Cutpoint			<ul style="list-style-type: none"> Because ambient air can contain micrometer-scale particles, an inlet that removes such particles must be used; PM10 and PM2.5 inlets are permitted.
4	Pre-separator			7.1	<ul style="list-style-type: none"> A pre-separator should be used if the aerosol to be measured includes a nontrivial amount of particles larger than can be measured by the particle sizer. The pre-separator can be an impactor or cyclone, and may be included either in the particle sizing instrument or in the sampling system.
5	Sample tube	Vertical	5.1.1	6.1.1	<ul style="list-style-type: none"> The primary sampling tube should ideally be entirely vertical.
6		Gas sampling			<ul style="list-style-type: none"> Particle sampling should be conducted independent from gas sampling.
7		Isoaxial sampling			<ul style="list-style-type: none"> The sampling system must draw in a much larger flow rate of air than is required by the particle measurement instruments. The purpose of this larger primary flow is to reduce losses of particles due to diffusion. The secondary flow – the portion of this primary flow that will go to the instrument(s) – should be sampled isoaxially (i.e. in a centered fashion) from the primary flow, and this sampling tube must be kept short.
8		Laminar flow			<ul style="list-style-type: none"> Within the primary sampling tube, the air flow should be laminar, in order to reduce particle loss due to turbulence within the sampling tube.
9	Materials	Sampling lines	5.1.1		<ul style="list-style-type: none"> The sampling system should be manufactured from a material that is conductive and corrosion-resistant. It must have a smooth surface and be electrically grounded.
10		Flexible tubing		6.1.1	<ul style="list-style-type: none"> Conductive flexible tubing may be used for connecting the sampling system to instrumentation, but the lengths of such tubing must be kept short (i.e. <50 cm).

The pre-separator (line item #4) is optional; if used, it may be housed in either the sampling system or within the MPSS. Refer to [Table 13](#) line item #1.

Sampling: Performance Requirements

Table 2: Performance requirements for the sampling inlet (not including the dryer).

Line item	Performance aspects	Section:		CEN requirement	
		16976	17434		
1	Diffusion losses	5.1.1		<ul style="list-style-type: none"> Diffusion losses within the sampling system must be <25% for 10 nm particles. 	
2			6.1.1	<ul style="list-style-type: none"> Diffusional losses of particles within the sampling system must be determined, and the particle data must be corrected for those losses. 	
3			8.3	<ul style="list-style-type: none"> When determining diffusion losses of particles, theoretical calculations may be used for simple geometries. For more complex geometries, either an experimental investigation of losses, or published peer-reviewed data, may be used. 	
4	Laminarity	7.6		<ul style="list-style-type: none"> Whether flow in the primary sampling tube is laminar or not can be determined by measuring the primary sampling flow, and using that measurement along with tube geometry to calculate the Reynolds number. The flow meter used to measure the primary flow must have an accuracy better than... 	5%
5			8.6		2%

The equivalent length of the sampling system (and thus diffusional losses within the system – see line item #3) depends upon the components used and the lengths of those components. Some aspects of the sampling system will necessarily vary from location to location – specifically, the length of the sampling tube, the optional inclusion of cyclone (and if included, which cut point of cyclone).

The resolution of the discrepancy regarding the flow meter accuracy (line items #4–5) is subject to revisions by the CEN committees. TSI® flow meters fulfill the stricter accuracy of ±2%.

Drying: Design and Performance Requirements

It is critical that the aerosol is dried sufficiently (and repeatably across sites) prior to measurement. This has several benefits. First, it ensures the accuracy of size measurements even when particles are prone to growing under humid conditions due to their chemical composition (hygroscopicity). Second, it permits intercomparisons of size measurements between sites since hygroscopic growth is no longer a complicating factor. Finally, drying the sample flow (as well as the particles contained within that flow) protects the instruments from condensation, thus protecting their performance and prolonging their maintenance interval.

Table 3: Design and performance requirements for the drying system included in the sampling inlet.

Line item	Design aspects	Section:		CEN requirement
		16976	17434	
1	Influence of ambient conditions on drying setup	5.1.2	6.1.2	<ul style="list-style-type: none"> ■ Whether drying is necessary depends upon ambient conditions. The CEN standards specify the following three scenarios: <ul style="list-style-type: none"> ■ For warm and very dry environments, no aerosol dryer is needed. ■ For moderately humid environments, the secondary flow must be dried. ■ For environments that are humid enough that the primary sampling flow may experience condensation upon being cooled to the temperature of the environmentally-controlled monitoring station, the primary flow must be dried. The secondary flow may require additional drying.
2	Drying method	5.1.2	6.1.2	<ul style="list-style-type: none"> ■ Either of two methods may be used to dry the aerosol: a membrane dryer, or dilution with dry air.
3	Permissible humidity at CPC and MPSS inlet	7.4	8.2, 8.4	<ul style="list-style-type: none"> ■ Sample drying must achieve a relative humidity, as measured at the instrument inlet, below 40% relative humidity (%RH). The humidity sensor must have an accuracy of 3% (CPC) and 5% (MPSS) in the range 20-80% RH¹.

¹ It is anticipated that as CEN/TS 17434 is finalized into an EN standard, the required accuracy for the RH sensor will change from 5% to 3%, in order to match the accuracy requirement in EN 16976:2024.

The TSI® Solution: Sampling System for Atmospheric Particles 3750200

The [Sampling System for Atmospheric Particles](#) from TSI® samples and conditions atmospheric aerosol in compliance with the requirements of EN 16976:2024 and CEN/TS 17434:2020 as detailed in Tables [1](#), [2](#), and [3](#).

The sampling system is designed specifically for aerosol sampling ([Table 1](#) line item #6) and delivers a representative sample of atmospheric aerosol to the particle measurement instruments attached to its outlet. Standard components – including a PM10 sampling head and optional PM2.5 cyclone – take in the sample from outside with a high, laminar primary flow (16.67 L/min). With a secondary flow (dried aerosol flow) of typically up to 4 L/min, the sampling system easily permits the use of several particle instruments simultaneously for continuous monitoring. Additional particle instrumentation for temporary comparison purposes can also be connected without changing the inlet characteristic (losses, drying efficiency).

The dryer used in the sampling system is a membrane (Nafion™) dryer ([Table 3](#) line item #2), and it achieves a relative humidity (RH) of <40% when a sufficient strong vacuum pump is used ([Table 3](#) line item #3). For locations that may experience dewpoints above 25°C, the sampling system can be configured with a pump which supplies a deeper vacuum to enhance dryer performance. For further details on the pumps, refer to the Solutions Brochure ([US](#)) and ([A4](#)).

The final RH of the sample flow is measured using the Relative Humidity and Temperature Sensor RHT3000, covered in [Section 3](#). This sensor is compatible with both the particle counter and particle sizer; whichever instrument it is connected to (via USB cable) will record the sample relative humidity and temperature alongside with particle data when using TSI® AIM Monitoring software.

Diffusion losses in the sampling system are smaller than 25% for 10 nm particles ([Table 2](#) line item #1), assuming a primary sampling tube length of 1.5 m and including all components (PM10 head, PM2.5 cyclone, Nafion™ dryer, flow splitter and fittings). Effective lengths for all sampling system components have been determined ([Table 2](#) line items #2–3).

The optional dilution aspect of the sampling is described in [Section 2](#).



Figure 1.
Sampling System
for Atmospheric
Particles
Model 3750200.

Section 2: Dilution (optional)

Aerosol number concentrations can vary widely by location. Some locations have both a high particle concentration and a high potential impact on human well-being; for example, traffic junctions, airports, or seaports. While it's desirable to measure ambient particles in these impactful settings, the high concentration of the particles makes the measurement challenging. Diluting the aerosol sample prior to measurement can solve this problem.

From the perspective of EN 16976:2024 and CEN/TS 17434:2020, dilution is optional, and should only be used when local concentrations exceed the concentration a CPC can handle in single particle mode. Please refer to [Table 4](#) line item #1, and Section 5.1.3 of EN 16976.

Table 4: Design and performance requirements of the (optional) dilution system.

Line item	Design or Performance aspects	Section:		CEN requirement	
		16976	17434		
1	Particle-free air	5.1.3	6.1.2	<ul style="list-style-type: none"> When it is not possible for the CPC at a given site to accurately measure the particle concentrations without using photometric mode, the sample must be diluted using particle-free air. 	
2	Dilution factor accuracy	7.2		<ul style="list-style-type: none"> If dilution is used, the dilution factor must be stable with time, and it must be accurate within... 	5%
3			8.2		6.5%

The stability of the dilution factor (line items 2-3) is required to be $\pm 5\%$ according to EN 16976, but $\pm 6.5\%$ according to CEN/TS 17434. The resolution of the discrepancy is subject to revisions by the CEN committees. As described below, TSI® Incorporated's Aerosol Diluter Model 3333-10 controls the dilution factor within the tighter limit of $\pm 5\%$.

The TSI® Solution: Aerosol Diluter Model 3333-10

Some atmospheric monitoring locations occasionally experience particle number concentrations higher than 100,000 particles/cm³. In such cases, use of a diluter will keep the number concentration within the measurement range of the CPC (Model 3750-10 or 3750-CEN10).

The [Aerosol Diluter Model 3333-10](#) dilutes the sampled aerosol in compliance with the requirements of EN 16976:2024 as detailed in [Table 4](#). It follows exactly the design suggestion from the Annex E in the EN standard: dilution system with partial flow filtration (E.2.2).

The Aerosol Diluter provides a dilution ratio of 10 with an uncertainty of $\pm 5\%$. An aerosol flow through the diluter of 1 L/min is driven by the attached CPC 3750-10 or 3750-CEN10 (described below)¹. The dilution flow is monitored by an internal mass flow meter, and controlled by an internal blower to keep the dilution ratio stable over the long term. The dilution ratio, diluter flow, and other parameters can be communicated to the CPC via a direct USB connection.



Figure 2. Aerosol Diluter Model 3333-10.

¹ The Aerosol Diluter 3333-10 also works with CPC Model 3750. The 3750 differs from the 3750-CEN10 in that the 3750 a) has a D50 of 7 nm (not 10 nm), and b) does not include the CEN calibration.

Section 3: Relative Humidity Measurement

Measuring the temperature and relative humidity (RH) in the sampled flow provides valuable data, from both a scientific perspective as well as with respect to complying with CEN requirements.

Performance Requirements

[Table 5](#) provides performance requirements for a relative humidity sensor, used to measure the RH (in %) of the air sample that enters the CPC inlet.

Table 5: Performance requirements for the relative humidity sensor.

Line item	Design aspects	Section:		CEN requirement	
		16976	17434		
1	Humidity monitoring at instrument inlet(s)	5.1.2	6.1.2	<ul style="list-style-type: none"> The relative humidity of the sampled air must be monitored at the instrument inlets. 	
2	Accuracy of relative humidity sensor	7.4		<ul style="list-style-type: none"> The relative humidity sensor must be calibrated and able to confirm that measured humidity values between 20% and 80% are accurate to within... 	3%
3			8.4		5%

The resolution of the discrepancy regarding the accuracy of the humidity measurement (lines 2–3) is subject to revisions by the CEN committees. The TSI[®] solution discussed below – the RHT3000 humidity and temperature sensor – fulfills the stricter accuracy of $\pm 3\%$.

The TSI[®] Solution: Aerosol Humidity and Temperature Sensor Model RHT3000

Regardless of whether the ambient air is very humid or very dry, it is required to ensure that the aerosol sample that enters the CPC inlet is monitored and meets the requirement of <40% RH, as specified in EN 16976 [Section 7.4](#) (see [Table 3](#), line item 3).

The [Aerosol Humidity and Temperature Sensor Model RHT3000](#) measures both relative humidity (RH) and temperature (T) as the aerosol passes into the CPC. It is designed to fit directly onto the inlet of TSI[®] CPCs, and also fits onto the TSI particle sizer relevant to CEN/TS 17434; see [Section 5](#) for further details on that particle sizer. The sensor communicates with the instruments via a USB cable. When connected this way, RH (in %) and temperature (in °C) data are stored in the instrument right alongside particle data.

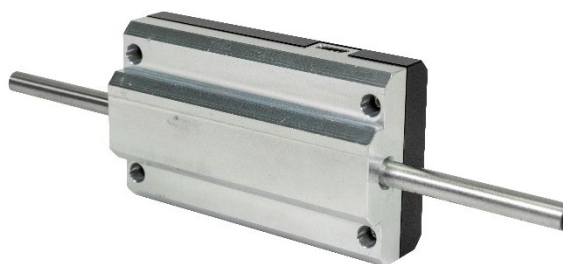


Figure 3. Aerosol Humidity and Temperature Sensor Model RHT3000.

Section 4: Particle Number Concentration Measurement

Condensation particle counters (CPCs) are designed to measure the number concentration of airborne particles. CPCs can detect particles as small as a few nanometers in size (depending upon the design of the CPC), and have been used to monitor ambient air globally for years. A CPC is specifically required by EN 16976:2024 as the tool to use when measuring atmospheric aerosol.

EN 16976:2024 specifies requirements for CPCs that pertain to their design, performance, operation, and calibration. Maintenance actions to be performed by users are also specified by CEN, but are outside the scope of this document. For guidance on regular maintenance, please refer to the relevant TSI® resources (especially manuals and maintenance guides).

CPC: Design Requirements

Table 6: Design requirements of the CPC.

Line item	Design aspects	Section in 16976	CEN requirement
1	No photometric mode	5.2.2	EN16976:2024 prohibits CPCs from using photometric mode when measuring the particle number concentration.
2	Counting mode	6.2	<ul style="list-style-type: none"> All performance criteria refer to the CPC's performance when in counting mode (including coincidence correction).
3	No internal flow split		<ul style="list-style-type: none"> The design of the CPC must be such that all of the volumetric flow that enters the inlet also goes through the optics. Phrased differently, the flow does not split internally within the CPC (i.e. in a way that does not readily permit an external flow rate check), and internal dilution is not used.
4	Working fluid		<ul style="list-style-type: none"> The CPC must use n-butanol as its working fluid.
5	Data averaging		<ul style="list-style-type: none"> Particle concentration data produced by the CPC must be averaged over an interval of one minute.
6	Clock synchronization		<ul style="list-style-type: none"> The internal clock of the CPC must be able to be synchronized.
7	Required data and operating parameters		<ul style="list-style-type: none"> The following parameters must be recorded by the CPC in 1-minute intervals: <ul style="list-style-type: none"> Date, start time, and end time of each concentration measurement Flow rate used in calculations Concentration values, both before and after corrections are applied Temperatures of two key stages in the CPC instrument Temperature and pressure associated with the flow rate measurement
			<ul style="list-style-type: none"> Flags of instrument warnings and errors

Performance Requirements

Within EN 16976:2024, Section 6.5 details not only *what* results the CPC must demonstrate when being tested on the various aspects of CPC performance, but also *how* those tests should be conducted. In this Buyer’s Guide this is split into four parts:

- [Table 7](#) pertains to general CPC characteristics;
- [Table 8](#) refers to the CPC inlet flow;
- [Table 9](#) refers to CPC detection efficiency; and
- [Table 10](#) pertains to CPC linearity.

All tables contain information both as to how CPC performance must be assessed in these regards, and also the associated performance criteria for the CPC under test. Details pertaining to specific line items within these tables may be found in the text following the relevant table.

Table 7: Requirements for manufacturers when verifying general aspects of CPC performance.

Line item	Performance aspects	Section in 16976 ¹	CEN requirement
1	Test conditions: temperature	6.3	<ul style="list-style-type: none"> ▪ Laboratory tests for CPC performance characteristics must be conducted such that the air surrounding the CPC is 20 – 30°C. Exceptions are specified.
2	Number concentration measurement range	6.5.2	<ul style="list-style-type: none"> ▪ The CPC must exhibit a concentration range (with or without coincidence correction) as defined by: <ul style="list-style-type: none"> ▪ A lower concentration limit equal to or below 100 cm⁻³ ▪ An upper concentration limit equal to or exceeding 10⁴ cm⁻³ (including coincidence correction); ▪ A dynamic range that covers at least three orders of magnitude in concentration.
3	Lower concentration detection limit	6.5.3	<ul style="list-style-type: none"> ▪ The number concentration detection limit must be lower than 100 particles/cm³.
4	Zero count rate	6.5.8	<ul style="list-style-type: none"> ▪ The zero-count rate (false count rate) of the CPC must be below one particle per minute, over the course of a 60-minute (or longer) test using an ULPA filter.
5	Response time	6.5.9	<ul style="list-style-type: none"> ▪ A CPC’s response time is a measure of how quickly it responds to a sudden change (i.e. step change) in particle number concentration. Section 6.5.9 defines this property, specifies how the test must be conducted, and how the data must be analyzed. $t_{rise} < 5 \text{ s} \quad t_{fall} < 5 \text{ s} \quad \left \frac{t_{rise} - t_{fall}}{t_{rise}} \right < 10\% \text{ or } < 0.5 \text{ s}$
6	Accuracy of temperature, pressure sensor calibration	6.5.11	<ul style="list-style-type: none"> ▪ Temperature and pressure sensors must be appropriately calibrated to ensure that the measured values are accurate to within 3 K and 1 kPa, respectively.
7	Effect of failure of mains voltage	6.5.12	<ul style="list-style-type: none"> ▪ In the case of loss of power the instrument parameters must be saved. ▪ The instrument must automatically resume normal performance upon return of power.

¹ Numerical values for all requirements are summarized in Section 6.4 (Table 1) of EN 16976:2024, while descriptions of the requirements are provided in the sections listed here.

Table 8: Requirements when verifying aspects of CPC performance related to the CPC's inlet flow.

Line item	Performance aspects	Section in 16976	CEN requirement
1	Test conditions: temperature	6.3	<ul style="list-style-type: none"> Laboratory tests for CPC performance characteristics must be conducted such that the air surrounding the CPC is 20 – 30°C. Exceptions to this requirement are detailed in the standard where appropriate.
2	Inlet flow rate, test conditions: temperature	6.5.1	<ul style="list-style-type: none"> The inlet flow rate of the CPC must be measured using a calibrated reference flow meter. This measurement must be performed at atmospheric pressure.
4	Inlet flow rate accuracy		<ul style="list-style-type: none"> The inlet flow rate of the CPC must be measured using a reference flow meter that has an expanded uncertainty of $\leq 2\%$ (95 % confidence). The inlet flow rate measured by that reference flow meter must differ from the nominal flow rate by $\leq 10\%$.
5	Dependence of flow rate on supply voltage	6.5.10	<ul style="list-style-type: none"> The inlet flow rate of the CPC must not vary by greater than 5% as the supply voltage to the CPC (or external pump, if used) varies. This shall be determined by measuring the CPC inlet flow rate using supply voltages of 210 V, 230V, and 245V.

Table 9: Requirements when verifying CPC detection efficiency.

Line item	Performance aspects	Section in 16976	CEN requirement
1	Test conditions: temperature	6.3	<ul style="list-style-type: none"> Laboratory tests for CPC performance characteristics must be conducted such that the air surrounding the CPC is 20 – 30°C.
2	Aerosol composition, concentration, and size	6.5.6	<ul style="list-style-type: none"> The detection efficiency of the CPC must be measured in accordance with the requirements of ISO 27891. The following particle sizes shall be used: 7 nm, 9 nm, 10 nm, 11 nm, 14 nm, 20 nm, 30 nm and 40 nm, all monodisperse silver particles in a concentration range of 1 000 cm⁻³ to 3 000 cm⁻³. The aerosol used must have specific characteristics as to its size, concentration, and chemical composition. The CPC must exhibit a D₅₀ of 10 nm ± 1,0 nm. The CPC must exhibit a D₉₀ of <20 nm.
3	Upper particle size detection limit	6.5.7	<ul style="list-style-type: none"> The detection efficiency of the CPC for large particles (1000 nm) must be determined. The CPC must exhibit >90% detection efficiency at 1000 nm ±100 nm.

Measuring the number concentration of aerosols depends on the ability to detect that a particle is present. As suggested by their name (Condensation Particle Counters), CPCs condense a vapor onto particles to grow them large enough to be detected. Different CPC designs can do this successfully for particles of different size ranges. The D50 of a CPC is the particle size at which the CPC can successfully detect 50% of the particles. The D50 is a fundamental specification of a CPC, and varies by CPC model.

Table 10: Requirements when verifying linearity of CPC measurements.

Line item	Performance aspects	Section in 16976	CEN requirement
1	Test conditions (temperature)	6.3	<ul style="list-style-type: none"> Laboratory tests for CPC performance characteristics must be conducted such that the air surrounding the CPC is 20 – 30°C.
2	Test conditions (pressure)	6.5.5	<ul style="list-style-type: none"> The linearity of the CPC response must be determined by comparing CPC performance to that of a reference instrument. The reference instrument must be a CPC or a Faraday Cage Aerosol Electrometer (FCAE); regardless of reference detector type, the reference detector must be calibrated at least annually.
3	Aerosol composition and size		<ul style="list-style-type: none"> When assessing CPC linearity, the procedure in ISO 27891 must be followed. The aerosol used for assessing CPC linearity must be composed of silver, and be 40 nm in size.
4	Number concentration of calibration aerosol		<ul style="list-style-type: none"> CPC linearity should be assessed by presenting the CPC with “challenge” concentrations of approximately 1,000 particles/cm³, and stepping up to about 2,000, 4,000, 8,000, 12,000, 25,000 and 50,000 particles/cm³ to the upper concentration limit of the CPC when in count mode.
5	Coincidence correction		<ul style="list-style-type: none"> Number concentration measurements made during the assessment of CPC linearity must be coincidence corrected.
6	Multiply-charged particles		<ul style="list-style-type: none"> Corrections for multiply-charged particles should be made if they are found to be present and if an aerosol electrometer is used as a reference instrument.
7	Data analysis		<ul style="list-style-type: none"> The data from the CPC linearity assessment must be analyzed by performing a regression analysis.
			<ul style="list-style-type: none"> The resulting slope must be $1 \pm 0,05$. The resulting residuals must be <4%.

Regular Calibration Requirements

All CPCs used in CEN-compliant measurement efforts are required by EN 16976:2024 Section 9.2. to undergo annual calibration.

Table 11: Requirements of annual CPC calibration.

Line item	Calibration aspects	Section in 16976	CEN requirement
1	Counting efficiency	9.2.3	<ul style="list-style-type: none"> ▪ The detection efficiency of the CPC must be assessed on both an “as-found” basis and also after any maintenance is performed. ▪ This assessment shall be in accordance with the requirements of ISO 27891, and shall use silver particles with a size of 30 – 50 nm. ▪ The resulting CPC detection efficiency must be $0,95 \leq \eta(D_p) \leq 1,05$. ▪ If the CPC exhibits a detection efficiency outside of that range, further maintenance is required.
2	Linearity		<ul style="list-style-type: none"> ▪ CPC linearity must be assessed using the same procedure as was used for assessing counting efficiency. ▪ Specified particle number concentrations must be used. ▪ The residuals resulting from a regression analysis of this data must be <4%. ▪ If the residuals exceed 4%, further maintenance is required.

In general, CPCs require at least annual cleaning and calibration services, which is usually offered by the manufacturer. In addition, calibration centers, such as members of the [European Center for Aerosol Calibration and Characterization](#) (ECAC), may be available to conduct CEN/TS specific calibration services.

The TSI® Solution: Condensation Particle Counter Model 3750-10 / 3750-CEN10

The [Condensation Particle Counter \(CPC\) Model 3750-CEN10](#) complies with the requirements specified in EN 16976:2024.

CPC Model 3750-CEN10 builds on the legacy of multiple generations of butanol-based CPCs from TSI®. It is designed for 24/7/365 operation, can store data internally or send to network computers, and responds quickly to rapid changes in aerosol concentrations.

Due to their expertise at calibrating CPCs according to the requirements of EN 16976:2024, TSI® chose the World Calibration Center for Aerosol Physics (WCCAP) located at the Leibniz Institute for Tropospheric Research (TROPOS) to conduct CEN/TS-specific CPC calibrations. Every new compliant CPC is routed through this member of the European Center for Aerosol Calibration and Characterization ([ECAC](#)). If required the CPC can be purchased without this specific calibration as model 3750-10.

In between annual calibrations, users can conduct preventative maintenance on a preventative and/or as-needed basis. Guidance in this regard is available in the Preventative Maintenance Guide for the CPC 3750/3750-10. This guide may be requested [here](#).

The flow through the CPC is controlled by a critical orifice. Because of this, the flow is not dependent upon the supply voltage (Table 8 line item #5).



Figure 4. Condensation Particle Counter Model 3750-CEN10.

Section 5: Particle Size Distribution Measurement

A Mobility Particle Size Spectrometer (MPSS) measures the size distribution of aerosol particles. It does this by performing several different functions in concert with each other. While all of these functions are performed simultaneously by the MPSS system, they are described here in the order in which an individual particle passes through them:

Aerosol neutralization	Provides the incoming aerosol with a known (electrical) charge distribution. Known percentages of particles will have no charge, +1 charge, -1 charge, and so on. The distribution of charges varies by particle size, as larger particles are better able to carry multiple charges.
Mobility classification	This step size-selects the particles by taking advantage of their behavior in an electrical field, and the known charge state imparted in the “neutralization” step. This step moves through particle sizes over time by sweeping through a range of voltages in one specific component the Differential Mobility Analyzer (DMA). At any given moment, only particles of one specific size are selected to exit the DMA.
Particle counting	Once the particles have been size-selected and exit the DMA, they are counted using a CPC. When the DMA emits size-selected particles, the CPC counts those particles. When these two functions work together, a size distribution can be built. CEN/TS 17434:2020 specifies that the CPC used in an MPSS system must be compliant with EN 16976:2024; please see Table 12 line item #1.

Due to the need to perform all of the above functions (as well as perform the necessary data processing), MPSS systems are complex instruments. CEN/TS 17434:2020 specifies requirements for MPSS systems that pertain to their design, performance, and annual calibration. Maintenance actions to be performed by users are also specified by CEN, but are outside the scope of this document. For guidance on regular maintenance, please refer to the relevant TSI® resources (especially manuals and maintenance guides), and/or contact [TSI® Incorporated](#).

Design requirements

Sections 6.2.6 and 7.1 specify the performance requirements for MPSS systems. In this Buyer's Guide this is split into two parts:

- [Table 12](#) pertains to requirements of two MPSS components (the CPC and the DMA), and
- [Table 13](#) pertains to the remaining elements of an MPSS system.

Details pertaining to specific line items within these tables may be found in the text following the relevant table.

Table 12: Design requirements of the CPC and DMA components of an MPSS.

Line item	Design aspects	Section in 17434	CEN requirement	
1	CPC	Compliance w/ EN 16976	7.1	<ul style="list-style-type: none"> ■ The CPC used in an MPSS must be compliant with all the requirements of EN 16976:2024.
2		CPC characterization	6.2.6	<ul style="list-style-type: none"> ■ The detection efficiency curve of the CPC used in an MPSS must be determined in accordance with EN 16976:2024.
3	DMA	General design	7.1	<ul style="list-style-type: none"> ■ The DMA in an MPSS must be cylindrical. ■ The sheath and excess air must flow in a closed loop that includes a HEPA filter and dryer.
4		Temperature and humidity measurements		<ul style="list-style-type: none"> ■ Both aerosol and sheath flows within an MPSS must include temperature and relative humidity measurements.
5		Humidity requirements		<ul style="list-style-type: none"> ■ The sheath air must have a relative humidity <40% at the outlet of the DMA.
6		Pressure measurement		<ul style="list-style-type: none"> ■ The absolute pressure must be measured either at the aerosol inlet or in the sheath air flow.
7		Size resolution		<ul style="list-style-type: none"> ■ The idealized (theoretical) size resolution of the DMA should be: $\frac{\Delta Z_p}{Z_p^*} \leq 0.125 \text{ or } \frac{Q_s}{Q_A} \geq 4$

Table 13: Design requirements of the remaining elements of an MPSS system (i.e. aside from CPC and DMA).

Line item	Design aspects	Section in 17434	CEN requirement
1	Pre-separator	7.1	<ul style="list-style-type: none"> A pre-separator should be used if the aerosol to be measured includes a nontrivial amount of particles larger than can be measured by the particle sizer. The pre-separator can be an impactor or cyclone, and may be included either in the particle sizing instrument or in the sampling system.
2	Neutralizer		<ul style="list-style-type: none"> A radioactive ionizer is recommended; a bipolar charge distribution may be assumed.
3	High voltage supply		<ul style="list-style-type: none"> It is recommended that the voltage output of the high voltage supply be able to be measured independently.
4	Delay time check		<ul style="list-style-type: none"> An MPSS system must have the capability to perform, at least for purposes of calibration, an upscan and downscan at high size resolution.
5	Data deconvolution		<ul style="list-style-type: none"> An MPSS system must have at least 16 size bins per size decade (order of magnitude in particle size). The size bins must be geometrically equally spaced.
6	Time to measure a particle number size distribution		<ul style="list-style-type: none"> An MPSS system must be able to perform a measurement of the particle size distribution in two to ten minutes.
7	Data availability		<ul style="list-style-type: none"> An MPSS system must be capable of providing its data in a defined format.
8	Diffusion correction in MPSS software for sampling system losses	6.2.5	<ul style="list-style-type: none"> Diffusion losses must be adequately corrected for to ensure data accuracy and harmonization. A common method utilizing the concept of equivalent length is recommended. This can be accomplished in one of two ways: <ul style="list-style-type: none"> Applying a correction for the entire system after having disabled any diffusion correction performed in the commercial software; or, Inserting site-specific parameters into the commercial software, if the software permits this.

Performance Requirements

Within CEN/TS 17434:2020, Section 7.2 specifies not only what results the MPSS must demonstrate when being tested on the various aspects of MPSS performance, but also *how* the manufacturer should conduct those tests. In this Buyer’s Guide this is split into two parts:

- Table 14 pertains to aerosol flow and number concentration measurements;
- Table 15 pertains to the size range, and the accuracy of both particle size and particle size distribution measurements.

These tables contain information both as to how MPSS system performance must be tested in these regards, and also the associated performance criteria for the MPSS under test. Details pertaining to specific line items within these tables may be found in the text following the relevant table.

Table 14: Performance requirements pertaining to aerosol flow within, and particle number concentration measured by, the MPSS.

Line item	Performance aspect	Section in 17434	CEN requirement
1	Actual vs. calibration aerosol flow rate	7.2.1	<ul style="list-style-type: none"> ▪ The aerosol flow rate of an MPSS system must be measured with a reference flow meter. ▪ The reference flow meter must have a relative uncertainty of $\leq 2\%$ at the relevant flow rate. ▪ The aerosol flow rate measurement must differ from the nominal aerosol flow rate by $\leq 5\%$.
2	DMA flow conditions	7.2.6	<ul style="list-style-type: none"> ▪ Sample flow inside the DMA must be laminar. ▪ If flow is laminar and an electric field is not applied, particles entering the DMA cannot reach the DMA outlet. ▪ Because of this, a zero-check test can confirm laminarity within the DMA. ▪ The DMA can be concluded to have laminar flow if the CPC measures $< 0,01 \text{ cm}^{-3}$ for 10 seconds or longer.
3	False background number concentration	7.2.5	<ul style="list-style-type: none"> ▪ The false background measurement of an MPSS system must be assessed. ▪ The false background is the number concentration measured over all size bins scanned by the MPSS. ▪ This number concentration must be $< 0,01 \text{ cm}^{-3}$ over the course of a 10-minute measurement of air that has passed through a HEPA filter.
4	Accuracy of integrated particle number concentration	7.2.4	<ul style="list-style-type: none"> ▪ The number concentration measured by the MPSS must be compared to a reference CPC; this reference must be compliant with EN 16976:2024. ▪ The comparison must be done using ambient air. ▪ The data must be analyzed via linear regression. ▪ The result from this analysis must demonstrate that the MPSS-CPC comparison has: <ul style="list-style-type: none"> ▪ A slope between 0,9 and 1,1 (forced through origin) ▪ An R^2 value $\geq 0,9$

The laminarity of DMA sheath flow is critical as described in line item #2. Experience has shown that using ambient air when high concentrations of particles $\sim 10 \text{ nm}$ (or smaller) are present can produce biased test results for many DMAs. Best practice is to utilize controlled and/or well-characterized aerosol sources, with stable size distributions that do not contain high concentrations of sub-10 nm particles.

Table 15: Performance requirements pertaining to the particle size range of, and to the accuracy of both particle size measurements and particle size distribution measurements made by, the MPSS.

Line item	Performance aspects	Section in 17434	CEN requirement
1	Particle size range	7.2.2	<ul style="list-style-type: none"> ■ The particle size range that a particular MPSS is capable of scanning over can be determined theoretically, based upon geometric parameters and high voltage range. ■ An MPSS system must be able to cover the range from 10 nm to 800 nm in electrical mobility diameter.
2	Particle size calibration accuracy	7.2.3	<ul style="list-style-type: none"> ■ The particle sizing accuracy of an MPSS system must be investigated experimentally. ■ Certified monodisperse polystyrene latex sphere (PSL) particles must be used for this investigation; it is recommended to use PSL particles between 100 and 300 nm in size. ■ The size of these PSL particles, as measured by the MPSS, must differ from the manufacturer-certified size of the PSL by $\leq 3\%$. ■ If the measured size differs from the certified size of the latex particles, the MPSS sheath air flow rate may be adjusted to bring the agreement to within 3%.
3	Particle number size distribution accuracy	7.2.7	<ul style="list-style-type: none"> ■ The accuracy of particle size distribution measurements made by an MPSS system must be investigated experimentally. ■ This is done by comparing the MPSS' measurements to that of a calibrated reference MPSS system when both are sampling atmospheric aerosol. ■ When comparing the resulting data, particle concentrations measured by the two systems are compared one size bin at a time. Acceptance criteria depend upon particle size: <ul style="list-style-type: none"> ■ $\leq 50\%$ for size bins in the range 10 nm to 20 nm ■ $\leq 10\%$ for size bins in the range 20 nm to 200 nm ■ $\leq 20\%$ for size bins in the range 200 nm to 800 nm

Annual Calibration Requirements

All Mobility Particle Size Spectrometer (MPSS) systems used in CEN-compliant measurement efforts are required by CEN/TS 17434:2020 to undergo annual calibration. In this Buyer's Guide this is split into two parts:

- [Table 16](#) pertains to general characteristics of an MPSS system;
- [Table 17](#) pertains to flows within an MPSS system, and to the comparison of an MPSS system's measurements with those of reference instruments.

Details pertaining to specific line items within these tables may be found in the text following the relevant table.

Table 16: Requirements of annual MPSS calibration that pertain to general characteristics of an MPSS system.

Line item	Calibration aspects	Section in 17434	CEN requirement
1	False background concentration check (MPSS)	7.2.5	<ul style="list-style-type: none"> ▪ During MPSS calibration, the false background concentration of the MPSS system must be measured. ▪ This measurement is performed by connecting a HEPA filter to the MPSS inlet and allowing the MPSS to measure the particle size distribution over the course of ten minutes. ▪ The resulting number concentration must be $<0,01 \text{ cm}^{-3}$
2	Mean false background concentration check (CPC)	10.3.7	<ul style="list-style-type: none"> ▪ A false background concentration check of the CPC should be done only if the false background concentration of the MPSS (above) fails. ▪ To pass, the CPC must measure an average count rate of fewer than 15 counts per minute.
3	Sensor's calibration	10.3.4	<ul style="list-style-type: none"> ▪ During MPSS calibration, the sensors that measure the relative humidity both in the sheath loop and the aerosol flow must be calibrated to ensure that the measurements are accurate to within $\pm 3\%$.
4	CPC calibration	10.3.5	<ul style="list-style-type: none"> ▪ The CPC used within the MPSS must be calibrated in accordance with the requirements of EN 16976:2024.
5	Delay time check	10.3.6	<ul style="list-style-type: none"> ▪ To ensure that the delay time between DMA and CPC is correct, an upscan and downscan must be performed. ▪ If the particle size distribution measurements made during the upscan and downscan are identical, the delay time is accurate.
6	Particle size calibration accuracy	7.2.3	<ul style="list-style-type: none"> ▪ During MPSS calibration, the particle sizing accuracy of the MPSS system must be investigated experimentally. ▪ This investigation must utilize polystyrene latex sphere (PSL) particles; refer to ISO 15900. ▪ The size of these PSL particles, as measured by the MPSS, must differ from the manufacturer-certified size of the PSL by $\leq 3\%$. ▪ If the measured size differs from the certified size of the latex particles, the MPSS sheath air flow rate may be adjusted to bring the agreement to within 3%.

Table 17: Requirements of annual MPSS calibration that pertain to flows within an MPSS system, and to the comparison of that system's final measurements to those of reference instruments.

Line item	Calibration aspects	Section in 17434	CEN requirement
1	Aerosol flow rate calibration (MPSS)	10.3.2	<ul style="list-style-type: none"> ■ The aerosol flow rate of an MPSS system must be measured during MPSS calibration. ■ The measured flow rate must not differ from the nominal flow rate by 5% or greater.
2	Aerosol flow rate calibration (CPC)	10.3.3	<ul style="list-style-type: none"> ■ The inlet flow rate of the CPC that is used in an MPSS system must be measured during MPSS calibration. ■ The CPC inlet flow and the MPSS inlet flow must be identical to each other, within the range of uncertainty.
3	Flow condition check	7.2.6	<ul style="list-style-type: none"> ■ Sample flow inside the DMA must be laminar. ■ If flow is laminar and an electric field is not applied, particles entering the DMA cannot reach the DMA outlet; a zero-check test can confirm laminarity within the DMA. ■ The DMA can be concluded to have laminar flow if the CPC measures $<0,01 \text{ cm}^{-3}$ for 10 seconds or longer.
4	Leak check	10.3.8	<ul style="list-style-type: none"> ■ The potential for leaks in the MPSS must be assessed. ■ The system may be concluded to be free of leaks if: <ul style="list-style-type: none"> ■ The MPSS aerosol (inlet) flow rate and the CPC inlet flow rate are equal, and ■ The mean false background check was passed.
5	Comparison to a reference instrument	7.2.4	<ul style="list-style-type: none"> ■ The number concentration measured by the MPSS must be compared to a reference CPC; this reference must be compliant with EN 16976:2024. ■ The comparison must be done using ambient air. ■ The data must be analyzed via linear regression. ■ The result from this analysis must demonstrate that the MPSS-CPC comparison has: <ul style="list-style-type: none"> ■ A slope between 0,9 and 1,1 (forced through origin) <ul style="list-style-type: none"> ■ An R^2 value $\geq 0,9$
6	Comparison to a reference MPSS	7.2.7	<ul style="list-style-type: none"> ■ The accuracy of particle size distribution measurements made by an MPSS system must be investigated experimentally. ■ This is done by comparing the MPSS' measurements to that of a calibrated reference MPSS system when both are sampling atmospheric aerosol. ■ When analyzing the resulting data, particle concentrations measured by the two systems are compared one size bin at a time. Acceptance criteria vary by particle size: <ul style="list-style-type: none"> ■ $\leq 50\%$ for size bins in the range 10 nm to 20 nm ■ $\leq 10\%$ for size bins in the range 20 nm to 200 nm ■ $\leq 20\%$ for size bins in the range 200 nm to 800 nm

In general, annual cleaning and calibration service is recommended for MPSS systems, and is in fact required by CEN/TS 17434:2020 as detailed above. Such service is usually offered by the manufacturer. In addition, calibration centers, such as the World Calibration Center for Aerosol Physics (WCCAP) at Leibniz Institute for Tropospheric Research (TROPOS), may be available to conduct CEN/TS specific services.

The TSI® Solution: Scanning Mobility Particle Sizer™ Spectrometer for Ambient Air Monitoring, Model 3938W50-CEN10

While “Mobility Particle Size Spectrometer” (MPSS) is the general term that CEN/TS 17434:2020 uses to describe such instruments, the TSI® instrument with the same capabilities is called a [Scanning Mobility Particle Sizer™](#) (SMPS™) spectrometer.

The SMPS™ [Model 3938W50-CEN10](#) complies with the requirements specified in CEN/TS 17434:2020.

SMPS™ Model 3938W50-CEN10 builds on the legacy of multiple generations of mobility particle sizers from TSI®. It is capable of scanning from 10 – 800 nm in a single scan, automatically resumes operation following power outage, and provides measurement data in a comprehensive export format, which can be easily integrated into the databases of the monitoring station. The software includes data from the aerosol humidity and temperature sensor, if used, can export raw and calculated particle concentrations and correct the size distribution for particle losses in the sampling system.

Due to their expertise at calibrating MPSS systems according to the requirements of CEN/TS 17434, TSI® chose the World Calibration Center for Aerosol Physics (WCCAP) located at the Leibniz Institute for Tropospheric Research (TROPOS) to conduct CEN/TS-specific calibrations. Every new compliant SMPS™ system is routed through this member of the European Center for Aerosol Calibration and Characterization ([ECAC](#)). Subsequent calibrations are available on demand or as service contracts from TSI.



Figure 5. Scanning Mobility Particle Sizer™ Spectrometer Model 3938W50-CEN10.

The Full TSI® Solution for Compliance with EN 16976:2024 and CEN/TS 17434:2020

Making ultrafine particle measurements in compliance with the CEN standards requires the right tools. [TSI® offers a full solution](#) that includes sampling, drying, and diluting the aerosol, as well as measurement of relative humidity and temperature, particle number concentration, and particle size distribution.

Each of these components was developed with CEN compliance in mind, and is based on TSI's decades of experience designing, manufacturing, and supporting particle measurement instrumentation. Compliance of the full TSI® solution with the requirements of EN16976:2024 and CEN/TS 17434:2020 is summarized in [Table 18](#).

Table 18: Summary of compliance status for all components of TSI's full solution for CEN-compliant monitoring of atmospheric ultrafine particles.

System component		Tables	Compliance with all relevant CEN requirements
Name	Model		
Sampling system for atmospheric aerosol	3750200	1-3	✓
Aerosol diluter	3333-10	4	✓
Relative humidity and temperature sensor	RHT3000	5	✓
Condensation Particle Counter (CPC)	3750-CEN10	6-11	✓
Scanning Mobility Particle Sizer (SMPS™) system*	3938W50-CEN10	12-17	✓

*Referred to as MPSS within the CEN standards

Both the CPC and the SMPS™ system undergo CEN/TS-specific calibrations at the World Calibration Center for Aerosol Physics (WCCAP), located at the Leibniz Institute for Tropospheric Research (TROPOS). WCCAP is a member of the European Center for Aerosol Calibration and Characterization ([ECAC](#)), and is an ACTRIS calibration facility. From design through calibration, the TSI ultrafine particle monitoring solution delivers full CEN compliance.

Additional Accessories

A vacuum pump is required to drive the system flows, and an optional catalytic vapor filter removes butanol vapor from the exhaust of the CPC and SMPS™ system. These accessories do not have requirements set for them by EN 16976:2024, nor by CEN/TS 17434. Please refer to the Solutions Brochure ([US](#)) and ([A4](#)) for more information on these accessories.



Figure 6. The Ultrafine Particle Monitoring solution from TSI®. This solution is compliant with EN 16976:2024 and CEN/TS 17434, as summarized in [Table 18](#). Diluter (optional) and pump not shown.

For further information on any component, please refer to the Solutions Brochure ([US](#)) and ([A4](#)), as well as specification sheets for all system components. Please feel free to contact TSI® at any time with questions, or for assistance in configuring an ultrafine particle monitoring solution for your specific needs.

References

1. EN 16976:2024. [Ambient air – Determination of the particle number concentration of atmospheric aerosol.](#)
2. CEN/TS 17434:2020. [Ambient air – Determination of the particle size spectra of atmospheric aerosol using a Mobility Particle Size Spectrometer \(MPSS\).](#)
3. UFP Solutions brochure [US](#) and [A4](#).
4. Sampling System for Atmospheric Aerosol 3750200 specification sheet, [US](#) and [A4](#).
5. Aerosol Diluter 3333-10 specification sheet, [US](#) and [A4](#).
6. Aerosol Humidity and Temperature Sensor RHT3000 specification sheet, [US](#) and [A4](#).
7. CPC 3750-CEN specification sheet, [US](#) and [A4](#).
8. SMPS 3938W50-CEN specification sheet, [US](#) and [A4](#).
9. “Flow Rate Correction of the Model 3790 Engine Exhaust Condensation Particle Counter (EECPC),” Application Note EECPC-001, [US](#) and [A4](#).



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