TÜV RHEINLAND
ENERGIE UND UMWELT GMBH

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Deutsche Akkreditierungsstelle
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Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM_{10} and $PM_{2.5}$

TÜV-report: 936/21219977/A
Cologne, 26th March 2014

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TÜV

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The department of Environmental Protection of TÜV Rheinland Energie und Umwelt GmbH
is accredited for the following work areas:

- Determination of air quality and emissions of air pollution and odour substances;
- Inspection of correct installation, function and calibration of continuously operating emission measuring instruments, including data evaluation and remote emission monitoring systems;
- Combustion chamber measurements;
- Performance testing of measuring systems for continuous monitoring of emissions and ambient air, and of electronic data evaluation and remote emission monitoring systems;
- Determination of stack height and air quality projections for hazardous and odour substances;
- Determination of noise and vibration emissions and pollution, determination of sound power levels and execution of sound measurements at wind energy plants

according to EN ISO/IEC 17025.

The accreditation is valid up to 22-01-2018. DAkkS-register number: D-PL-11120-02-00.

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DAkkS Deutsche Akkreditierungsstelle D-PL-11120-02-00

Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM10 and PM2.5

Instrument tested: Air Pollution Monitor 2 (APM-2)

Manufacturer: Comde-Derenda GmbH
Kieler Straße 9
14532 Stahnsdorf
Germany

Test period: April 2012 until March 2014

Date of report: 26th March 2014

Report number: 936/21219977/A

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1. General and certification proposal

1.1 General

According to Directive 2008/50/EC dated 21st May 2008 (replaces air quality framework directive 96/62/EC dated 27th September 1996 including the related daughter directives 1999/30/EC, 2000/69/EC, 2002/3/EC as well as the Council decision 97/101/EC) on “ambient air quality and cleaner air for Europe”, the reference method for measuring the PM_{10} concentration as per “Air quality – Determination of the PM_{10} fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods of equality” given in EN 12341 and the reference method for measuring the $PM_{2,5}$ concentration as per “Ambient air quality – Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter” given in EN 14907 shall be used. A Member State can, in the case of particulate matter, use any other method which the Member State concerned can demonstrate displays a consistent relationship to the reference method. In that event the results achieved by that method must be corrected to produce results equivalent to those that would have been achieved by using the reference method (2008/50/EC, Annex VI, B).

The Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods” [5] which was developed by an ad-hoc EC working group in January 2010

(Source: http://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf)

describes a method for testing for equivalence of non-standardized measurement methods.

The requirements set out in the Guide for equivalence testing have been included in the last revision of the VDI Standards 4202, Sheet 1 and VDI 4203, Sheet 3.

In this performance testing the following limit values were applied:

	$PM_{2.5}$	**PM_{10}**
Daily limit DL (24 h)	Not defined	50 µg/m³
Annual limit AL (1 a)	25 µg/m³*	40 µg/m³

as well as for the calculations according to the Guide [5]

	$PM_{2.5}$	**PM_{10}**
Limit value	30 µg/m³	50 µg/m³

The 2002 VDI guideline 4202, Sheet 1 describes the "Minimum requirements for suitability tests for ambient air quality systems". General parameters for the related tests are set out in VDI Standard 4203, Sheet 1 "Testing of automated measuring systems – General concepts" of October 2001 and further specified in VDI 4203, Sheet 3 "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants" of August 2004.

VDI Standards 4202, Sheet 1 and 4203, Sheet 3 underwent extensive revision and were newly published in September 2010. Unfortunately, after this revision there are some ambiguities and contradictions in relation to the performance testing of particulate measuring systems as far as minimum requirements on the hand and the general relevance of test items on the other hand are concerned. The following test items require clarification:

6.1 5.3.2 Repeatability standard deviation at zero point

→ no minimum requirement defined

6.1 5.3.3 Repeatability standard deviation at reference point

→ not relevant to particulate measuring systems

6.1 5.3.4 Linearity (lack of fit)

→ not relevant to particulate measuring systems

6.1 5.3.7 Sensitivity coefficient of surrounding temperature

→ no minimum requirement defined

6.1 5.3.8 Sensitivity coefficient of supply voltage

→ no minimum requirement defined

6.1 5.3.11 Standard deviation from paired measurements

→ no minimum requirement defined

6.1 5.3.12 Long-term drift

→ no minimum requirement defined

6.1 5.3.13 Short-term drift

→ not relevant to particulate measuring systems

6.1 5.3.18 Overall uncertainty

→ not relevant to particulate measuring systems, covered by 5.4.10.

In order to determine a concerted procedure for dealing with the inconsistencies in the guidelines, an official enquiry was directed to the relevant body in Germany.

The following procedure was suggested:

As before, the test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 are evaluated based on the minimum requirements set out in VDI 4202, Sheet 1 of 2002 (i.e. using the reference values B_0, B_1, and B_2).

The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 are omitted as they are not relevant to particulate measuring systems.

The relevant body in Germany approved of the suggested procedure by decisions of 27 June 2011 and 7 October 2011.

The reference values which shall be used according to the applied guidelines explicitly refer to the measured component $PM_{10.}$ Therefore, the following reference values are suggested for the measured component $PM_{2.5}$:

	$PM_{2,5}$	**PM_{10}**
B_0	2 µg/m³	2 µg/m³
B_1	25 µg/m³	40 µg/m³
B_2	200 µg/m³	200 µg/m³

B_1 shall merely be adjusted to the level of the limit value for the annual mean.

Comde-Derenda GmbH has commissioned TÜV Rheinland Energie und Umwelt GmbH to carry out a performance test of the Air Pollution Monitor (APM-2) measuring system for the components suspended particulate matter PM_{10} and $PM_{2.5}$.

- VDI Standard 4202, Sheet 1, "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants", September 2010/June 2002
- VDI Standard 4203, Sheet 3, "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", September 2010/August 2004
- Standard EN 12341, "Air quality – Determination of the PM_{10} fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods of equality", German version EN 12341: 1998
- Standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005
- Guidance document "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version of January 2010

The measuring system Air Pollution Monitor (APM-2) operates according to the principle of scattered light measurement. By means of a pump ambient air is sucked in via a PM_{10}-impactor inlet (3.3 l/min) and splitted into two partial streams by a virtual impactor. Via magnetic valves, either the aerosol out of the axial flow (enrichment mode for determination of PM_{10}-concentration) or the aerosol out of the side flow (normal mode for determination of $PM_{2.5}$-concentration) is lead to the measurement sensor. At this point, the PM_{10}- respectively $PM_{2.5}$-concentration is measured in switch-over mode by means of scattered light measurement technique.

The tests were performed in the laboratory and during a field test that lasted several months.

The field test which lasted several months was performed at the test sites given in Table 1.

Table 1: Description of test sites

	Cologne, parking lot, winter	Bonn, street crossing, winter	Cologne, parking lot, summer	Rodenkirchen, motorway A555, summer
Period	11/2012 – 02/2013	02/2013 – 05/2013	05/2013 – 07/2013	07/2013 – 09/2013
No. of paired values: candidates	69	61	54	53
Characteristics	Urban background	Influenced by traffic	Urban background	Rural structure + motorway
Level of ambient air pollution	Average to high	Average to high	Low to average	Low

During the performance of the type approval test, the calculation algorithm for the measured PM values has been further optimized by the instrument manufacturer. For this the instrument software had to be revised and a new software version (Version 3.0.1) was provided during winter 2014. In order to qualify the now implemented modification of the calculation algorithm in the instrument software, all measured values of the comparison campaigns according to table 1 have been manually recalculated with the new calculation algorithm and re-evaluated. Furthermore an additional comparison campaign at the test site Cologne, parking lot with two candidates and the new software version (Version 3.0.1) was carried out for further qualification. Table 2 gives an overview on the additional campaign. The results of these additional investigations are presented in chapter 7 starting with page 194.

Table 2: Description of test site (validation campaign 2014)

	Cologne, parking lot, winter
Period	01/2014 – 03/2014
No. of paired values: candidates	53
Characteristics	Urban background
Level of ambient air pollution	Average to high

The minimum requirements were fulfilled during performance testing.

TÜV Rheinland Energie und Umwelt GmbH therefore suggests its approval as a performance tested measuring system for continuous monitoring of ambient air pollution by suspended particulate matter PM_{10} and $PM_{2.5}$.

1.2 Certification proposal

Due to the positive results achieved, the following recommendation is put forward for the notification of the AMS as a performance-tested measuring system:

AMS designation:

Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM_{10} and $PM_{2.5}$

Manufacturer:

Comde-Derenda GmbH, Stahnsdorf

Field of application:

Continuous and parallel measurement of the PM_{10} and $PM_{2.5}$ fractions in ambient air (stationary operation).

Measuring ranges during performance testing:

Component	Certification range	Unit
PM_{10}	0 – 1.000	µg/m³
$PM_{2,5}$	0 – 1.000	µg/m³

Software version:

3.0.1

Restriction:

None

Notes:

1. The requirements according to the guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" are met for the measured components PM_{10} und $PM_{2.5}$ after application of the determined correction factors/terms.
2. The requirements on the equivalence test according to Standard EN 12341:1998 for PM_{10} have not been met by the candidates.
3. The long-term drift of the sensitivity of the particle sensor could not be determined during the field test.
4. The measuring system can be telemetrically monitored, but not operated.
5. The measuring system determines the PM_{10}- and the $PM_{2.5}$-fraction of suspended particulate matter in an alternating way – within the scope of the type approval test, the switch-over between the two fractions has been carried out every two minutes.
6. The measuring system shall be calibrated on site with the gravimetric PM_{10} reference method as per EN 12341 on a regular basis. Preferably a seasonal calibration rhythm is to follow.
7. The measuring system shall be calibrated on site with the gravimetric $PM_{2.5}$ reference method as per EN 14907 on a regular basis. Preferably a seasonal calibration rhythm is to follow.
8. This report on the performance testing can be viewed on the internet at www.qal1.de.

Test report:

TÜV Rheinland Energie und Umwelt GmbH, Cologne

Report no.: 936/21219977/A of 26th March 2014

1.3 Summary of test results

Performance criterion	Specification	Test result	Fulfilled	Page
4 Requirements on instrument design				
4.1 General requirements				
4.1.1 Measured value display	Shall be available.	The measuring system provides a display that shows the measured values.	yes	64
4.1.2 Easy maintenance	Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.	Maintenance work can be carried out from the outside with commonly available tools and reasonable time and effort.	yes	66
4.1.3 Functional check	If the operation or the functional check of the measuring system requires particular instruments, they shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.	All functions described in the operator's manual are available, can be activated, and work properly. The current instrument status is continuously monitored and different warning messages are displayed in the case of problems.	yes	70
4.1.4 Setup times and warm-up times	Shall be specified in the instruction manual.	Setup and warm-up times were determined.	yes	72
4.1.5 Instrument design	Shall be specified in the instruction manual.	The instrument design specifications listed in the operator's manual are complete and correct.	yes	73
4.1.6 Unintended adjustment	It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation.	The measuring system is secured against illicit or unintentional adjustments of instrument parameters. Additional protection against unauthorized access is provided by the lockable door of the weatherproof housing.	yes	74
4.1.7 Data output	The output signals shall be provided digitally and/or as analogue signals	The measured signals are stored on SD-card or offered digitally (via RS232).	yes	75

Performance criterion	Requirement	Test result	Fulfilled	Page
5. Performance criteria				
5.1 General	The manufacturer's specifications in the instruction manual shall not contradict the results of the performance test.	No differences between the instrument design and the descriptions given in the manuals were found.	yes	77
5.2 General requirements				
5.2.1 Certification ranges	Shall comply with the requirements of Table 1 of VDI Standard 4202, Sheet 1.	Assessment of AMS in the range of the relevant limit values is possible.	yes	78
5.2.2 Measuring range	The upper limit of measurement of the measuring systems shall be greater or equal to the upper limit of the certification range.	The upper limit of measurement is greater than the corresponding upper limit of the certification range.	yes	79
5.2.3 Negative output signals	Negative output signals or measured values may not be suppressed (life zero).	Negative output signals are directly displayed by the AMS and can be output via corresponding data outputs. Yet, they are not to be expected due to measuring principle and instrument design.	yes	80
5.2.4 Failure in the mains voltage	Uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.	All parameters are secured against loss by buffering. When mains voltage returns the AMS returns to failure-free operation mode and automatically resumes measuring after re-stabilization of the photometer temperature and two-minutes zero air purging.	yes	81
5.2.5 Operating states	The measuring system shall allow the control of important operating states by telemetrically transmitted status signals.	The measuring systems can be monitored and operated extensively from an external PC via modem or router.	yes	82
5.2.6 Switch-over	Switch-over between measurement and functional check and/or calibration shall be possible telemetrically by computer control or manual intervention.	The measuring system can be monitored by the user directly or via remote control. A telemetric control is not yet implemented, but already planned for the future.	no	83
5.2.7 Maintenance interval	If possible 3 months, minimum 2 weeks.	The maintenance interval of 4 weeks has been determined by regular maintenance work.	yes	84

Performance criterion	Specification	Test result	Fulfilled	Page
5.2.8 Availability	Minimum 95 %.	The availability was 100 % for SN3 and 98.9 % for SN4 without test-related downtimes. Including test-related downtimes it was 91.6 % for SN3 and 90.5 % for SN4.	yes	85
5.2.9 Instrument software	The version of the instrument software to be tested shall be displayed during switch-on of the measuring system. The test institute shall be informed on changes in the instrument software, which have influence on the performance of the measuring system.	The version of the instrument software is shown in the display. The test institute is informed on any changes in the instrument software.	yes	87
5.3 Requirements on measuring systems for gaseous air pollutants				
5.3.1 General	Minimum requirement according to VDI 4202, Sheet 1.	The test was carried out on the basis of the performance criteria stated in VDI Standard 4202, Sheet 1 (September 2010). However, the test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 were evaluated on the basis of the performance criteria stated in the 2002 version of VDI Standard 4202, Sheet 1 (i.e. applying the reference values B_0, B_1, and B_2). The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 were omitted as they are irrelevant to particulate measuring devices.	yes	90
5.3.2 Repeatability standard deviation at zero point	The repeatability standard deviation at zero point shall not exceed the requirements of Table 2 in the certification range according to Table 1 of VDI Standard 4202, Sheet 1 (September 2010). For PM: Max. B_0.	The tests resulted in detection limits of 0.03 µg/m³ (PM_{10}) and <0.01 µg/m³ ($PM_{2.5}$) for System 1 (SN3), and 0.09 µg/m³ (PM_{10}) and 0.10 µg/m³ ($PM_{2.5}$) for System 2 (SN4).	yes	92
5.3.3 Repeatability standard deviation at reference point	The repeatability standard deviation at reference point shall not exceed the requirements of Table 2 in the certification range according to Table 1 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	94

Performance criterion	Specification	Test result	Fulfilled	Page
5.3.4 Linearity (lack of fit)	The analytical function describing the relationship between the output signal and the value of the air quality characteristic shall be linear.	Particulate measuring systems for PM_{10} shall be tested according to performance criterion 5.4.2 “Equivalency of the sampling system”. Particulate measuring systems for $PM_{2.5}$ shall be tested according to performance criterion 5.4.10 “Calculation of expanded uncertainty between systems under test”.	-	95
5.3.5 Sensitivity coefficient of sample gas pressure	The sensitivity coefficient of the sample gas temperature at reference point shall not exceed the specifications of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	96
5.3.6 Sensitivity coefficient of sample gas temperature	The sensitivity coefficient of the surrounding temperature at zero and reference point shall not exceed the specifications of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	97
5.3.7 Sensitivity coefficient of surrounding temperature	The sensitivity coefficient of the surrounding temperature at zero and reference point shall not exceed the specifications of Table 2 of VDI Standard 4202, Sheet 1 (September 2010). For PM: Zero point value for ΔTu of 15 K between +5 °C and +20 °C or 20 K between +20 °C and +40 °C shall not exceed B_0. The measurement value in the range of B_1 shall not exceed ± 5 % for ΔTu of 15 K between +5 °C and +20 °C or for 20 K between +20 °C and +40 °C	The ambient temperature range tested at the AMS installation site was -20 °C to +50 °C. Looking at the values that were output by the AMS, the maximum dependence of ambient temperature in the range of -20 °C to +50 °C at zero was 0.1 µg/m³ for $PM_{2.5}$ and 0.2 µg/m³ for PM_{10}. At reference point, no deviations > 2.7 % in relation to the default temperature of 20 °C were observed.	yes	98

Performance criterion	Specification	Test result	Fulfilled	Page
5.3.8 Sensitivity coefficient of supply voltage	The sensitivity coefficient of the electric voltage at reference point shall not exceed the specifications made in Table 2 of VDI Standard 4202, Sheet 1 (September 2010). For PM: Change in measured value at B_1 maximum B_0 within the voltage interval (230 +15/-20) V.	No deviations > 1.3 % in relation to the default value of 230 V due to changes in supply voltage were detected.	yes	102
5.3.9 Cross-sensitivity	The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010) at zero and reference point.	Not applicable.	-	104
5.3.10 Averaging effect	For gaseous components the measuring system shall allow the formation of hourly averages. The averaging effect shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	105
5.3.11 Standard deviation from paired measurements	The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test. It shall not exceed the specifications stated in Table 2 of VDI Standard 4202, Sheet 1 (September 2010). For PM: RD $\geq$ 10 related to B_1.	In the field test, the reproducibility for the full dataset was 20 for $PM_{2.5}$ and 16 for PM_{10}.	yes	106

Performance criterion	Specification	Test result	Fulfilled	Page
5.3.12 Long-term drift	The long-term drift at zero point and reference point shall not exceed the requirements of Table 2 in the field test of VDI Standard 4202, Sheet 1 (September 2010) in the field test. For PM: Zero point: within 24 h and within the maintenance interval a maximum of B0. As reference point: within 24 h and within the maintenance interval a maximum 5 % of B1.	For PM2.5, the maximum deviation at zero point was -1.4 µg/m³ in relation to the previous value and 2.4 µg/m³ in relation to the start value. Thus, it lies within the permissible limits of B0 = 2 µg/m³. For PM_{10}, the maximum deviation at zero point was 1.5 µg/m³ for in relation to the previous value and 2.7 µg/m³ in relation to the start value and thus related to the start value outside of the permissible limit of B_0 = 2 µg/m³. This deviation only occurred one time during the entire field test campaign, a cause could not be determined. There was no externally triggered adjustment of the measuring device. A regular external check of the sensitivity over the field test period could not be carried out, as suitable test equipment was not available before December 2013. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].	no	109
5.3.13 Short-term drift	The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test.	Not applicable.	-	115
5.3.14 Response time	The response time (rise) of the measuring systems shall not exceed 180 s. The response time (fall) of the measuring systems shall not exceed 180 s. The difference between the response time (rise) and response time (fall) of the measuring system shall not exceed 10 % of response time (rise) or 10 s, whatever value is larger.	Not applicable.	-	116

Performance criterion	Specification	Test result	Fulfilled	Page
5.3.15 Difference between sample and calibration port	The difference between the measured values obtained by feeding gas at the sample and calibration port shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	117
5.3.16 Converter efficiency	In the case of measuring systems with a converter, the efficiency of the converter shall be at least 98 %.	Not applicable.	-	118
5.3.17 Increase of NO2 concentration due to residence in the AMS	In case of NO_x measuring systems, the increase of NO_2 concentration due to residence in the measuring system shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	119
5.3.18 Overall uncertainty	The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the applicable EU Directives on air quality listed in Annex A, Table A1 of VDI Standard 4202, Sheet 1 (September 2010).	By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.	-	120
5.4 Requirements on measuring systems for particulate air pollutants				
5.4.1 General	Test according to the minimum requirement stated in Table 5 of VDI Standard 4202, Sheet 1. Furthermore, the particle mass concentration shall be related to a defined volume.	The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010). The APM-2 measuring system is an optical measuring system which first determines the scattered light signal, induced by particles in a defined measured volume, and then converts the available information into concentration values by means of an algorithm. The measured signal for the particles is therefore related to a defined volume (measured volume).	yes	121

Performance criterion	Specification	Test result	Fulfilled	Page
5.4.2 Equivalency of the sampling system	The equivalency to the reference method according to EN 12341 [T2] shall be demonstrated.	For SN3, the reference equivalence functions for the (uncorrected) datasets lie outside the limits of the respective acceptance envelope for all test sites with exception of Cologne, winter, for SN4 only the reference equivalence function for the field campaign Rodenkirchen is outside of the respective acceptance envelope. Moreover, the variation coefficient R^2 of the calculated reference equivalence function in the concentration range concerned is < 0.95 for all comparison campaigns with exception of Cologne, winter. The demonstration of equivalence according to EN 12341:1998 is thus not possible. Nevertheless, the equivalence test according to the EC-guide, which is relevant for the end user, is passed after application of the necessary correction factors for all test sites without restrictions (refer to 6.1 5.4.11 Application of correction factors and terms).	no	122
5.4.3 Reproducibility of the sampling systems	This shall be demonstrated in the field test for two identical systems according to EN 12341 [T2].	The two-sided confidence interval CI95 of max. 3.58 µg/m³ is below the permissible limit of 5 µg/m³.	yes	130
5.4.4 Calibration	The systems under test shall be calibrated in the field test by comparison measurements with the reference method according to EN 12341 and EN 14907. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall be determined as a steady function.	A statistical correlation between the reference measuring method and the output signal could be demonstrated.	yes	136
5.4.5 Cross sensitivity	Shall not exceed 10 % of the limit value.	No deviation of the measured signal from the nominal value > -1.1 µg/m³ caused by interference due to moisture in the sample could be observed for $PM_{2.5}$. For PM_{10}, no deviation of the measured signal from the nominal value > 0.9 µg/m³ caused by interference due to moisture in the sample could be observed. The comparability of the candidates with the reference method according to the Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods” [5] is ensured even for days with a relative humidity of > 70 %.	yes	139

Performance criterion	Specification	Test result	Fulfilled	Page
5.4.6 Averaging effect	The measuring system shall allow the formation of 24 h mean values. The time of the sum of all filter changes within 24 h shall not exceed 1 % of this averaging time.	The measuring system allows the formation of valid daily mean values.	yes	143
5.4.7 Constancy of sample volumetric flow	± 3 % of the rated value during sampling; instantaneous values ± 5 % of the rated value during sampling.	All determined daily mean values deviate less than ± 3 % from the rated value and all instantaneous values deviate less than ± 5 %.	yes	144
5.4.8 Tightness of the measuring system	Leakage shall not exceed 1 % of the sample volume sucked.	The criterion for passing the leakage test, which has been specified by the manufacturer, (maximum pressure increase of 290 hPa in 5 min) proved to be an appropriate parameter for monitoring instrument tightness. The detected maximum leak rate of 10.4 ml/min is less than 1 % of the nominal flow rate which is 3.3 l/min.	yes	147
5.4.9 Determination of uncertainty between systems under test ubs	Shall be determined according to chapter 9.5.3.1 of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" in the field test for at two identical systems.	The uncertainty between the candidates u_{bs} with a maximum of 1.04 µg/m³ for $PM_{2.5}$ and a maximum of 2.28 µg/m³ for PM_{10} does not exceed the required value of 2.5 µg/m³.	yes	150
5.4.10 Calculation of expanded uncertainty between systems under test	Determination of the expanded uncertainty of the candidates according to chapters 9.5.3.2ff of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods".	Without application of correction factors, the determined uncertainties W_{CM} for $PM_{2.5}$ for all datasets under consideration lie below the defined expanded relative uncertainty W_{dqo} of 25 % for suspended particulate matter. Without application of correction factors, the determined uncertainties W_{CM} for PM_{10} for SN3 are for all datasets above the defined expanded relative uncertainty W_{dqo} of 25 % with exception of Cologne, Winter, for SN4 the data set Rodenkirchen, Summer and for both candidates together the data set ≥ 30 µg/m³ are also above the defined expanded relative uncertainty W_{dqo} of 25 % for suspended particulate matter. Correction factors shall be applied according to chapter 6.1 5.4.11 Application of correction factors and terms.	no	162

Performance criterion	Specification	Test result	Fulfilled	Page
5.4.11 Application of correction factors and terms	If the maximum expanded uncertainty of the systems under test exceeds the data quality objectives according to the European Directive on ambient air quality [8], the application of correction factors and terms is allowed. Values corrected shall meet the requirements of chapter 9.5.3.2 ff. of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods".	Due to application of the correction factors, the candidates meet the requirements on data quality of ambient air quality measurements for all datasets for $PM_{2.5}$ and PM_{10}. For $PM_{2.5}$, the requirements are met even without application of correction factors. The correction of slope nevertheless leads to an improvement of the expanded measurement uncertainties of the full data comparison.	yes	185
5.5 Requirements on multiple-component measuring systems	Shall comply with the requirements set for each component also in the case of simultaneous operation of all measuring channels.	Upon assessing the minimum requirements, the measured values for both components were available at the same time (alternating every two minutes between the measurement channels PM_{10} and $PM_{2.5}$).	yes	193

2. Task definition

2.1 Nature of test

Comde-Derenda GmbH has commissioned TÜV Rheinland Energie und Umwelt GmbH to carry out the type-approval test of the Air Pollution Monitor 2 (APM-2) measuring. The test was performed as a complete type approval test.

2.2 Objective

The measuring system shall determine the concentrations of suspended particulate matter PM_{10} and $PM_{2.5}$ within a concentration range of 0 to 1.000 µg/m³.

The performance test was carried out in accordance with the current standards for performance tests and with regard to the most recent developments.

The testing was performed with respect to the following standards:

- VDI Standard 4202, Sheet 1, “Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants”, September 2010/June 2002 [1]
- VDI Standard 4203, Sheet 3, “Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants”, September 2010/August 2004 [2]
- European Standard EN 12341, “Air quality – Determination of the PM_{10} fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods of equality”, German version EN 12341: 1998 [3]
- European Standard EN 14907, “Ambient air quality – Standard gravimetric measurement method for the determination of the $PM_{2,5}$ mass fraction of suspended particulate matter”, German version EN 14907: 2005 [4]
- Guidance document “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English Version: January 2010 [5]

3. Description of the AMS tested

3.1 Measuring principle

The measuring system Air Pollution Monitor 2 (APM-2) determines the concentrations of suspended particulate matter PM_{10} and $PM_{2,5}$ according to the measuring principle of scattered light measurement.

The implemented measuring method utilizes the physical characteristics of light scattering at micro particles. The used scattered light / photometer unit consists of an intensity-stabilized laser diode and a semiconductor photo detector. Both components are arranged to each other in an angle of 90°, thus it is a mono-angle scattered light sensor. The light, reflected by particles in an exactly defined measuring volume, is measured by the detector. The photo detector generates a corresponding voltage signal (0-5 V), which is then low-noise amplified and is a direct measure for the mass concentration of the aerosol in the measured volume. For zero point adjustment, filtered air is lead to the scattered light sensor in periodic intervals via a switching appliance.

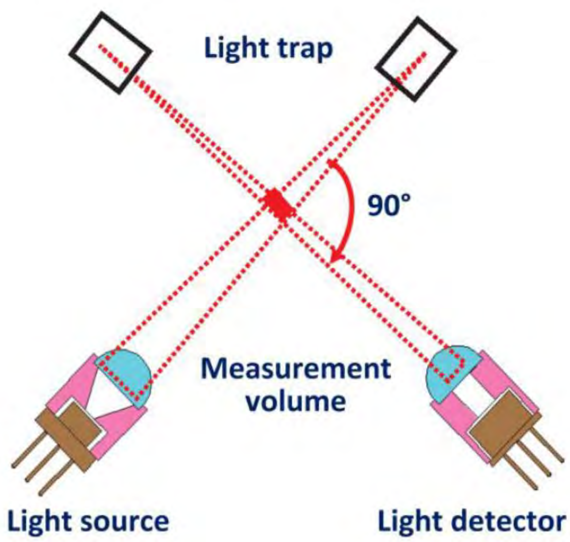

Figure 1: Operating principle of photometer unit

In order to exclude temperature dependency of the photometer signal, the photometer is installed in a case, which is thermally isolated and heated with a heating block, controlled on a temperature of 40 °C.

The physics of light scattering at particles causes, that aerosols with a diameter in the range of the used light wave length scatter the light in most efficient way, related to their mass, i.e. deliver the biggest contribution to the measured signal. For the utilized wavelength of approx. 650 nm, the maximum of sensitivity is in the particle size range between 0.5 and 1 µm. Because of that characteristic, the use of simple scattered light photometry for the measurement of PM_{10}-concentration is limited, as the measured signal is mainly dominated by the $PM_{2.5}$-fraction.

For the measurement of the fraction PM_{10}, the complementary coarse fraction $PM_{2,5-10}$ contributes significantly less to the scattered light signal (in relation to the mass), thus being underrepresented during the measurement. The sensitivity deficit for the coarse fraction is compensated in the device by a simple method – by selective enrichment of the concentration $PM_{2,5-10}$ by the factor 3.3 / 0.2 = 16.5 using a virtual impactor, which is arranged upstream of the scattered light sensor. The enrichment of concentration is equivalent to an increasement of sensitivity of the photometry for the $PM_{2,5-10}$ fraction.

The virtual impactor is located on the top of the case and is connected to the impactor inlet via the sampling tube. The ambient air (Q1), sucked in with 3.3 l/min using the integral pump, is divided into two partial streams by the virtual impactor. The division occurs in the area of two nozzles, which are arranged oppositely. The side flow Q2 (3.1 l/min) is hereby sucked between both nozzles perpendicular to the entering air stream. Particles, which do not follow the side flow due to their mass inertia, keep their path and thus get into the lower axial flow Q3 (0.2 l/min). Thus there is the separation into the side flow with only smaller and lighter particles of the fraction and the axial flow with the particle size und PM_{10}. Via low loss switching appliances (pinch valves with straight passage), either the aerosol out of the axial flow (enrichment mode) or out of the side flow (normal mode) enters the scattered light sensor. During the enrichment mode, the APM-2 determines the PM_{10}-concentration, during the normal mode it determines the $PM_{2.5}$-concentration. For zero point adjustment, filtered air is lead to the scattered light sensor in periodic intervals via a switching appliance.

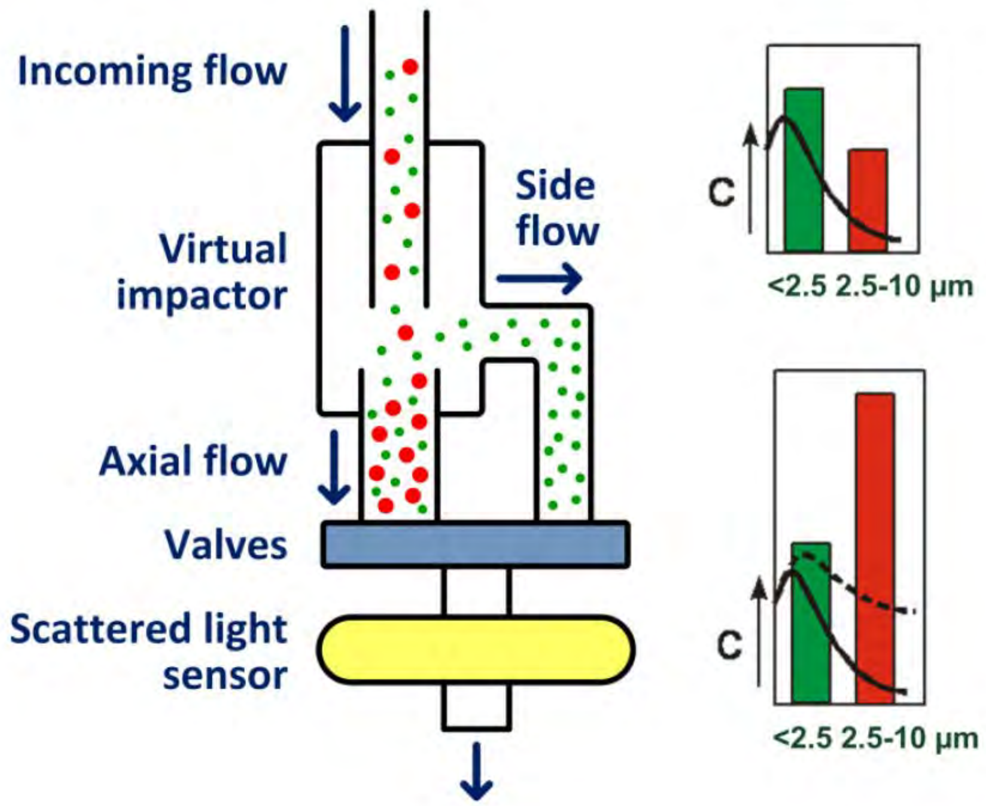

Figure 2: Operating principle of the virtual impactor

3.2 Principle of operation

The sample passes the PM_{10}-sampling inlet with a flow rate of 3.3 l/min and the sampling tube, which connects the sampling inlet with the virtual impactor. Inside of the virtual impactor, the sampled air is divided in two partial streams. Via magnetic valves, either the aerosol out of the axial flow (enrichment mode) or out of the side flow (normal mode) enters the scattered light sensor, where the measurement itself happens. During the type approval test, the measuring system was operated in switch mode between PM_{10} and $PM_{2,5}$ with a respective interval time of 2 min. Furthermore once per hour, zero air purging for approx. 2 min is performed for zero point adjustment – this is indicated in the display with „Flush". The determined measured data are stored in the instrument memory as well as – if installed – on a SD-card.

Figure 3 shows the overview schematic of APM-2.

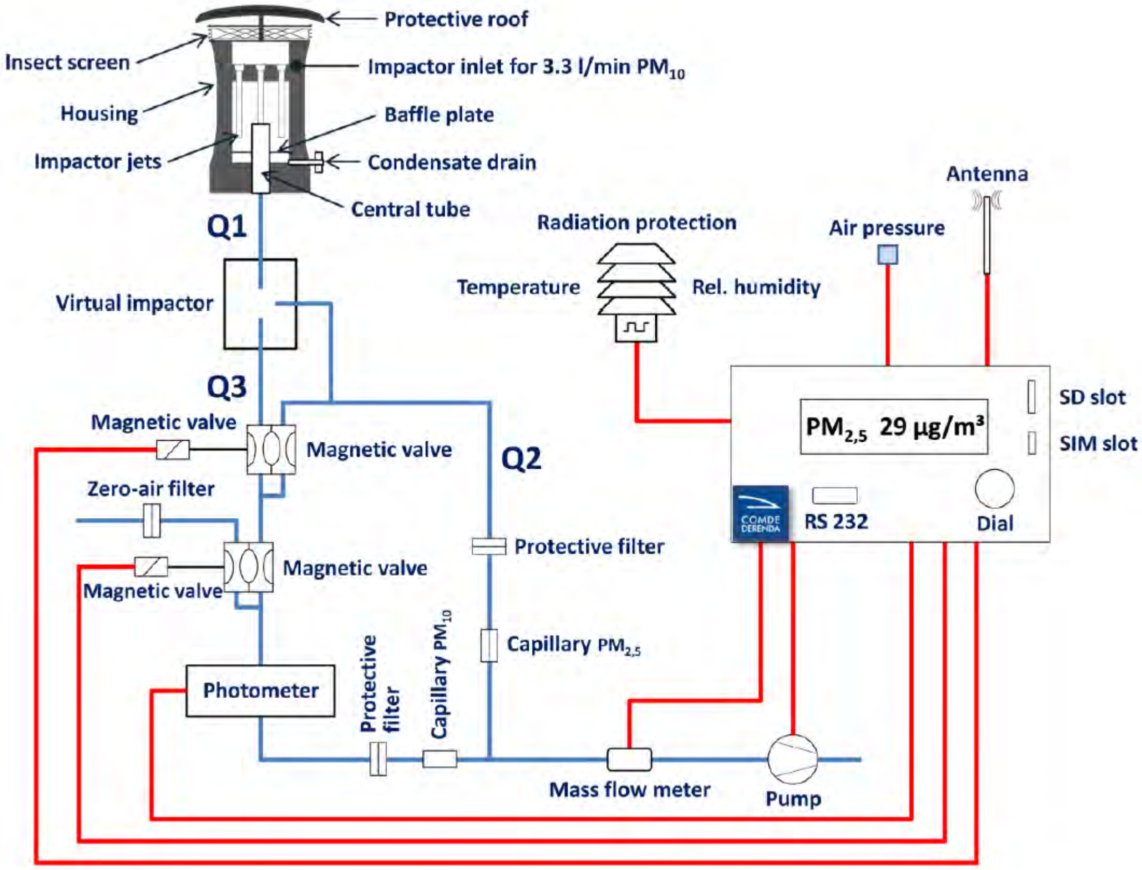

Figure 3: Overview schematic of APM-2

3.3 AMS scope and setup

The APM-2 measuring system for the measurement of ambient air pollution through suspended particulate matter is based upon the measurement principle of scattered light.

The tested measuring system consists of a PM10-sampling inlet, the sampling tube, the virtual impactor, the measuring device with control unit and scattered light / photometer unit, the ambient and manual in German respectively English language.

Figure 4: Overview on complete system APM-2

Figure 5: PM_{10}-sampling inlet for APM-2

Figure 6: Virtual impactor for APM-2

Figure 7: View on APM-2 (front door open)

Figure 8: View on APM-2 (rear door open)

Figure 9: Measuring systems APM-2 on measurement cabinet

The system is controlled and operated directly via the control unit with a Jog-Dial on the front of the device. Measured data are stored in the internal memory or on a SD-card – data transmission via RS232-interface is also possible (serial or Bayern-Hessen-Protocol). The operator can request measured data and system information, change parameters as well as perform tests for checking the correct operation of the measuring system.

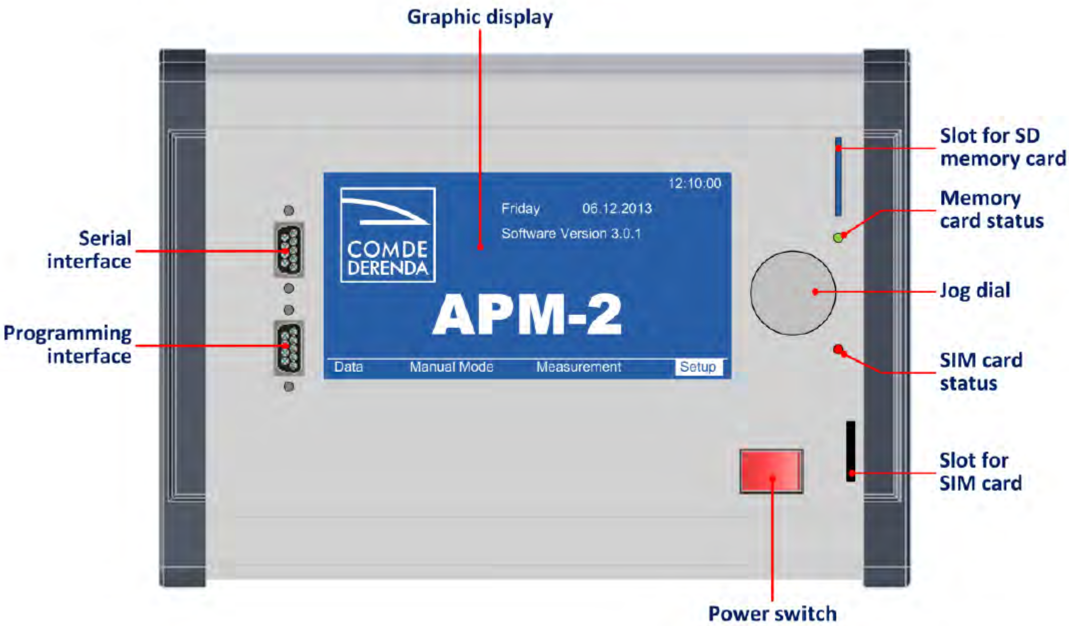

Figure 10: Control unit

On top level one can find the main window of the operator display – starting from here one can navigate into the respective submenus via Jog-Dial. Furthermore current date and time and the installed software version are displayed.

Menu „Data“: In this menu one finds all functionalities with respect to data storage (internally or SD-card).

Furthermore one can access the software update functionalities via this menu.

Menu „Manual Mode“: Here one can find the possibility to manually start the functionalities $PM_{2,5}$-measurement, PM_{10}-measurement and Purging. The chosen options will operate as long until they are interrupted again by the operator. This menu is mainly dedicated to service technicians for functional checks.

Menu „Measurement“: A measurement is initiated by clicking on.

Menu „Setup“: Via the menu „Setup“ the instrument parameters are set or tests for the correct operation are performed, e.g. language, date/time, check of sensitivity of photometer (test gas box), leak test, data transmission, system information, instrument settings (for service only, protected with factory password) and measurement parameters ($PM_{2,5}$, PM_{10} or switch mode, nominal temperature for heater block, interval for switch mode….)

Figure 11 gives an overview on the structure of the menu for APM-2.

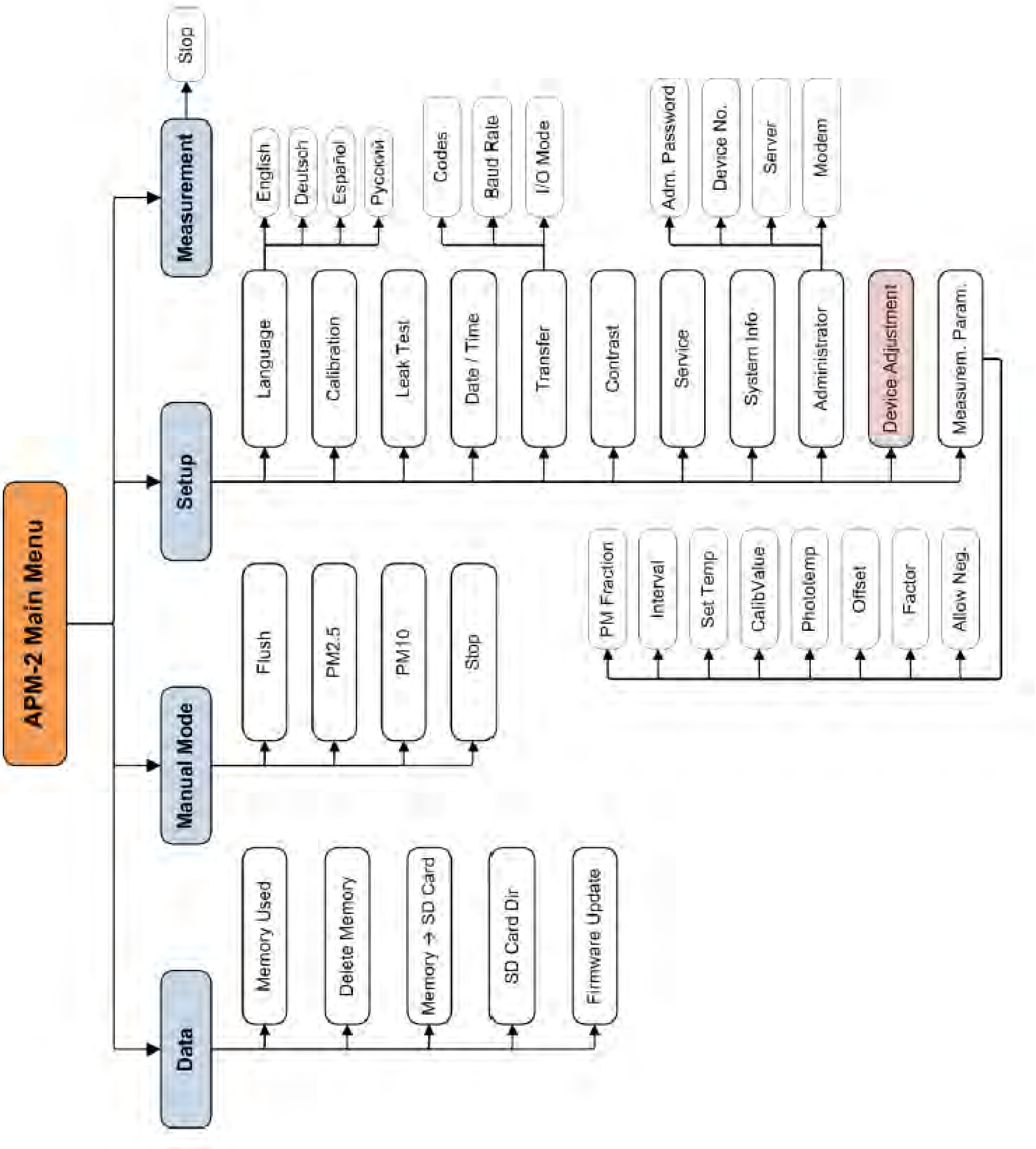

Figure 11: Structure of menu APM-2

Besides the direct communication via Jog-Dial and instrument display, there is also the possibility to communicate with the measuring system via RS232 (serial interface, Bayern-Hessen-Protocol). Measured data can e.g. be recorded on a PC in a simple way via RS232 and a terminal software. During the type approval test, the measured data have been accessed by download the measured data stored on the SD-card.

For external check of the zero point of the measuring system, a zero filter is installed at the instrument inlet. The use of this filter allows the supply of particulate-free air.

Figure 12: Zero filter

For external check of the sensitivity of the photometer, the instrument´s manufacturer has developed the following optional test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements (refer to Table 3), so that the test method itself is to be considered sufficiently stable and reproducible.

Table 3: Test on repeatability with test gas box

Measurement	Time	Measured value [mV]
1	8:48	363
2	8:54	366
3	9:02	370
4	9:09	370
5	9:16	369
6	9:28	368
7	9:33	364
8	9:40	367
9	9:48	365
10	9:57	369
11	10:05	363
12	10:14	372
13	10:22	373
14	10:30	364
15	10:37	370
No. of values		15
Mean value		367.53
Standard deviation s_{x0}		3.25
Detection limit X [% of mean value]		**1.90**

Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

Figure 13: Test gas box for checking the sensitivity

Figure 14: ´Test set-up APM-2 + test gas box

For checking the tightness of the measuring device, a test appliance for tightness check is available. A vacuum is created in the device with the help of the instrument´s pump and after switching off the pump, the rise in pressure over a time period of five minutes is monitored. In case of a rise in pressure > 290 hPa, the test on tightness is regarded as failed.

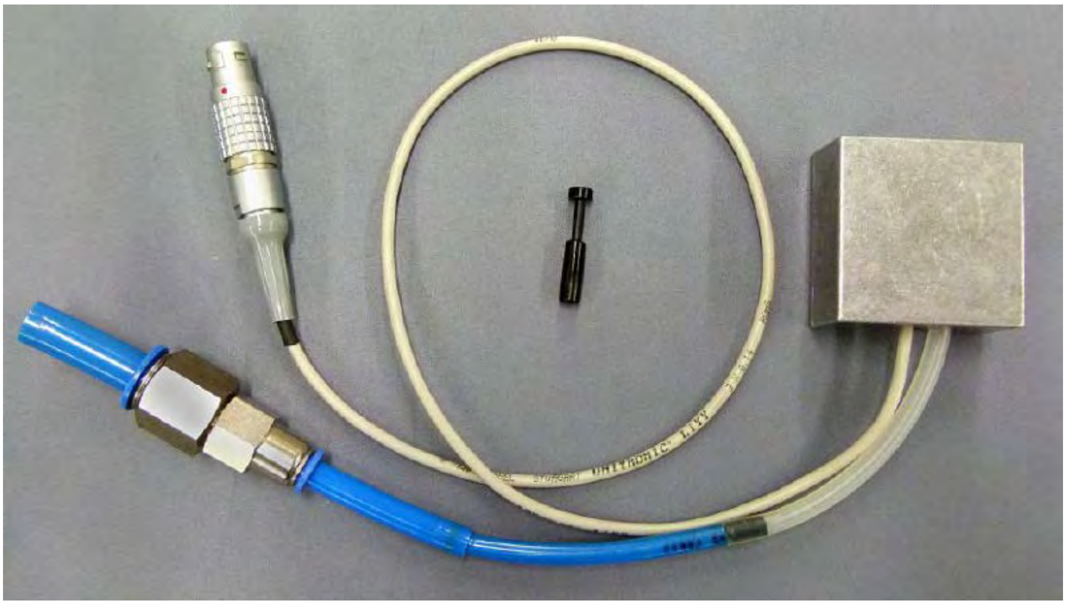

Figure 15: Test appliance for tightness check

Table 4 contains a list of important device-related characteristics of the APM-2 measuring system for suspended particulate matter in the ambient air

Table 4: Device-related data of the APM-2 (manufacturer's data)

Dimensions / Weight	**APM-2**
Measuring system	320 x 560 x 270 mm / 15 kg
Sampling line	0.5 m between inlet and virtual impactor, customized lengths available on request
Sampling inlet	PM_{10}, general shape and manufacture according to DIN EN 12341, downscaled to 3.3 l/min
Power requirements	230 V, 50/60 Hz
Power input	ca. 80 W
Ambient conditions	
Temperature	-20 to +50 °C
Humidity	Outdoor-assembly, protection class IP65
Sample flow rate (Inlet)	3.3 l/min
Virtual impactor	
Side flow	3.1 l/min, $PM_{2,5}$
Axial flow	0.2 l/min, PM_{10}
Aerosol sensor	
Measuring principle	Scattered light, One-angle (90°)
Nominal temperature photometer	40 °C
Measuring range	0 – 1000 µg/m³
Resolution	1 µg/m³
Operating method	During type approval test PM_{10} and $PM_{2,5}$ in switch mode with switching interval of 2 min, different switching intervals (5,10 and 15 min) as well as option to single operation of either PM_{10} or $PM_{2,5}$ are available
Storage capacity data (internal)	3.5 MB corresponds to 27,000 data sets, non-volatile ring buffer
Device inputs and outputs	1 x SD-card for storage of measured values 1 x RS232 interface for communication via serial interface / Bayern-Hessen-Protocol 1 x RS232 interface as programming interface (service only)
Status signals / Error messages	Available (manual, chapter 11)

4. Test programme

4.1 General

The performance test was carried out with two identical devices with the serial numbers SN3 and SN4.

The test was started in the year 2012 with software version 1.3. During the test work, the software was constantly developed and optimized, especially for the implementation of the test gas measurement.

With start of the field test in November 2012, the software version 2.1.0 was installed, updated to version 2.3.1 in February 2013 before the campaign „Bonn, winter“ and updated again to version 2.5.2 in June 2013 before the campaign „Cologne, summer“. This version was kept over the complete remaining field test (Cologne, summer and Rodenkirchen).

All implemented modification until version 2.5.2 are related in first line to the implementation of the test gas measurement and have no impact on the performance of the measuring system (refer to Table 5).

For the outstanding lab investigations at the reference point, the software version 3.0.0.d. respectively 3.0.1 was finally made available in December 2013 respectively January 2014.

These software versions contain an optimization of the calculation algorithm by introducing a linearity correction for the measured PM values. As this modification has an impact on the formation of measured values, the following measures for qualification of the new software – in addition to the outstanding lab investigations – have been agreed upon:

All available measured values of the four past comparison campaigns have been re-calculated manually with the new calculation algorithm and evaluated again. The results of these investigations can be found in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test.

Furthermore an additional comparison campaign at the test site Cologne, parking lot has been conducted with two candidates and the new software version for qualification. For this the following test program was carried out in detail:

- Performance of a comparison campaign with at minimum 40 valid data pairs reference vs. candidate
- Determination of the in-between uncertainty for the candidates u_{bs} according to the Guide
- Calculation of the expanded uncertainty of the candidates according to the Guide
- Application of the correction factors and terms determined in chapter 6.1 5.4.11 Application of correction factors and terms
- Re-calculation of the equivalence for the 4 data sets of the type approval at hand + additional data set from the validation campaign „Cologne, winter 2014“ according to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9]

The results of the additional tests can be found in chapter 7 Investigations for the validation of the instrument software 3.0.1.

Table 5 gives an overview on the software releases during the type approval test and the changes between the different versions.

Table 5: Overview of software releases during the type approval test

Version	Description of changes	Status during type approval test
1.3	Start version	Lab test
2.0.0	• Process control optimized, as crashes during active heating were possible • Bug fix for volume flow calibration • Data transmission either on request (BH) or on regular base • Internal storage, which can later be transferred to the SD-card	Not installed
2.1.0	• Implementation test gas measurement with-CO_2	Field test campaign 1
2.2.2	• Decimal place added for „SpülOffset“, „Gas-Offset“, „ugM³_PM2.5“ and „ugM3_PM10“ • CO_2-Test: 2 seconds break between evacuation and filling	Not installed
2.3.0	• CO_2-Test: Pre-measurement with 67 % instead of 100 % pump voltage	Not installed
2.3.1	• CO_2-Test: CO_2-pre-measurement only 20 s instead of 40 s	Field test campaign 2
2.4.0	• GPRS-Modem can be used internally • Last concentration before purging is kept during purging in the BH-protocol • Flagging of purge step by „5“ in the BH-operational status	Not installed
2.5.0	• New test gas measurement – without bag, 3times exchange with zero air, propane instead of CO_2 • Test gas timeline: 50 s zero air, 20 s propane with pump, 50 s propane without pump • Test gas display in mV with 2 decimals	Not installed

2.5.1	• Test gas measurement: Standard deviation implemented • Test gas measurement: Repeating through „Start“ in the same menu	Not installed
2.5.2	• Test gas timeline now 60-10-50 s • Test gas display in mV with 1 decimal	Field test campaign 3 and 4
2.5.3	• Graphical improvements in test gas menu • Stop button in test gas menu	Not installed
2.5.5	• In the test gas menu, the magnetic valve is switched to zero air, so that no propane can outpour (provided that the bypass is closed)	Not installed
3.0.0.b	• Calibration function for barometer developed • Linearity correction implemented • Error display as superposed window • Calibration factor for photometer implemented • Factory-calibration of ADC-input now possible • Display of negative measured values can be switched on/off as an option • Leak test implemented	Not installed
3.0.0.d	• Optional inversion of valve $PM_{2,5}$/PM_{10} during test gas measurements	Test gas measurements for lab test
3.0.1	• Leak test shows leak rate • Leak test: Vacuum pressure is determined a couple of seconds after switching off the pump • Communication via serial interface stabilized	Campaign 5 for validation 3.0.1

The reliability of operation of the measuring system is increased continuously by the modifications. No significant impact on the instrument performance is to be expected for the changes up to version 3.0.0.b. The implemented modification in the calculation algorithm since version 3.0.0.b has been validated through an extensive test program (refer to chapter 7 starting with page 194 in this report).

The test comprised of a laboratory test for the assessment of performance characteristics as well as a field test, conducted over several months and at various field sites.

All obtained concentrations are given in µg/m³ (operating conditions). Additionally, the PM_{10} concentrations for evaluation according to Standard EN 12341 for standard conditions are given in µg/m³ (273 K, 101.3 kPa) as well.

In the following report, the performance criteria according to the considered Standards [1, 2, 3, 4, 5] are stated in the caption of each test item with number and wording.

4.2 Laboratory test

The laboratory test was carried out with two identical devices of the type APM-2 with the serial numbers SN3 and SN4. In conformity with the applicable standards [1, 2], the following performance criteria were tested in the laboratory:

- Description of device functions
- Determination of detection limit
- Dependence of zero point / sensitivity on ambient temperature
- Dependence of sensitivity on mains voltage

In the laboratory test, the following devices were used for the determination of performance characteristics

- climatic chamber (temperature range from -20 °C to +50 °C, accuracy better than 1 °C)
- Isolation transformer
- 1 mass flow meter Model 4043 (Manufacturer: TSI)
- Zero filter for external zero point check
- Test gas box (propane)
- Test appliance for tightness check

The recording of measurement values at zero point was performed by device-internal recording on the SD-card

For external check of the sensitivity of the photometer, the instrument´s manufacturer has developed the following optional test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity.

The results of the laboratory tests are summarized in chapter 6.

4.3 Field test

The field test was carried out with two identical measuring systems:

System 1: SN3

System 2: SN4

The following performance criteria were tested in the field:

- Comparability of the systems under test according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"
- Comparability of the systems under test with the reference method according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"
- Check of constancy of the volume flow rate
- Calibration capability, analytical function
- Reproducibility
- Zero drift and sensitivity drift*
- Leak tightness of the sampling system
- Dependence of the measured values on sample humidity
- Maintenance interval
- Availability
- Total uncertainty of tested systems

* Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent com parison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely ab stain from this test point in future for type approval testing according to EN TS 16450 [9].

The following auxiliary devices were used during the field test:

- TÜV Rheinland measuring cabinet, air conditioned to approx. 20 °C
- Weather station (WS 500 of ELV Elektronik AG) for the detection of meteorological parameters such as ambient temperature, atmospheric pressure, humidity, wind velocity, wind direction and amount of precipitation.
- 2 reference measuring systems LVS3 for PM_{10} as per item 5
- 2 reference measuring systems LVS3 for $PM_{2.5}$ as per item 5
- 1 gas meter, dry
- 1 mass flow meter Model 4043 (Manufacturer: TSI)
- Power consumption measuring device type Metratester 5 (manufactured by Gossen Metrawatt)
- Zero filter for external zero point checks

The recording of measurement values was performed by device-internal recording on the SD-card

During the field test, two APM-2 systems and two reference systems for $PM_{2.5}$ and PM_{10} were operated simultaneously for a period of 24 hours. The reference system operates discontinuously, that is to say the filter needs to be changed manually after sampling.

During the testing, the impaction plates of the PM_{10} and $PM_{2.5}$ sampling heads of the reference systems were cleaned and lubricated with silicone grease approx. every 2 weeks in order to ensure a safe separation and deposition of particulates. The sampling inlets of the candidates were cleaned approx. every 4 weeks according to manufacturer's information. The sampling head shall always be cleaned in accordance with the instructions provided by the manufacturer. Local concentrations of suspended particulate matter shall also be considered in this procedure.

Before and after each change of test site, the flow rate was tested on each candidate as well as on each reference system with a dry gas meter and a mass flow meter, which connects to the system inlet via hose line.

Test sites and AMS placement

For the field test at the test sites Cologne and Bonn, the measuring systems were installed completely outside on the roof of the measuring cabinet. At these sites, the entire reference equipment (LVS3) was installed outdoors on the roof of the cabinet as well. The installation of the candidates and the reference devices at test site Rodenkirchen was carried out on platforms with approx. 0.5 m height.

The field test was carried out at the following test sites:

Table 6: Field test sites

No.	Test site	Period	Characterization
1	Cologne, winter	11/2012 – 02/2013	Urban background
2	Bonn, road junction, winter	02/2013 – 05/2013	Influence of traffic
3	Cologne, summer	05/2013 – 07/2013	Urban background
4	Rodenkirchen, summer	07/2013 – 09/2013	Rural structure + influence of traffic
5	Cologne, winter*	01/2014 – 03/2014	Urban background

* Validation campaign for software 3.0.1, refer to chapter 7 Investigations for the validation of the instrument software 3.0.1Investigations for the validation of the instrument software 3.0.1 at page 194.

Figure 16 to Figure 25 show the course of PM concentrations at the measuring locations in the field as recorded by the reference measuring systems.

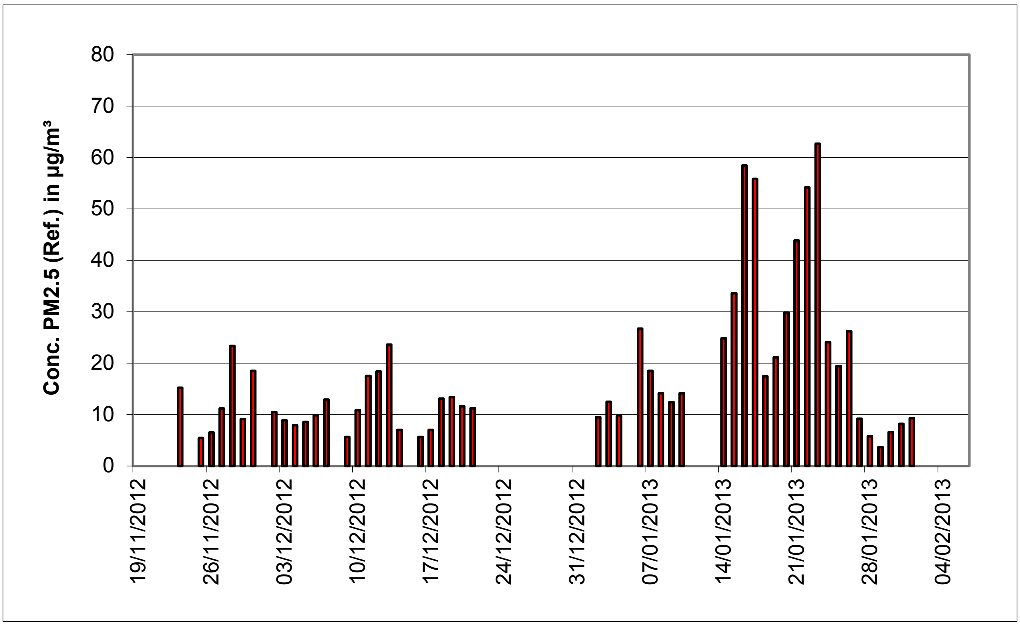

Figure 16: Course of $PM_{2.5}$ concentrations (reference) at test site “Cologne, winter”

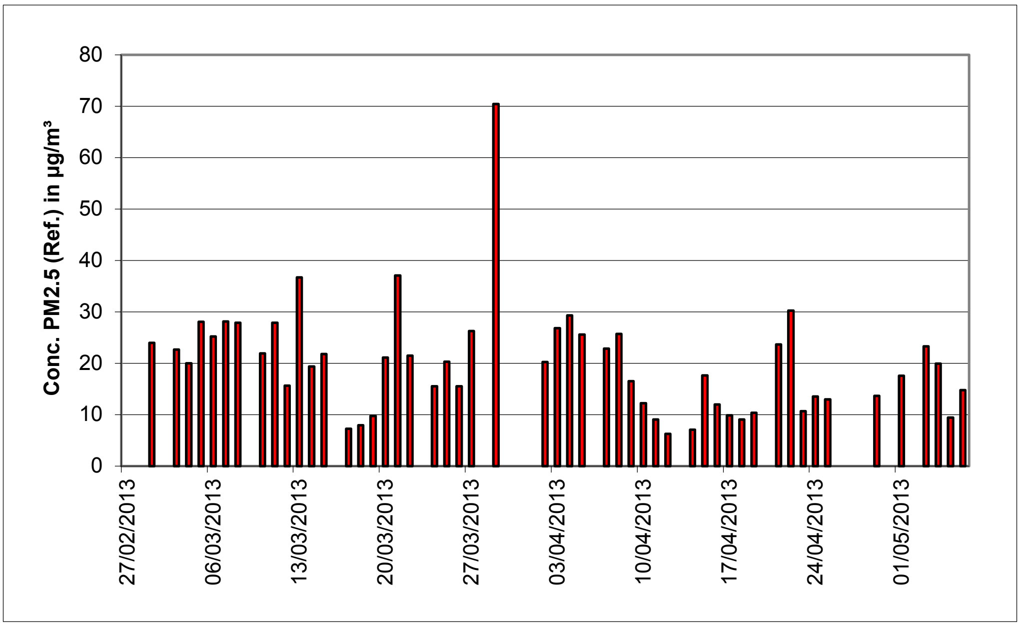

Figure 17: Course of $PM_{2.5}$ concentrations (reference) at test site “Bonn, winter”

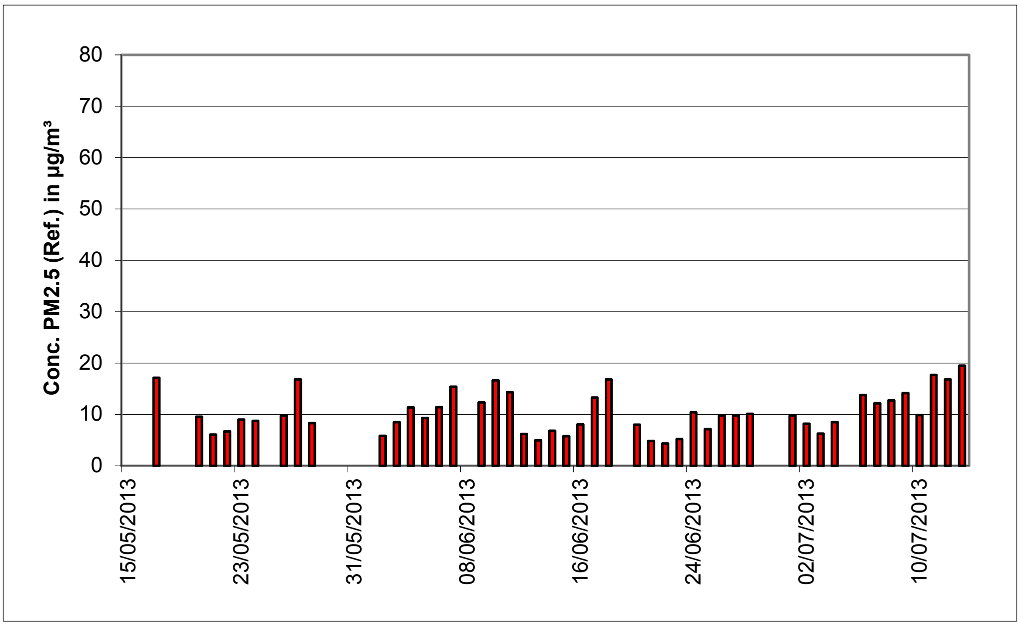

Figure 18: Course of $PM_{2.5}$ concentrations (reference) at test site “Cologne, summer”

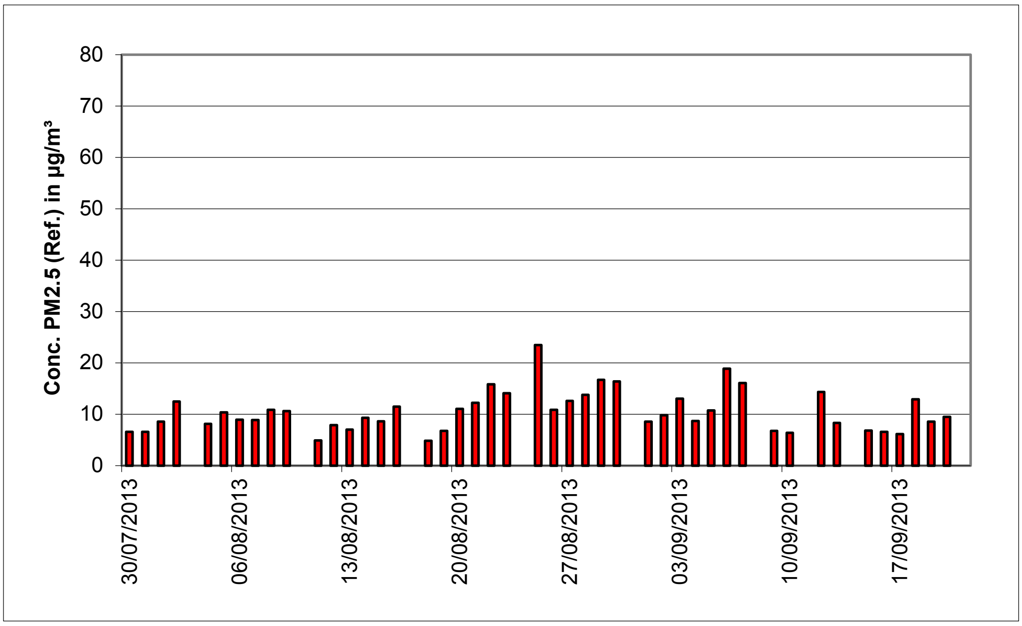

Figure 19: Course of $PM_{2.5}$ concentrations (reference) at test site “Rodenkirchen, summer”

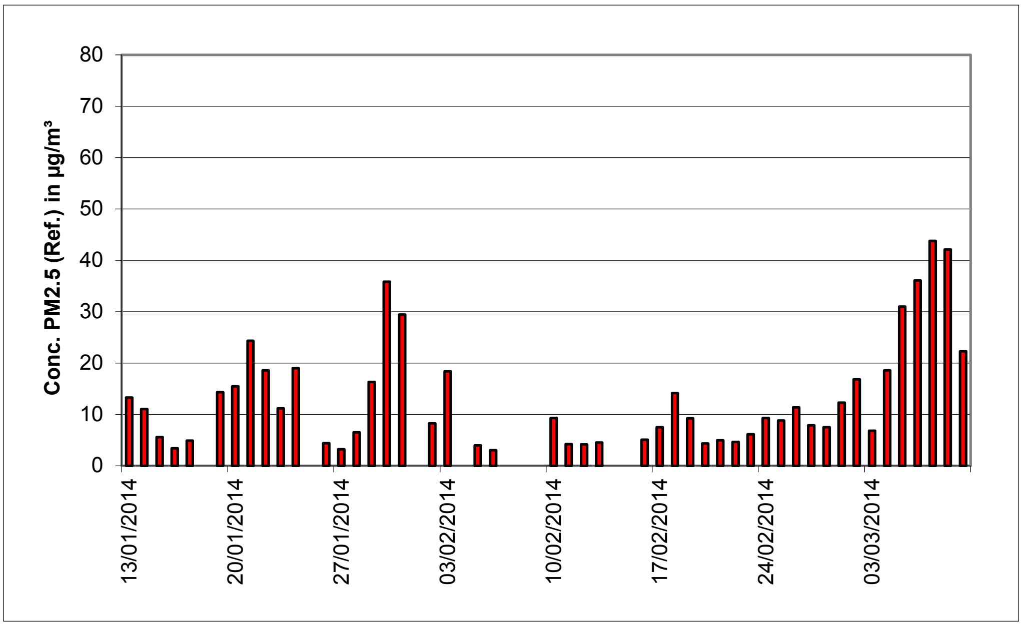

Figure 20: Course of $PM_{2.5}$ concentrations (reference) at test site "Cologne, winter 2014"

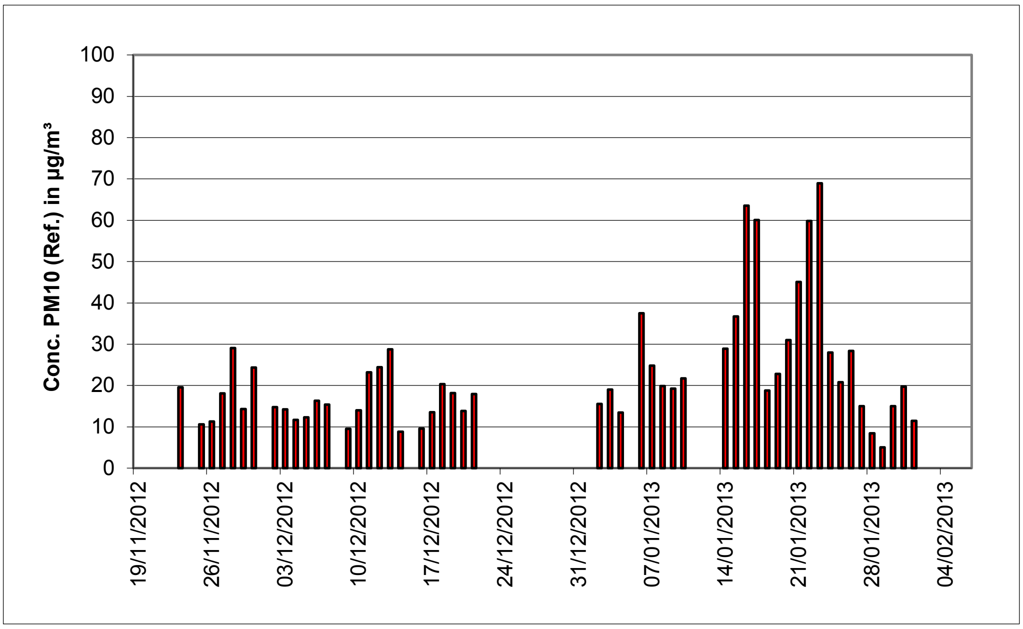

Figure 21: Course of PM_{10} concentrations (reference) at test site "Cologne, winter"

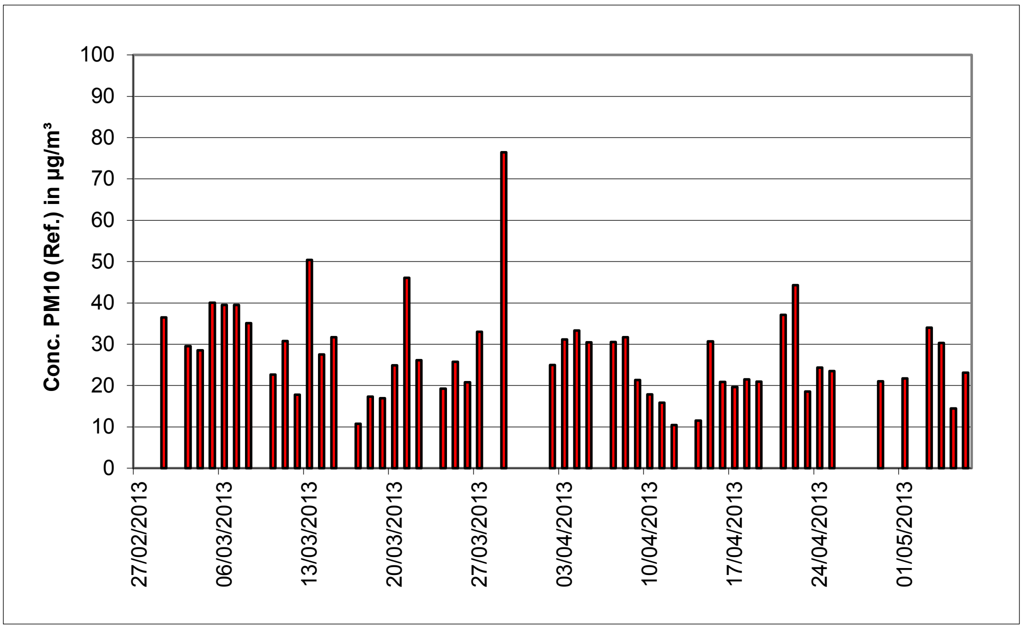

Figure 22: Course of PM_{10} concentrations (reference) at test site "Bonn, winter"

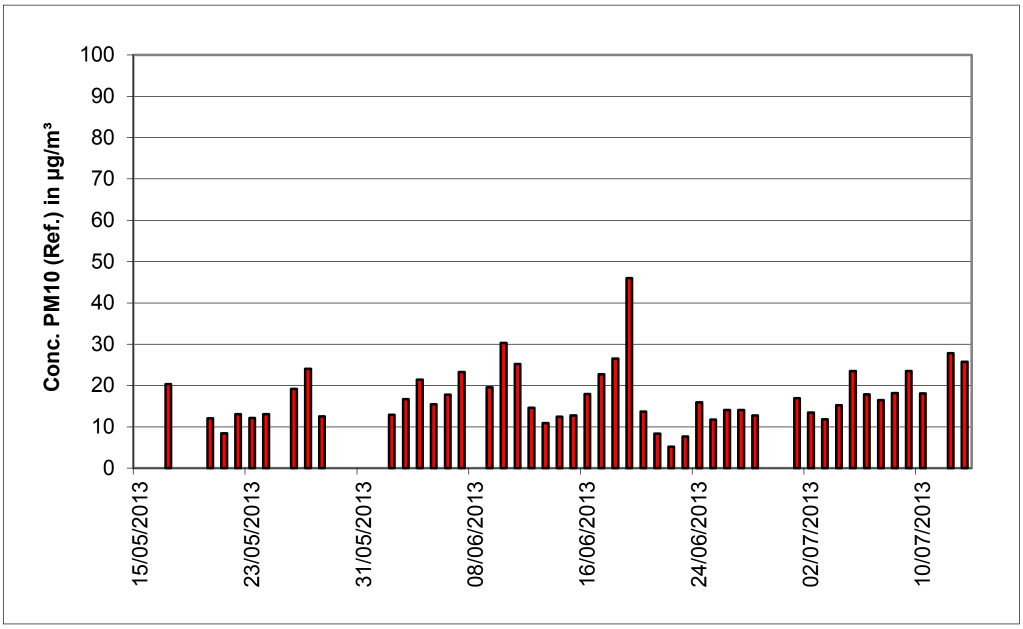

Figure 23: Course of PM_{10} concentrations (reference) at test site "Cologne, summer"

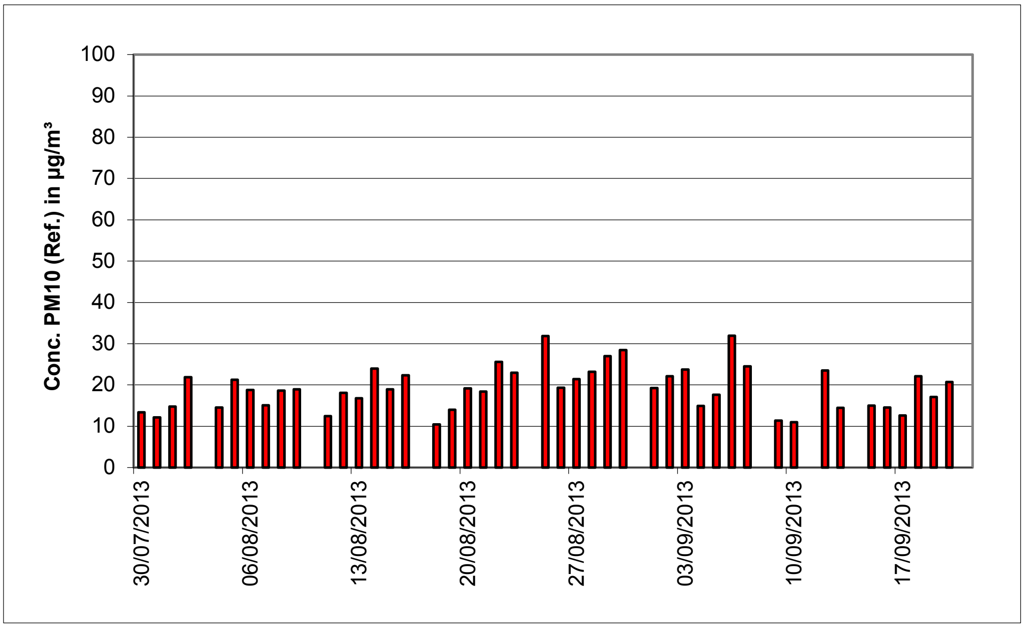

Figure 24: Course of PM_{10} concentrations (reference) at test site "Rodenkirchen, summer"

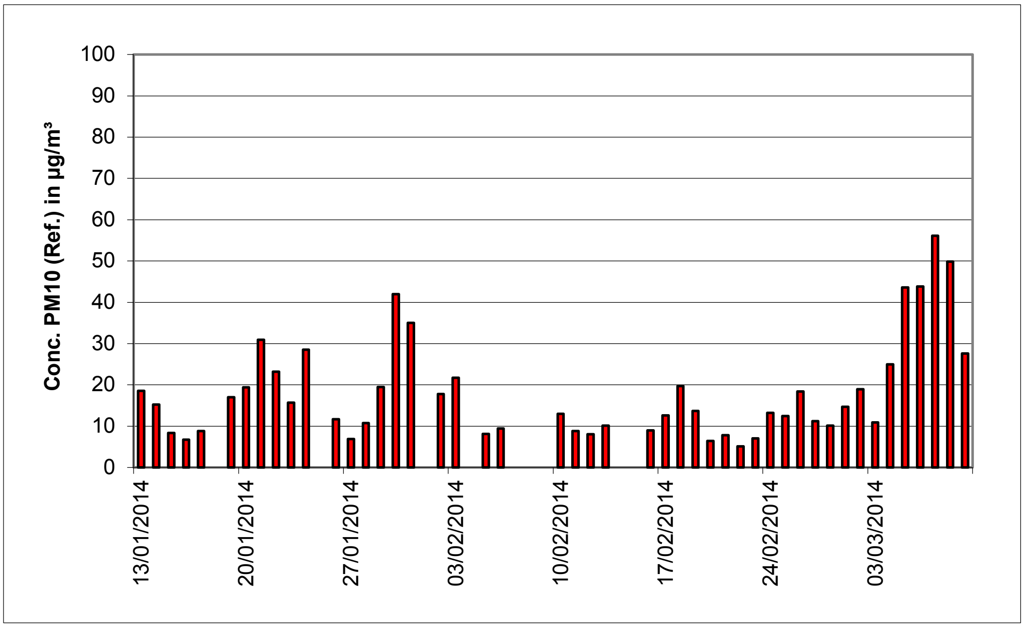

Figure 25: Course of PM_{10} concentrations (reference) at test site “Cologne, winter 2014”

The following figures show the measuring cabinet at the field test sites Cologne, Bonn and Rodenkirchen.

Figure 26: Field test site Cologne, summer & winter

Figure 27: Field test site Bonn, winter

Figure 28: Field test site Rodenkirchen, summer

In addition to the measuring systems for the measurement of ambient air pollution through suspended particulate matter, a data acquisition system for meteorological parameters was installed on the cabinet/at the test site where the measurement was carried out. Ambient temperature, ambient pressure, humidity, wind velocity, wind direction, and the amount of precipitation were monitored continuously. 30-minutes mean values were stored.

The cabinet setup and the arrangement of the sample probes had the following dimensions:

- Height of cabinet roof: 2.50 m
- Sampling height for tested system 0.96 m / 0.51 m above cabinet roof
- Sampling height for reference system 3.46 / 3.01 m above ground
- Height of wind vane: 4.5 m above ground

The following Table 7 therefore contains an overview of the most important meteorological parameters that have been obtained during the measurements at the 4 field test sites (+ validation campaign Cologne, winter 2014) as well as an overview of the concentrations of suspended particulate matter during the test period. All single values are provided in annexes 5 and 6.

Table 7: Ambient conditions at the field test sites, daily mean values

	Cologne, winter	Bonn, winter	Cologne, summer	Rodenkirchen, summer	Cologne, winter 2014*
Number of value pairs Reference PM_{10}	52	51	47	45	46
Number of value pairs Reference $PM_{2.5}$	52	51	46	45	47
$PM_{2.5}$ ratio in PM_{10} [%]					
Range	41.6 – 97.2	42.2 – 96.5	42.5 – 84.1	38.8 – 73.6	32.0 – 90.9
Mean value	73.8	70.5	62.2	54.0	68.5
Ambient temperature [°C]					
Range	-3.3 – 11.9	-3.4 – 20.0	6.3 – 28.2	9.9 – 27.8	2.5 – 13.1
Mean value	4.6	7.9	16.7	17.2	6.5
Ambient pressure [hPa]					
Range	988 – 1027	985 – 1021	993 – 1021	988 – 1016	984 – 1022
Mean value	1004	1004	1008	1005	1000
Rel. humidity [%]					
Range	70.0 – 91.2	42.8 – 85.8	51.4 – 89.5	48.6 – 96.4	46.8 – 87.2
Mean value	81.2	63.2	68.4	75.6	74.4
Wind velocity [m/s]					
Range	0.0 – 3.3	0.4 – 4.2	0.1 – 2.7	1.2 – 5.0	0.0 – 3.0
Mean value	0.9	1.6	0.8	2.6	0.0
Amount of precipitation [mm/d]					
Range	0.0 – 25.7	0.0 – 13.2	0.0 – 32.4	0.0 – 21.3	0.0 – 18.9
Mean value	2.9	0.9	3.7	1.9	1.7

* Validation campaign for software 3.0.1, refer to chapter 7 Investigations for the validation of the instrument software 3.0.1 on page 194

Sampling duration

According to Standard EN 12341, the sampling time shall be 24 h. However, for low concentrations longer sampling times are permissible while for high concentrations shorter sampling times are allowed as well.

According to Standard EN 14907, the sampling time shall be 24 h ± 1 h.

During the field test, a sampling time of 24 h was set for all devices (10:00 – 10:00 (Cologne) and 7:00 – 7:00 (Bonn) and 9:00 – 9:00 (Rodenkirchen)).

Data handling

Before the respective analyses for each test site were carried out, the paired reference values determined during the field test were subject to a statistical outlier test according to Grubbs (99 %) in order to prevent any effects of evidently implausible data on the test results. Value pairs identified as significant outliers may be discarded from the pool of values as long as the critical value of test statistic does not fall below the target. According to the Guide [5] of January 2010, not more than 2.5 % of data pairs shall be determined as outliers and discarded.

As far as candidates are concerned, the measured values are usually not discarded unless there are proven technical reasons for implausible values. Throughout the testing no values measured by the candidates were discarded.

Table 8 and Table 9 provide an overview of the number of value pairs that were identified as significant outliners and therefore removed at each site (reference).

The following value pairs were discarded:

Table 8: Results of the Grubbs' outlier test – reference PM_{10}

Test site	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Cologne, summer	11.07.2013	31.0	28.1

Table 9: Results of the Grubbs' outliner test – reference $PM_{2.5}$

Test site	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Cologne, summer	05.07.2013	14.6	17.4

Filter handling– mass determination

The following filters were used in the performance test:

Table 10: Used filter materials

Measuring system	Filter material, type	Manufacturer
Reference systems LVS3	Emfab™, ∅ 47 mm	Pall

The filters were handled in compliance with Standard EN 14907.

Details on filter handling and weighing processes are describes in annex 2 of this report.

5. Reference measurement method

In accordance with Standards EN 12341 and EN 14907, the following devices were used in the testing:

1. as reference device for PM_{10}: Small Filter Device Low Volume Sampler LVS3
Manufacturer: Ingenieurbüro Sven Leckel,
Leberstraße 63, Berlin, Germany
Date of construction: 2007
PM_{10} sampling head

2. as reference device for $PM_{2.5}$: Small Filter Device Low Volume Sampler LVS3
Manufacturer: Ingenieurbüro Sven Leckel,
Leberstraße 63, Berlin, Deutschland
Date of construction: 2007 and 2010
$PM_{2.5}$ sampling head

During the testing, two reference systems for each PM_{10} and $PM_{2.5}$ were operated simultaneously with a flow rate of 2.3 m³/h. Under real operating conditions the volume flow control accuracy is < 1 % of the nominal flow rate.

The sampling head of the small filter device LVS3 sucks in the sample air via a rotary vane vacuum pump. The sample volume flow is then measured by means of a measuring orifice between filter and vacuum pump. The suctioned air then streams out of the pump via a separator for the abrasion of the rotary vanes and towards the air outlet.

As soon as the sampling is complete the electronic measurement equipment displays the sucked-in sample air volume in standard or operating m³.

The PM_{10} and $PM_{2.5}$ concentrations were determined by dividing the amount of suspended particulate matter on each filter that had been determined gravimetrically in the laboratory by the respective sampling volume in operating m³.

6. Test results

6.1 4.1.1 Measured value display

The AMS shall have a means to display the measured values.

6.2 Equipment

Additional equipment is not required.

6.3 Method

It was checked whether the AMS has a means to display the measured values.

6.4 Evaluation

The measuring system provides a display that shows the measured values. During measurement mode, the currently measured PM_x-concentration (respectively during the purge mode the measured voltage value in mV) is shown at the right hand side of the display. On the left hand side the following measured values are shown:

PM2.5 avg: Mean value of the measured mass concentration $PM_{2,5}$ (moving, updated every second)

PM10 avg: Mean value of the measured mass concentration PM_{10} (moving, updated every second)

Fl.Offset: Photometer-Offset, determined during zero air purging

Phototemp: Photometer temperature

Ext.temp: Ambient temperature

Humidity: Ambient relative humidity

Pressure: Ambient pressure

6.5 Assessment

The measuring system provides a display that shows the measured values.

Performance criterion met? yes

6.6 Detailed presentation of test results

Figure 29 shows the user interface with the current concentrations.

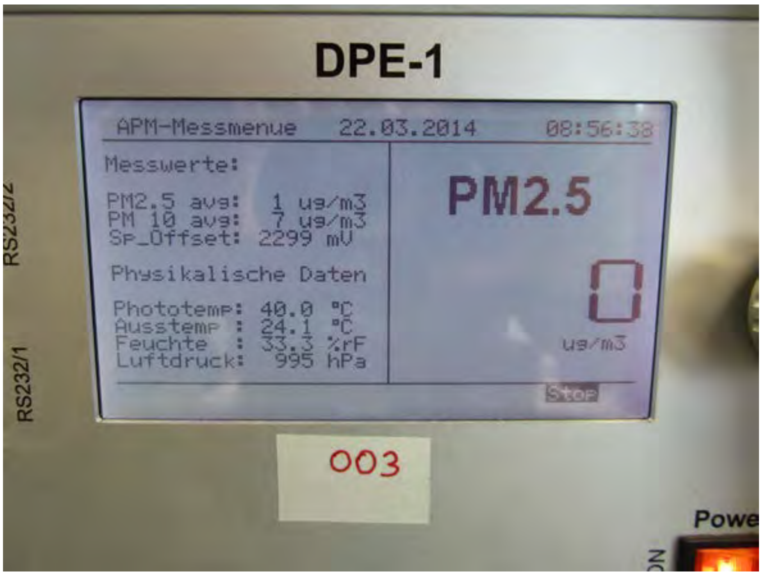

Figure 29: Display of measured concentrations (here: $PM_{2.5}$, German language setup)

6.1 4.1.2 Easy maintenance

Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.

6.2 Equipment

Additional equipment is not required.

6.3 Method

Necessary regular maintenance work was carried out according to the instructions given in the manual.

6.4 Evaluation

The operator shall carry out the following maintenance work:

1. Check of system status.
   The system status can be monitored and controlled directly or online.
2. The sampling inlet has to be cleaned in general according to the instructions provided by the manufacturer, at which the local PM conditions have to be considered (during the type approval test approx. every 4 weeks).
3. A check of the sensors for ambient temperature and ambient pressure should be carried out every 3 months according to EN TS 16450 [9].
4. A check of the flow rate should be carried out every 3 months according to EN TS 16450 [9].
5. In the context of the check of the flow rate, a check on tightness should also be carried out every 3 months.
6. The virtual impactor has to be cleaned latest every 3 months.
7. According to the manufacturer, the internal filters in the device (zero air filter, outlet filter for photometer, bypass filter and pump outlet filter) shall be exchanged latest every 6 months.
8. The photometer should be sent to the manufacturer for re-calibration at least once a year.

   According to the manufacturer, the photometer has to be completely replaced, if:

   - the completely collected PM mass exceeds 50 mg (correspond to approx. 200 days with an average concentration of 50 µg/m³)
   - the photometer offset exceeds 2500 mV.

     After the annual maintenance of the photometer, the measuring system is to be calibrated at the measurement site with the gravimetric PM_{10}-reference method according to EN 12341 respectively with the gravimetric $PM_{2,5}$-reference method according to EN 14907. Preferably a seasonal calibration rhythm is to follow.

9. During the annual basic maintenance the cleaning of the sampling tube has also to be considered.
10. The vacuum pump has a life time of approx. 2 years – after reaching the lifetime, the pump must be completely replaced. Failure of the pump is displayed on the system with an error message

Maintenance work shall be carried out according to the instructions provided in the manual (chapter 10). In general, all work can be carried out with commonly available tools.

6.5 Assessment

Maintenance work can be carried out from the outside with commonly available tools and reasonable time and effort. The operations described in item 6ff shall only be performed when the device is on standstill. These works occur every 3 months (cleaning of virtual impactor), every 6 months (filter replacement), once a year (photometer) respectively every 2 years (pump). In the meantime, maintenance work is limited to the check of contaminations, plausibility and possible status/error messages.

Performance criterion met? yes

6.6 Detailed presentation of test results

During the testing, work on the devices was carried out on the basis of operations and work processes described in the manuals. However, there was no replacement of the photometer. By adhering to the described procedures no difficulties were observed. Up to this point, all maintenance could be carried out without difficulty and with conventional tools.

6.1 4.1.3 Functional check

If the operation or the functional check of the measuring system requires particular instruments, they shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.
Test gas units included in the measuring system shall indicate their operational readiness to the measuring system by a status signal and shall provide direct as well as remote control via the measuring system.

6.2 Technical equipment

Operator's manual, zero filter, test gas box (optional).

6.3 Method

The system status is monitored continuously and problems are indicated by a series of different status messages. The current status of the monitored parameters can be viewed directly on the instrument display or they can be taken from the data record. If there is an error message, the message is shown in the display permanently.

The zero point of the measuring system can also be checked externally by applying a zero filter to the instrument's inlet. The use of this filter allows the provision of particulate-free air.

During the testing, the zero point was determined using a zero filter approx. every 4 weeks.

For external check of the sensitivity of the photometer, the instrument manufacturer has developed the following test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements (refer to Table 11), so that the test method itself is to be considered sufficiently stable and reproducible.

Table 11: Test on repeatability with test gas box

Measurement	Time	Measured value [mV]
1	8:48	363
2	8:54	366
3	9:02	370
4	9:09	370
5	9:16	369
6	9:28	368
7	9:33	364
8	9:40	367
9	9:48	365
10	9:57	369
11	10:05	363
12	10:14	372
13	10:22	373
14	10:30	364
15	10:37	370
No. of values		15
Mean value		367.53
Standard deviation s_{x0}		3.25
Detection limit X [% of mean value]		**1.90**

Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

6.4 Evaluation

All functions described in the operator's manual are available or can be activated. The current instrument status is continuously monitored and different warning messages are displayed in the case of problems.

External zero point checks by means of a zero filter can be carried out at any time.

An external check of the sensitivity of the photometer can also be carried out at any time with the help of the test gas check, however it could not be verified during the field test campaigns within the context of the type approval test During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements, so that the test method itself is to be considered sufficiently stable and reproducible and in general suitable for a stability check of the measuring system.

6.5 Assessment

All functions described in the operator's manual are available, can be activated, and work properly. The current instrument status is continuously monitored and different warning messages are displayed in the case of problems.

The results of the external zero point checks by means of zero filter that were carried out during the field tests are described in Chapter 6.1 5.3.12 Long-term drift in this report.

An external check of the sensitivity of the photometer can also be carried out at any time with the help of the test gas check, however it could not be verified during the field test campaigns within the context of the type approval test During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements, so that the test method itself is to be considered sufficiently stable and reproducible and in general suitable for a stability check of the measuring system.

Performance criterion met? yes

6.6 Detailed presentation of test results

See chapter 6.1 5.3.12 Long-term drift

6.1 4.1.4 Setup times and warm-up times

The AMS' setup and warm-up times shall be stated in the manual.

6.2 Equipment

A timer was provided additionally.

6.3 Method

The measuring systems were activated according to the manufacturer's specifications. The amounts of time required for setup and warm-up were recorded separately.

Structural measures taken before installation, like for instance the set-up of the power supply line or necessary measures for protection of the measuring system, have not been assessed here.

6.4 Evaluation

The setup time comprises the time needed for all necessary works from system installation to start-up.

The APM-2 measuring system is equipped with weatherproof housing and thus designed for outdoor installation. As a result, all that is needed at the installation site is a 220V power connection.

The following steps are required for the (initial) installation of the measuring system:

- Unpacking and Installation of the AMS
- Installation of sampling tube, impactor inlet and ambient sensor
- Power connection
- Power-up of AMS
- After a warm-up period of at least 1 h (photometer temperature has to be at 40°C:

  - Test on tightness
  - Check of ambient sensor
  - Check of volume flow
  - (optional) Check with test gas

- Optional connection of peripheral logging systems (RS232) to the corresponding port

These operations, and therefore the setup time for the first-time installation, require approx. 1-2 h. If mounted once, the measuring system is easy to transport as a whole and can be moved from one measuring test site to another.

The warm-up time is the time between the start of operation of the measuring system and the point when it is ready for measurement.

Upon power-up of the system, the measurement can be started directly by selecting the menu-point “Measurement” after the nominal temperature of the photometer has been reached. The measurement starts with two minutes of purging the photometer with zero air and following zero point adjustment. This zero point purging is carried out automatically for a time period of two minutes during measurement operation. The measurement itself starts immediately after the first purging. After that, the measuring systems carries out – dependent on the switching interval (during the type approval test every 2 min) – alternatingly the $PM_{2.5}$ respectively PM_{10}-measuremements. The warm-up time is thus in normal case at least 15-30 min – depending on the time needed to reach the nominal temperature of the photometer.

If necessary, any changes to basic parameters can quickly be carried out in a few minutes by personnel that are familiar with the AMS. However, normal measuring operation is interrupted for this.

6.5 Assessment

Setup and warm-up times were determined.

The measuring system can easily be operated at various measuring sites. The setup time amounts to approximately 1-2 h at first-time installation. The warm-up time amounts to 15-30 min, depending on the necessary stabilization time.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 4.1.5 Instrument design

The instruction manual shall include specifications of the manufacturer regarding the design of the measuring system. These elements are:
Instrument shape (e.g. bench mounting, rack mounting, free mounting)
mounting position (e.g. horizontal or vertical mounting)
safety requirements
dimensions
weight
power consumption.

6.2 Equipment

Additionally, a measuring device for recording the power consumption and a balance were used to test this performance criterion.

6.3 Method

The supplied instruments were compared to the descriptions in the manuals. The specified power consumption is determined over a 24 h-standard operation during the field test.

6.4 Evaluation

The measuring system APM-2 is equipped with weatherproof housing and thus designed for outdoor installation. The AMS shall be installed in horizontal position.

Dimensions and weight of the AMS match the information given in the operator's manual.

According to the manufacturer, the power consumption of the AMS with the used pump is about 80 W at maximum for the complete system. During a 24 h test the total power demand of the AMS was determined. During this test, the stated value was not exceeded at any time.

6.5 Assessment

The instrument design specifications listed in the operator's manual are complete and correct.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 4.1.6 Unintended adjustment

It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation.

6.2 Technical equipment

No additional tools are required here.

6.3 Method

The measuring system is operated via the control unit with a Jog-Dial on the front of the device.

The menu levels which are not protected by password mostly allow reviewing measurements, parameters etc. respectively carrying out functional checks.

The adjustment of parameters for the measurement is password protected (Menu: Setup/Measurement Parameter). Instrument parameters, which are implemented in the system, can only be accessed by specifically authorized personnel via the menu “Setup/Device Adjustment”, which is protected by the factory-password.

Moreover, the door of the weatherproof housing is protected by two locks which prevent unauthorized access to the measuring system.

6.4 Evaluation

Unintended adjustment of instrument parameters can be avoided by password protection. Moreover, additional protection against unauthorized intervention is given by the weatherproof housing with lockable door.

6.5 Assessment

The measuring system is secured against illicit or unintentional adjustments of instrument parameters. Additional protection against unauthorized access is provided by the lockable door of the weatherproof housing.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 4.1.7 Data output

The output signals shall be provided digitally (e.g. RS232) and/or as analogue signals (e.g. 4 mA to 20 mA).

6.2 Equipment

PC with "HyperTerminal" software

6.3 Method

The measuring system has got an internal buffer with 3.5 MB capacity. The buffer is designed as a non-volatile ring buffer. Additionally the measured data can be saved directly on a SD-card.

During type approval test, the measured data have been saved device-internally on the SD-card and have been readout. The measuring system also offers the possibility to output measured signals or communicate via serial interface RS232 (serial, Bayern-Hessen protocol). The transfer of measured data via RS 232 to a terminal software is easily possible.

The AMS does not provide analogue output signals.

6.4 Evaluation

The measured signals are offered as follows on the front side of the instrument:

- 1 x SD card for saving measured values
- 1 x RS232 interface for communication via serial interface / Bayern-Hessen-Protocol
- 1 x RS232 interface as programming interface (for service only)

6.5 Assessment

The measured signals are stored on SD-card or offered digitally (via RS232).

Performance criterion met? yes

6.6 Detailed presentation of test results

Figure 30 shows the instrument's front side with the various data outputs.

Figure 30: Front side of the APM-2 (top right side: SD-card slot, left side RS232)

6.1 5.1 General

The manufacturer's information provided in the operator's manual shall not contradict the findings of the performance test.

6.2 Equipment

Not required here.

6.3 Method

The test results are compared with the information given in the manual.

6.4 Evaluation

Instances where the first draft of the manual deviated from the actual design of the instrument have been corrected.

6.5 Assessment

No differences between the instrument design and the descriptions given in the manuals were found.

Performance criterion met? yes

6.6 Detailed presentation of test result

For this module, refer to item 6.4.

6.1 5.2.1 Certification ranges

The certification range over which the AMS will be tested shall be determined.

6.2 Equipment

No additional tools are required here.

6.3 Method

The certification range over which the AMS will be tested shall be determined.

6.4 Evaluation

VDI Standard 4202, Sheet 1 lists the following minimum requirements for the certification ranges of measuring systems intended for the measurement ambient air pollution through suspended particulate matter:

Table 12: Certification ranges

Component	Minimum value cr	Maximum value cr	Limit value	Assessment period
	in µg/m³	in µg/m³	in µg/m³	
PM_{10}	0	100	50	24h
$PM_{2,5}$	0	50	25	Calendar year

Certification ranges are related to the limit value with the shortest assessment period and used for the assessment period of the measuring system in the range of the limit value. This assessment of the measuring system in the range of the limit value is performed as part of the determination of the expanded uncertainty of the candidates according to the guide [5]. For this purpose, the following values are used as reference values in accordance with the specifications of the Guide:

PM_{10}: 50 µg/m³

$PM_{2.5}$: 30 µg/m³

Refer to test item 6.1 5.4.10 Calculation of expanded uncertainty between systems under test in this report.

6.5 Assessment

Assessment of AMS in the range of the relevant limit values is possible.

Performance criterion met? yes

6.6 Detailed presentation of test results

Refer to test item 6.1 5.4.10 Calculation of expanded uncertainty between systems under test in this report.

6.1 5.2.2 Measuring range

The upper limit of measurement of the measuring system shall be greater or equal to the upper limit of the certification range.

6.2 Equipment

No additional tools are required.

6.3 Method

It was examined whether the upper limit of measurement is greater or equal to the upper limit of the certification range.

6.4 Evaluation

The measuring system has a default measuring range of 0 – 1,000 µg/m³.

Measuring range:	0 – 1,000 µg/m³	
Upper limit of certification range:	PM_{10}:	100 µg/m³
	$PM_{2.5}$:	50 µg/m³

6.5 Assessment

The upper limit of measurement is greater than the corresponding upper limit of the certification range.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.3 Negative output signals

Negative output signals or measured values may not be suppresses (life zero).

6.2 Equipment

No additional tools are required here.

6.3 Method

In the field test and during laboratory testing, it was examined whether the AMS has a means to output negative measured values as well.

6.4 Evaluation

The measuring system can output negative values both via the display and via the data outputs, though no negative output signals occurred during performance testing. Due to measuring principle and instrument design, negative output signals are not to be expected.

6.5 Assessment

Negative output signals are directly displayed by the AMS and can be output via corresponding data outputs. Yet, they are not to be expected due to measuring principle and instrument design.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.4 Failure in the mains voltage

In case of malfunction of the measuring system or failure in the mains voltage for a period of up to 72 h, uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.

6.2 Equipment

Not required here.

6.3 Method

A failure in the mains voltage was simulated and it was tested, whether the AMS remains undamaged and is ready for measurement after the restart of power supply.

6.4 Evaluation

The measuring systems do not require operation gas or calibration gas, therefore uncontrolled emission of gases is not possible.

When mains voltage returns after a power failure, the AMS automatically returns to the measuring mode after re-stabilization of the photometer temperature and two-minutes zero air purging (see also item 6.1 4.1.4 Setup times and warm-up times).

6.5 Assessment

All parameters are secured against loss by buffering. When mains voltage returns the AMS returns to failure-free operation mode and automatically resumes measuring after re-stabilization of the photometer temperature and two-minutes zero air purging.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.5 Operating states

The measuring system shall allow control of important operating states by telemetrically transmitted status signals.

6.2 Equipment

PC for data acquisition.

6.3 Method

A PC was connected locally via RS232 to the measuring system to check data transfer and instrument status.

The use of corresponding routers or modems enables tele monitoring.

6.4 Evaluation

The AMS allows telemetric monitoring and control via various ports (Ethernet, RS232).

6.5 Assessment

The measuring systems can be monitored and operated extensively from an external PC via modem or router.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.6 Switch-over

Switch-over between measurement and functional check and/or calibration shall be possible telemetrically by computer control or manual intervention.

6.2 Equipment

Not required here.

6.3 Method

The operator can monitor the AMS directly or via remote control. A telemetric control is not yet implemented.

6.4 Evaluation

All operating procedures that do not require practical work on site can be monitored by the user directly or via telemetric remote control. A telemetric control is not yet implemented.

6.5 Assessment

The measuring system can be monitored by the user directly or via remote control. A telemetric control is not yet implemented, but already planned for the future.

Performance criterion met? no

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.7 Maintenance interval

The maintenance interval of the measuring system shall be determined during the field test and specified. The maintenance interval should be three months, if possible, but at least two weeks.

6.2 Equipment

Not required here.

6.3 Method

The types of maintenance and the maintenance intervals required to ensure proper functioning of the AMS were determined in this performance criterion. In order to determine the maintenance interval, the results of the determination of the drift at zero point according to chapter 6.1 5.3.12 Long-term drift have been taken into account.

6.4 Evaluation

During the entire field test no impermissible drifts at zero have been observed in the candidates.

An external check of the sensitivity of the photometer is possible with the help of the test gas procedure, but could not be checked in the field test campaign during the type approval test. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements, so that the test method itself is to be considered sufficiently stable and reproducible and in general suitable for the stability check of the measuring system. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

Thus, the maintenance interval is determined by regularly necessary maintenance work (see also module 4.1.2).

During operating time, maintenance may be limited to contamination checks, plausibility checks and possible status and error messages.

6.5 Assessment

The maintenance interval of 4 weeks has been determined by regular maintenance work.

Performance criterion met? yes

6.6 Detailed presentation of results

For necessary maintenance work refer to item (module) 4.1.2 in this report or chapter 10 in the operator’s manual.

6.1 5.2.8 Availability

The availability of the measuring system shall be determined during the field test and shall be at least 95 %.

6.2 Equipment

Not required here.

6.3 Method

The start and end point of the availability checks are determined by the start and end point at each of the field test sites. For this purpose, all interruptions, for instance those caused by malfunctioning or maintenance work, are recorded as well.

6.4 Evaluation

Table 13 and Table 14 provide lists of operation times, time used for maintenance, and malfunction times. The measuring systems were operated over a period of 264 days in total during the field test (4 comparison campaigns). This period includes 22 days of zero filter operation respectively device audits during the type approval test (see also annex 5).

Downtimes caused by external influences which the instrument cannot be blamed for have been recorded on 31 December 2012 and 01 January 2013 (failure in the mains voltage). As a consequence of these external influences, the total operation time has been reduced to 262 days.

The following instrument malfunctions have been recorded:

SN3:

There have been none instrument malfunctions.

SN4:

Between 24 May 2013 and 26 May 2013 there has been no data recording due to unknown reasons for SN4 – thus there have been three days of downtime.

Apart from that no further instrument malfunctions were recorded.

Downtimes caused by maintenance of the sampling heads, regular checks of flow rates (respectively tightness) amount to 0.5 to 1 h per system. Daily mean values affected by this have not been discarded.

6.5 Assessment

The availability was 100 % for SN3 and 98.9 % for SN4 without test-related downtimes. Including test-related downtimes it was 91.6 % for SN3 and 90.5 % for SN4.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 13: Determination of availability (without test-related downtimes)

		System 1 (SN3)	System 2 (SN4)
Operating time	d	262	262
Downtime	d	0	3
Maintenance	d	0	0
Actual operating time	d	262	259
Availability	%	100	98.9

Table 14: Determination of availability (incl. test-related downtimes)

		System 1 (SN3)	System 2 (SN4)
Operating time	d	262	262
Downtime	d	0	3
Maintenance incl. zero filter	d	22	22
Actual operating time	d	240	237
Availability	%	91.6	90.5

6.1 5.2.9 Instrument software

The version of the instrument software to be tested shall be displayed during switch-on of the measuring system. The test institute shall be informed on changes in the instrument software, which have influence on the performance of the measuring system.

6.2 Equipment

Not required here.

6.3 Method

It was checked whether the measuring system has a means of displaying the instrument software. The manufacturer was advised to inform the test institute on any changes in the instrument software.

6.4 Evaluation

The current software version is displayed in the main menu as well as under menu point "Setup/System info".

The test was started in the year 2012 with software version 1.3. During the test work, the software was constantly developed and optimized, especially for the implementation of the test gas measurement.

With start of the field test in November 2012, the software version 2.1.0 was installed, updated to version 2.3.1 in February 2013 before the campaign „Bonn, winter" and updated again to version 2.5.2 in June 2013 before the campaign „Cologne, summer". This version was kept over the complete remaining field test (Cologne, summer and Rodenkirchen).

All implemented modification until version 2.5.2 are related in first line to the implementation of the test gas measurement and have no impact on the performance of the measuring system (refer to Table 5).

For the outstanding lab investigations at the reference point, the software version 3.0.0.d. respectively 3.0.1 was finally made available in December 2013 respectively January 2014.

These software versions contain an optimization of the calculation algorithm by introducing a linearity correction for the measured PM values. As this modification has an impact on the formation of measured values, the following measures for qualification of the new software – in addition to the outstanding lab investigations – have been agreed upon:

All available measured values of the four past comparison campaigns have been re-calculated manually with the new calculation algorithm and evaluated again. The results of these investigations can be found in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test.

Furthermore an additional comparison campaign at the test site Cologne, parking lot has been conducted with two candidates and the new software version (Version 3.0.1) for qualification. For this the following test program was carried out in detail:

- Performance of a comparison campaign with at minimum 40 valid data pairs reference vs. candidate
- Determination of the in-between uncertainty for the candidates u_{bs} according to the Guide
- Calculation of the expanded uncertainty of the candidates according to the Guide

- Application of the correction factors and terms determined in chapter 6.1 5.4.11 Application of correction factors and terms
- Re-calculation of the equivalence for the 4 data sets of the type approval at hand + additional data set from the validation campaign „Cologne, winter 2014“ according to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9]

The results of the additional tests can be found in chapter 7 Investigations for the validation of the instrument software 3.0.1.

An overview on the implemented modifications since start of the test work can be found in chapter 4.1 General.

The reliability of operation of the measuring system is increased continuously by the modifications. No significant impact on the instrument performance is to be expected for the changes up to version 3.0.0.b. The implemented modification in the calculation algorithm since version 3.0.0.b has been validated through an extensive test program (refer to chapter 7 starting with page 194 in this report).

6.5 Assessment

The version of the instrument software is shown in the display. The test institute is informed on any changes in the instrument software.

Performance criterion met? yes

6.6 Detailed presentation of test results

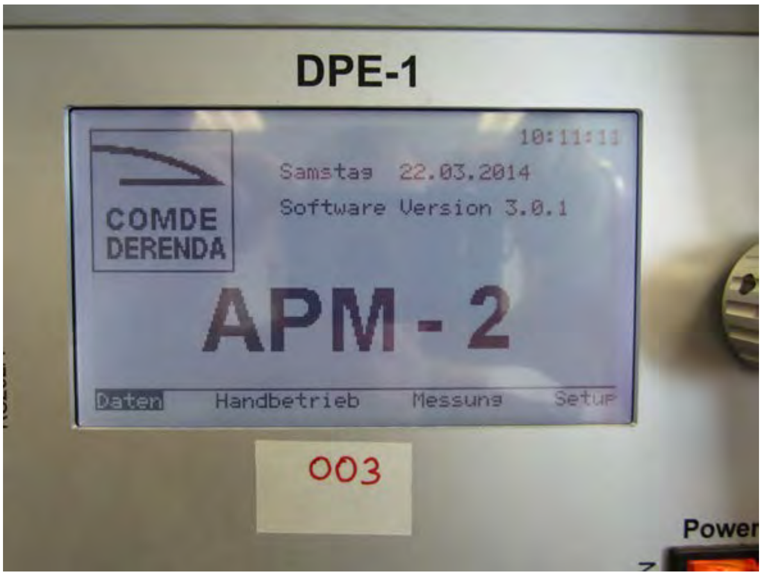

Figure 31: Display of software version 3.0.1

6.1 5.3.1 General

The testing is performed on the basis of the minimum requirements stated in VDI Standard 4202, Sheet 1 (September 2010).

6.2 Equipment

Not required here.

6.3 Method

The testing is performed on the basis of the minimum requirements stated in VDI Standard 4202, Sheet 1 (September 2010).

6.4 Evaluation

After extensive revision, the VDI Standards 4202, Sheet 1 and 4203, Sheet 3 has been newly published in September 2010. Unfortunately, after this revision there are several ambiguities and inconsistencies in relation to concrete minimum requirements and the general significance of particular test items as far as the testing of particulate measuring systems is concerned. The following test items are in need of clarification:

6.1 5.3.2 Repeatability standard deviation at zero point

→ no performance criterion defined

6.1 5.3.3 Repeatability standard deviation at reference point

→ not applicable to particulate measuring devices

6.1 5.3.4 Linearity (lack of fit)

→ not applicable to particulate measuring devices

6.1 5.3.7 Sensitivity coefficient of surrounding temperature

→ no performance criterion defined

6.1 5.3.8 Sensitivity coefficient of supply voltage

→ no performance criterion defined

6.1 5.3.11 Standard deviation from paired measurements

→ no performance criterion defined

6.1 5.3.12 Long-term drift

→ no performance criterion defined

6.1 5.3.13 Short-term drift

→ not applicable to particulate measuring devices

6.1 5.3.18 Overall uncertainty

→ not applicable to particulate measuring devices

For this reason, an official enquiry was made to the relevant body in Germany, to define a coordinated procedure for dealing with the inconsistencies in the guideline.

The following procedure was suggested:

The test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 are evaluated as before on the basis of the minimum requirements stated in the 2002 version of VDI Standard 4202, Sheet 1 (i.e. applying the reference values B_0, B_1, and B_2).

The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 are omitted as they are irrelevant to particulate measuring devices.

The relevant body in Germany agreed with the suggested procedure by decisions of 27 June 2011 and 07 October 2011.

6.5 Assessment

The test was carried out on the basis of the performance criteria stated in VDI Standard 4202, Sheet 1 (September 2010). However, the test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 were evaluated on the basis of the performance criteria stated in the 2002 version of VDI Standard 4202, Sheet 1 (i.e. applying the reference values B_0, B_1, and B_2). The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 were omitted as they are irrelevant to particulate measuring devices.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.3.2 Repeatability standard deviation at zero point

The repeatability standard deviation at zero point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010) in the certification range according to Table 1 in VDI Standard 4202, Sheet 1 (September 2010).

In case of deviating certification ranges, the repeatability standard deviation at zero point shall not exceed 2 % of the upper limit of this certification range.

Note:

With regard to dust measuring devices, this test item cannot be evaluated on the basis of the current version of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010). By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following minimum requirement in the previous version of this guideline (VDI Standard 4202, Sheet 1; June 2002):

The detection limit of the measuring system shall not exceed the reference value B_0. The detection limit shall be determined during the field test.

6.2 Equipment

Zero filter for testing the zero point.

6.3 Method

The detection limits of the candidates, SN3 and SN4, were determined by means of zero filters which were installed at the inlets of instruments. Over a period of 15 days and 24 h/day, particulate-free sample air was fed into the systems. The detection limit was determined in the laboratory test because long-term provision of particulate-free air proved impossible under field conditions.

6.4 Evaluation

The detection limit X is calculated from the standard deviation s_{x0} from the measured values when particulate-free sample air is sucked in by the two candidates. It corresponds to the standard deviation from the mean value s_{x0} of the measured values x_{0i} for each candidate multiplied by the Student's factor:

$$X = t_{n-1;0.95} \cdot s_{x0} \qquad \text{with} \cdot s_{x0} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Reference value: $B_0 = 2$ µg/m³

6.5 Assessment

The tests resulted in detection limits of 0.03 µg/m³ (PM_{10}) and <0.01 µg/m³ ($PM_{2.5}$) for System 1 (SN3), and 0.09 µg/m³ (PM_{10}) and 0.10 µg/m³ ($PM_{2.5}$) for System 2 (SN4).

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 15: Detection limit PM_{10}

		SN 3	SN 4
No. of values n		15	15
Mean of zero values	µg/m³	0.00	0.04
Standard deviation of values	µg/m³	0.01	0.04
Student-Factor $t_{n-1;0,95}$		2.14	2.14
Detection limit x	µg/m³	**0.03**	**0.09**

Table 16: Detection limit $PM_{2.5}$

		SN 3	SN 4
No. of values n		15	15
Mean of zero values	µg/m³	0.00	0.03
Standard deviation of values	µg/m³	0.00	0.05
Student-Factor $t_{n-1;0,95}$		2.14	2.14
Detection limit x	µg/m³	**<0,01**	**0.10**

The single measured values used in the determination of the detection limit are given in Annex 1 of this report.

6.1 5.3.3 Repeatability standard deviation at reference point

The repeatability standard deviation at reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010) in the certification range according to Table 1 in VDI Standard 4202, Sheet 1 (September 2010). The limit value or the alert threshold shall be used as reference point.

In case of deviating certification ranges, the repeatability standard deviation at reference point shall not exceed 2 % of the upper limit of this certification range. In this case a value c_t at 70 % to 80 % of the upper limit of this certification range shall be used as reference point.

Note:

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.4 Linearity (lack of fit)

The analytical function describing the relationship between the output signal and the value of the air quality characteristic shall be linear.

Reliable linearity is given, if deviations of the group averages of measured values about the calibration function meet the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010) in the certification range according to Table 1 in VDI Standard 4202, Sheet 1 (September 2010).

For all other certification ranges the group averages of measured values about the calibration function shall not exceed 5 % of the upper limit of the corresponding certification range.

Note:

By resolution of the relevant body in Germany (refer to module 5.3.1), this test item is irrelevant to particulate measuring systems. Particulate measuring systems for PM_{10} shall be tested according to performance criterion 5.4.2 “Equivalency of the sampling system”. Particulate measuring systems for $PM_{2.5}$ shall be tested according to performance criterion 5.4.10 “Calculation of expanded uncertainty between systems under test”.

6.2 Equipment

Refer to modules 5.4.2. (PM_{10}) and 5.4.10 ($PM_{2.5}$)

6.3 Method

Particulate measuring systems for PM_{10} shall be tested according to performance criterion 5.4.2 “Equivalency of the sampling system”.

Particulate measuring systems for $PM_{2.5}$ shall be tested according to performance criterion 5.4.10 “Calculation of expanded uncertainty between systems under test”.

6.4 Evaluation

Refer to modules 5.4.2. (PM_{10}) and 5.4.10 ($PM_{2.5}$)

6.5 Assessment

Particulate measuring systems for PM_{10} shall be tested according to performance criterion 5.4.2 “Equivalency of the sampling system”.

Particulate measuring systems for $PM_{2.5}$ shall be tested according to performance criterion 5.4.10 “Calculation of expanded uncertainty between systems under test”.

Performance criterion met? -

6.6 Detailed presentation of test results

Refer to modules 5.4.2 (PM_{10}) and 5.4.10 ($PM_{2.5}$)

6.1 5.3.5 Sensitivity coefficient of sample gas pressure

The sensitivity coefficient of sample gas pressure at reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.6 Sensitivity coefficient of sample gas temperature

The sensitivity coefficient of sample gas temperature at reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.7 Sensitivity coefficient of surrounding temperature

The sensitivity coefficient of surrounding temperature at zero and reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used at reference point.

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

If the surrounding temperature changes by 15 K in the range +5 °C to +20 °C or by 20 K in the range +20 °C to +40 °C, the temperature dependence of the measured value at zero point shall not exceed the reference value B_0.

The temperature dependence of the measured value in the range of the reference value B_1 shall not be greater than ± 5 % of the measured value when a change in temperature by 15 K in the range of +5 °C to +20 °C or +20 °C to +40 °C occurs.

6.2 Equipment

Climatic chamber for a temperature range of -20 to +50 °C, zero filter for testing the zero point, test gas method with propane for testing the reference point.

6.3 Method

According to the manufacturer, the permissible ambient temperature range amounts to -20 °C to +50 °C.

In order to test the dependence of zero point and measured values on the surrounding temperature, the complete measuring systems were operated within a climatic chamber.

For the zero point test particle free sampling air was applied to both measuring systems SN3 and SN4 by means of zero filters installed at the instrument inlets.

For the reference point test, a measured signal was created and evaluated by offering propane to the photometer cell in order to test the stability of the sensitivity of both candidates SN3 and SN4 (test gas method).

The ambient temperature within the climatic chamber was altered in the sequence

20 °C – -20 °C – 20 °C – 50 °C – 20 °C.

The measured values at zero point (3 x 24 h per temperature level) and the measured values at reference point (3 x per temperature level) were recorded after an equilibration period of 24 h per temperature level.

6.4 Evaluation

Zero point:

The measured concentration values obtained in the individual 24-hour measurements were collected and evaluated. The absolute deviation in µg/m³ per temperature level in relation to the default temperature of 20 °C is considered.

Reference value: B_0 = 2 µg/m³

Reference point:

The measured value's change in percentage for each temperature level in relation to the initial temperature of 20 °C is checked.

6.5 Assessment

The ambient temperature range tested at the AMS installation site was -20 °C to +50 °C. Looking at the values that were output by the AMS, the maximum dependence of ambient temperature in the range of -20 °C to +50 °C at zero was 0.1 µg/m³ for $PM_{2.5}$ and 0.2 µg/m³ for PM_{10}.

At reference point, no deviations > 2.7 % in relation to the default temperature of 20 °C were observed..

In case of permanent exposition of the device to direct sun radiation combined with very high ambient temperatures (> 35 °C), the instrument manufacturer recommends a sun-protected installation of the device.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 17: Dependence of zero point on ambient temperature, deviations in µg/m³, mean value of three measurements, PM_{10}, SN3 & SN4

Ambient temperature		Deviation	
Start temperature	End temperature	SN 3	SN 4
°C	°C	µg/m³	µg/m³
20	-20	0.0	0.2
-20	20	0.0	0.0
20	50	0.0	0.0
50	20	0.0	0.0

Table 18: Dependence of zero point on ambient temperature, deviations in µg/m³, mean value of three measurements, $PM_{2.5}$, SN3 & SN4

Ambient temperature		Deviation	
Start temperature	End temperature	SN 3	SN 4
°C	°C	µg/m³	µg/m³
20	-20	0.0	0.1
-20	20	0.0	0.0
20	50	0.0	0.0
50	20	0.0	0.0

Table 19: Dependence of sensitivity (test gas values) on ambient temperature, deviation in %, mean value of three measurements, SN3 & SN4

Ambient temperature		Deviation	
Start temperature	End temperature	SN 3	SN 4
°C	°C	[%]	[%]
20	-20	-0.4	-1.5
-20	20	2.7	-0.8
20	50	1.7	0.6
50	20	-1.7	-0.4

For the respective results of the 3 individual measurements refer to annex 2 and annex 3.

6.1 5.3.8 Sensitivity coefficient of supply voltage

The sensitivity coefficient of supply voltage shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

Change in the measured value at reference value B_1 caused by the common changes in the mains voltage in the interval (230 +15/-20) V shall not exceed B_0.

6.2 Equipment

Isolation transformer, test gas method with propane for testing the reference point.

6.3 Method

In order to examine the dependence of measured signal on supply voltage, the latter was reduced from 230 V to 210 V and then increased over an intermediate stage of 230 V to 245 V.

For the reference point test, a measured signal was created and evaluated by offering propane to the photometer cell in order to test the stability of the sensitivity of both candidates SN3 and SN4 (test gas method).

As the AMS is not designed for mobile use, separate testing of the dependence of measurement signal on mains frequency was abstained from.

6.4 Evaluation

At reference point, the changes in percentage of the determined measured values were examined for each voltage step in relation to the default voltage of 230 V.

6.5 Assessment

No deviations > 1.3 % in relation to the default value of 230 V due to changes in supply voltage were detected.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 20 presents a summary of test results.

Table 20: Dependence of measured value on supply voltage, deviation in %, SN3 & SN4

Mains voltage		Deviation	
Start voltage	End voltage	SN 3	SN 4
V	V	[%]	[%]
230	210	0.6	-0.2
210	230	1.2	-0.9
230	245	1.3	-1.3
245	230	1.0	-1.2

For the individual results refer to annex 4 in this report.

6.1 5.3.9 Cross-sensitivity

The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010) at zero and reference point.

Note:

This test item is irrelevant to particulate measuring systems. As minimum requirement 5.4.5 applies in this case, the test results are stated in module 5.4.5.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.10 Averaging effect

For gaseous components the measuring system shall allow the formation of hourly averages.

The averaging effect shall not exceed the requirements of Table 2 (VDI Standard 4202 Sheet 1; September 2010).

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.11 Standard deviation from paired measurements

The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test. It shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010).

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

The "Reproduzierbarkeit" [reproducibility] R_D of the measuring system shall be determined by parallel measurements with two identical measuring systems and shall be at least equal to 10. B_1 shall be used as reference value.

6.2 Equipment

For the determination of reproducibility, the additional measuring systems described in chapter 5 were used.

6.3 Method

Reproducibility is defined as the maximum difference between two randomly chosen single values that have been obtained under equal conditions. Reproducibility was determined using two identical measuring systems that were operated simultaneously during the field test. For this purpose, all measurement data obtained during the entire field test was evaluated.

6.4 Evaluation

The reproducibility is calculated as follows:

$$R = \frac{B_1}{U} \geq 10 \quad \text{with} \quad U = \pm s_D \cdot t_{(n;0,95)} \quad \text{and} \quad s_D = \sqrt{\frac{1}{2n} \cdot \sum_{i=1}^{n} (x_{1i} - x_{2i})^2}$$

- R = Reproducibility at B_1
- U = Uncertainty
- B_1 = 40 µg/m³ for PM_{10} and 25 µg/m³ for $PM_{2.5}$
- s_D = Standard deviation from paired measurements
- n = No. of paired measurements
- $t_{(n;0.95)}$ = Student's factor at confidence level of 95 %
- x_{1i} = Measured signal of system 1 (e.g. SN3) at i^{th} concentration
- x_{2i} = Measured signal of system 2 (e.g. SN4) at i^{th} concentration

6.5 Assessment

In the field test, the reproducibility for the full dataset was 20 for $PM_{2.5}$ and 16 for PM_{10}.

Performance criterion met? yes

6.6 Detailed presentation of test results

The test results are summarized in Table 21 and Table 22. The graphical representation for PM_{10} is given in Figure 60 to Figure 64 and for $PM_{2.5}$ in Figure 53 to Figure 57.

Note: The determined uncertainties are related to reference value B_1 for each site:

Table 21: Concentration mean values, standard deviation, uncertainty range, and reproducibility in the field, measured component PM_{10}

Test site	Number	$\overline{c}$ (SN3)	$\overline{c}$ (SN4)	$\overline{c}_{ges}$	s_D	t	U	R
		µg/m³	µg/m³	µg/m³	µg/m³		µg/m³	
Cologne, winter	69	16.8	18.5	17.6	1.335	1.995	2.66	15
Bonn, winter	61	21.9	24.0	23.0	1.667	2.000	3.33	12
Cologne, summer	54	13.8	15.1	14.4	0.943	2.005	1.89	21
Rodenkirchen, summer	53	12.6	12.9	12.8	0.426	2.006	0.85	47
All sites	237	16.5	17.9	17.2	1.256	1.970	2.47	16

Table 22: Concentration mean values, standard deviation, uncertainty range, and reproducibility in the field, measured component $PM_{2.5}$

Site	Number	$\overline{c}$ (SN3)	$\overline{c}$ (SN4)	$\overline{c}_{ges}$	s_D	t	U	R
		µg/m³	µg/m³	µg/m³	µg/m³		µg/m³	
Cologne, winter	69	14.2	14.9	14.5	0.638	1.995	1.27	20
Bonn, winter	61	18.2	19.3	18.8	0.853	2.000	1.71	15
Cologne, summer	54	10.9	11.6	11.2	0.508	2.005	1.02	25
Rodenkirchen, summer	53	9.8	9.5	9.7	0.328	2.006	0.66	38
All sites	237	13.5	14.1	13.8	0.640	1.970	1.26	20

- $\overline{c}$ (SN3): Mean value of concentrations System SN3
- $\overline{c}$ (SN4): Mean value of concentrations System SN4
- $\overline{c}_{ges}$: Mean value of concentrations Systems SN3 & SN4

For individual values refer to annex 5 of the appendix.

6.1 5.3.12 Long-term drift

The long-term drift at zero point and reference point shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010) in the field test. A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

The temporal change in the measured value at zero concentration shall not exceed the reference value B_0 in 24 h and in the maintenance interval.
The temporal change in the measured value in the range of the reference value B_1 shall not be greater than ± 5 % of B_1 in 24 h and in the maintenance interval.

6.2 Equipment

Zero filter for testing the zero point

6.3 Method

The test was carried out as part of the field test over a period of about 10 months altogether (comparison campaigns 1-4) respectively approx. 15 months if considering the validation campaign during winter 2014.

In the context of the regular checks approximately once a month (including those at the beginning and end of tests at each field test site), both measuring systems were operated with zero filters applied to their inlets for at least 24 h. The measured zero values were then evaluated.

For external check of the sensitivity of the photometer, the instrument´s manufacturer has developed the following optional test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity.

Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

For quality assurance - according to the manufacturer - the photometer has to be sent once a year to the manufacturer for check and re-calibration. By this, also the requirements on ongoing quality assurance according to chapter 8.4.10 of EN TS 16450 [9] can be accommodated.

6.4 Evaluation

While it is possible to assess zero point drift and drift of the measured value within a 24 h period, it is not useful for particulate measuring systems.

The measuring system carries out a zero point check / adjustment with zero air at the start of a measurement as well as at each hour during operation.

The evaluation at zero point is made on the basis of the measurement results of the regular external zero point measurement by comparing the respective values with the corresponding “measured values” of the previous test and the “measured value” of the first test.

On 31 March 2013 a zero value of 2.7 µg/m³ for PM_{10} was measured for SN 4 – this value deviates from the start value with 2.7 µg/m³ and is outside of the permissible range of ± 2 µg/m³. A cause for this outlier could not be determined and all corresponding evaluations did not show any exceedance of the permissible limits. There was no externally triggered adjustment of the measuring device.

A regular external check of the sensitivity over the field test period could not be carried out, as suitable test equipment was not available before December 2013. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

6.5 Assessment

For $PM_{2.5}$, the maximum deviation at zero point was -1.4 µg/m³ in relation to the previous value and 2.4 µg/m³ in relation to the start value. Thus, it lies within the permissible limits of B_0 = 2 µg/m³.

For PM_{10}, the maximum deviation at zero point was 1.5 µg/m³ for in relation to the previous value and 2.7 µg/m³ in relation to the start value and thus related to the start value outside of the permissible limit of B_0 = 2 µg/m³. This deviation only occurred one time during the entire field test campaign, a cause could not be determined. There was no externally triggered adjustment of the measuring device.

A regular external check of the sensitivity over the field test period could not be carried out, as suitable test equipment was not available before December 2013. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

Performance criterion met? no

6.6 Detailed presentation of test results

Table 23 and Table 24 provide the obtained measured values for zero point as well as the calculated deviations in relation to the previous and the starting value in µg/m³.

Figure 32 to Figure 35 provide a graphic representation of zero point drift over the course of testing.

Table 23: Zero point drift SN3 & SN4, PM_{10}, with zero filter

Date	SN3			Date	SN4		
	Measured Value	Deviation from previous value	Deviation from start value		Measured Value	Deviation from previous value	Deviation from start value
	µg/m³	µg/m³	µg/m³		µg/m³	µg/m³	µg/m³
11/19/2012	0.0	-	-	11/19/2012	0.0	-	-
11/20/2012	0.0	0.0	0.0	11/20/2012	0.0	0.0	0.0
11/21/2012	0.8	0.8	0.8	11/21/2012	0.8	0.8	0.8
1/11/2013	0.7	0.0	0.7	1/11/2013	0.1	-0.7	0.1
1/12/2013	0.4	-0.4	0.4	1/12/2013	0.0	0.0	0.0
1/13/2013	1.4	1.1	1.4	1/13/2013	1.0	1.0	1.0
2/5/2013	0.1	-1.3	0.1	2/5/2013	0.1	-0.9	0.1
2/6/2013	0.0	-0.1	0.0	2/6/2013	0.2	0.1	0.2
2/27/2013	1.0	0.9	1.0	2/27/2013	1.8	1.5	1.8
2/28/2013	1.4	0.4	1.4	2/28/2013	2.4	0.6	2.4
3/30/2013	1.2	-0.2	1.2	3/30/2013	2.0	-0.4	2.0
3/31/2013	1.0	-0.1	1.0	3/31/2013	2.7	0.8	2.7
4/1/2013	1.1	0.0	1.1	4/1/2013	2.2	-0.5	2.2
4/26/2013	1.1	0.1	1.1	4/26/2013	1.2	-1.0	1.2
4/27/2013	1.8	0.6	1.8	4/27/2013	1.6	0.4	1.6
4/28/2013	1.9	0.1	1.9	4/28/2013	1.8	0.2	1.8
5/15/2013	1.4	-0.5	1.4	5/15/2013	1.7	-0.1	1.7
5/16/2013	1.2	-0.2	1.2	5/16/2013	1.7	0.0	1.7
6/29/2013	1.6	0.4	1.6	6/29/2013	2.4	0.7	2.4
6/30/2013	1.5	-0.1	1.5	6/30/2013	2.2	-0.2	2.2
9/21/2013	1.5	0.0	1.5	9/21/2013	1.7	-0.5	1.7
2/7/2014*	1.8	0.3	1.8	2/7/2014	1.3	-0.4	1.3
2/8/2014*	2.4	0.6	2.4	2/8/2014	1.1	-0.2	1.1
2/9/2014*	1.9	-0.5	1.9	2/9/2014	1.2	0.1	1.2

* Cologne, Winter 2014, validation campaign

Table 24: Zero point drift SN3 & SN4, $PM_{2.5}$, with zero filter

Date	SN3			Date	SN4		
	Measured Value	Deviation from previous value	Deviation from start value		Measured Value	Deviation from previous value	Deviation from start value
	µg/m³	µg/m³	µg/m³		µg/m³	µg/m³	µg/m³
11/19/2012	0.0	-	-	11/19/2012	0.0	-	-
11/20/2012	0.0	0.0	0.0	11/20/2012	0.0	0.0	0.0
11/21/2012	0.6	0.6	0.6	11/21/2012	0.6	0.6	0.6
1/11/2013	0.7	0.1	0.7	1/11/2013	0.1	-0.6	0.1
1/12/2013	0.3	-0.4	0.3	1/12/2013	0.0	0.0	0.0
1/13/2013	1.4	1.1	1.4	1/13/2013	1.0	0.9	1.0
2/5/2013	0.1	-1.4	0.1	2/5/2013	0.1	-0.8	0.1
2/6/2013	0.0	0.0	0.0	2/6/2013	0.2	0.1	0.2
2/27/2013	1.1	1.0	1.1	2/27/2013	1.7	1.5	1.7
2/28/2013	1.3	0.3	1.3	2/28/2013	2.4	0.6	2.4
3/30/2013	1.2	-0.1	1.2	3/30/2013	2.3	-0.1	2.3
3/31/2013	1.0	-0.2	1.0	3/31/2013	1.7	-0.6	1.7
4/1/2013	0.9	-0.1	0.9	4/1/2013	1.8	0.1	1.8
4/26/2013	1.1	0.2	1.1	4/26/2013	1.2	-0.5	1.2
4/27/2013	1.5	0.4	1.5	4/27/2013	1.6	0.4	1.6
4/28/2013	1.7	0.2	1.7	4/28/2013	1.7	0.1	1.7
5/15/2013	1.3	-0.3	1.3	5/15/2013	1.7	0.0	1.7
5/16/2013	1.1	-0.2	1.1	5/16/2013	1.6	-0.1	1.6
6/29/2013	1.5	0.4	1.5	6/29/2013	2.3	0.7	2.3
6/30/2013	1.5	-0.1	1.5	6/30/2013	2.2	-0.1	2.2
9/21/2013	1.5	0.0	1.5	9/21/2013	2.0	-0.2	2.0
2/7/2014*	2.0	0.5	2.0	2/7/2014	1.5	-0.5	1.5
2/8/2014*	2.4	0.4	2.4	2/8/2014	1.4	-0.1	1.4
2/9/2014*	2.1	-0.3	2.1	2/9/2014	1.4	0.0	1.4

* Cologne, winter 2014, validation campaign

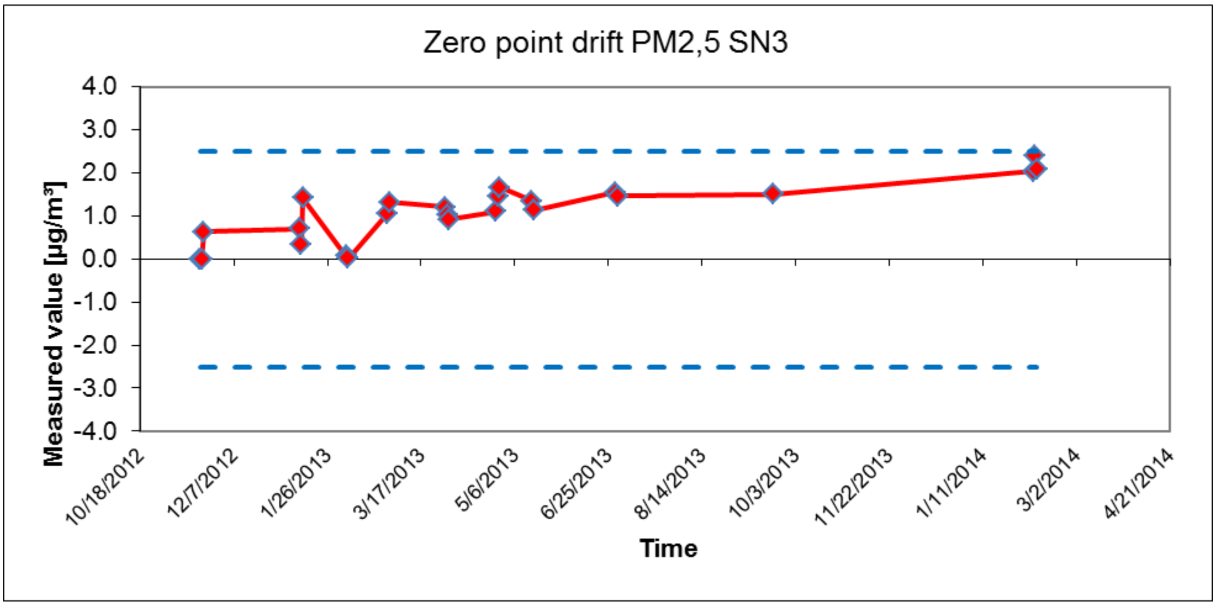

Figure 32: Zero point drift SN3, measured component $PM_{2.5}$

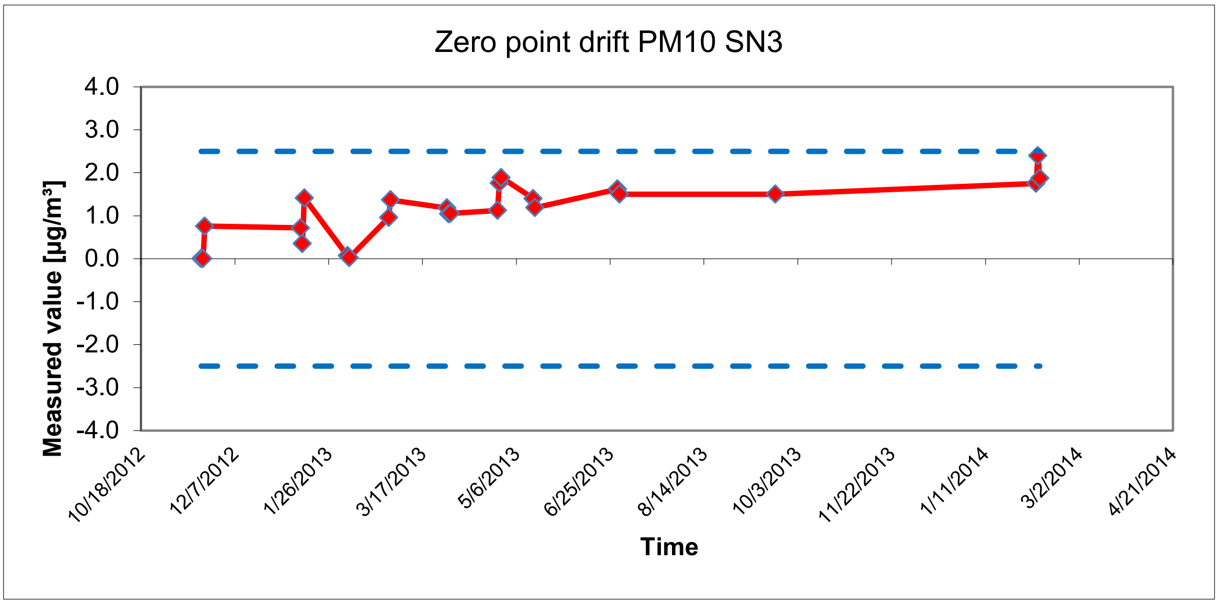

Figure 33: Zero point drift SN3, measured component PM_{10}

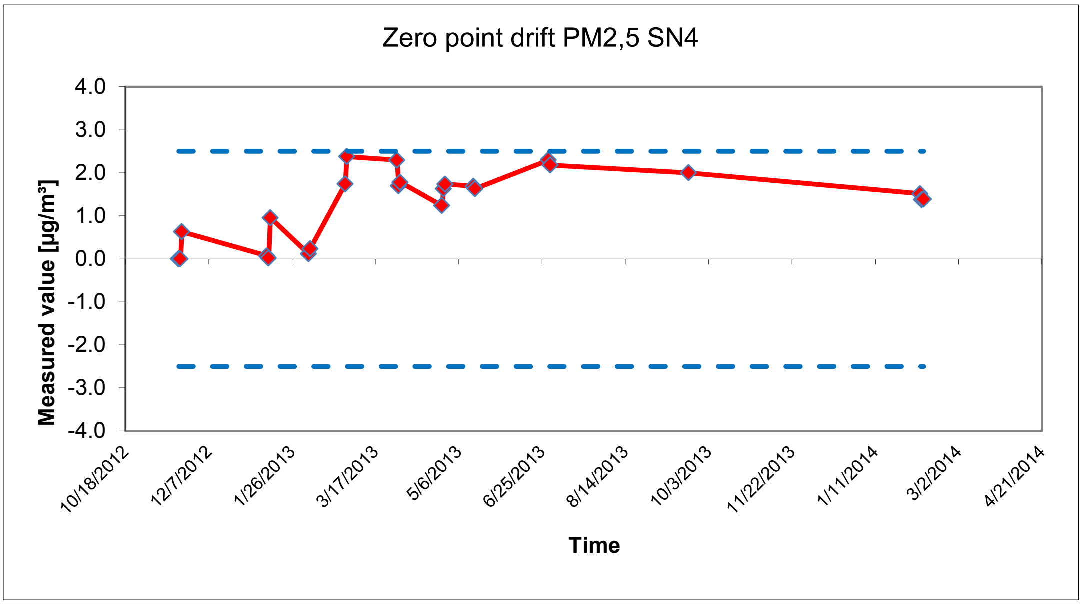

Figure 34: Zero point drift SN4, measured component $PM_{2.5}$

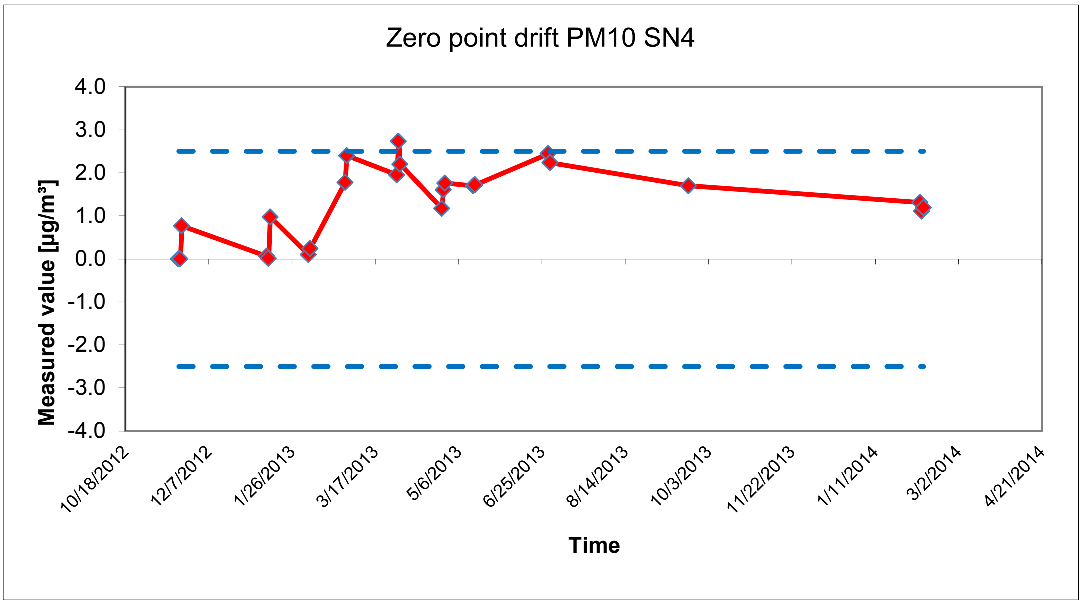

Figure 35: Zero point drift SN4, measured component PM_{10}

6.1 5.3.13 Short-term drift

The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test. A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.14 Response time

The response time (rise) of the measuring system shall not exceed 180 s.

The response time (fall) of the measuring system shall not exceed 180 s.

The difference between the response time (rise) and the response time (fall) of the measuring system shall not exceed 10 % of response time (rise) or 10 s, whatever value is larger.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.15 Difference between sample and calibration port

The difference between the measured values obtained by feeding gas at the sample and calibration port shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.16 Converter efficiency

In case of measuring systems with a converter, the converter efficiency shall be at least 98 %.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.17 Increase of NO_2 concentration due to residence in the AMS

In case of NO_x measuring systems the increase of NO_2 due to residence in the measuring system shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).

The requirements of Table 2 of VDI Standard 4202, Sheet 1 apply to certification ranges according to Table 1 of VDI Standard 4202, Sheet 1 (September 2010). For deviating certification ranges the requirements shall be proportionally converted.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.18 Overall uncertainty

The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the applicable EU Directives on air quality listed in Annex A, Table A 1 of VDI Standard 4202, Sheet 1 (September 2010).

Note:

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.2 Equipment

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.3 Method

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.4 Evaluation

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.5 Assessment

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

Performance criterion met? -

6.6 Detailed presentation of test results

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.1 5.4.1 General

The testing of particulate measuring systems shall be carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010). Particle mass concentrations shall be related to a defined volume. The relation to volume with respect to pressure and temperature shall be comprehensively described.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010).

To determine whether the measured particle mass concentrations are related to a defined volume was the objective of the test.

6.4 Evaluation

The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010).

The APM-2 measuring system is an optical measuring system which first determines the scattered light signal, induced by particles in a defined measured volume, and then converts the available information into concentration values by means of an algorithm. The measured signal for the particles is therefore related to a defined volume (measured volume).

6.5 Assessment

The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010).

The APM-2 measuring system is an optical measuring system which first determines the scattered light signal, induced by particles in a defined measured volume, and then converts the available information into concentration values by means of an algorithm. The measured signal for the particles is therefore related to a defined volume (measured volume).

Performance criterion met? yes

6.6 Detailed presentation of test results

No equipment is necessary to test this performance criterion.

6.1 5.4.2 Equivalency of the sampling system

The equivalency between the PM_{10} sampling system and the reference method according to Standard EN 12341 [T5] shall be demonstrated.

Not applicable to $PM_{2.5}$ sampling systems. Please refer to module 5.4.10 in this report.

6.2 Equipment

The performance criterion was tested with the additional equipment described in chapter 5 of this report.

6.3 Method

As described in chapter 4 of this report, the test was carried out at various sites during the field test. Different seasons as well as different PM_{10} concentrations were taken into account.

At least 15 valid data pairs were obtained at each test site.

6.4 Evaluation

Requirement according to Standard EN 12341:

The calculated functional correlation y = f(x) between the candidate (y) and the concentration values measured by the reference device (x) shall be limited by a two sided acceptance envelope. This acceptance envelope is defined by:

$y = (x \pm 10)$ µg/m³ for concentration mean values $\leq$ 100 µg/m³ and

$y = 0.9x$ µg/m³ or $1.1x$ µg/m³ for concentration mean values > 100 µg/m³

Furthermore, the variation coefficient R^2 of the calculated reference-equivalence function shall not fall below the value of 0.95.

The test is directed towards the functional correlation between the concentration values obtained from paired determinations between the candidate and the reference device. Ideally, both systems measure the same mass fraction of suspended particulate matter so that y = x. The evaluation procedure is as follows:

A linear regression analysis was carried out for the measured values obtained at all four test sites individually and as a whole.

A reference equivalence function corresponding to the equation below is determined for each measured value y_i of the respective candidate and of the reference device x (both in µg/m³).

$$y_i = m \cdot x + b$$ with i = candidate APM-2

6.5 Assessment

For SN3, the reference equivalence functions for the (uncorrected) datasets lie outside the limits of the respective acceptance envelope for all test sites with exception of Cologne, winter, for SN4 only the reference equivalence function for the field campaign Rodenkirchen is outside of the respective acceptance envelope. Moreover, the variation coefficient R^2 of the calculated reference equivalence function in the concentration range concerned is < 0.95 for all comparison campaigns with exception of Cologne, winter. The demonstration of equivalence according to EN 12341:1998 is thus not possible. Nevertheless, the equivalence test according to the EC-guide, which is relevant for the end user, is passed after application of the necessary correction factors for all test sites without restrictions (refer to 6.1 5.4.11 Application of correction factors and terms).

Performance criterion met? no

6.6 Detailed presentation of test results

Table 25 and Table 26 present a summary of the results of the regression analyses. Figure 36 to Figure 45 provide graphical representations which illustrate these findings. In addition to the regression lines of both candidates, the diagrams show the curve y = x, which is considered ideal and the two-sided acceptance envelope All individual values for the candidates as well as for the reference devices are listed separately for each test site in annex 5 of the appendix.

Table 25: Results of the linear regression analysis of measurements with both candidates SN3 and SN4 at all four sites, raw data

SN3	Number of paired values N	Slope m	Intercept b	R²
Cologne, winter	52	0.922	-1.779	0.968
Bonn, winter	51	0.876	-2.419	0.861
Cologne, summer	47	0.830	-1.253	0.911
Rodenkirchen, summer	45	0.880	-3.745	0.804
SN4	**Number of paired values N**	**Slope m**	**Intercept b**	**R²**
Cologne, winter	52	0.976	-1.068	0.974
Bonn, winter	51	0.964	-2.705	0.863
Cologne, summer	45	0.927	-1.669	0.917
Rodenkirchen, summer	45	0.893	-4.320	0.822

Table 26: Results of the linear regression analysis of measurements with both candidates SN3 and SN4 (total), raw data

Candidate	Number of paired values N	Slope m	Intercept b	R²
SN3	195	0.894	-2.590	0.914
SN4	193	0.972	-3.010	0.907

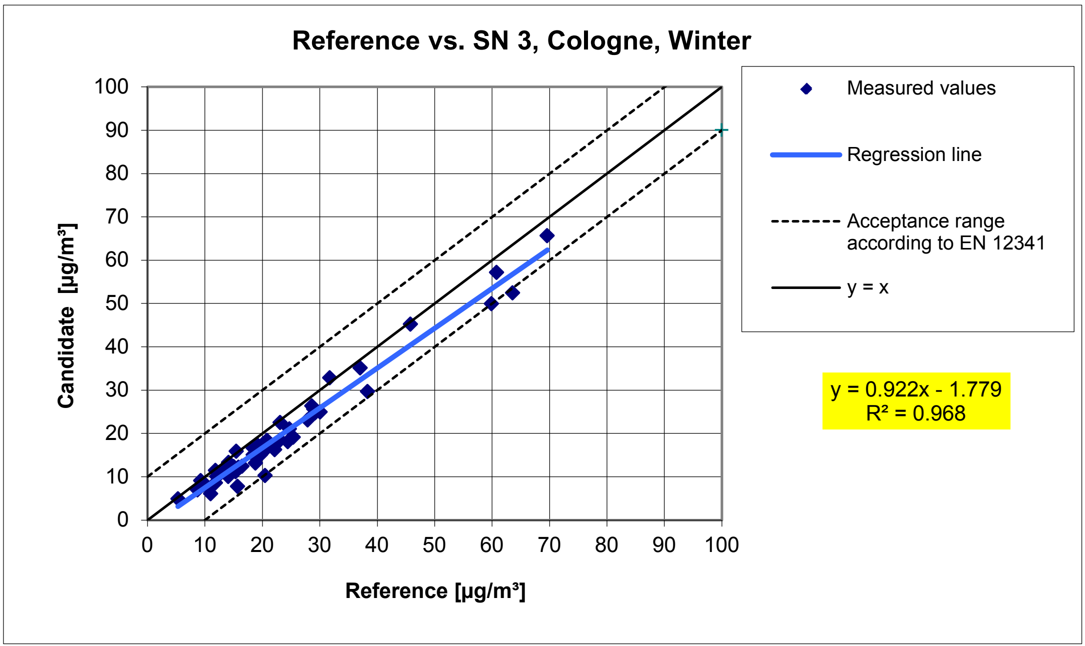

Figure 36: Reference equivalence function SN3, test site Cologne, winter

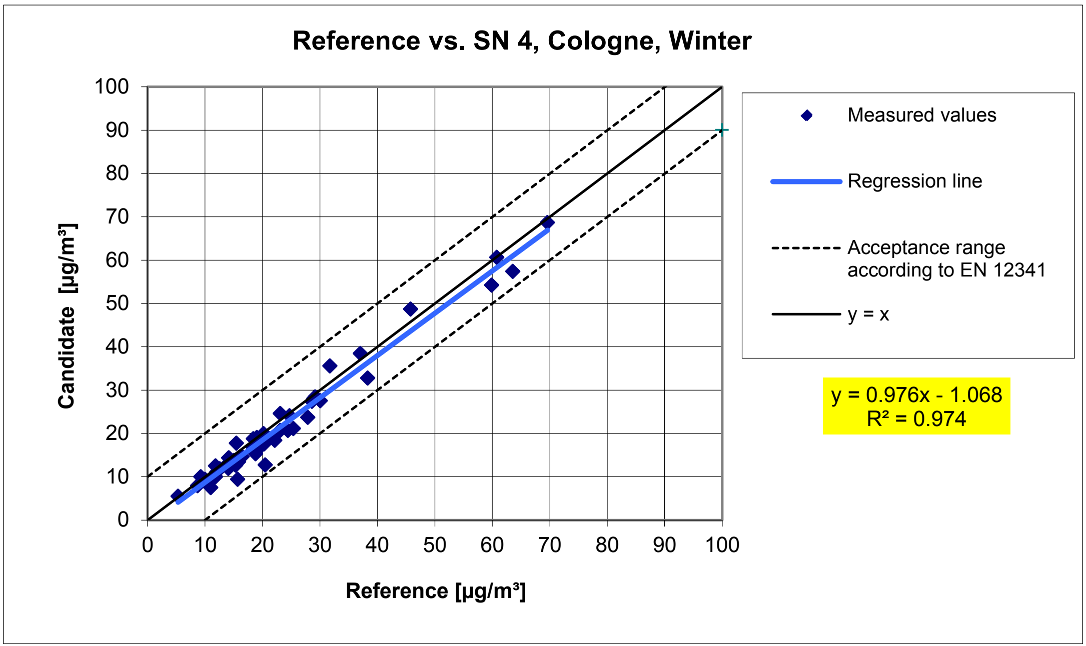

Figure 37: Reference equivalence function SN4, test site Cologne, winter

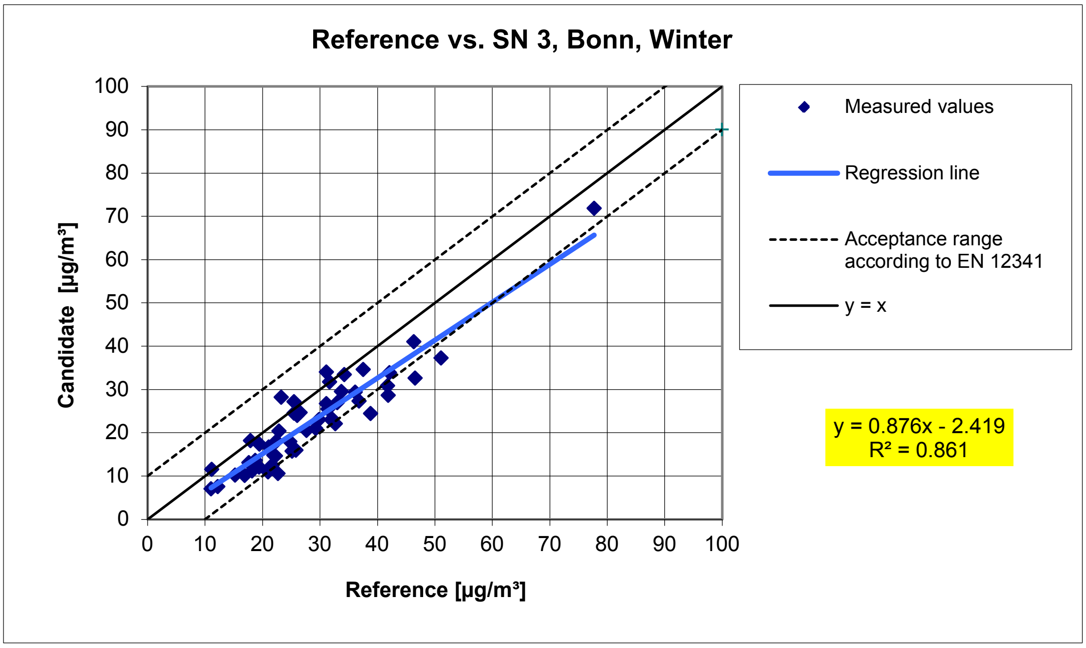

Figure 38: Reference equivalence function SN3, test site Bonn, winter

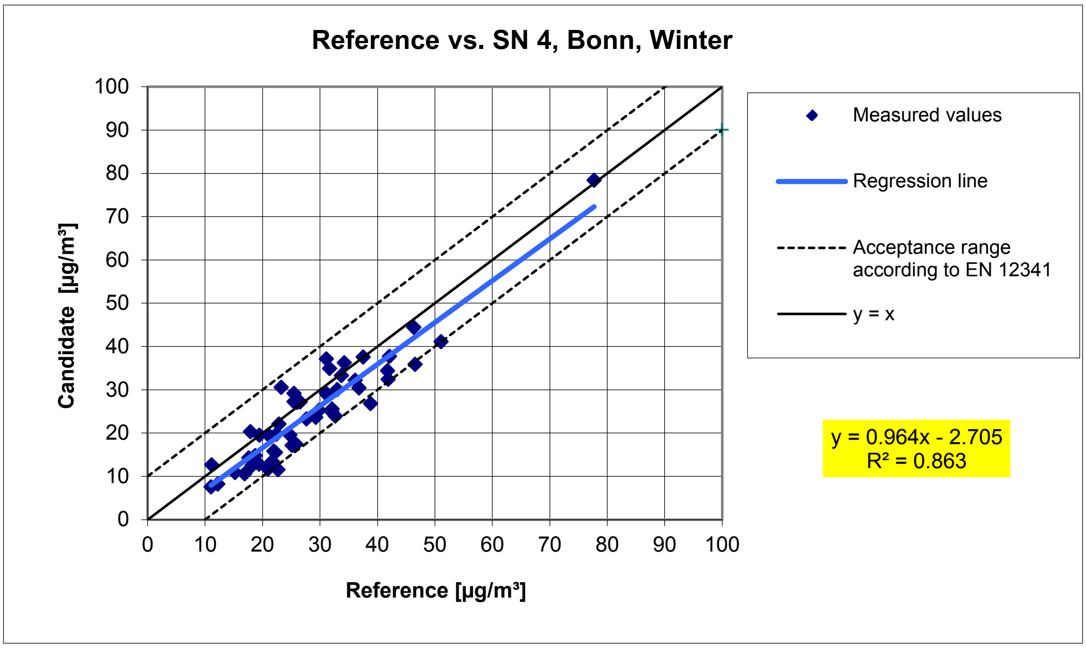

Figure 39: Reference equivalence function SN4, test site Bonn, winter

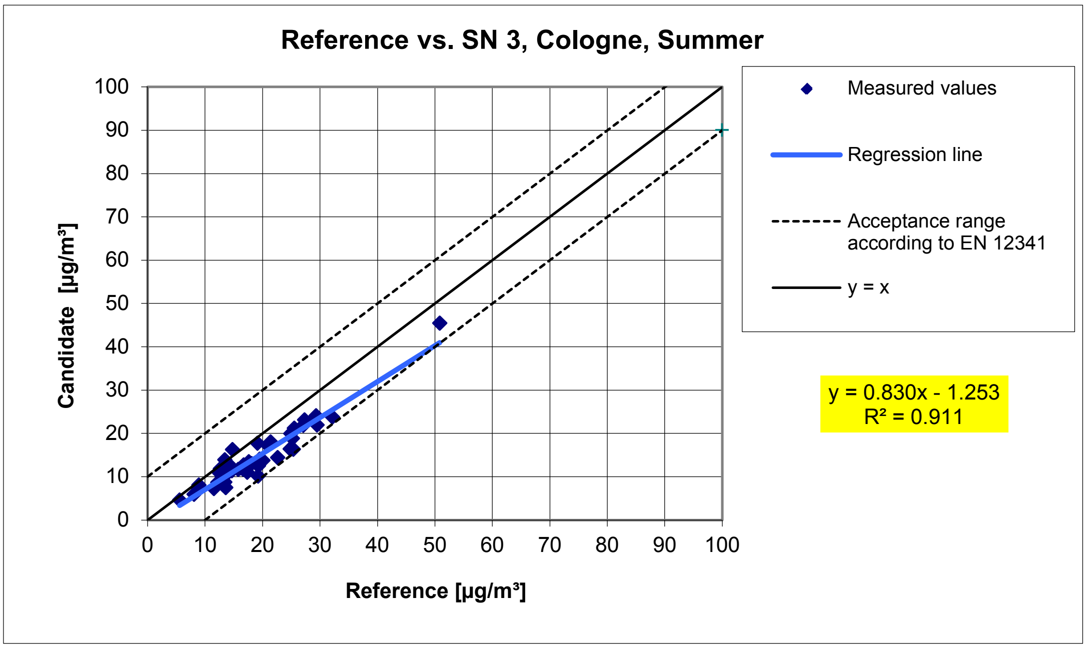

Figure 40: Reference equivalence function SN3, test site Cologne, summer

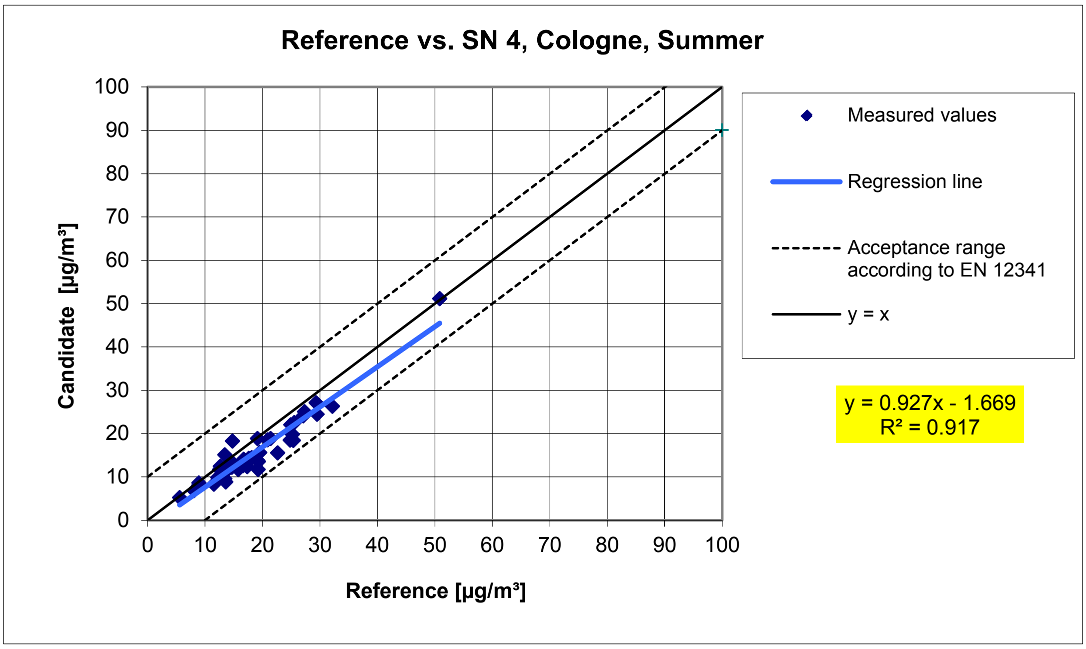

Figure 41: Reference equivalence function SN4, test site Cologne, summer

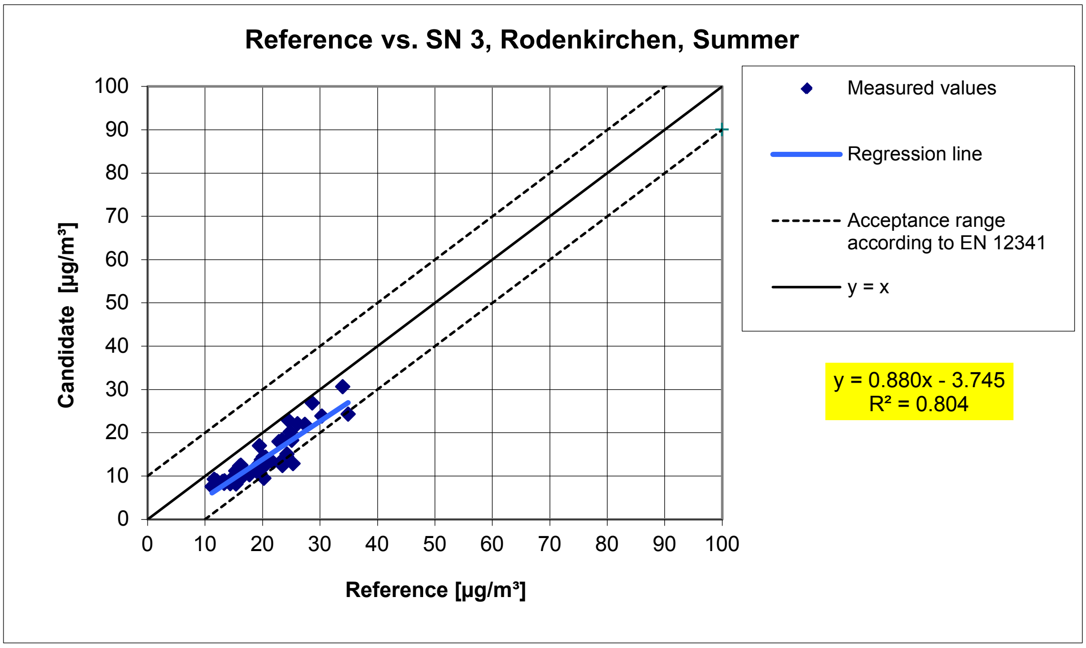

Figure 42: Reference equivalence function SN3, test site Rodenkirchen, summer

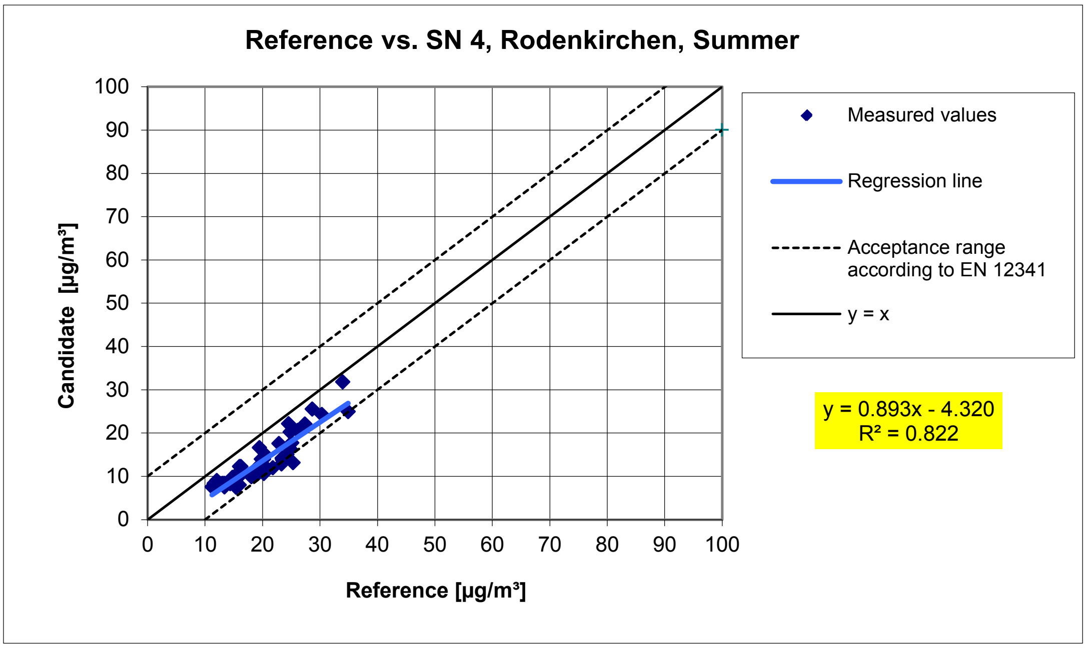

Figure 43: Reference equivalence function SN4, test site Rodenkirchen, summer

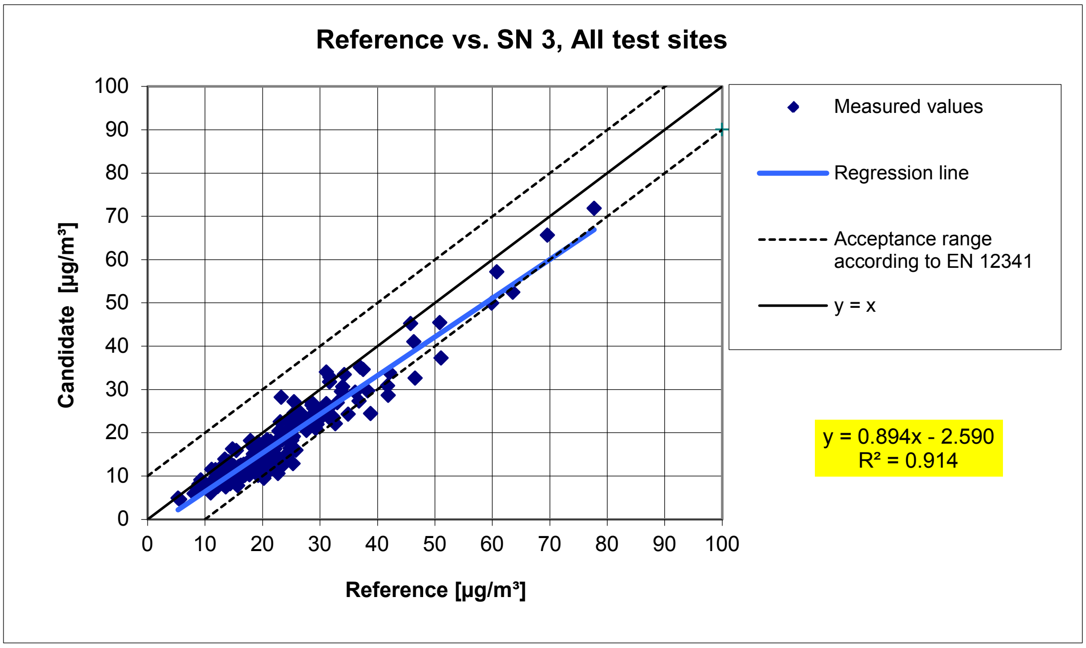

Figure 44: Reference equivalence function SN3, all sites

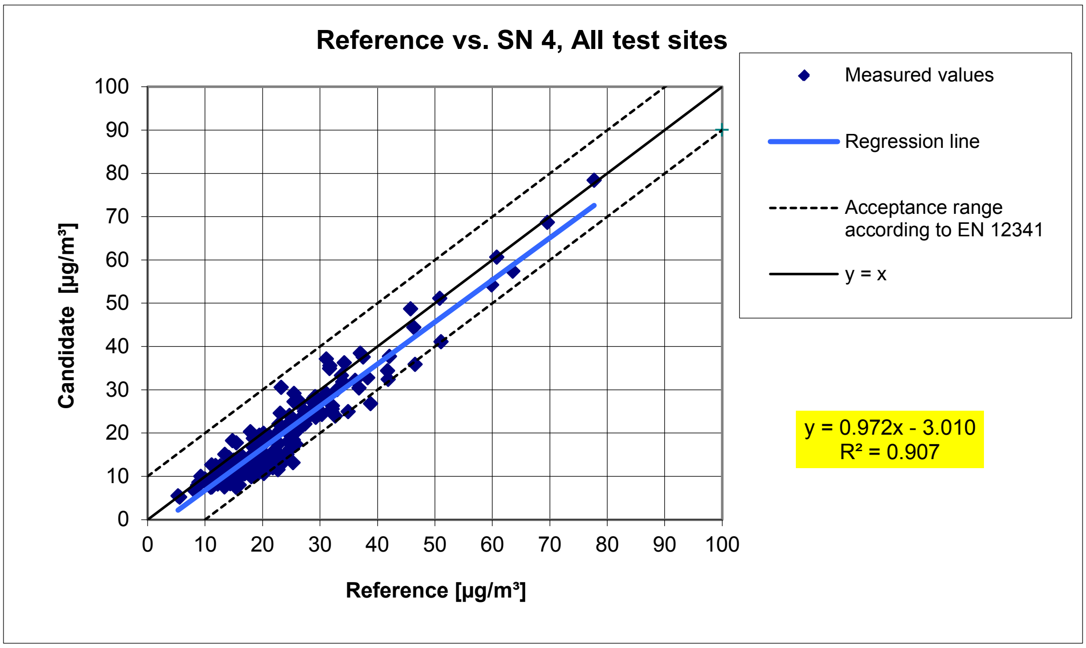

Figure 45: Reference equivalence function SN4, all sites

6.1 5.4.3 Reproducibility of the sampling systems

The PM_{10} sampling systems of two identical systems under test shall be reproducible among themselves according to Standard EN 12341 [T5]. This shall be demonstrated in the field test.

Not applicable to $PM_{2.5}$ sampling systems. Please refer to module 5.4.10 in this report.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

The test was carried out at various test sites according to item 4 in this report. Different seasons as well as different PM_{10} concentrations were taken into account.

At least 15 valid data pairs were obtained per site.

6.4 Evaluation

The two-sided confidence interval CI_{95} calculated from the concentration mean values measured by the candidates shall not exceed 5 µg/m³ if the average concentration is ≤ 100 µg/m³. If the average concentration is > 100 µg/m³, the confidence interval shall not exceed 0.05.

The demonstration of the reproducibility of the candidates focuses on the differences D_i between the concentration values Y_i measured by the candidates. Ideally, both candidates are identical and therefore measure the same mass fraction of suspended particulate matter so that $D_i = 0$. The evaluation procedure is as follows:

First, the concentration mean values Y_i are calculated from the concentration values measured simultaneously by both candidates. Then the concentration mean values Y_i are split into two separate datasets:

a) Dataset with $Y_i \leq 100$ µg/m³ with number of data pairs $n_{\leq}$ and
b) Dataset with $Y_i > 100$ µg/m³ with number of data pairs $n_{>}$

With respect to a):

The data pairs of the dataset with $Y_i \leq 100$ µg/m³ are used to calculate the absolute standard deviation s_a:

$$s_a = \sqrt{\left(\sum D_i^2 / 2n_{\leq}\right)}$$

The Student's factor $t_{f_{\leq};0,975}$, which is defined as the 0.975 quantile of the two-sided 95 % confidence interval of the Student's t-distribution with $f_{\leq} = n_{\leq} - 2$ degrees of freedom, is applied.

The two-sided 95% confidence interval CI_{95} for concentration mean values ≤ 100 µg/m³ is calculated as follows:

$$CI_{95} = s_a \cdot t_{f_{\leq};0{,}975}$$

With respect to b):

The relative standard deviation s_r is calculated from the data pairs of the dataset with Y_i > 100 µg/m³:

$$s_r = \sqrt{\left(\sum (D_i / Y_i)^2 / 2n_{>}\right)}$$

Again, the Student's factor $t_{f_{>};0{,}975}$ defined as 0.975 quantile of the two-sided 95 % confidence interval of the Student's t-distribution with $f_{>} = n_{>} - 2$ degrees of freedom is applied.

The two-sided 95 % confidence interval CI_{95} for concentration mean values > 100 µg/m³ is calculated as follows:

$$CI_{95} = s_r \cdot t_{f_{>};0{,}975}$$

During the field tests, no concentration values > 100 µg/m³ were observed. For that reason, a statistical evaluation is not possible. Hence, consideration according to b) is not required.

6.5 Assessment

The following is applicable to all field test sites:

The two-sided confidence interval CI_{95} of max. 3.58 µg/m³ is below the permissible limit of 5 µg/m³.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 27 lists the calculated values of the standard deviation s_a and the two-sided confidence interval CI_{95}. Figure 46 to Figure 50 provide the graphical representation. Aside from the regression line of both candidates (calculated by means of linear regression analysis), the diagram shows the y = x curve, which is considered ideal, and the two-sided acceptance envelope. All single values for the candidates are provided in annex 5.

Table 27: Two-sided 95% confidence interval CI_{95} for the tested devices SN3 and SN4

Candidates	**Test site**	**Number of values**	**Standard deviation s_a**	**Student's-factor t_f**	**Confidence interval CI_{95}**
SN			µg/m³		µg/m³
SN3/SN4	Cologne, winter	69	1.44	1.996	2.87
SN3/SN4	Bonn, winter	61	1.79	2.001	3.58
SN3/SN4	Cologne, summer	54	1.16	2.007	2.32
SN3/SN4	Rodenkirchen, summer	53	0.69	2.008	1.38
SN3/SN4	Total	237	1.35	1.970	2.67

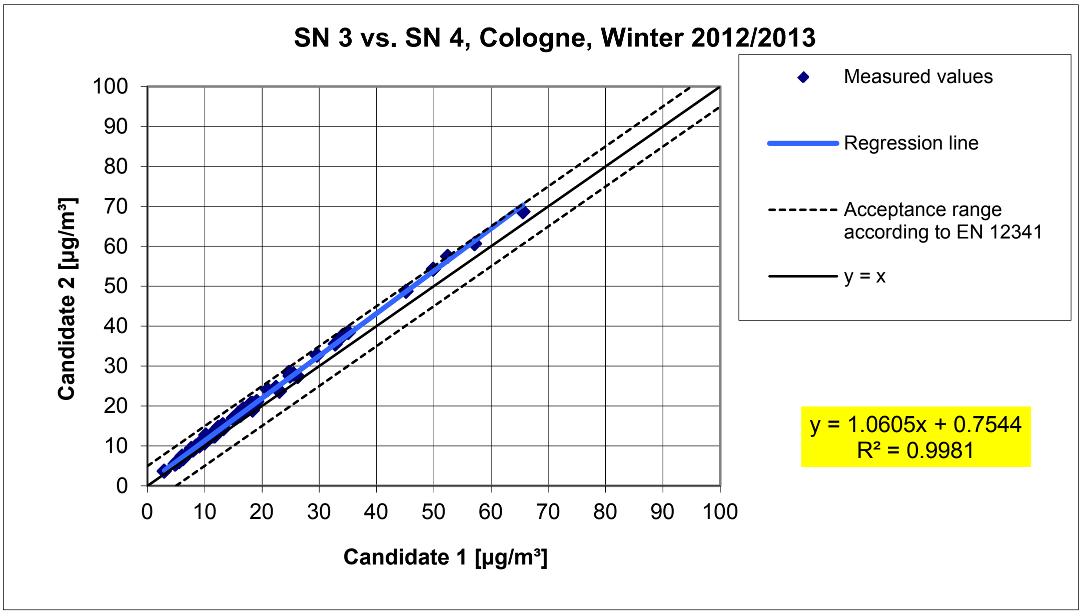

Figure 46: Results of parallel measurements with the tested devices SN3 / SN4, test site Cologne, winter

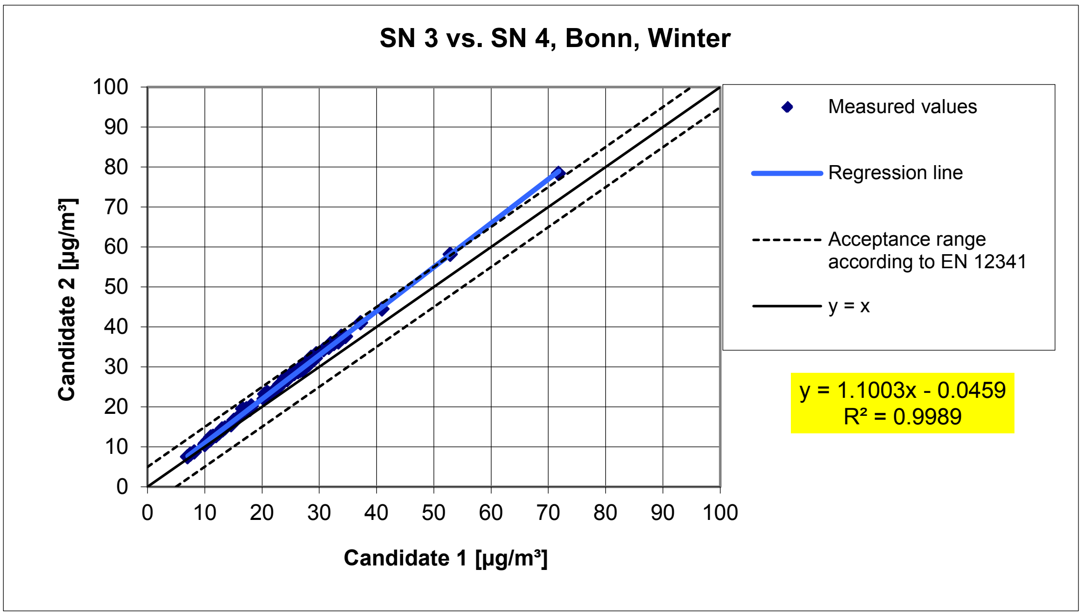

Figure 47: Results of parallel measurements with the tested devices SN3 / SN4, test site Bonn, winter

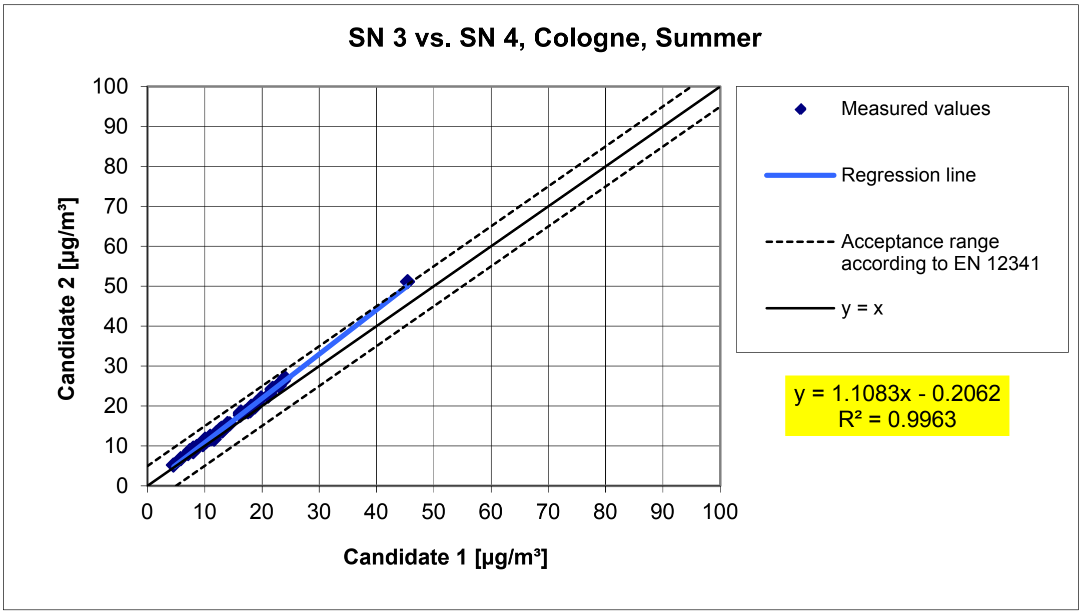

Figure 48: Results of parallel measurements with the tested devices SN3 / SN4, test site Cologne, summer

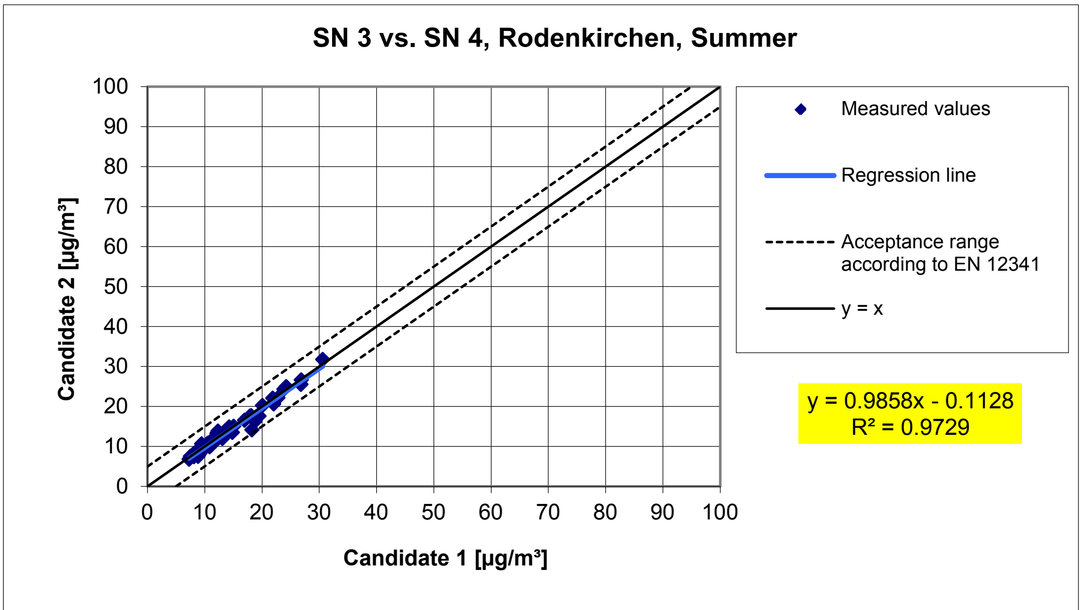

Figure 49: Results of parallel measurements with the tested devices SN3 / SN4, test site Rodenkirchen, summer

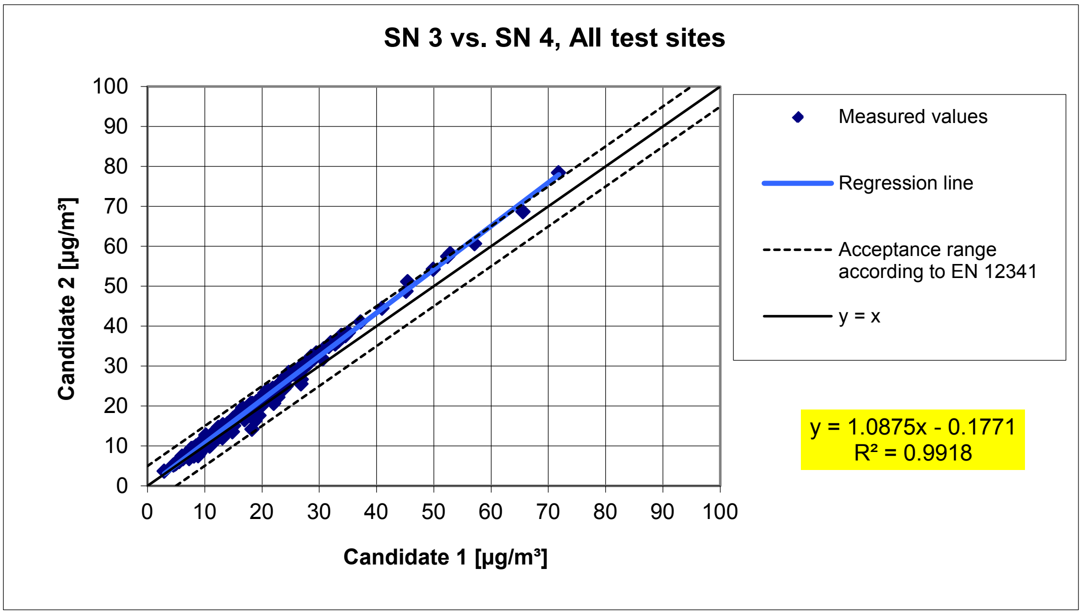

Figure 50: Results of parallel measurements with the tested devices SN3 / SN4, all test sites

6.1 5.4.4 Calibration

The systems under test shall be calibrated in the field test by comparison measurements with the reference method according to Standard EN 12341 respectively EN 14907. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall be determined as a steady function.

6.2 Equipment

Refer to module 5.4.2. or module 5.4.10

6.3 Method

For PM_{10}:

The reproducibility of the measuring systems was proven during testing (refer to module 5.4.2).

In order to determine the calibration function and the analytical function, the complete dataset was used (195 valid data pairs (SN3) and 193 valid data pairs (SN4)).

The quantities of the calibration function

$$y = m * x + b$$

were determined by means of linear regression. The analytical function is the inverse of the calibration function. It is:

$$x = 1/m * y - b/m$$

The slope m of the regression line describes the sensitivity of the measuring system; the y-intercept b describes the zero point.

For $PM_{2.5}$:

The reproducibility of the measuring systems as per module 5.4.10 was proven during testing.

In order to determine the calibration function and the analytical function, the complete dataset was used (194 valid data pairs (SN3) and 192 valid data pairs (SN4)).

The quantities of the calibration function

$$y = m * x + b$$

were determined by means of orthogonal regression. The analytical function is the inverse of the calibration function. It is:

$$x = 1/m * y – b/m$$

The slope m of the regression line describes the sensitivity of the measuring system, the y-intercept b describes the zero point.

6.4 Evaluation

The resulting quantities for PM_{10} are given in Table 28.

Table 28: Results of the calibration function and analytical function, measured component PM_{10}

Device no.	Calibration function		Analytical function	
	Y = m * x + b		x = 1/m * y - b/m	
	m	b	1/m	b/m
	µg/m³ / µg/m³	µg/m³	µg/m³ / µg/m³	µg/m³
System 1 (SN3)	0.894	-2.590	1.119	-2.897
System 2 (SN4)	0.972	-3.010	1.029	-3.097

The resulting quantities for $PM_{2.5}$ are given in Table 29.

Table 29: Results of the calibration function and analytical function, measured component $PM_{2.5}$

Device no.	Calibration function		Analytical function	
	Y = m * x + b		x = 1/m * y - b/m	
	m	b	1/m	b/m
	µg/m³ / µg/m³	µg/m³	µg/m³ / µg/m³	µg/m³
System 1 (SN3)	0.896	0.382	1.116	0.426
System 2 (SN4)	0.943	0.267	1.060	0.283

6.5 Assessment

A statistical correlation between the reference measuring method and the output signal could be demonstrated.

Performance criterion met? yes

6.6 Detailed presentation of test results

Refer to modules 5.4.2. and 5.4.10.

6.1 5.4.5 Cross sensitivity

The interference caused by moisture in the sample may not exceed 10 % of the limit value in the range of the limit value.

6.2 Equipment

Not required here.

6.3 Method

The interference caused by moisture in the sample was determined under field conditions.

Using the data from field test days with a relative humidity of > 70 % the difference between the obtained reference value (= nominal value) and the measured values of each candidate was calculated and the mean difference was applied as a conservative estimate for the interference caused by moisture in the sample.

In addition to that, reference/equivalence functions were determined for both devices using the data from field test days with a relative humidity of > 70 %.

6.4 Evaluation

Using the data from field test days with a relative humidity of > 70 %, the mean difference between the calculated reference value (= nominal value) and the measured value of the respective candidate was calculated and the relative deviation from the mean concentration was determined.

Annual limit value $PM_{2.5}$ = 25 µg/m³ 10 % of the annual limit value = 2.5 µg/m³

Annual limit value PM_{10} = 40 µg/m³ 10 % of the annual limit value = 4 µg/m

It was also examined whether the reproducibility of the measuring systems under test using the reference method according to Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods” [5] can be ensured even if the measured values were obtained on days with a relative humidity of > 70 %.

6.5 Assessment

No deviation of the measured signal from the nominal value > -1.1 µg/m³ caused by interference due to moisture in the sample could be observed for $PM_{2.5.}$ For PM_{10}, no deviation of the measured signal from the nominal value > 0.9 µg/m³ caused by interference due to moisture in the sample could be observed. The comparability of the candidates with the reference method according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" [5] is ensured even for days with a relative humidity of > 70 %.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 30 and Table 31 provide summaries of the results.

Table 30: Deviation between reference measurement and candidate on days with a relative humidity of > 70 %, measured component $PM_{2.5}$

Field test, days with rel. humidity >70 %				
		Reference	SN 3	SN 4
Mean value	µg/m³	15.5	14.4	15.0
Dev. to mean value of reference in µg/m³	µg/m³	-	-1.1	-0.4
Dev. in % of mean value reference	%	-	-6.8	-2.9
Deviation in % of annual LV	%	-	-4.2	-1.8

Table 31: Deviation between reference measurement and candidate on days with a relative humidity of > 70 %, measured component PM_{10}

Field test, days with rel. humidity >70 %				
		Reference	SN 3	SN 4
Mean value	µg/m³	21.5	21.0	22.4
Dev. to mean value of reference in µg/m³	µg/m³	-	-0.4	0.9
Dev. in % of mean value reference	%	-	-2.1	4.4
Deviation in % of annual LV	%	-	-1.1	2.4

Single values are provided in annexes 5 and 6.

The measurement uncertainties W_{CM} on days with a relative humidity of > 70 % are presented in Table 32 and Table 33. Single values are provided in annexes 5 and 6.

Table 32: Comparison of the candidates SN3 / SN4 with the reference device, rel. humidity > 70 %, all test sites, measured component $PM_{2.5}$

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN3 & SN4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All test sites, rH>70%					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.63**	**µg/m³**			
	SN3			**SN4**	
Number of data pairs	**116**			**116**	
Slope b	**0.885**			**0.927**	
Uncertainty of b	**0.013**			**0.014**	
Ordinate intercept a	**0.729**			**0.671**	
Uncertainty of a	**0.263**			**0.280**	
Expanded meas. uncertainty W_{CM}	**21.29**	**%**		**15.71**	**%**

Table 33: Comparison of the candidates SN3 / SN4 with the reference device, rel. humidity > 70 %, all test sites, measured component PM_{10}

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN3 & SN4	
			Limit value	50	µg/m³
Status of measured values	Offset corrected		Allowed uncertainty	25	%
All test sites, rH>70%					
Uncertainty between Reference	**0.56**	**µg/m³**			
Uncertainty between Candidates	**1.29**	**µg/m³**			
	SN3			**SN4**	
Number of data pairs	**116**			**116**	
Slope b	**0.947**			**1.021**	
Uncertainty of b	**0.022**			**0.025**	
Ordinate intercept a	**0.635**			**0.471**	
Uncertainty of a	**0.557**			**0.611**	
Expanded measured uncertainty W_{CM}	**14.55**	**%**		**14.64**	**%**

6.1 5.4.6 Averaging effect

The measuring system shall allow the formation of 24 h mean values.

The time of the sum of all filter changes within 24 h shall not exceed 1 % of this averaging time.

6.2 Equipment

Additionally a timer was used.

6.3 Method

It was tested, whether the AMS allows the formation of daily mean values.

6.4 Evaluation

The APM-2 measuring system switches alternatingly every two minutes between the measuring channels for PM_{10} and $PM_{2.5}$. Additionally once per hour the photometer unit is purged with zero air for two minutes.

Thus the available acquisition per PM-fraction is ((60min-2min)/2) = 29 min per hour and thus at 48.3 % of the total time.

The results from the field investigations according to chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test and chapter 6.1 5.4.11 Application of correction factors and terms in the report at hand nevertheless show, that the comparability of the candidate systems with the reference method has been demonstrated in the tested candidate configuration and that the formation of valid daily mean values is possible – this is also valid for the strongly traffic-influenced test site at the crossroads in Bonn.

Thus, the formation of daily mean values can be guaranteed.

6.5 Assessment

The measuring system allows the formation of valid daily mean values.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.4.7 Constancy of sample volumetric flow

The sample volumetric flow averaged over the sampling time shall be constant within ± 3 % of the rated value. All instantaneous values of the sample volumetric flow shall be within a range of ± 5 % of the rated value during sampling.

6.2 Equipment

As indicated in chapter 4, a flow meter was used in the testing of this performance criterion.

6.3 Method

The sample volumetric flow was calibrated before testing at the first field test site. Before testing at the other field test sites it was checked for correctness with a mass flow meter and readjusted if necessary.

The APM-2 measuring system operates with a flow rate of 3.3 l/min.

In order to determine the constancy of sample volumetric flow, the flow rate was recorded over 24 h (SN4) respectively 21 h (SN3) by means of a mass flow meter and evaluated according to the relevant upcoming test item 7.4.5 “Constancy of sample flow rate” of Technical Specification EN TS 16450 (May 2013) [9].

6.4 Evaluation

The obtained measured values for the flow rate were used to calculate mean value, standard deviation as well as maximum and minimum value.

6.5 Assessment

The results of the flow rate checks carried out at each field test site are given in Table 34.

Table 34: Results of flow rate checks

Flow rate check before testing at	SN3		SN4	
Test site:	[l/min]	Deviation from nominal value [%]	[l/min]	Deviation from nominal value [%]
Cologne, winter	3.31	0.3	3.30	0
Bonn, winter	3.32	0.6	3.28	-0.6
Cologne, summer	3.33	0.9	3.29	-0.3
Rodenkirchen, summer	3.36	1.8	3.33	0.9

The graphical representations of flow rate constancy show that none of the values obtained during sampling deviates from the respective nominal value by more than ±5 %. The 24 h mean values for the total flow rate of 3.3 l/min also deviate significantly less than the permissible ±3 % from the nominal value.

All determined daily mean values deviate less than ± 3 % from the rated value and all instantaneous values deviate less than ± 5 %.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 35 shows the parameters determined for the flow. Figure 51 and Figure 52 present a graphic representation of the flow measurements of the two candidates SN3 and SN4.

Table 35: Parameters for total flow measurement (24 h mean), SN3 & SN4

Device	Mean [l/min]	Deviation from nominal [%]	Std. dev. [l/min]	Max [l/min]	Min [l/min]
SN3	3.29	-0.43	0.033	3.45	3.20
SN4	3.31	0.24	0.030	3.37	3.27

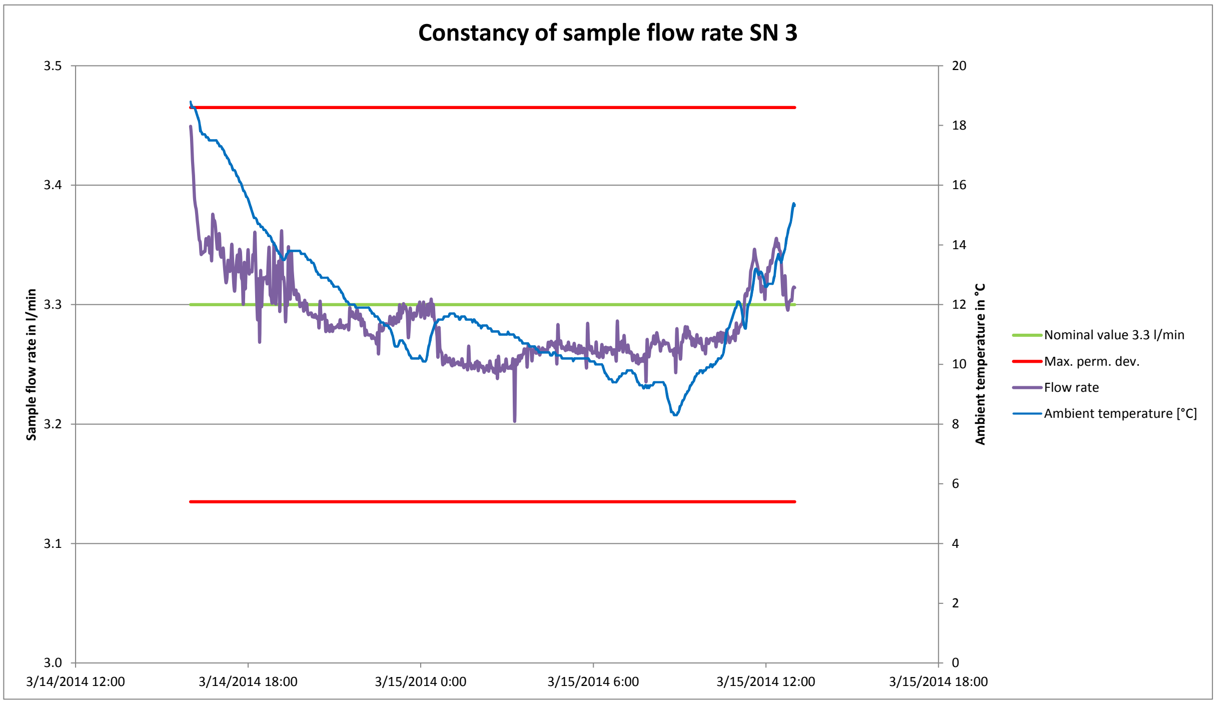

Figure 51: Flow rate of device SN3 (field conditions)

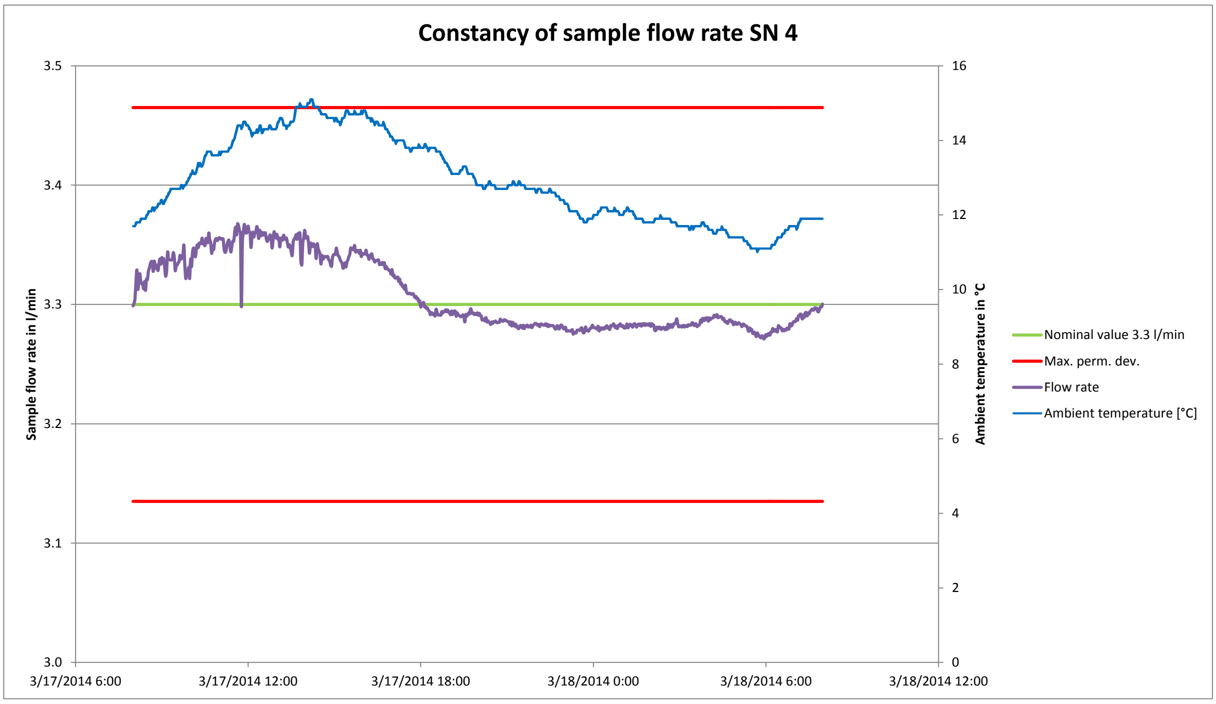

Figure 52: Flow rate of device SN4 (field conditions)

6.1 5.4.8 Tightness of the measuring system

The complete measuring system shall be checked for tightness. Leakage shall not exceed 1 % of the sample volume sucked.

6.2 Equipment

Not required here.

6.3 Method

The flow meter of the APM-2 measuring system is located directly upstream the pump. To determine the leak rate of the AMS, a leak test according to chapter 9.7 of the manual is performed with the help of a test appliance for tightness check, provided by the instrument manufacturer. For this a vacuum is created in the device with the help of the instrument´s pump and after switching off the pump, the rise in pressure over a time period of five minutes is monitored. In case of a rise in pressure > 290 hPa, the test on tightness is regarded as failed and the device needs close inspection. The system volume is 215 ml. Furthermore the instrument offers also the leak rate in ml/min as additional information.

The flow rate is 3.3 l/min, i.e. the maximum permissible leak rate is 0.033 l/min or 33 ml/min.

This procedure was finally implemented in the software not before January 2014 and was tested afterwards in the lab.

It is recommended to check the tightness of the measuring system by means of the aforementioned procedure every three months.

6.4 Evaluation

Leakage testing was performed in the laboratory.

The criterion for passing the leakage test, which has been proposed by the manufacturer (maximum pressure increase of 290 hPa in 5 min) proved to be an appropriate parameter for monitoring instrument tightness.

The detected maximum leak rate of 10.4 ml/min is less than 1 % of the nominal flow rate which is 3.3 l/min.

6.5 Assessment

The criterion for passing the leakage test, which has been specified by the manufacturer, (maximum pressure increase of 290 hPa in 5 min) proved to be an appropriate parameter for monitoring instrument tightness. The detected maximum leak rate of 10.4 ml/min is less than 1 % of the nominal flow rate which is 3.3 l/min.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 36 lists the values obtained in leakage testing.

Table 36: Results from leakage testing

Test	SN3		SN4		max. permissible leak rate in ml/min
	Pressure increase in 5 min in hPa	Leak rate in ml/min	Pressure increase in 5 min in hPa	Leak rate in ml/min	
1	108	8.2	151	10.4	33
2	104	8.0	143	10.1	33
3	102	8.0	139	9.9	33

6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11)

According to the January 2010 version of the Guide [5], the following 5 criteria shall be met in order to prove equivalence:

1. At least 20 % of the concentration values from the complete dataset (determined by means of reference method) shall exceed the upper assessment threshold for annual limit values determined in 2008/50/EC [8], i.e. 28 µg/m³ for PM_{10} and 17 µg/m³ for $PM_{2.5}$.
2. The uncertainty between the candidates must be less than 2.5 µg/m³ for all data and for two sub datasets corresponding to all the data split greater than or equal to and lower than 30 µg/m³ or 18 µg/m³ for PM_{10} and $PM_{2.5}$ respectively.
3. The uncertainty between the reference devices must be less than 2.0 µg/m³.
4. The expanded uncertainty (W_{CM}) is calculated at 50 µg/m³ for PM_{10} and 30 µg/m³ for $PM_{2.5}$ for each candidate against the mean value of the reference method. In each of the following cases, the expanded uncertainty shall not exceed 25 %:
   - Full dataset;
   - Dataset with PM concentrations greater/equal 30 µg/m³ for PM_{10} or greater/equal 18 µg/m³ for $PM_{2.5}$, provided that the dataset contains 40 or more valid data pairs;
   - Datasets for each field test site.
5. For the complete dataset to be accepted it is required that the slope b differs insignificantly from 1: $\left| b-1 \right| \leq 2 \cdot u(b)$ and that the intercept a differs insignificantly from 0: $\left| a \right| \leq 2 \cdot u(a)$. Should these requirements not be met, the candidates may be calibrated using the values for slope and/or intercept from the complete dataset.

In the following 5 chapters, compliance with the 5 criteria is tested:

In chapter 6.1 5.4.9 Determination of uncertainty between systems under test u_{bs} criteria 1 and 2 will be checked.

In chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test criteria 3, 4, and 5 will be checked.

In chapter 6.1 5.4.11 Application of correction factors and terms there is an exemplary evaluation for the event that criterion 5 cannot be met without application of correction factors or terms.

6.1 5.4.9 Determination of uncertainty between systems under test u_{bs}

For the test of $PM_{2.5}$ measuring systems the uncertainty between the systems under test shall be determined according to chapter 9.5.3.1 of the Guide "Demonstration of equivalence of Ambient Air Monitoring Methods" in the field test at least at four sampling sites representative of the future application.

The tests were also carried out for the component PM_{10}.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

The test was carried out at four different comparisons during the field test. Different seasons and varying concentrations for $PM_{2.5}$ and PM_{10} were taken into consideration.

At least 20 % of the concentration values from the complete dataset determined with the reference method shall exceed the upper assessment threshold according to 2008/50/EC [8]. The upper assessment threshold is 17 µg/m³ for $PM_{2.5}$ and 28 µg/m³ for PM_{10}.

At least 40 valid data pairs were determined per comparison. Out of the complete dataset (4 test sites, PM_{10}: 195 valid data pairs for SN3 and 193 valid data pairs for SN4; $PM_{2.5}$: 194 valid data pairs for SN3 and 192 valid data pairs for SN4), 28.6 % of the measured values exceed the upper assessment threshold of 17 µg/m for $PM_{2.5}$ and a total of 20.7 % of the measured values exceed the upper assessment threshold of 28 µg/m³ for PM_{10}. The measured concentrations were brought into relation with ambient conditions.

6.4 Evaluation

According to **chapter 9.5.3.1** of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" the following applies:

The uncertainty between the candidates u_{bs} shall be ≤ 2.5 µg/m³. If the uncertainty between the candidates exceeds 2.5 µg/m³, one or both systems might not be working properly. In such a case, equivalence cannot be declared.

Uncertainty is determined for:

- All test sites/comparisons together (full dataset)
- 1 dataset with measured values ≥ 18 µg/m³ for $PM_{2.5}$ (basis: mean values of reference measurement)
- 1 dataset with measured values ≥ 30 µg/m³ for PM_{10} (basis: mean values of reference measurement)

In addition to that, this report provides an evaluation of the following datasets:

- Each test site/comparison separately
- 1 dataset with measured values < 18 µg/m³ for $PM_{2.5}$ (basis: mean values of reference measurement)
- 1 dataset with measured values < 30 µg/m³ for PM_{10} (basis: mean values of reference measurement)

The uncertainty between the candidates u_{bs} is calculated from the differences of all daily mean values (24 h values) of the simultaneously operated candidates by means of the following equation:

$$u_{bs}^2 = \frac{\sum_{i=1}^{n}(y_{i,1} - y_{i,2})^2}{2n}$$

with $y_{i,1}$ and $y_{i,2}$ = results of the parallel measurements of individual 24 h values i

n = number of 24 h values

6.5 Assessment

The uncertainty between the candidates u_{bs} with a maximum of 1.04 µg/m³ for $PM_{2.5}$ and a maximum of 2.28 µg/m³ for PM_{10} does not exceed the required value of 2.5 µg/m³.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 37 and Table 38 list the calculated values for the uncertainty between candidates u_{bs}. Graphical representations of the results are provided in Figure 53 to Figure 66.

Table 37: Uncertainty between candidates u_{bs} for the devices SN3 and SN4, measured component $PM_{2.5}$

Device	**Test site**	**No. of values**	**Uncertainty u_{bs}**
SN			µg/m³
SN3 / SN4	**All test sites**	**237**	**0.65**
Single test sites			
SN3 / SN4	Cologne, summer	69	0.65
SN3 / SN4	Cologne, winter	61	0.88
SN3 / SN4	Bonn, winter	54	0.57
SN3 / SN4	Rodenkirchen, summer	53	0.33
Classification over reference value			
SN3 / SN4	**Values ≥ 18 µg/m³**	**49**	**1.04**
SN3 / SN4	Values < 18 µg/m³	143	0.42

Table 38: Uncertainty between candidates u_{bs} for the devices SN3 and SN4, measured component PM_{10}

Device	**Test site**	**No. of values**	**Uncertainty u_{bs}**
SN			µg/m³
SN3 / SN4	**All test sites**	**237**	**1.27**
Single test sites			
SN3 / SN4	Cologne, summer	69	1.38
SN3 / SN4	Cologne, winter	61	1.72
SN3 / SN4	Bonn, winter	54	1.06
SN3 / SN4	Rodenkirchen, summer	53	0.43
Classification over reference values			
SN3 / SN4	**Values ≥ 30 µg/m³**	**33**	**2.28**
SN3 / SN4	Values < 30 µg/m³	160	0.96

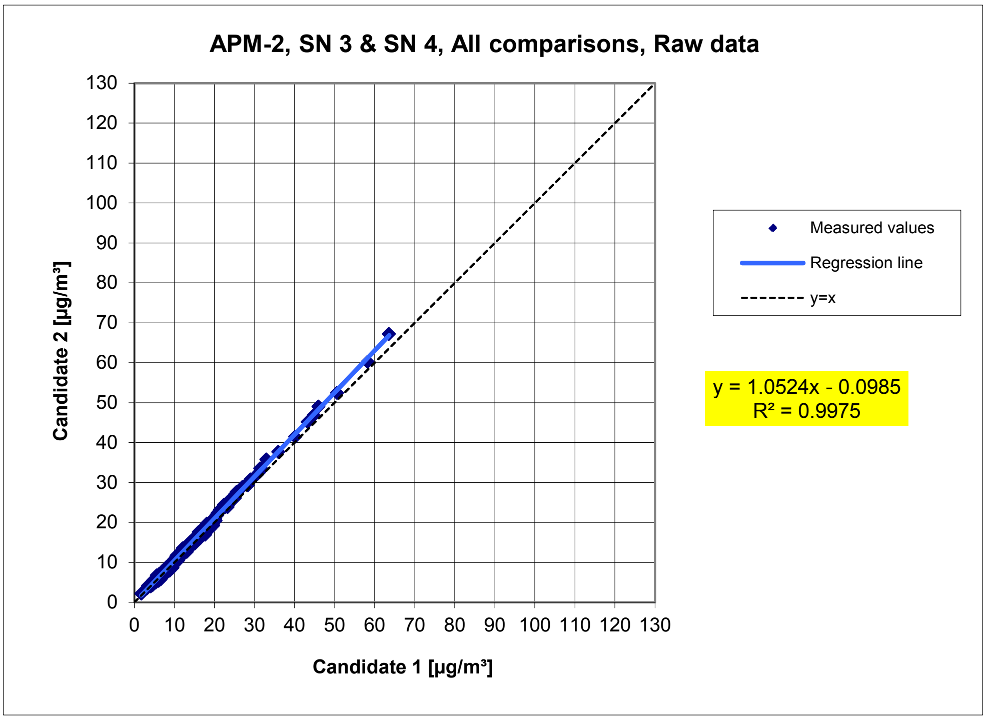

Figure 53: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, all test sites

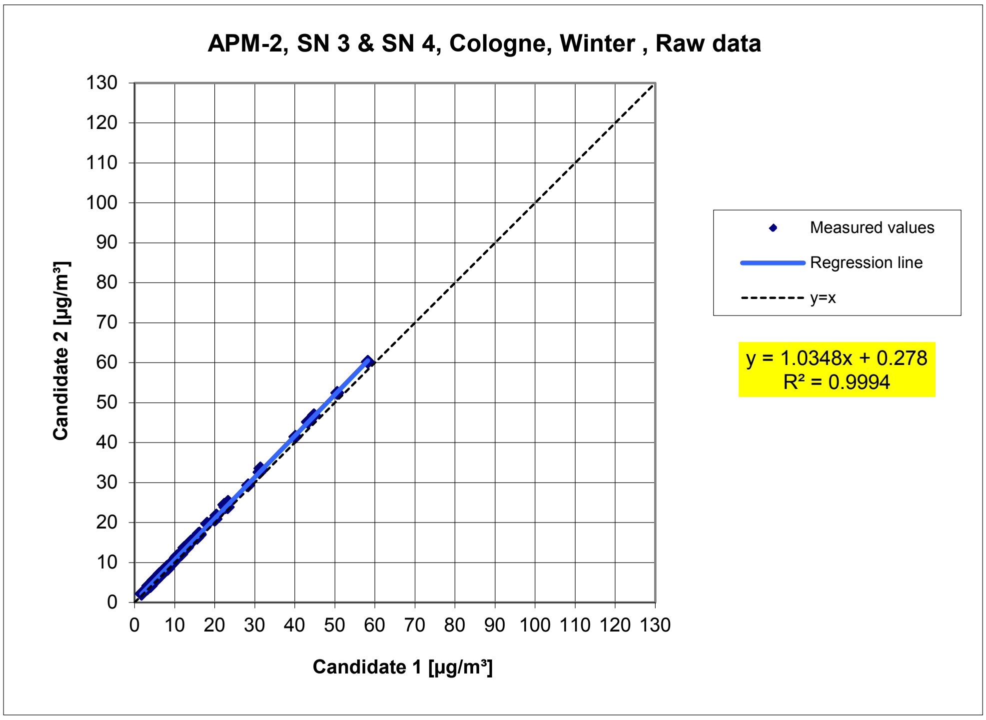

Figure 54: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, test site Cologne, winter

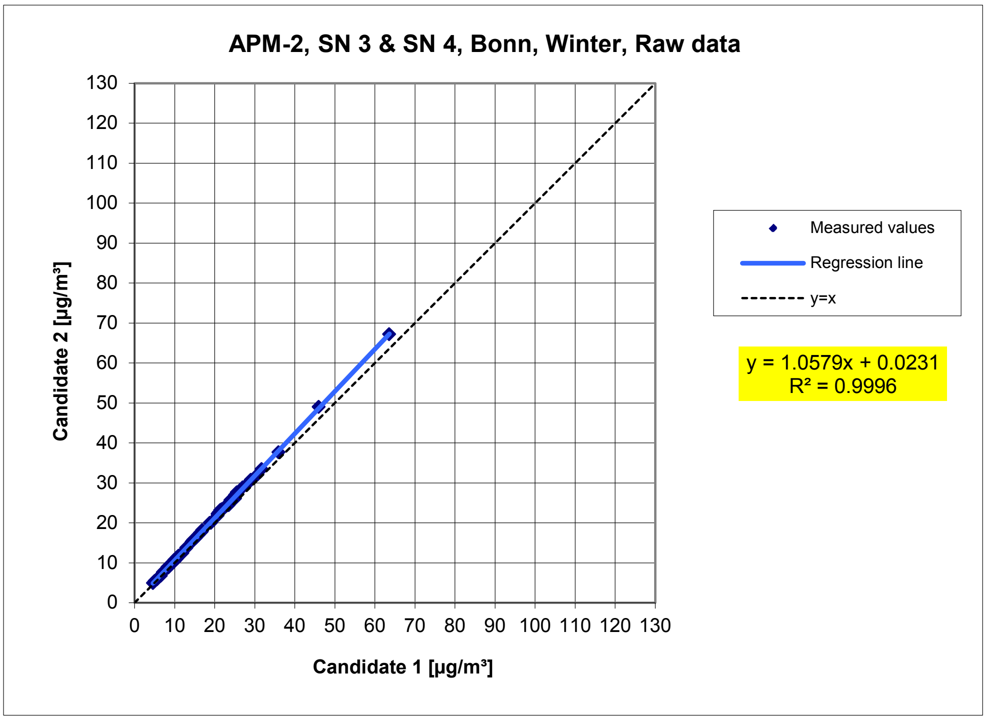

Figure 55: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, test site Bonn, winter

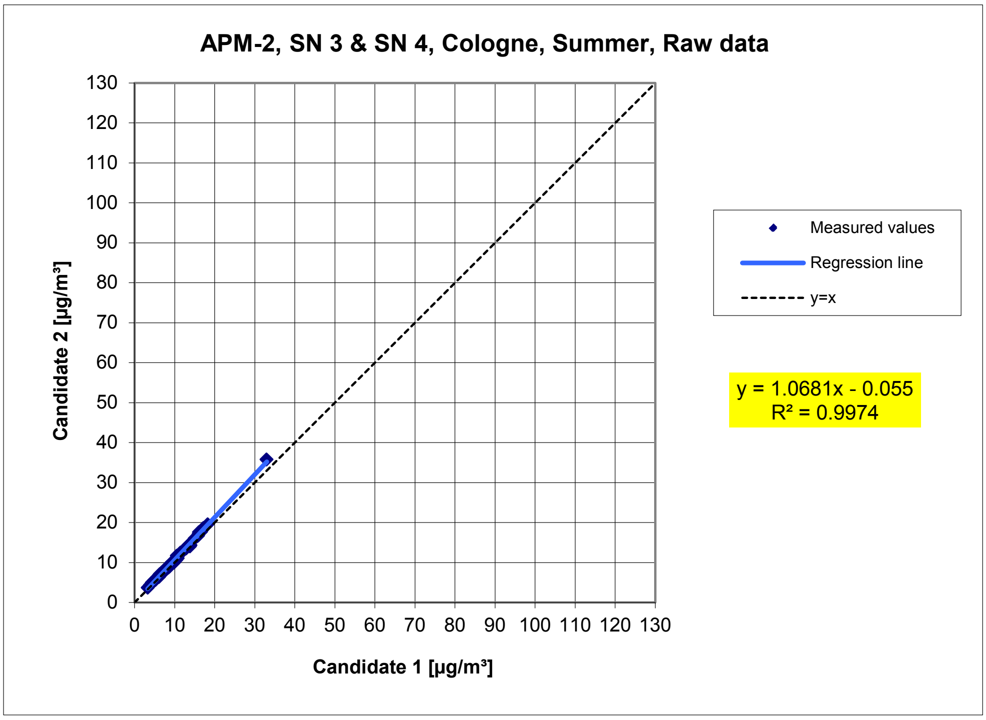

Figure 56: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, test site Cologne, summer

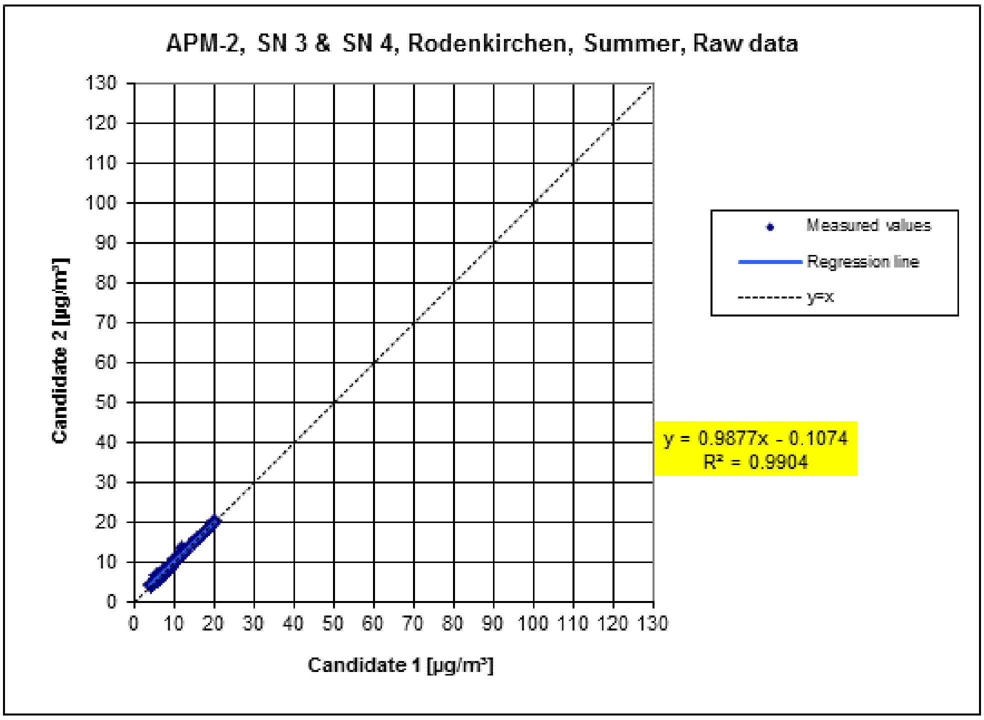

Figure 57: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, test site Rodenkirchen, summer

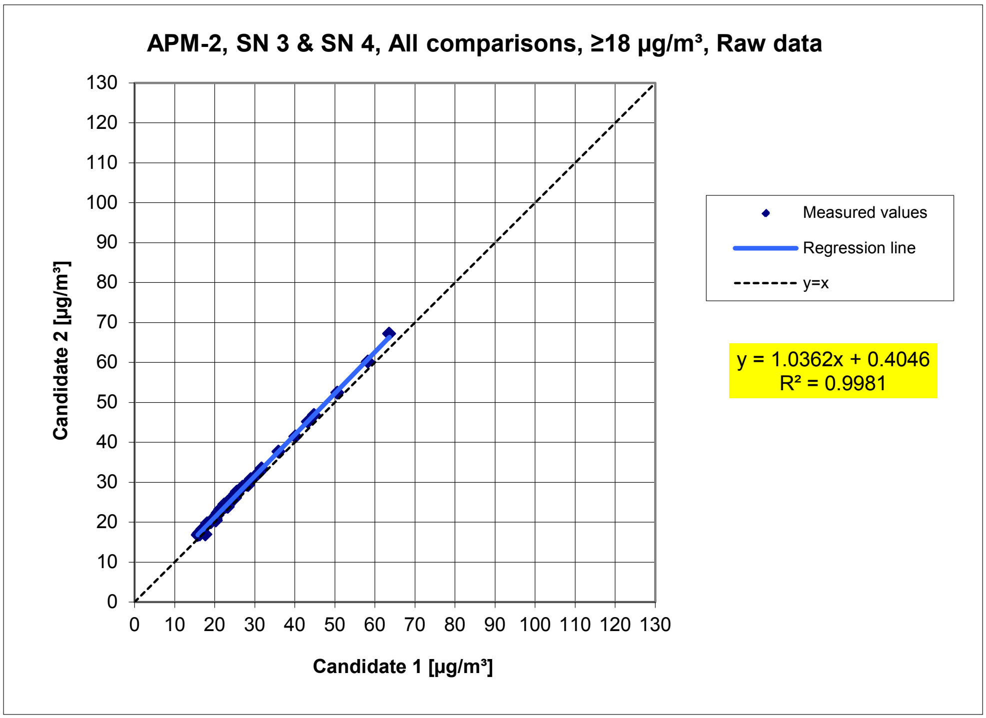

Figure 58: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, all test sites, values ≥ 18 µg/m³

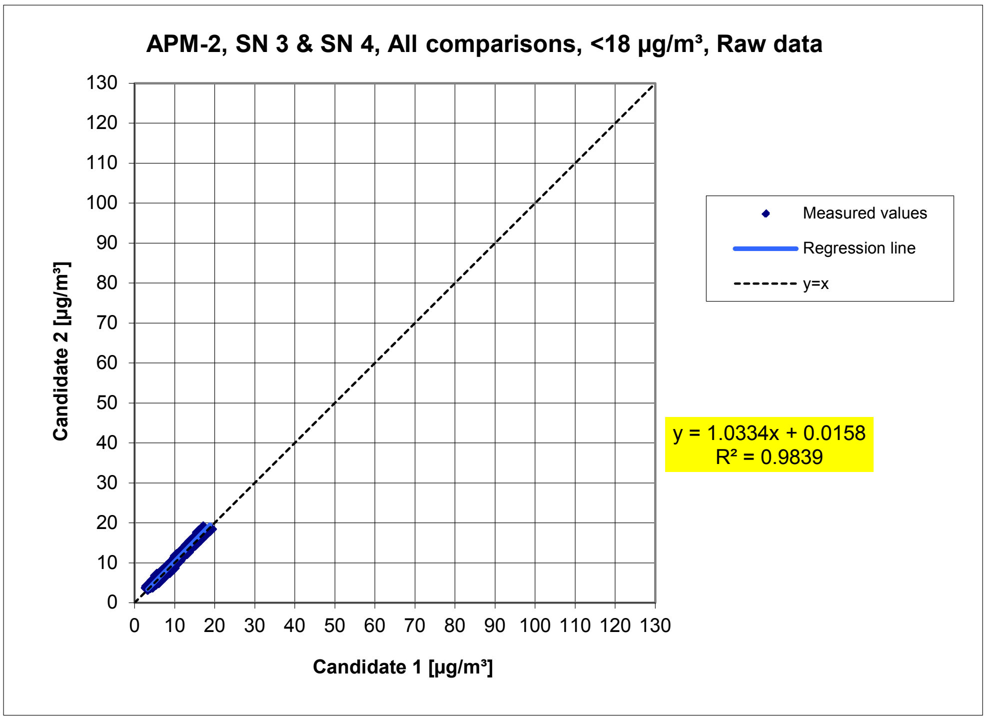

Figure 59: Results of the parallel measurements with the devices SN3 / SN4, measured component $PM_{2.5}$, all test sites, values < 18 µg/m³

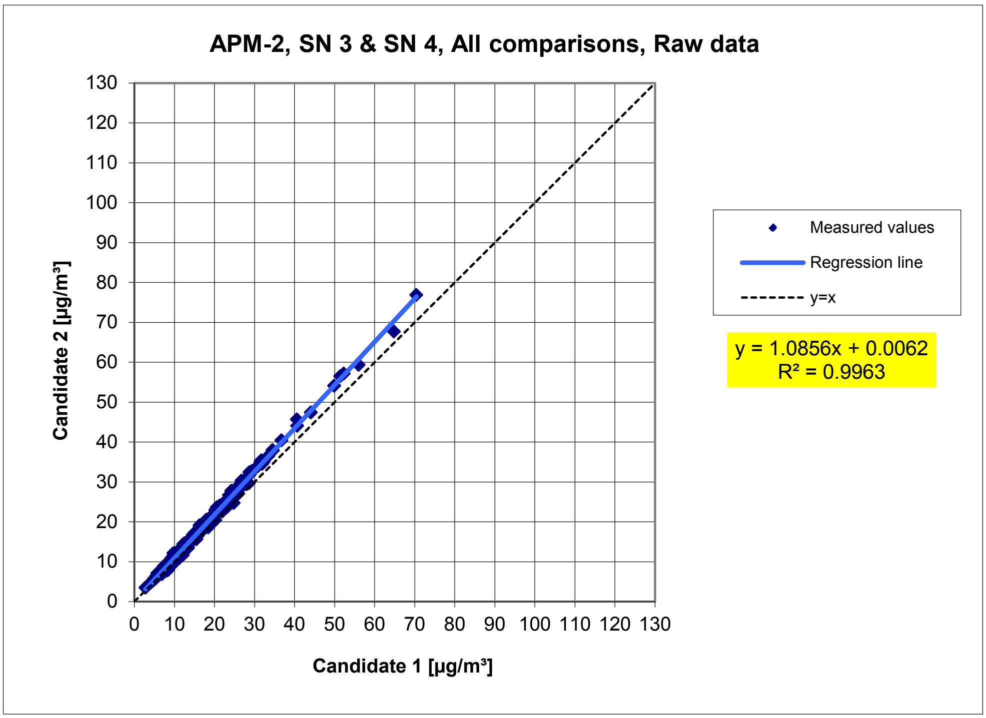

Figure 60: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, all test sites

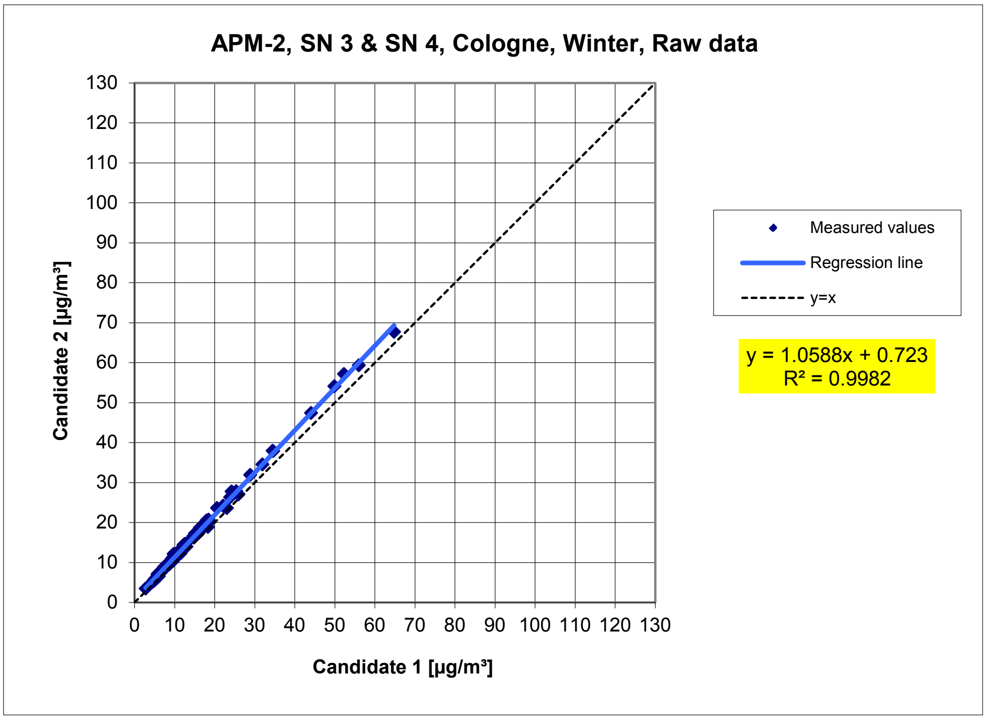

Figure 61: *Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, test site Cologne, winter*

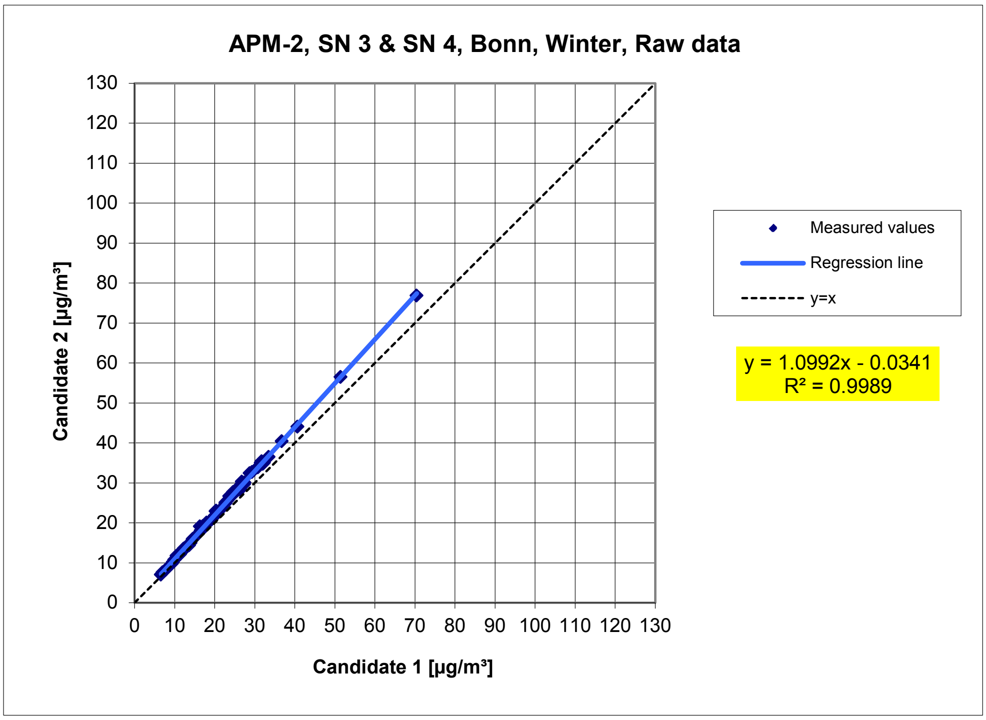

Figure 62: *Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, test site Bonn, winter*

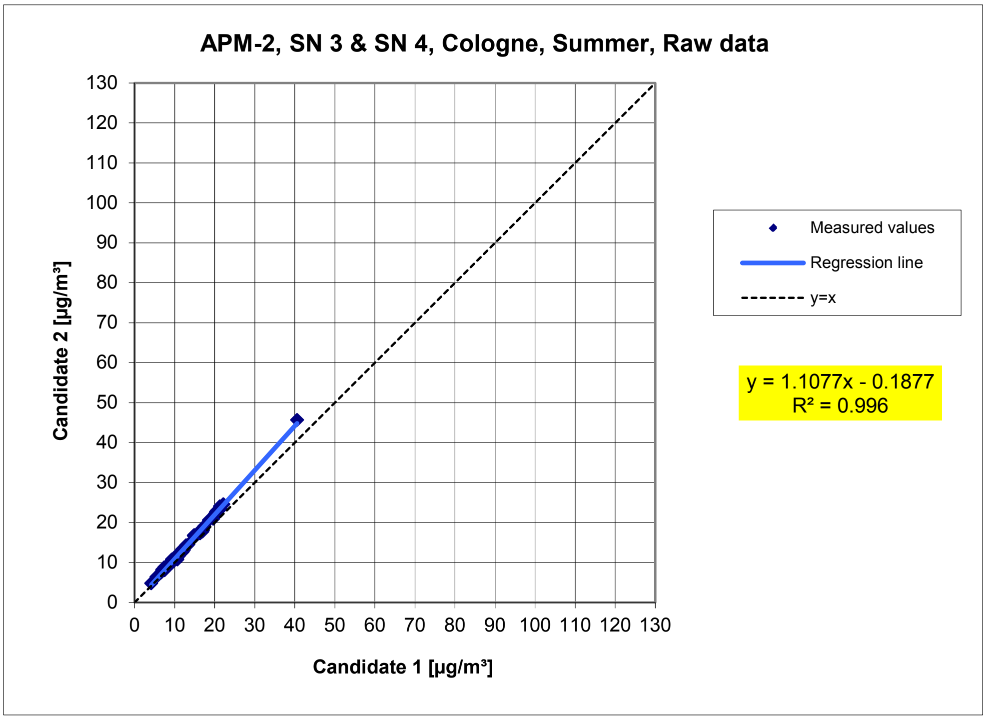

Figure 63: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, test site Cologne, summer

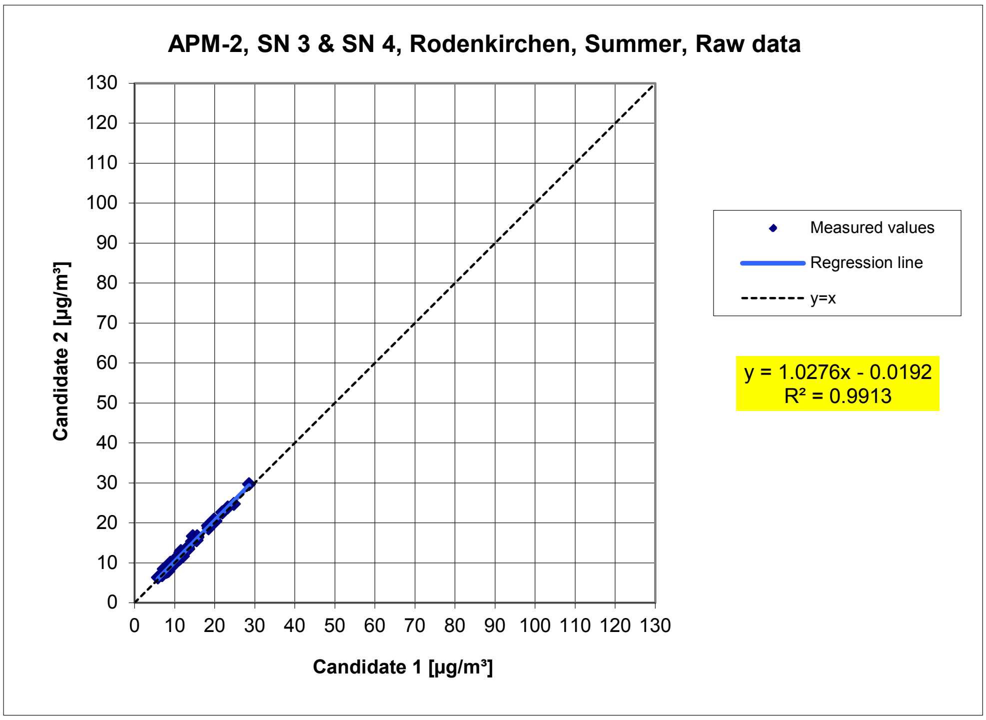

Figure 64: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, test site Rodenkirchen, summer

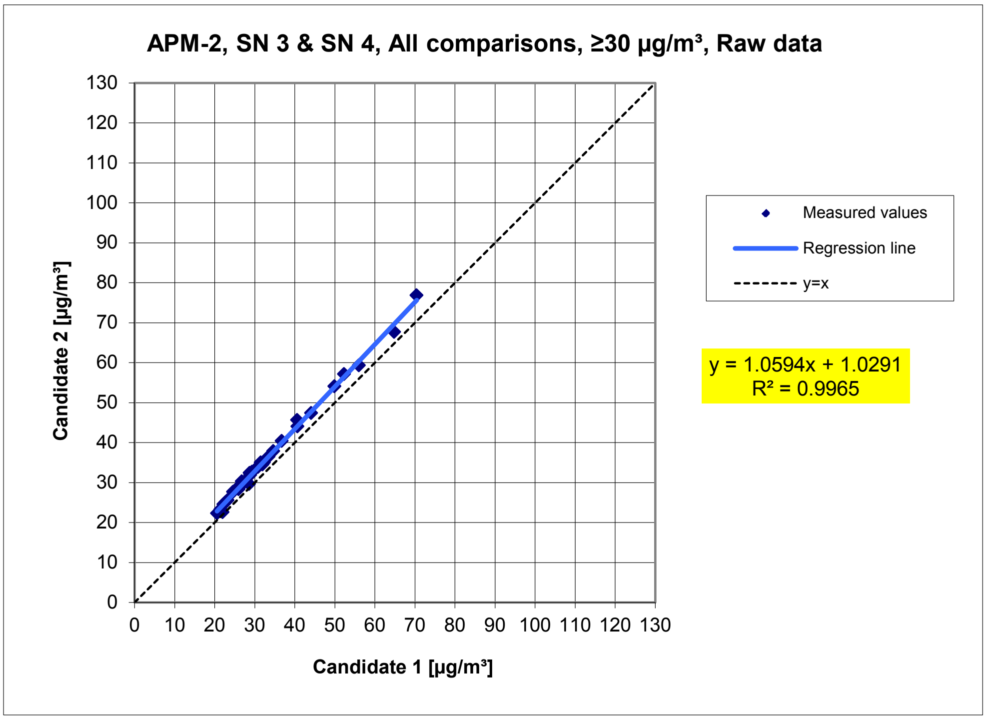

Figure 65: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, all test sites, values ≥ 30 µg/m³

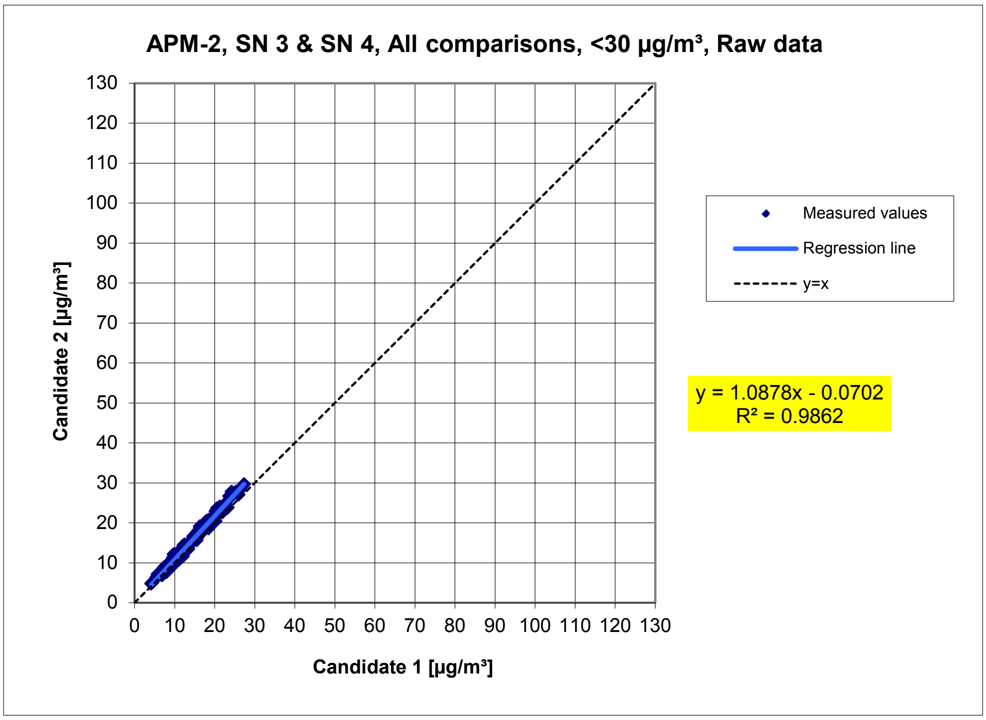

Figure 66: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{10}, all test sites, values < 30 µg/m³

6.1 5.4.10 Calculation of expanded uncertainty between systems under test

For the test of $PM_{2.5}$ measuring systems the equivalency with reference method shall be demonstrated according to chapter 9.5.3.2 to 9.6 of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" in the field test at least at four sampling sites representative of the future application. The maximum expanded uncertainty of the systems under test shall be compared with data quality objectives to Annex A of VDI Standard 4202, Sheet 1 (September 2010).

The tests were also carried out for the component PM_{10}.

6.2 Equipment

Additional instruments according to item 5 of this report were used in the testing of this performance criterion.

6.3 Method

The test was carried out at four different comparisons during the field test. Different seasons and varying concentrations for $PM_{2.5}$ and PM_{10} were taken into consideration.

At least 20 % of the concentration values from the complete dataset determined with the reference method shall exceed the upper assessment threshold according to 2008/50/EC [8]. The upper assessment threshold is 17 µg/m³ for $PM_{2.5}$ and 28 µg/m³ for PM_{10}.

At least 40 valid data pairs were determined per comparison. Out of the complete dataset (4 test sites, PM_{10}: 195 valid data pairs for SN3 and 193 valid data pairs for SN4; $PM_{2.5}$: 194 valid data pairs for SN3 and 192 valid data pairs for SN4), 28.6 % of the measured values exceed the upper assessment threshold of 17 µg/m for $PM_{2.5}$ and a total of 20.7 % of the measured values exceed the upper assessment threshold of 28 µg/m³ for PM_{10}. The measured concentrations were brought into relation with ambient conditions.

6.4 Evaluation

[Item 9.5.3.2] The calculation of expanded uncertainty is preceded by an uncertainty check between the two simultaneously operated reference devices u_{ref}.

The uncertainty between the simultaneously operated reference devices is determined analogous to the uncertainty between the candidates and shall be ≤ 2 µg/m³.

The evaluated results are given in 7.6 of this test item.

In order to evaluate the comparability between the candidates y and the reference method x, a linear correlation $y_i = a + bx_i$ between the measured results obtained from both methods is assumed. The correlation between the mean values of the reference devices and the candidates, which shall be assessed individually, is established by means of orthogonal regression.

Regression is calculated for:

- All test sites/comparisons together
- Each test site/comparison separately
- 1 dataset with measured values ≥ 18 µg/m³ for $PM_{2.5}$ (basis: mean values of reference measurement)
- 1 dataset with measured values ≥ 30 µg/m³ for PM_{10} (basis: mean values of reference measurement)

For further evaluation, the results of the uncertainty u_{c_s} of the candidates compared with the reference method is described in the following equation, which describes u_{CR} as a function of the OM concentration x_i.

$$u_{CR}^2(y_i) = \frac{RSS}{(n-2)} - u^2(x_i) + [a + (b-1)x_i]^2$$

With RSS = Sum of the (relative) residuals from orthogonal regression

$u(x_i)$ = random uncertainty of the reference procedure, if the value u_{bs}, which is calculated for using the candidates, can be used in this test (refer to item 6.1 5.4.9 Determination of uncertainty between systems under test ubs)

Algorithms for the calculation of intercept a as well as slope b and its variances by means of orthogonal regression are specified in Annex B of [5].

The sum of the (relative) residuals RSS is calculated using the following equation:

$$RSS = \sum_{i=1}^{n} (y_i - a - bx_i)^2$$

Uncertainty u_{CR} is calculated for:

- All test sites/comparisons together
- Each test site/comparison separately
- 1 dataset with measured values ≥ 18 µg/m³ for $PM_{2.5}$ (basis: mean values of reference measurement)
- 1 dataset with measured values ≥ 30 µg/m³ for PM_{10} (basis: mean values of reference measurement)

According to the Guide, preconditions for acceptance of the full dataset are that:

- the slope b differs insignificantly from 1: $|b-1| \leq 2 \cdot u(b)$

and that

- the intercept a differs insignificantly from 0: $|a| \leq 2 \cdot u(a)$

with u(b) and u(a) being the standard uncertainties of slope and intercept, each calculated as the square root of their variances. If these preconditions are not met, the candidates may be calibrated according to item 9.7 of the guideline (refer to 6.1 5.4.11 Application of correction factors and terms. The calibration shall only be applied to the full dataset.

[Item 9.5.4] The combined uncertainty of the candidates $w_{c,CM}$ is calculated for each dataset by combining the contributions from 9.5.3.1 and 9.5.3.2 according to the following equation:

$$w_{c,CM}^2(y_i) = \frac{u_{CR}^2(y_i)}{y_i^2}$$

For each dataset, the uncertainty $w_{c,CM}$ is calculated at the level of y_i = 30 µg/m³ for $PM_{2.5}$ and at the level of y_i = 50 µg/m³ for PM_{10}.

[Item 9.5.5] The expanded relative uncertainty of the results of the candidates is calculated for each dataset by multiplying $w_{c,CM}$ with a coverage factor k according to the following equation:

$$W_{CM} = k \cdot w_{CM}$$

In praxis k=2 for large n

[Item 9.6] The highest resulting uncertainty W_{CM} is compared with the requirements on data quality of ambient air measurements according to EU Standard [8] and assessed. There are two possible results:

1. $W_{CM} \leq W_{dqo}$ → Candidate method is considered equivalent to the reference method
2. $W_{CM} > W_{dqo}$ → Candidate method is considered not equivalent to the reference method

The specified expanded relative uncertainty W_{dqo} for particulate matter is 25 % [8].

6.5 Assessment

Without application of correction factors, the determined uncertainties W_{CM} for $PM_{2.5}$ for all datasets under consideration lie below the defined expanded relative uncertainty W_{dqo} of 25 % for suspended particulate matter.

Without application of correction factors, the determined uncertainties W_{CM} for PM_{10} for SN3 are for all datasets above the defined expanded relative uncertainty W_{dqo} of 25 % with exception of Cologne, Winter, for SN4 the data set Rodenkirchen, Summer and for both candidates together the data set ≥ 30 µg/m³ are also above the defined expanded relative uncertainty W_{dqo} of 25 % for suspended particulate matter.

Correction factors shall be applied according to chapter 6.1 5.4.11 Application of correction factors and terms.

Performance criterion met? no

Table 39 and Table 40 provide an overview of all results from the equivalence test of the APM-2 for $PM_{2.5}$ and PM_{10}. In the event that a criterion has not been met, the respective cell is marked in yellow.

Table 39: Overview of equivalence test of APM-2 for $PM_{2.5}$

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.55**	**µg/m³**			
Uncertainty between Candidates	**0.65**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**192**				
Slope b	**0.919**	**significant**			
Uncertainty of b	**0.012**				
Ordinate intercept a	**0.327**	**not significant**			
Uncertainty of a	**0.216**				
Expanded meas. uncertainty W_{CM}	**17.68**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.63**	**µg/m³**			
Uncertainty between Candidates	**1.04**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**49**				
Slope b	**0.887**				
Uncertainty of b	**0.030**				
Ordinate intercept a	**1.248**				
Uncertainty of a	**0.937**				
Expanded meas. uncertainty W_{CM}	**21.92**	**%**			
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.42**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**143**				
Slope b	**1.040**				
Uncertainty of b	**0.030**				
Ordinate intercept a	**-0.928**				
Uncertainty of a	**0.327**				
Expanded meas. uncertainty W_{CM}	**7.98**	**%**			

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	**0.54**	**µg/m³**			
Uncertainty between Candidates	**0.65**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**52**			**52**	
Slope b	**0.855**			**0.883**	
Uncertainty of b	**0.017**			**0.018**	
Ordinate intercept a	**1.068**			**1.387**	
Uncertainty of a	**0.389**			**0.400**	
Expanded meas. uncertainty W_{CM}	**24.56**	**%**		**18.11**	**%**
Bonn, Winter					
Uncertainty between Reference	**0.62**	**µg/m³**			
Uncertainty between Candidates	**0.88**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**51**			**51**	
Slope b	**0.952**			**1.007**	
Uncertainty of b	**0.029**			**0.029**	
Ordinate intercept a	**-0.834**			**-0.849**	
Uncertainty of a	**0.649**			**0.666**	
Expanded meas. uncertainty W_{CM}	**20.54**	**%**		**14.80**	**%**
Cologne, Summer					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.57**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**46**			**44**	
Slope b	**0.966**			**1.019**	
Uncertainty of b	**0.041**			**0.045**	
Ordinate intercept a	**-0.221**			**-0.174**	
Uncertainty of a	**0.453**			**0.508**	
Expanded meas. uncertainty W_{CM}	**10.59**	**%**		**7.90**	**%**
Rodenkirchen, Summer					
Uncertainty between Reference	**0.52**	**µg/m³**			
Uncertainty between Candidates	**0.33**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**45**			**45**	
Slope b	**1.053**			**1.037**	
Uncertainty of b	**0.046**			**0.047**	
Ordinate intercept a	**-1.230**			**-1.320**	
Uncertainty of a	**0.519**			**0.521**	
Expanded meas. uncertainty W_{CM}	**7.76**	**%**		**7.54**	**%**
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.63**	**µg/m³**			
Uncertainty between Candidates	**1.04**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**49**			**49**	
Slope b	**0.871**			**0.904**	
Uncertainty of b	**0.030**			**0.031**	
Ordinate intercept a	**1.046**			**1.438**	
Uncertainty of a	**0.921**			**0.96**	
Expanded meas. uncertainty W_{CM}	**24.98**	**%**		**19.63**	**%**
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.42**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**145**			**143**	
Slope b	**1.019**			**1.065**	
Uncertainty of b	**0.029**			**0.031**	
Ordinate intercept a	**-0.877**			**-1.020**	
Uncertainty of a	**0.317**			**0.344**	
Expanded meas. uncertainty W_{CM}	**7.80**	**%**		**10.37**	**%**
All comparisons					
Uncertainty between Reference	**0.55**	**µg/m³**			
Uncertainty between Candidates	**0.65**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**194**			**192**	
Slope b	**0.896**	**significant**		**0.943**	**significant**
Uncertainty of b	**0.012**			**0.012**	
Ordinate intercept a	**0.382**	**not significant**		**0.267**	**not significant**
Uncertainty of a	**0.209**			**0.225**	
Expanded meas. uncertainty W_{CM}	**21.09**	**%**		**14.84**	**%**

The results of the check of the five criteria given in chapter 6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11) are as follows:

Criterion 1: More than 20 % of the data are greater than 17 µg/m³.

Criterion 2: The uncertainty between the candidates is less than 2.5 µg/m³.

Criterion 3: The uncertainty between the reference devices is less than 2.0 µg/m³.

Criterion 4: All expanded uncertainties are below 25 %.

Criterion 5: The slopes for evaluation of the complete dataset are significantly greater than the permissible values for both devices.

Other: For both candidates together, the slope is 0.919 and the intercept is 0.327 at an expanded overall uncertainty of 17.68 % for the full dataset.

Table 40: Overview of equivalence test of APM-2 for PM_{10}

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.58**	**µg/m³**			
Uncertainty between Candidates	**1.27**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**193**				
Slope b	**0.977**	**nicht signifikant**			
Uncertainty of b	**0.020**				
Ordinate intercept a	**-3.758**	**signifikant**			
Uncertainty of a	**0.502**				
Expanded measured uncertainty WCM	**23.25**	**%**			
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0.72**	**µg/m³**			
Uncertainty between Candidates	**2.28**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**33**				
Slope b	**1.035**				
Uncertainty of b	**0.063**				
Ordinate intercept a	**-6.432**				
Uncertainty of a	**2.681**				
Expanded measured uncertainty WCM	**25.88**	**%**			
All comparisons, <30 µg/m³					
Uncertainty between Reference	**0.55**	**µg/m³**			
Uncertainty between Candidates	**0.96**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**160**				
Slope b	**0.971**				
Uncertainty of b	**0.040**				
Ordinate intercept a	**-3.579**				
Uncertainty of a	**0.751**				
Expanded measured uncertainty WCM	**23.05**	**%**			

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	0.54	µg/m³			
Uncertainty between Candidates	1.38	µg/m³			
	SN 3			SN 4	
Number of data pairs	52			52	
Slope b	0.931			0.982	
Uncertainty of b	0.023			0.022	
Ordinate intercept a	-2.007			-1.290	
Uncertainty of a	0.611			0.582	
Expanded measured uncertainty W_{CM}	23.70	%		12.30	%
Bonn, Winter					
Uncertainty between Reference	0.38	µg/m³			
Uncertainty between Candidates	1.72	µg/m³			
	SN 3			SN 4	
Number of data pairs	51			51	
Slope b	0.943			1.043	
Uncertainty of b	0.049			0.054	
Ordinate intercept a	-4.224			-4.829	
Uncertainty of a	1.477			1.604	
Expanded measured uncertainty W_{CM}	32.57	%		20.66	%
Cologne, Summer					
Uncertainty between Reference	0.60	µg/m³			
Uncertainty between Candidates	1.06	µg/m³			
	SN 3			SN 4	
Number of data pairs	47			45	
Slope b	0.852			0.954	
Uncertainty of b	0.039			0.043	
Ordinate intercept a	-1.667			-2.156	
Uncertainty of a	0.733			0.809	
Expanded measured uncertainty W_{CM}	36.90	%		19.49	%
Rodenkirchen, Summer					
Uncertainty between Reference	0.76	µg/m³			
Uncertainty between Candidates	0.43	µg/m³			
	SN 3			SN 4	
Number of data pairs	45			45	
Slope b	0.944			0.983	
Uncertainty of b	0.063			0.063	
Ordinate intercept a	-5.390			-5.818	
Uncertainty of a	1.252			1.258	
Expanded measured uncertainty W_{CM}	33.83	%		28.11	%
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	0.72	µg/m³			
Uncertainty between Candidates	2.28	µg/m³			
	SN 3			SN 4	
Number of data pairs	33			33	
Slope b	1.003			1.068	
Uncertainty of b	0.062			0.065	
Ordinate intercept a	-6.650			-6.252	
Uncertainty of a	2.639			2.74	
Expanded measured uncertainty W_{CM}	31.43	%		21.54	%
All comparisons, <30 µg/m³					
Uncertainty between Reference	0.55	µg/m³			
Uncertainty between Candidates	0.96	µg/m³			
	SN 3			SN 4	
Number of data pairs	162			160	
Slope b	0.921			1.025	
Uncertainty of b	0.037			0.043	
Ordinate intercept a	-3.223			-4.000	
Uncertainty of a	0.698			0.807	
Expanded measured uncertainty W_{CM}	30.60	%		16.42	%
All comparisons					
Uncertainty between Reference	0.58	µg/m³			
Uncertainty between Candidates	1.27	µg/m³			
	SN 3			SN 4	
Number of data pairs	195			193	
Slope b	0.935	signifikant		1.020	nicht signifikant
Uncertainty of b	0.019			0.022	
Ordinate intercept a	-3.552	signifikant		-3.981	signifikant
Uncertainty of a	0.474			0.531	
Expanded measured uncertainty W_{CM}	29.69	%		17.80	%

The results of the check of the five criteria given in chapter 6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11) are as follows:

Criterion 1: More than 20 % of the data are greater than 28 µg/m³.

Criterion 2: The uncertainty between the candidates is less than 2.5 µg/m³.

Criterion 3: The uncertainty between the reference devices is less than 2.0 µg/m³.

Criterion 4: For SN3 all of the expanded uncertainties are above 25 % with the exception of Cologne, winter.

For SN4 all of the expanded uncertainties are below 25 % with the exception of Rodenkirchen, summer.

For SN3 and SN4 together, the expanded uncertainty for the data set ≥30 µg/m³ is above 25 %.

Criterion 5: For SN3 the slope as well as the intercept of the evaluation of the full dataset are significantly greater than the permissible values.

For SN4 the intercept of the evaluation of the full dataset is significantly greater than the permissible values.

Other: For both candidates, the total slope is 0.977 and the intercept is -3.758 at an expanded overall uncertainty of 23.25 % for the full dataset.

The January 2010 version of the Guide is ambiguous with respect to which slope and which intercept should be used to correct a candidate should it fail the test of equivalence. After consultation with the convenor (Mr Theo Hafkenscheid) of the EC working group responsible for setting up the Guide, it was decided that the requirements of the November 2005 version of the Guide are still valid, and that the slope and intercept from the orthogonal regression of all the paired data be used. These are stated additionally under “Other” in the above.

The 2006 UK Equivalence Report [10] has highlighted this was a flaw in the mathematics required for equivalence as per the November 2005 version of the Guide as it penalized instruments that were more accurate (Annex E Section 4.2 therein). This same flaw is copied in the January 2010 version. It is proposed that the same pragmatic approach is taken here that was previously undertaken in earlier studies.

Therefore, according to Table 39, the slope must be corrected for $PM_{2.5}$ due to the determined significance. For PM_{10}, the slope and intercept must be corrected due to exceedance of the permissible expanded uncertainty for several comparison campaigns and due to the determined significance according to Table 40. Nonetheless it should be noted that, even without application of correction factors, the determined uncertainties W_{CM} for $PM_{2.5}$ lie below the specified expanded relative uncertainty W_{dqo} of 25 % for particulate matter for all datasets considered.

For $PM_{2.5}$:

The slope for the complete dataset is 0.919. Thus, an additional evaluation applying the respective calibration factors to the datasets is made in chapter 6.1 5.4.11 Application of correction factors and terms.

For PM_{10}:

The slope for the complete dataset is 0.977. The intercept for the complete dataset is -3.758. An additional evaluation where the respective calibration factors are applied to the datasets is made in chapter 6.1 5.4.11 Application of correction factors and terms.

The revised January 2010 version of the Guide requires that, in order to monitor the processes in compliance with the guidelines, random checks shall be performed on a number of systems within a measuring network and that the number of measuring sites shall depend on the expanded uncertainty of the system. Either the network operator or the responsible authority of the member state is responsible for the appropriate realization of the requirement mentioned above. However, TÜV Rheinland recommends that the expanded uncertainty for the full dataset (here: uncorrected raw data) shall be referred to, i.e. 17.68 % for $PM_{2.5}$, which would require annual checks at 4 sites, and 23.25 %, for PM_{10}, which would require annual checks a 5 sites (Guide [5], Chapter 9.9.2, Table 6). Due to the necessary application of the corresponding calibration factors, this assessment should be made on the basis of the evaluation of the corrected datasets (refer to chapter 6.1 5.4.11 Application of correction factors and terms).

6.6 Detailed presentation of test results

Table 41 and Table 42 present an overview of the uncertainties between the reference devices u_{ref} obtained in the field tests.

Table 41: Uncertainty between reference devices u_{ref} for $PM_{2.5}$

Reference devices	Test site	No. of values	Uncertainty u_{bs}
No.			µg/m³
1 / 2	Cologne, winter	52	0.54
1 / 2	Bonn, winter	51	0.62
1 / 2	Cologne, summer	46	0.53
1 / 2	Rodenkirchen, summer	45	0.52
1 / 2	All test sites	194	0.55

Table 42: Uncertainty between reference devices u_{ref} for PM_{10}

Reference devices	Test site	No. of values	Uncertainty u_{bs}
Nr.			µg/m³
1 / 2	Cologne, winter	52	0.54
1 / 2	Bonn, winter	51	0.38
1 / 2	Cologne, summer	47	0.60
1 / 2	Rodenkirchen, summer	33	0.72
1 / 2	All test sites	195	0.58

The uncertainty between the reference devices u_{ref} is < 2 µg/m³ for all test sites.

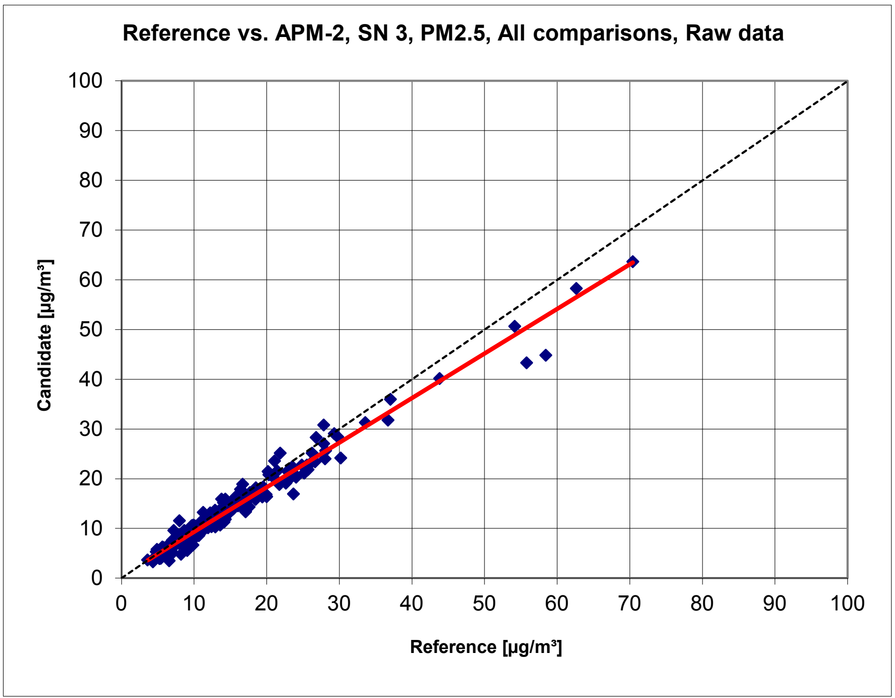

Figure 67: Reference device vs. candidate, SN3, measured component $PM_{2.5}$, all test sites

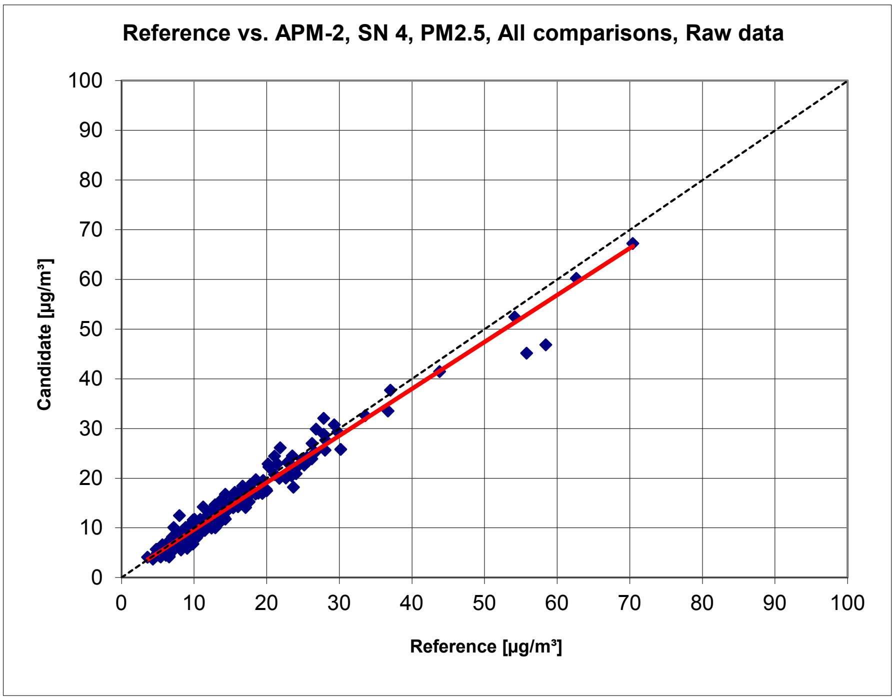

Figure 68: Reference device vs. candidate, SN4, measured component $PM_{2.5}$, all test sites

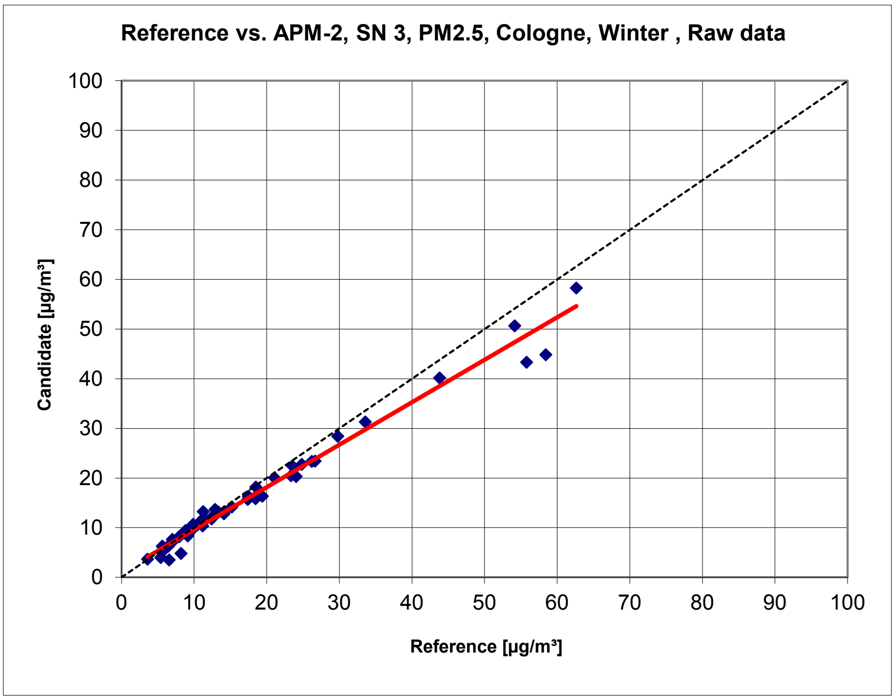

Figure 69: Reference device vs. candidate, SN3, measured component $PM_{2.5}$, Cologne, winter

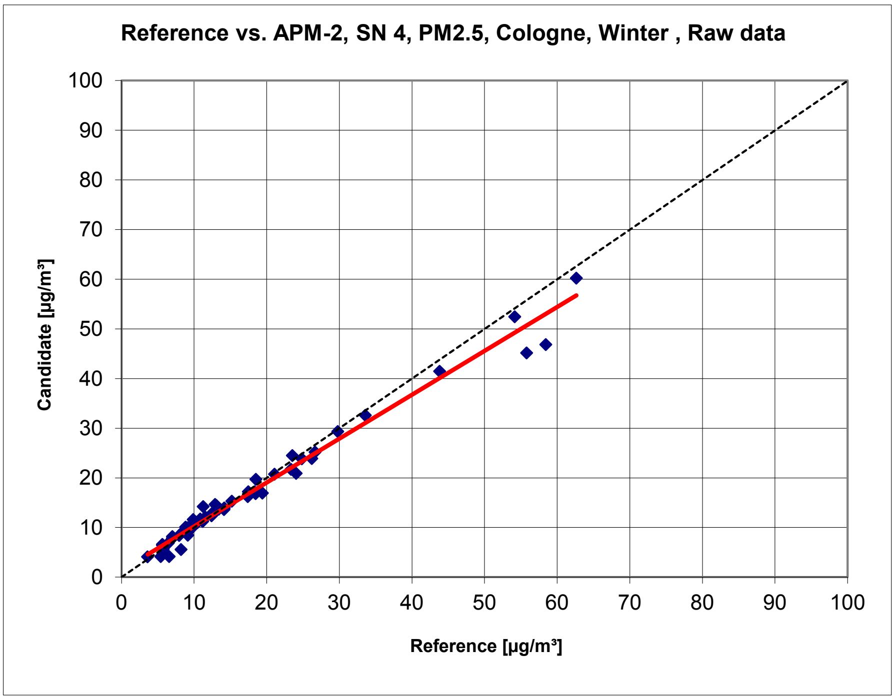

Figure 70: Reference device vs. candidate, SN4, measured component $PM_{2.5}$, Cologne, winter

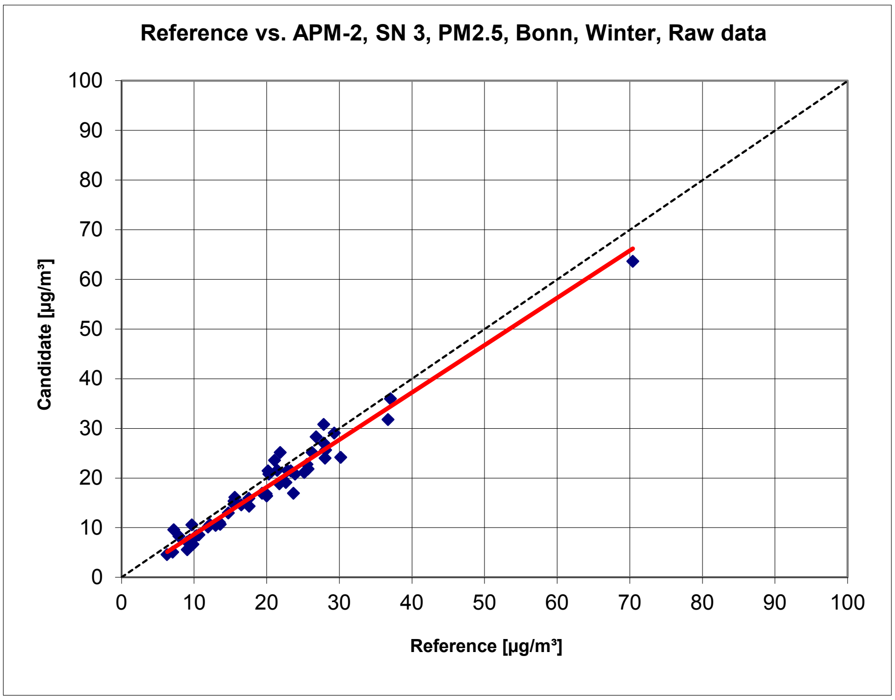

Figure 71: Reference device vs. candidate, SN3, measured component $PM_{2.5}$, Bonn, winter

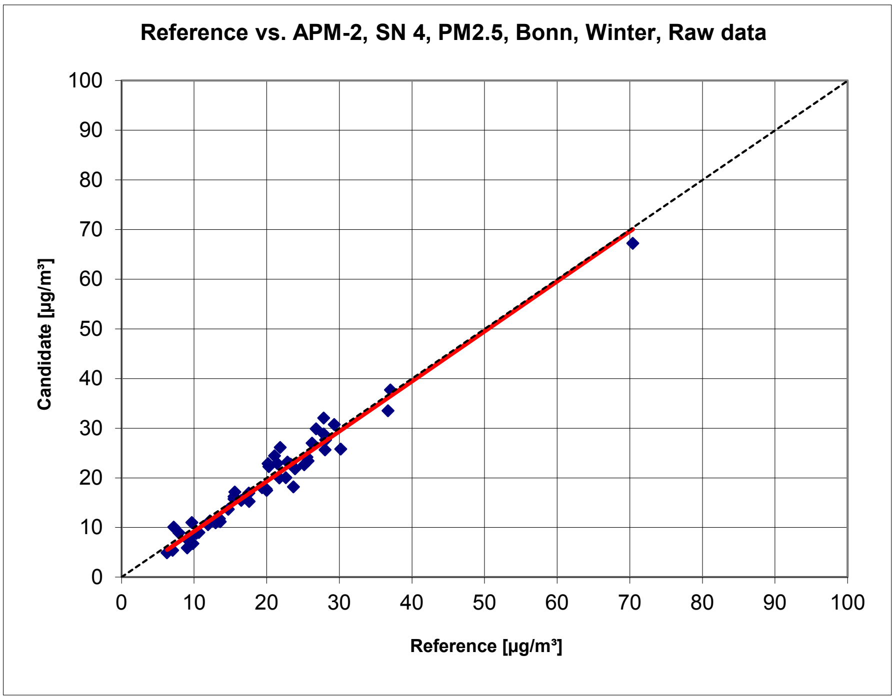

Figure 72: Reference device vs. candidate, SN4, measured component $PM_{2.5}$, Bonn, winter

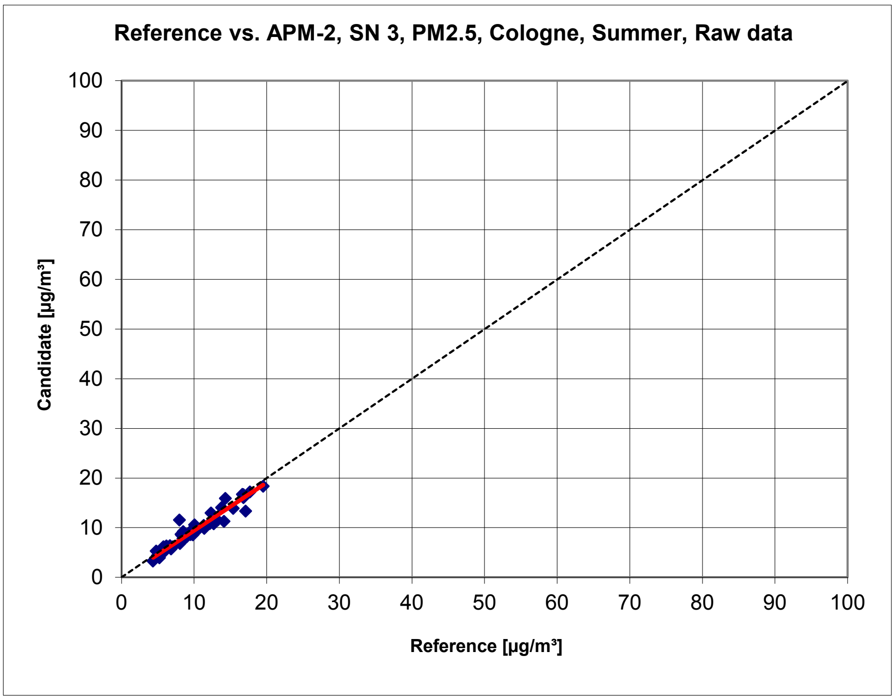

Figure 73: Reference device vs. candidate, SN3, measured component $PM_{2.5}$, Cologne, summer

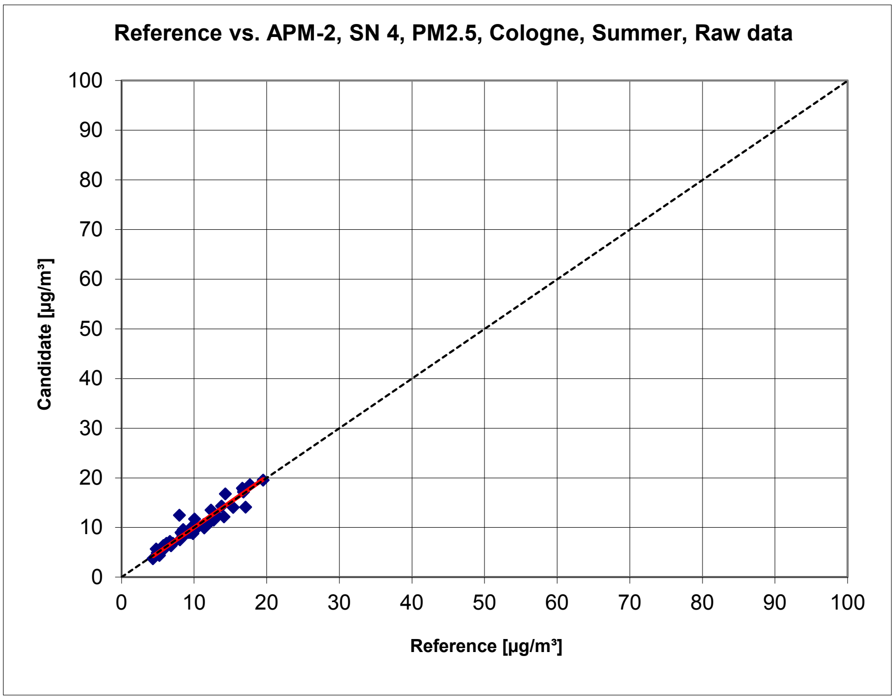

Figure 74: Reference device vs. candidate, SN4, measured component $PM_{2.5}$, Cologne, summer

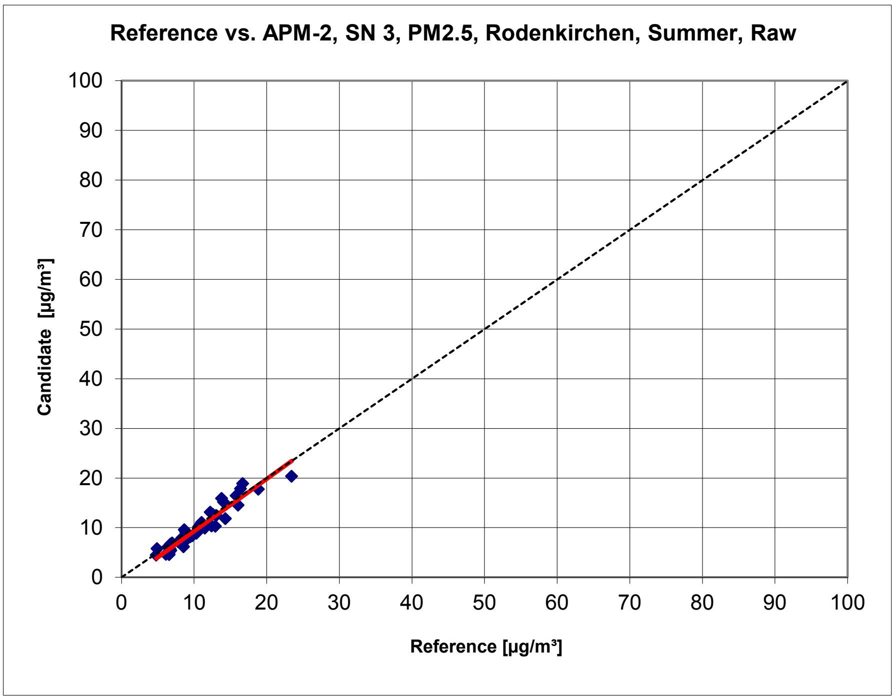

Figure 75: Reference device vs. candidate, SN3, measured component $PM_{2.5}$, Rodenkirchen, summer

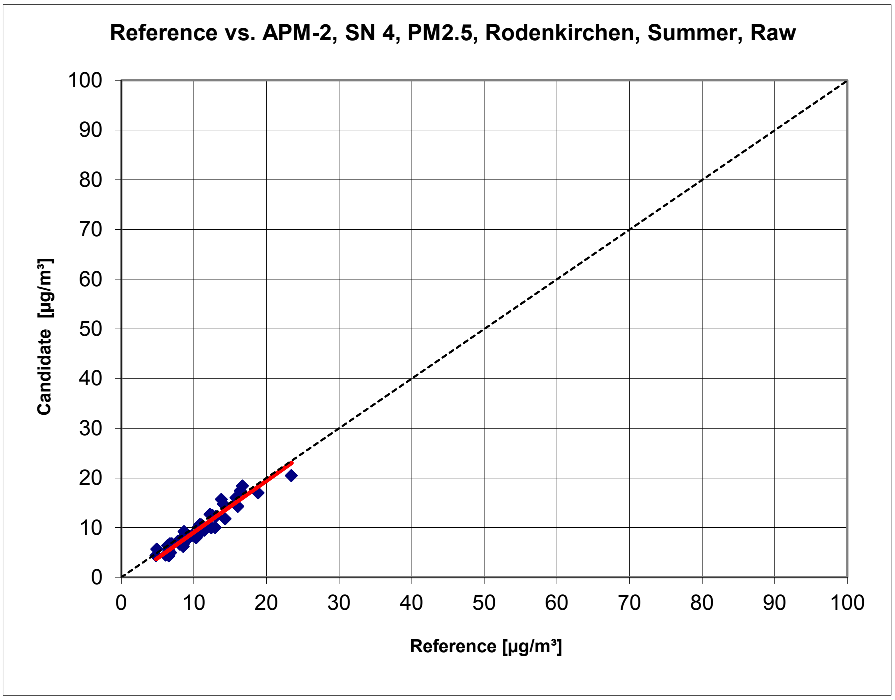

Figure 76: Reference device vs. candidate, SN4, measured component $PM_{2.5}$, Rodenkirchen, summer

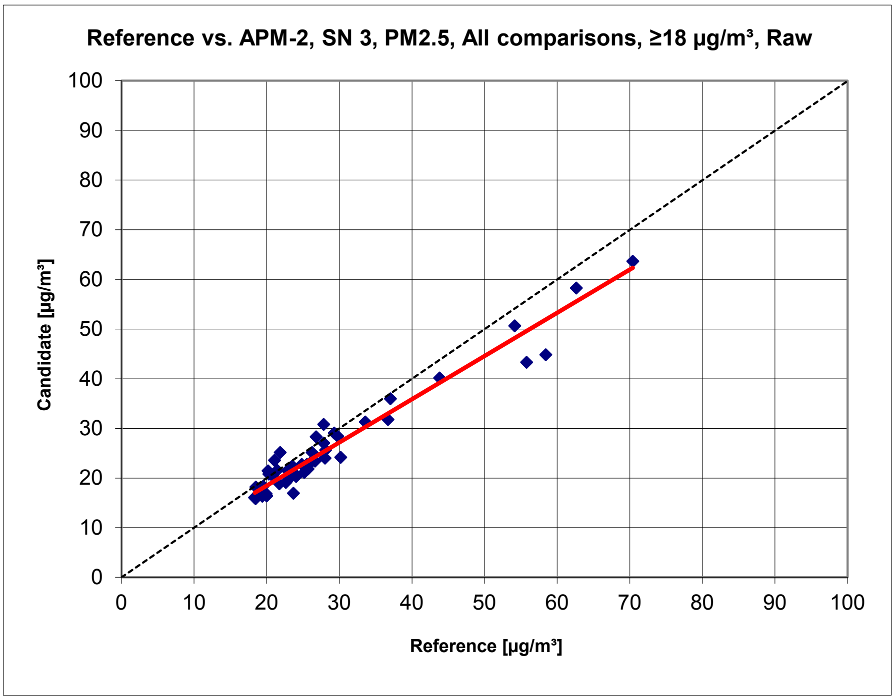

Figure 77: Reference device vs. candidate, SN3, measured component $PM_{2.5}$, values ≥ 18 µg/m³

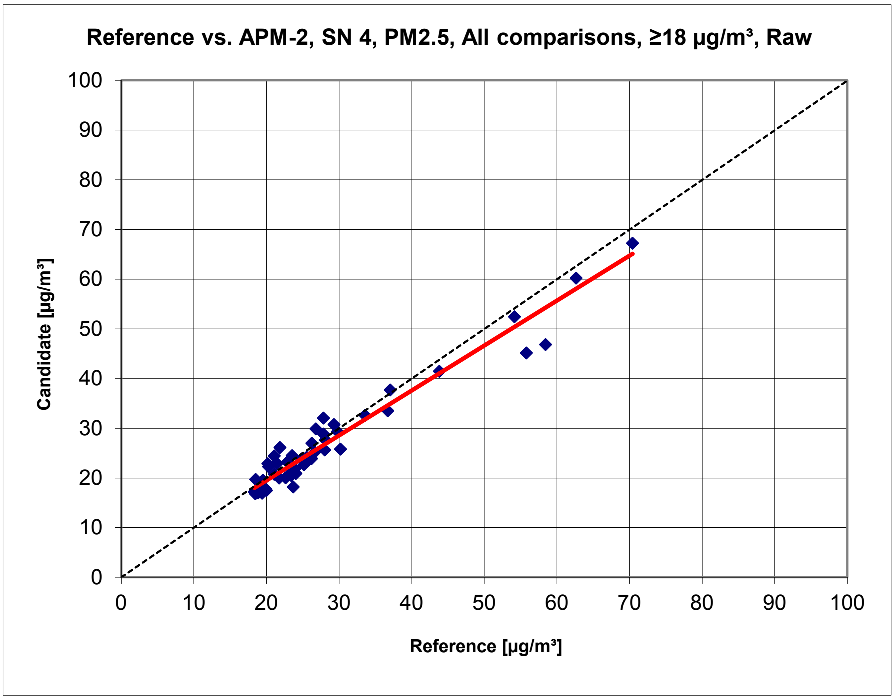

Figure 78: Reference device vs. candidate, SN4, measured component $PM_{2.5}$, values ≥ 18 µg/m³

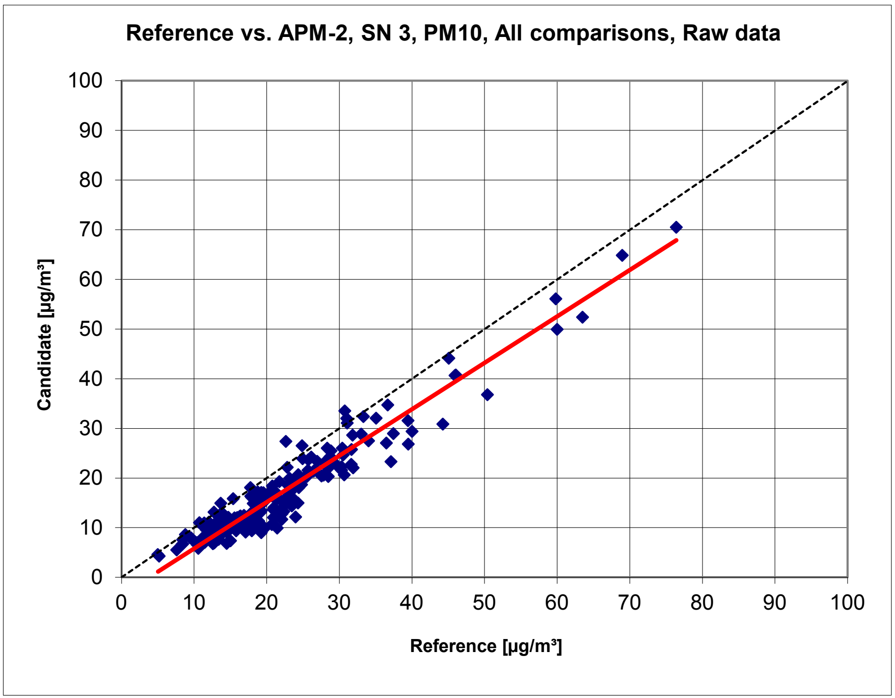

Figure 79: Reference device vs. candidate, SN3, measured component PM_{10}, all test sites

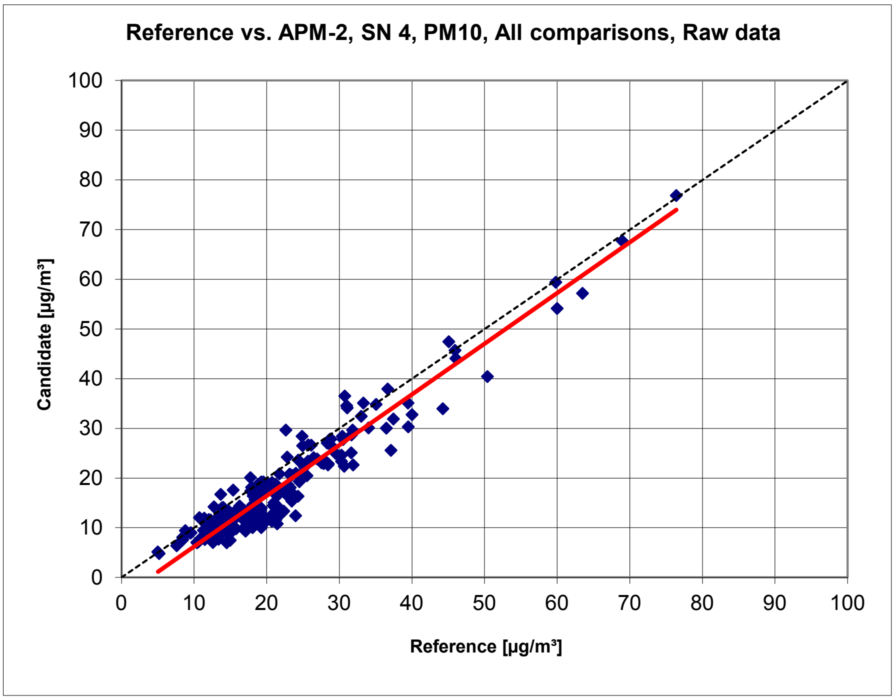

Figure 80: Reference device vs. candidate, SN4, measured component PM_{10}, all test sites

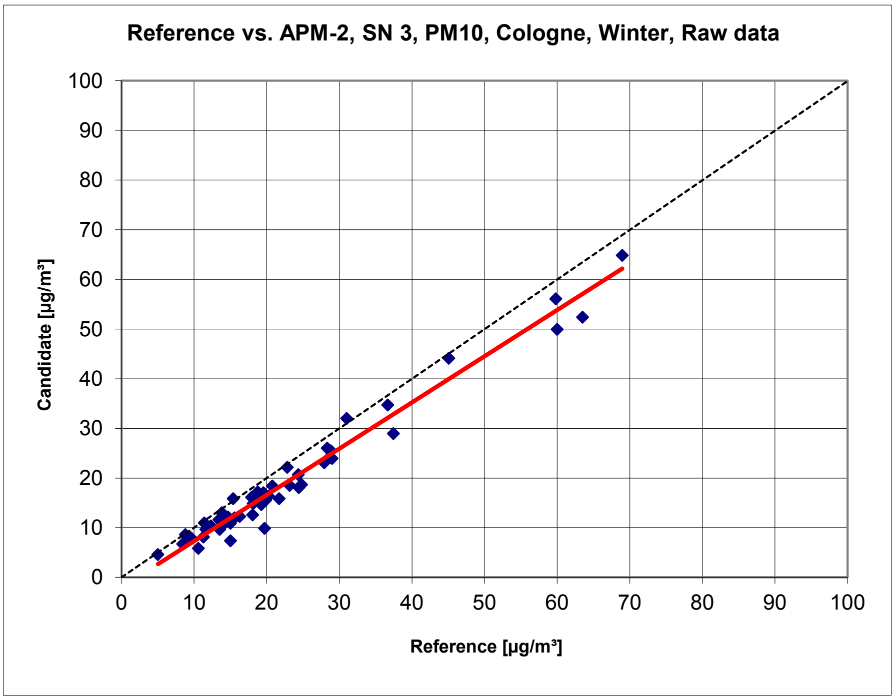

Figure 81: Reference device vs. candidate, SN3, measured component PM_{10}, Cologne, winter

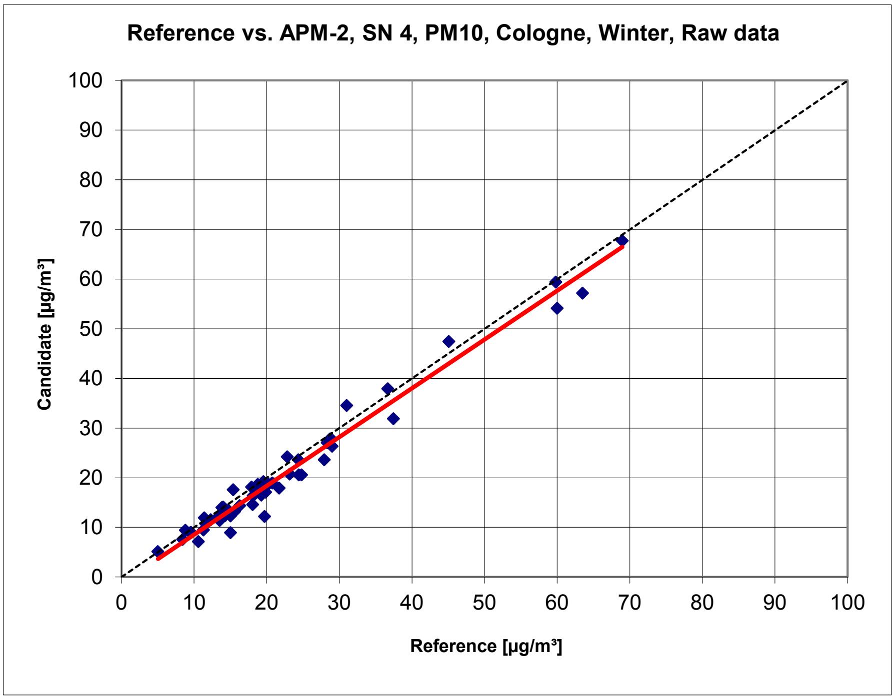

Figure 82: Reference device vs. candidate, SN4, measured component PM_{10}, Cologne, winter

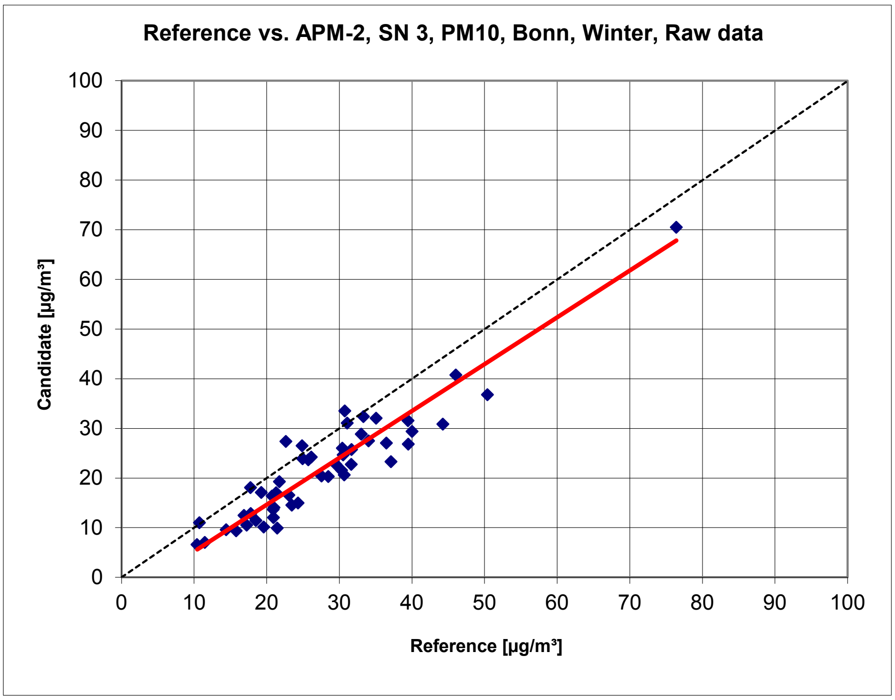

Figure 83: Reference device vs. candidate, SN3, measured component PM_{10}, Bonn, winter

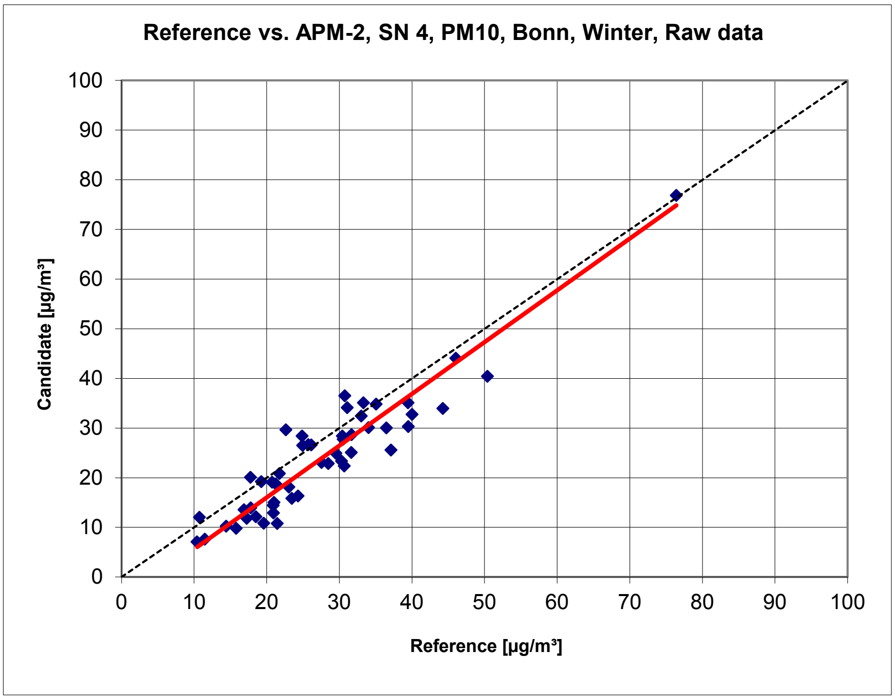

Figure 84: Reference device vs. candidate, SN4, measured component PM_{10}, Bonn, winter

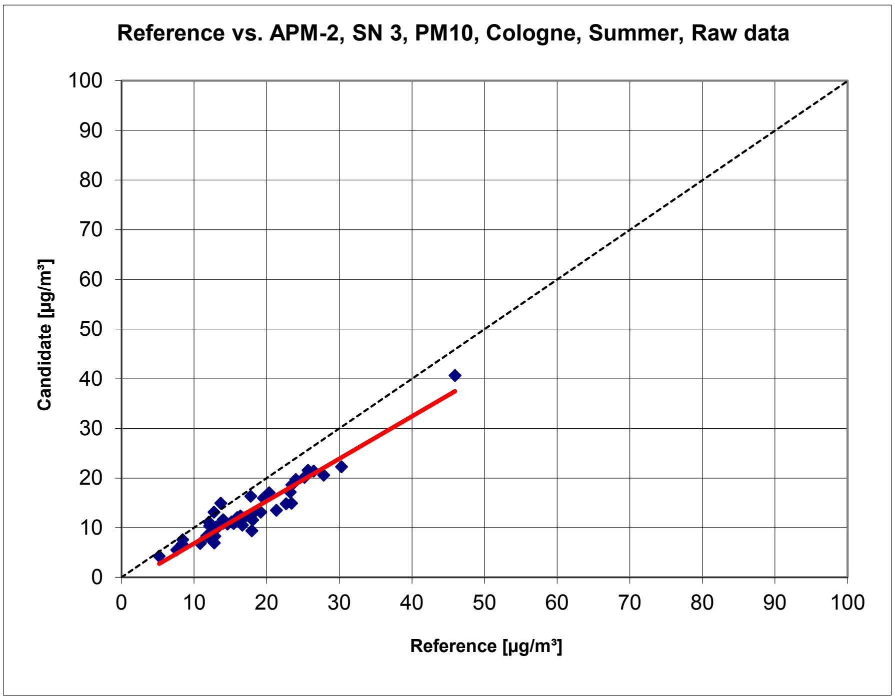

Figure 85: *Reference device vs. candidate, SN3, measured component PM_{10}, Cologne, summer*

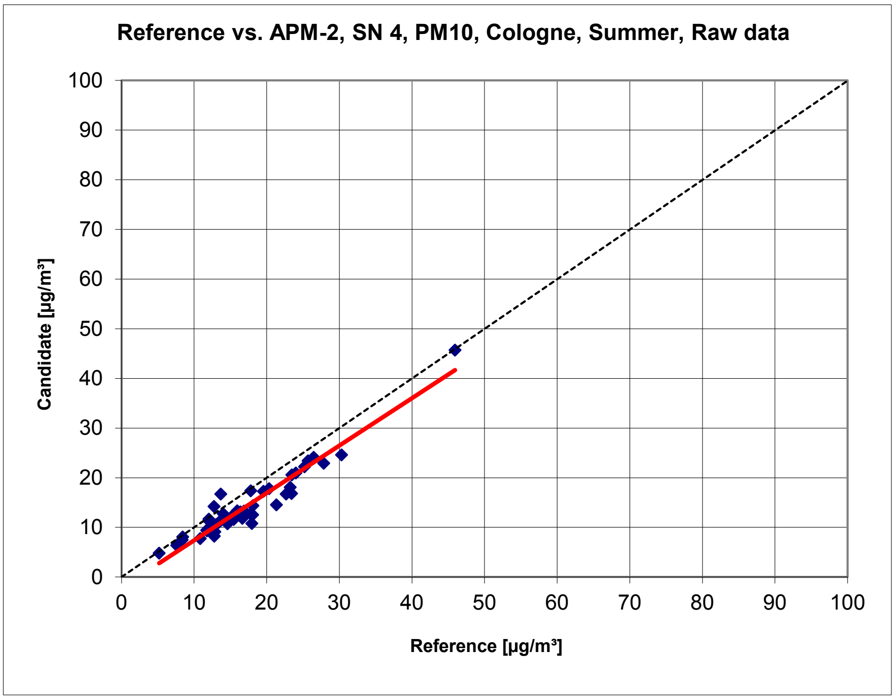

Figure 86: *Reference device vs. candidate, SN4, measured component PM_{10}, Cologne, summer*

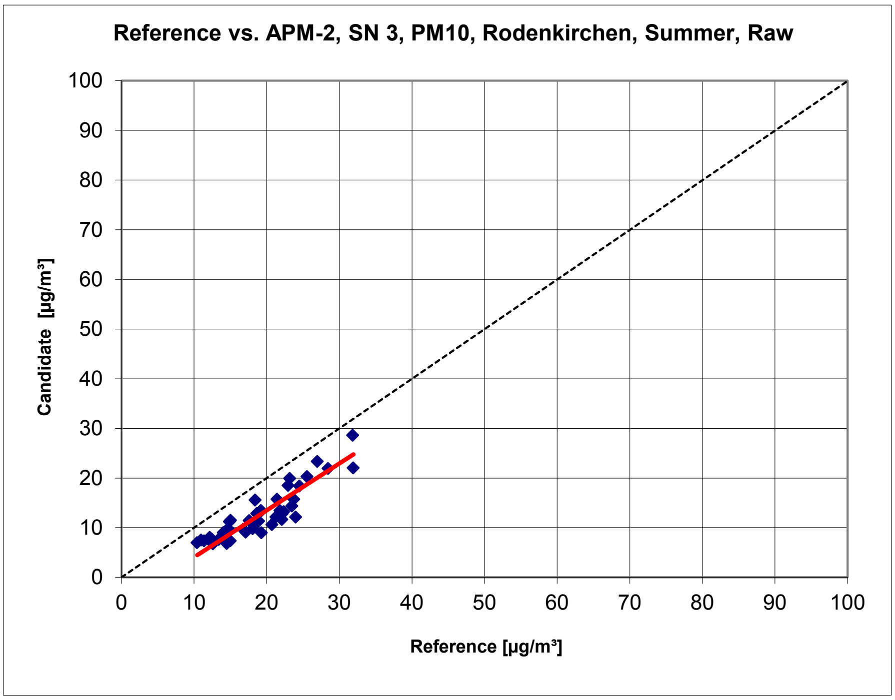

Figure 87: Reference device vs. candidate, SN3, measured component PM_{10}, Rodenkirchen, summer

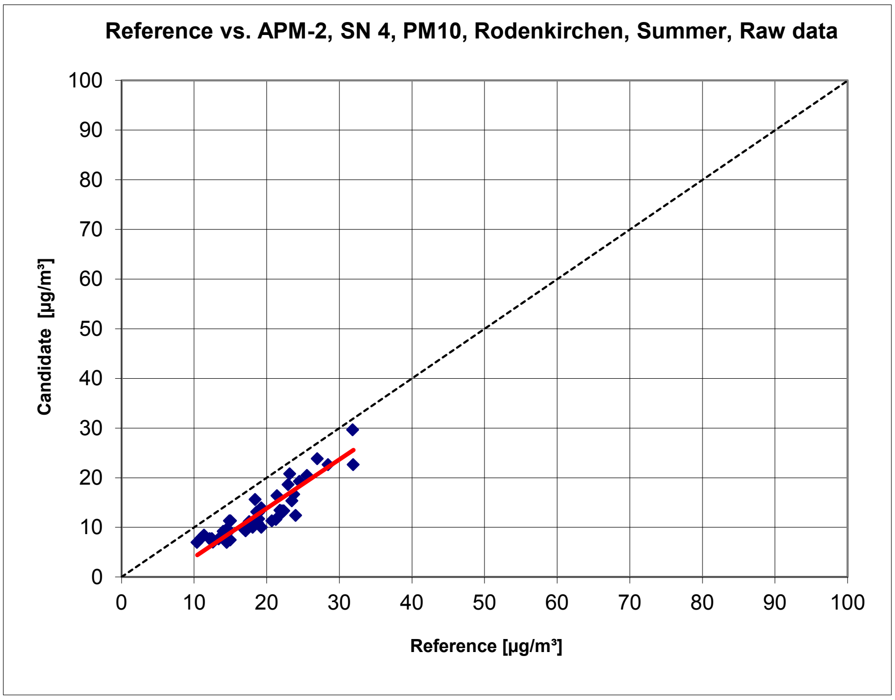

Figure 88: Reference device vs. candidate, SN4, measured component PM_{10}, Rodenkirchen, summer

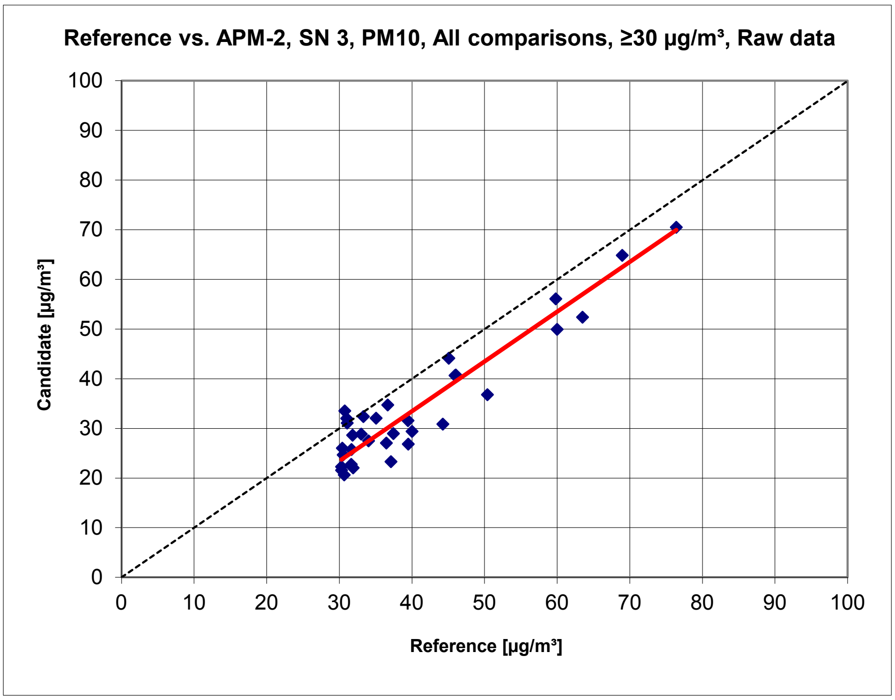

Figure 89: Reference device vs. candidate, SN3, measured component PM_{10}, values ≥ 30 µg/m³

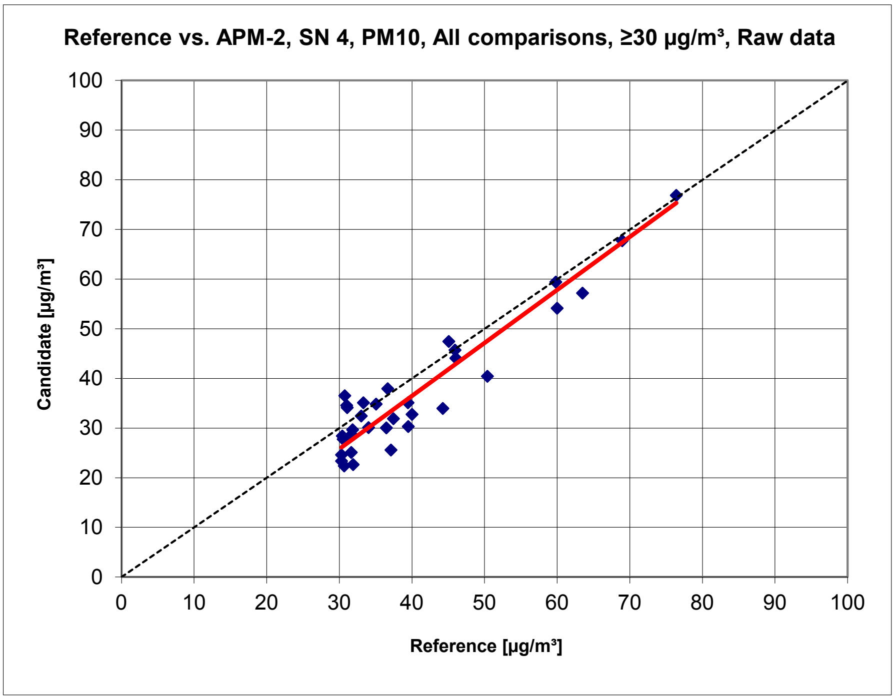

Figure 90: Reference device vs. candidate, SN4, measured component PM_{10}, values ≥ 30 µg/m³

6.1 5.4.11 Application of correction factors and terms

If the maximum expanded uncertainty of the systems under test exceeds the data quality objectives according to Annex B of Standard VDI 4202, Sheet 1 (September 2010) for the test of $PM_{2.5}$ measuring systems, the application of factors and terms is allowed. Values corrected shall meet the requirements of chapter 9.5.3.2ff of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods".

The tests were also carried out for the component PM_{10}.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

Refer to module 5.4.10.

6.4 Evaluation

If evaluation of the raw data according to module 5.4.10 leads to a case where $W_{CM} > W_{dqo}$, which means that the candidate systems is not regarded equivalent to the reference method, it is permitted to apply a correction factor or term resulting from the regression equation obtained from the full dataset. The corrected values shall satisfy the requirements for all datasets or subsets (refer to module 5.4.10). Moreover, a correction factor may be applied even for $W_{CM} \leq W_{dqo}$ in order to improve the accuracy of the candidate systems.

Three different cases may occur:

a) Slope b not significantly different from 1: $|b-1| \leq 2u(b)$,
   intercept a significantly different from 0: $|a| > 2u(a)$

b) Slope b significantly different from 1: $|b-1| > 2u(b)$,
   intercept a not significantly different from 0: $|a| \leq 2u(a)$

c) Slope b significantly different from 1: $|b-1| > 2u(b)$
   intercept a significantly different from 0: $|a| > 2u(a)$

With respect to a)

The value of the intercept a may be used as a correction term to correct all input values y_i according to the following equation.

$$y_{i,corr} = y_i - a$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{c\_s}(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + u^2(a)$$

with u(a) = uncertainty of the original intercept a, the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [4]. RSS is determined analogue to the calculation in module 5.4.10.

With respect to b)

The value of the slope b may be used as a term to correct all input values y_i according to the following equation.

$$y_{i,corr} = \frac{y_i}{b}$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{c\_s}(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + x_i^2 u^2(b)$$

with u(b) = uncertainty of the original slope b, the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [4]. RSS is determined analogue to the calculation in module 5.4.10.

With respect to c)

The values of the slope b and of the intercept a may be used as correction terms to correct all input values y_i according to the following equation.

$$y_{i,corr} = \frac{y_i - a}{b}$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{c\_s}(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + x_i^2 u^2(b) + u^2(a)$$

with u(b) = uncertainty of the original slope b, the value of which has been used to obtain $y_{i,corr}$ and with u(a) = uncertainty of the original intercept a, the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in Annex B of [5]. RSS is determined analogue to the calculation in module 5.4.10.

The values for $u_{c\_s,corr}$ are used for the calculation of the combined relative uncertainty of the candidate systems after correction according to the following equation:

$$w^2_{c,CM,corr}(y_i) = \frac{u^2_{c\_s,corr}(y_i)}{y_i^2}$$

For the corrected dataset, uncertainty $w_{c,CM,corr}$ is calculated at the daily limit value by taking y_i as the concentration at the limit value.

The expanded relative uncertainty $W_{CM,corr}$ is calculated according to the following equation:

$$W_{CM',corr} = k \cdot w_{CM,corr}$$

In practice: k=2 for large number of available experimental results

The highest resulting uncertainty $W_{CM,corr}$ is compared and assessed with the requirements on data quality of ambient air measurements according to EU Standard [8]. Two results are possible:

1. $W_{CM} \leq W_{dqo}$ → Candidate method is accepted as equivalent to the standard method.

2. $W_{CM} > W_{dqo}$ → Candidate method is not accepted as equivalent to the standard method.

The specified expanded relative uncertainty W_{dqo} for particulate matter is 25 % [8].

6.5 Assessment

Due to application of the correction factors, the candidates meet the requirements on data quality of ambient air quality measurements for all datasets for $PM_{2.5}$ and PM_{10}. For $PM_{2.5}$, the requirements are met even without application of correction factors. The correction of slope nevertheless leads to an improvement of the expanded measurement uncertainties of the full data comparison.

Performance criterion met? yes

The evaluation of the full dataset for both candidates shows a significant slope for $PM_{2.5}$ and a significant intercept for PM_{10}. For PM_{10} (SN3) also the slope has been significant.

For $PM_{2.5}$:

The slope for the full dataset is 0.919 (refer to Table 39).

For PM_{10}:

The slope for the full dataset is 0.977. The intercept for the full dataset -3.758 (refer to Table 40).

For $PM_{2.5}$ a slope correction and for PM_{10} a slope (due to SN3) and intercept correction for the complete dataset was applied and all datasets were then re-evaluated using the corrected values.

After correction, all datasets fulfil the requirements on data quality and the measurement uncertainties improve significantly at some sites.

The January 2010 version of the Guide requires that the systems are tested annually at a number of sites corresponding to the highest expanded uncertainty found during equivalence testing, if the AMS is operated within a network. The corresponding criterion for determining the number of test sites is divided into 5 % steps (Guide [4], chapter 9.9.2, Table 6). It should be noted that the highest expanded uncertainty determined for $PM_{2.5}$ lies in the range of 10 % to 15 % after correction, while it has been in the range of 15 % to 20 % before correction. For PM_{10}, the highest expanded uncertainty determined lies in the range of 10 % to 15 % after correction, while it has been in the range of 20 % to 25 % before correction.

The network operator or the responsible authority of the member state is responsible for the appropriate realization of the required regular checks in networks mentioned above. However, TÜV Rheinland recommends to use the expanded uncertainty for the full dataset, i.e. for $PM_{2.5}$: 17.68 % (uncorrected dataset) and 12.36 % (dataset after slope correction), which would require an annual test at 4 measurement sites (uncorrected) or 3 measurement sites (corrected); for PM_{10}: 23.25 % (uncorrected dataset) and 13.55 % (dataset after slope/offset correction), which would require an annual test at 5 measurement sites (uncorrected) or 3 measurement sites (corrected).

6.6 Detailed presentation of test results

Table 43 and Table 44 present the results of the evaluations of the equivalence test after application of the correction factors for slope and intercept on the complete dataset.

Table 43: Summary of the results of the equivalence test, SN3 & SN4, measured component $PM_{2.5}$ after correction of slope

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Slope corrected		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.55**	**µg/m³**			
Uncertainty between Candidates	**0.71**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**192**				
Slope b	**1.001**	**not significant**			
Uncertainty of b	**0.013**				
Ordinate intercept a	**0.335**	**not significant**			
Uncertainty of a	**0.235**				
Expanded meas. uncertainty W_{CM}	**12.36**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.63**	**µg/m³**			
Uncertainty between Candidates	**1.13**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**49**				
Slope b	**0.967**				
Uncertainty of b	**0.033**				
Ordinate intercept a	**1.292**				
Uncertainty of a	**1.019**				
Expanded meas. uncertainty W_{CM}	**18.46**	**%**			
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.46**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**143**				
Slope b	**1.137**				
Uncertainty of b	**0.032**				
Ordinate intercept a	**-1.073**				
Uncertainty of a	**0.355**				
Expanded meas. uncertainty W_{CM}	**22.20**	**%**			

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Slope corrected		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	**0.54**	**µg/m³**			
Uncertainty between Candidates	**0.71**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**52**			**52**	
Slope b	**0.931**			**0.962**	
Uncertainty of b	**0.019**			**0.019**	
Ordinate intercept a	**1.148**			**1.495**	
Uncertainty of a	**0.424**			**0.435**	
Expanded meas. uncertainty W_{CM}	**13.83**	**%**		**12.92**	**%**
Bonn, Winter					
Uncertainty between Reference	**0.62**	**µg/m³**			
Uncertainty between Candidates	**0.96**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**51**			**51**	
Slope b	**1.037**			**1.097**	
Uncertainty of b	**0.031**			**0.032**	
Ordinate intercept a	**-0.948**			**-0.964**	
Uncertainty of a	**0.706**			**0.725**	
Expanded meas. uncertainty W_{CM}	**15.33**	**%**		**20.40**	**%**
Cologne, Summer					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.62**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**46**			**44**	
Slope b	**1.054**			**1.113**	
Uncertainty of b	**0.044**			**0.049**	
Ordinate intercept a	**-0.279**			**-0.232**	
Uncertainty of a	**0.493**			**0.553**	
Expanded meas. uncertainty W_{CM}	**11.76**	**%**		**22.72**	**%**
Rodenkirchen, Summer					
Uncertainty between Reference	**0.52**	**µg/m³**			
Uncertainty between Candidates	**0.36**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**45**			**45**	
Slope b	**1.150**			**1.133**	
Uncertainty of b	**0.050**			**0.051**	
Ordinate intercept a	**-1.383**			**-1.482**	
Uncertainty of a	**0.565**			**0.567**	
Expanded meas. uncertainty W_{CM}	**22.45**	**%**		**18.78**	**%**
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.63**	**µg/m³**			
Uncertainty between Candidates	**1.13**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**49**			**49**	
Slope b	**0.949**			**0.986**	
Uncertainty of b	**0.032**			**0.034**	
Ordinate intercept a	**1.074**			**1.497**	
Uncertainty of a	**1.002**			**1.05**	
Expanded meas. uncertainty W_{CM}	**18.25**	**%**		**20.15**	**%**
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.53**	**µg/m³**			
Uncertainty between Candidates	**0.46**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**145**			**143**	
Slope b	**1.114**			**1.165**	
Uncertainty of b	**0.031**			**0.034**	
Ordinate intercept a	**-1.015**			**-1.179**	
Uncertainty of a	**0.345**			**0.375**	
Expanded meas. uncertainty W_{CM}	**18.31**	**%**		**26.94**	**%**
All comparisons					
Uncertainty between Reference	**0.55**	**µg/m³**			
Uncertainty between Candidates	**0.71**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**194**			**192**	
Slope b	**0.976**	**not significant**		**1.027**	**significant**
Uncertainty of b	**0.013**			**0.013**	
Ordinate intercept a	**0.396**	**not significant**		**0.269**	**not significant**
Uncertainty of a	**0.228**			**0.245**	
Expanded meas. uncertainty W_{CM}	**11.97**	**%**		**14.57**	**%**

Table 44: Summary of the results of the equivalence test, SN3 & SN4, measured component PM_{10} after correction of slope / intercept

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Slope and Offset corrected		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.58**	**µg/m³**			
Uncertainty between Candidates	**1.30**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**193**				
Slope b	**1.001**	**nicht signifikant**			
Uncertainty of b	**0.021**				
Ordinate intercept a	**-0.023**	**nicht signifikant**			
Uncertainty of a	**0.514**				
Expanded measured uncertainty WCM	**13.55**	**%**			
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0.72**	**µg/m³**			
Uncertainty between Candidates	**2.33**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**33**				
Slope b	**1.061**				
Uncertainty of b	**0.065**				
Ordinate intercept a	**-2.800**				
Uncertainty of a	**2.744**				
Expanded measured uncertainty WCM	**18.84**	**%**			
All comparisons, <30 µg/m³					
Uncertainty between Reference	**0.55**	**µg/m³**			
Uncertainty between Candidates	**0.99**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**160**				
Slope b	**0.998**				
Uncertainty of b	**0.041**				
Ordinate intercept a	**0.114**				
Uncertainty of a	**0.768**				
Expanded measured uncertainty WCM	**12.39**	**%**			

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Slope and Offset corrected		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	0.54	µg/m³			
Uncertainty between Candidates	1.41	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	52			52	
Slope b	0.953			1.006	
Uncertainty of b	0.023			0.022	
Ordinate intercept a	1.785			2.520	
Uncertainty of a	0.625			0.596	
Expanded measured uncertainty W_{CM}	10.65	%		15.00	%
Bonn, Winter					
Uncertainty between Reference	0.38	µg/m³			
Uncertainty between Candidates	1.76	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	51			51	
Slope b	0.967			1.069	
Uncertainty of b	0.051			0.055	
Ordinate intercept a	-0.523			-1.146	
Uncertainty of a	1.511			1.641	
Expanded measured uncertainty W_{CM}	19.25	%		20.76	%
Cologne, Summer					
Uncertainty between Reference	0.60	µg/m³			
Uncertainty between Candidates	1.09	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	47			45	
Slope b	0.873			0.978	
Uncertainty of b	0.040			0.044	
Ordinate intercept a	2.123			1.622	
Uncertainty of a	0.750			0.828	
Expanded measured uncertainty W_{CM}	18.93	%		9.59	%
Rodenkirchen, Summer					
Uncertainty between Reference	0.76	µg/m³			
Uncertainty between Candidates	0.44	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	45			45	
Slope b	0.969			1.008	
Uncertainty of b	0.065			0.065	
Ordinate intercept a	-1.719			-2.154	
Uncertainty of a	1.281			1.287	
Expanded measured uncertainty W_{CM}	16.42	%		12.16	%
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	0.72	µg/m³			
Uncertainty between Candidates	2.33	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	33			33	
Slope b	1.028			1.095	
Uncertainty of b	0.064			0.066	
Ordinate intercept a	-3.024			-2.618	
Uncertainty of a	2.701			2.81	
Expanded measured uncertainty W_{CM}	19.65	%		21.03	%
All comparisons, <30 µg/m³					
Uncertainty between Reference	0.55	µg/m³			
Uncertainty between Candidates	0.99	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	162			160	
Slope b	0.946			1.053	
Uncertainty of b	0.038			0.044	
Ordinate intercept a	0.486			-0.325	
Uncertainty of a	0.714			0.826	
Expanded measured uncertainty W_{CM}	14.64	%		16.26	%
All comparisons					
Uncertainty between Reference	0.58	µg/m³			
Uncertainty between Candidates	1.30	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	195			193	
Slope b	0.958	signifikant		1.045	signifikant
Uncertainty of b	0.020			0.022	
Ordinate intercept a	0.190	nicht signifikant		-0.253	nicht signifikant
Uncertainty of a	0.485			0.543	
Expanded measured uncertainty W_{CM}	15.03	%		16.38	%

6.1 5.5 Requirements on multiple-component measuring systems

Multiple-component measuring systems shall comply with the requirements set for each component, also in the case of simultaneous operation of all measuring channels.

6.2 Equipment

Not applicable.

6.3 Method

The APM-2 is an automated measuring system based on the measurement technology of light scattering. The output of measurements of PM fractions is continuous and alternating every two minutes between the measurement channels PM_{10} and $PM_{2.5}$.

The test was carried out in compliance with the requirements on testing the different PM fractions.

6.4 Evaluation

The evaluation of the individual performance criteria was made with regard to the respective measurement components.

6.5 Assessment

Upon assessing the minimum requirements, the measured values for both components were available at the same time (alternating every two minutes between the measurement channels PM_{10} and $PM_{2.5}$).

Performance criterion met? yes

6.6 Detailed presentation of test results

No equipment is necessary to test this performance criterion.

7. Investigations for the validation of the instrument software 3.0.1

The instrument manufacturer has developed a new instrument software 3.0.1 for the measuring system APM-2 for winter 2013/2014. This software version contains an optimization of the calculation algorithm by introducing a linearity correction for the measured PM values (an overview on the modifications can be found in Table 5 on page 47).

As this modification has an impact on the formation of measured values, and thus also on the already obtained measured values from the comparison campaigns during type approval test the following measures for qualification of the new software have been agreed upon:

All available measured values of the four past comparison campaigns have been re-calculated manually with the new calculation algorithm and evaluated again. The results of these investigations can be found in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test.

Furthermore an additional comparison campaign at the test site Cologne, parking lot has been conducted with two candidates and the new software version (Version 3.0.1) for qualification. For this the following test program was carried out in detail:

- Performance of a comparison campaign with at minimum 40 valid data pairs reference vs. candidate
- Determination of the in-between uncertainty for the candidates u_{bs} according to the Guide
- Calculation of the expanded uncertainty of the candidates according to the Guide
- Application of the correction factors and terms determined in chapter 6.1 5.4.11 Application of correction factors and terms
- Re-calculation of the equivalence for the 4 data sets of the type approval at hand + additional data set from the validation campaign „Cologne, winter 2014" according to the approach of chapter „8.2 Suitability test" of EN/TS 16450 [9]

The additional comparison campaign was carried out at the test site Cologne, parking lot between 13 January 2014 and 09 March 2014. Ambient conditions during that campaign are presented in Table 7. All single values can be found in Annex 5 (PM-measured values) and 6 (ambient conditions).

There have been 47 valid data pairs both for PM_{10} and $PM_{2,5}$.

The evaluation of the comparison measurements according to the Guide [5] lead to the following results:

Table 45: Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component $PM_{2,5}$, raw data

Cologne, Winter 2014				
Uncertainty between Reference	0.49	µg/m³		
Uncertainty between Candidates	0.61	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0.813		0.847	
Uncertainty of b	0.019		0.019	
Ordinate intercept a	3.122		2.055	
Uncertainty of a	0.320		0.313	
Expanded meas. uncertainty W_{CM}	18.58	%	18.83	%

Evaluation for $PM_{2,5}$:

1. The in-between uncertainty of the candidates is 0.61 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.

Table 46: Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component PM_{10}, raw data

Cologne, winter 2014				
Uncertainty between Reference	0.58	µg/m³		
Uncertainty between Candidates	0.72	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0.882		0.927	
Uncertainty of b	0.017		0.017	
Ordinate intercept a	2.073		1.120	
Uncertainty of a	0.380		0.376	
Expanded measured uncertainty W_{CM}	16.26	%	11.47	%

Evaluation for PM_{10}:

3. The in-between uncertainty of the candidates is 0.72 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
1. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.

The correction factors / terms, determined during the type approval test in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test are applied to the raw data sets.

Thus the data sets for SN3 and SN4 are corrected with the slope of 0.919 (uncertainty of slope 0.012) for $PM_{2,5}$ with the following results:

Table 47: Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component $PM_{2,5}$, slope corrected with 0.919

Cologne, Winter 2014				
Uncertainty between Reference	0.49	µg/m³		
Uncertainty between Candidates	0.66	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0.886		0.922	
Uncertainty of b	0.021		0.020	
Ordinate intercept a	3.385		2.225	
Uncertainty of a	0.348		0.341	
Expanded meas. uncertainty W_{CM}	9.66	%	9.47	%

Evaluation:

1. The expanded uncertainty for the data corrected with the slope of 0.919 is smaller than the permissible 25 %.

For PM_{10} the data sets for SN3 and SN4 are corrected with the slope of 0.977 (uncertainty of slope 0.020) and with the intercept of -3.758 (uncertainty of intercept 0.502) with the following results:

Table 48: Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component PM_{10}, slope corrected with 0.977, intercept corrected with -3.758

Cologne, winter 2014				
Uncertainty between Reference	0.58	µg/m³		
Uncertainty between Candidates	0.74	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0.903		0.949	
Uncertainty of b	0.018		0.018	
Ordinate intercept a	5.965		4.990	
Uncertainty of a	0.389		0.385	
Expanded measured uncertainty W_{CM}	8.39	%	12.00	%

Evaluation:

1. The expanded uncertainty for the data corrected with the slope of 0.977 and the intercept of -3.758 is smaller than the permissible 25 %.

According to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9], the corrected data set for Cologne, winter 2014 was finally added as a fifth data set to the original equivalence test during type approval (refer to Table 43 for $PM_{2.5}$ and Table 44 for PM_{10}) and it was checked, if the criteria of the equivalence test are still fulfilled.

Table 49: Results of equivalence test „Type approval + Cologne, winter 2014“, SN 3 & SN 4, measured component $PM_{2,5}$, slope corrected with 0.919

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Slope corrected		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.54**	**µg/m³**			
Uncertainty between Candidates	**0.70**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**239**				
Slope b	**0.981**	**not significant**			
Uncertainty of b	**0.012**				
Ordinate intercept a	**0.872**	**significant**			
Uncertainty of a	**0.209**				
Expanded meas. uncertainty W_{CM}	**12.39**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.64**	**µg/m³**			
Uncertainty between Candidates	**1.03**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**61**				
Slope b	**0.953**				
Uncertainty of b	**0.030**				
Ordinate intercept a	**1.663**				
Uncertainty of a	**0.932**				
Expanded meas. uncertainty W_{CM}	**18.09**	**%**			
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.51**	**µg/m³**			
Uncertainty between Candidates	**0.52**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**178**				
Slope b	**1.069**				
Uncertainty of b	**0.029**				
Ordinate intercept a	**-0.010**				
Uncertainty of a	**0.308**				
Expanded meas. uncertainty W_{CM}	**16.79**	**%**			

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Slope corrected		Allowed uncertainty	25	%
Cologne, winter					
Uncertainty between Reference	0.54	µg/m³			
Uncertainty between Candidates	0.71	µg/m³			
	SN 3			SN 4	
Number of data pairs	52			52	
Slope b	0.931			0.962	
Uncertainty of b	0.019			0.019	
Ordinate intercept a	1.148			1.495	
Uncertainty of a	0.424			0.435	
Expanded meas. uncertainty W_{CM}	13.83	%		12.92	%
Bonn, winter					
Uncertainty between Reference	0.62	µg/m³			
Uncertainty between Candidates	0.96	µg/m³			
	SN 3			SN 4	
Number of data pairs	51			51	
Slope b	1.037			1.097	
Uncertainty of b	0.031			0.032	
Ordinate intercept a	-0.948			-0.964	
Uncertainty of a	0.706			0.725	
Expanded meas. uncertainty W_{CM}	15.33	%		20.40	%
Cologne, summer					
Uncertainty between Reference	0.53	µg/m³			
Uncertainty between Candidates	0.62	µg/m³			
	SN 3			SN 4	
Number of data pairs	46			44	
Slope b	1.054			1.113	
Uncertainty of b	0.044			0.049	
Ordinate intercept a	-0.279			-0.232	
Uncertainty of a	0.493			0.553	
Expanded meas. uncertainty W_{CM}	11.76	%		22.72	%
Rodenkirchen, summer					
Uncertainty between Reference	0.52	µg/m³			
Uncertainty between Candidates	0.36	µg/m³			
	SN 3			SN 4	
Number of data pairs	45			45	
Slope b	1.150			1.133	
Uncertainty of b	0.050			0.051	
Ordinate intercept a	-1.383			-1.482	
Uncertainty of a	0.565			0.567	
Expanded meas. uncertainty W_{CM}	22.45	%		18.78	%
Cologne, Winter 2014					
Uncertainty between Reference	0.49	µg/m³			
Uncertainty between Candidates	0.66	µg/m³			
	SN 3			SN 4	
Number of data pairs	47			47	
Slope b	0.886			0.922	
Uncertainty of b	0.021			0.020	
Ordinate intercept a	3.385			2.225	
Uncertainty of a	0.348			0.341	
Expanded meas. uncertainty W_{CM}	9.66	%		9.47	%
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	0.64	µg/m³			
Uncertainty between Candidates	1.03	µg/m³			
	SN 3			SN 4	
Number of data pairs	61			61	
Slope b	0.935			0.972	
Uncertainty of b	0.030			0.032	
Ordinate intercept a	1.602			1.688	
Uncertainty of a	0.919			0.97	
Expanded meas. uncertainty W_{CM}	17.91	%		19.54	%
All comparisons, <18 µg/m³					
Uncertainty between Reference	0.51	µg/m³			
Uncertainty between Candidates	0.52	µg/m³			
	SN 3			SN 4	
Number of data pairs	180			178	
Slope b	1.048			1.099	
Uncertainty of b	0.031			0.028	
Ordinate intercept a	0.133			-0.242	
Uncertainty of a	0.329			0.301	
Expanded meas. uncertainty W_{CM}	14.77	%		20.44	%
All comparisons					
Uncertainty between Reference	0.54	µg/m³			
Uncertainty between Candidates	0.70	µg/m³			
	SN 3			SN 4	
Number of data pairs	241			239	
Slope b	0.956	significant		1.006	not significant
Uncertainty of b	0.012			0.012	
Ordinate intercept a	1.030	significant		0.693	significant
Uncertainty of a	0.212			0.212	
Expanded meas. uncertainty W_{CM}	12.62	%		13.71	%

Table 50: Results of equivalence test „Type approval + Cologne, winter 2014“, SN 3 & SN 4, measured component PM_{10}, slope corrected with 0.977, intercept corrected with -3.758

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Slope and Offset corrected		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.58**	**µg/m³**			
Uncertainty between Candidates	**1.22**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**240**				
Slope b	**0.975**	**nicht signifikant**			
Uncertainty of b	**0.019**				
Ordinate intercept a	**1.346**	**signifikant**			
Uncertainty of a	**0.454**				
Expanded measured uncertainty WCM	**14.03**	**%**			
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0.68**	**µg/m³**			
Uncertainty between Candidates	**2.17**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**40**				
Slope b	**1.052**				
Uncertainty of b	**0.060**				
Ordinate intercept a	**-2.041**				
Uncertainty of a	**2.563**				
Expanded measured uncertainty WCM	**18.48**	**%**			
All comparisons, <30 µg/m³					
Uncertainty between Reference	**0.56**	**µg/m³**			
Uncertainty between Candidates	**0.93**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**200**				
Slope b	**0.941**				
Uncertainty of b	**0.036**				
Ordinate intercept a	**1.975**				
Uncertainty of a	**0.653**				
Expanded measured uncertainty WCM	**13.56**	**%**			

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Slope and Offset corrected		Allowed uncertainty	25	%
Cologne, winter					
Uncertainty between Reference	0.54	µg/m³			
Uncertainty between Candidates	1.41	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	52			52	
Slope b	0.953			1.006	
Uncertainty of b	0.023			0.022	
Ordinate intercept a	1.785			2.520	
Uncertainty of a	0.625			0.596	
Expanded measured uncertainty W_{CM}	10.65	%		15.00	%
Bonn, winter					
Uncertainty between Reference	0.38	µg/m³			
Uncertainty between Candidates	1.76	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	51			51	
Slope b	0.967			1.069	
Uncertainty of b	0.051			0.055	
Ordinate intercept a	-0.523			-1.146	
Uncertainty of a	1.511			1.641	
Expanded measured uncertainty W_{CM}	19.25	%		20.76	%
Cologne, summer					
Uncertainty between Reference	0.60	µg/m³			
Uncertainty between Candidates	1.09	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	47			45	
Slope b	0.873			0.978	
Uncertainty of b	0.040			0.044	
Ordinate intercept a	2.123			1.622	
Uncertainty of a	0.750			0.828	
Expanded measured uncertainty W_{CM}	18.93	%		9.59	%
Rodenkirchen, summer					
Uncertainty between Reference	0.76	µg/m³			
Uncertainty between Candidates	0.44	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	45			45	
Slope b	0.969			1.008	
Uncertainty of b	0.065			0.065	
Ordinate intercept a	-1.719			-2.154	
Uncertainty of a	1.281			1.287	
Expanded measured uncertainty W_{CM}	16.42	%		12.16	%
Cologne, winter 2014					
Uncertainty between Reference	0.58	µg/m³			
Uncertainty between Candidates	0.74	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	47			47	
Slope b	0.903			0.949	
Uncertainty of b	0.018			0.018	
Ordinate intercept a	5.965			4.990	
Uncertainty of a	0.389			0.385	
Expanded measured uncertainty W_{CM}	8.39	%		12.00	%
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	0.68	µg/m³			
Uncertainty between Candidates	2.17	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	40			40	
Slope b	1.024			1.083	
Uncertainty of b	0.061			0.061	
Ordinate intercept a	-2.267			-1.935	
Uncertainty of a	2.595			2.58	
Expanded measured uncertainty W_{CM}	19.05	%		20.49	%
All comparisons, <30 µg/m³					
Uncertainty between Reference	0.56	µg/m³			
Uncertainty between Candidates	0.93	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	202			200	
Slope b	0.900			0.987	
Uncertainty of b	0.036			0.037	
Ordinate intercept a	2.238			1.597	
Uncertainty of a	0.652			0.665	
Expanded measured uncertainty W_{CM}	17.00	%		13.72	%
All comparisons					
Uncertainty between Reference	0.58	µg/m³			
Uncertainty between Candidates	1.22	µg/m³			
	SN 3			**SN 4**	
Number of data pairs	242			240	
Slope b	0.937	signifikant		1.014	nicht signifikant
Uncertainty of b	0.019			0.019	
Ordinate intercept a	1.556	signifikant		1.086	signifikant
Uncertainty of a	0.455			0.460	
Expanded measured uncertainty W_{CM}	15.47	%		15.91	%

Summary of evaluation:

In order to demonstrate equivalence of the data from the type approval test (comparison campaigns 1-4), manually calculated with the modified calculation algorithm of software 3.0.1. with data obtained with software 3.0.1 under practical conditions, an additional comparison campaign „Cologne, winter 2014“ was carried out with both candidates with software 3.0.1 and the obtained data were equivalence checked. The evaluation leads to the following results:

For $PM_{2,5}$:

1. The in-between uncertainty of the candidates is 0.61 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.
3. The expanded uncertainty for the data corrected with the slope of 0.919 (determined in type approval test) is smaller than the permissible 25 % for both SN3 and SN4.
4. The combined evaluation of the four original data sets during type approval (manually re-calculated with the new calculation algorithm and evaluated) with the additional fifth data set of Cologne, winter 2014 (software version 3.0.1 installed) leads also to fulfillment of the equivalence criteria according to the Guide [5].

For PM_{10}:

1. The in-between uncertainty of the candidates is 0.72 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.
3. The expanded uncertainty for the data corrected with the slope of 0.977 and the intercept of -3.758 (determined in type approval test) is smaller than the permissible 25 % for both SN3 and SN4.
4. The combined evaluation of the four original data sets during type approval (manually re-calculated with the new calculation algorithm and evaluated) with the additional fifth data set of Cologne, winter 2014 (software version 3.0.1 installed) leads also to fulfillment of the equivalence criteria according to the Guide [5].

Thus it has to be noted, that the demonstration of equivalence of the data from the type approval test (comparison campaigns 1-4), manually calculated with the modified calculation algorithm of software 3.0.1. with data obtained with software 3.0.1 under practical conditions could be shown and thus the validation of the current software version 3.0.1 could be finalized in a positive way.

8. Recommendations for practical use

8.1 Works in the maintenance interval (4 weeks)

The following procedures are required to be carried out at regular intervals:

- Check of instrument status
  The instrument status may be controlled directly at the instrument or monitored online.
- The sampling inlet has to be cleaned in general according to the instructions provided by the manufacturer, at which the local PM conditions have to be considered (during the type approval test approx. every 4 weeks).

As for the rest, the instructions and recommendations provided by the manufacturer shall be followed.

8.2 Further maintenance work

In addition to the regular maintenance work in the maintenance interval, the following procedures are necessary:

- A check of the sensors for ambient temperature and ambient pressure should be carried out every 3 months according to EN TS 16450 [9].
- A check of the flow rate should be carried out every 3 months according to EN TS 16450 [9].
- In the context of the check of the flow rate, a check on tightness should also be carried out every 3 months.
- The virtual impactor has to be cleaned latest every 3 months.
- According to the manufacturer, the internal filters in the device (zero air filter, outlet filter for photometer, bypass filter and pump outlet filter) shall be exchanged latest every 6 months.
- The photometer should be sent to the manufacturer for re-calibration at least once a year.

According to the manufacturer, the photometer has to be completely replaced, if:

- the completely collected PM mass exceeds 50 mg (correspond to approx. 200 days with an average concentration of 50 µg/m³)
- the photometer offset exceeds 2500 mV.

After the annual maintenance of the photometer, the measuring system is to be calibrated at the measurement site with the gravimetric PM_{10}-reference method according to EN 12341 respectively with the gravimetric $PM_{2,5}$-reference method according to EN 14907. Preferably a seasonal calibration rhythm is to follow.

- During the annual basic maintenance the cleaning of the sampling tube has also to be considered.
- The vacuum pump has a life time of approx. 2 years – after reaching the lifetime, the pump must be completely replaced. Failure of the pump is displayed on the system with an error message

Further details are provided in the user manual.

Department of Environmental Protection/Air Pollution Control

Dipl.-Ing. Karsten Pletscher	Dipl.-Ing. Guido Baum

Cologne, 26th March 2014
936/21219977/A

9. Literature

[1] VDI Standard 4202, Part 1, “Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants”, June 2002 & September 2010

[2] VDI Standard 4203, Part 3, “Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants”, August 2004 & September 2010

[3] Standard EN 12341, “Air quality – Determination of the PM10 fraction of suspended particulate matter. Reference method and field test procedure to demonstrate reference equivalence of measurement methods”, German version EN 12341: 1998

[4] Standard EN 14907, “Ambient air quality – Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter”, German version EN 14907: 2005

[5] Guidance document “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of January 2010

[6] Operator’s manual APM-2, Version 03/2014

[7] Operator’s manual LVS3, Stand 2000

[8] 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

[9] Technical Specification CEN/TS 16450, “Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM10; PM2.5)”; German version, August 2013

[10] Report “UK Equivalence Programme for Monitoring of Particulate Matter”, Report No.: BV/AQ/AD202209/DH/2396 of 5 June 2006

10. Annex

Appendix 1	**Measured and calculated values**
Annex 1:	Detection limit
Annex 2:	Temperature dependence of zero point
Annex 3:	Temperature dependence of the sensitivity
Annex 4:	Dependence on supply voltage
Annex 5:	Measured values at the field test sites
Annex 6:	Ambient conditions at the field test sites
Appendix 2	**Filter weighing procedure**
Appendix 3	**Manual**

Annex 1 **Detection limit** **Page 1 of 1**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No.: SN 3 / SN 4

Standards: ZP Zero point with absolute filter

No.	Date	Measured values $PM_{2,5}$ [µg/m³] SN 3	Measured values PM_{10} [µg/m³] SN 3	Measured values $PM_{2,5}$ [µg/m³] SN 4	Measured values PM_{10} [µg/m³] SN 4
1	4/18/2012	0.00	0.06	0.00	0.04
2	4/19/2012	0.00	0.00	0.00	0.03
3	4/20/2012	0.00	0.00	0.01	0.03
4	4/21/2012	0.00	0.00	0.00	0.06
5	4/22/2012	0.00	0.00	0.04	0.08
6	4/23/2012	0.00	0.00	0.01	0.01
7	4/24/2012	0.00	0.00	0.04	0.10
8	4/25/2012	0.00	0.00	0.04	0.10
9	4/26/2012	0.00	0.00	0.00	0.03
10	4/27/2012	0.00	0.00	0.00	0.00
11	4/28/2012	0.00	0.00	0.08	0.06
12	4/29/2012	0.00	0.00	0.17	0.13
13	4/30/2012	0.00	0.00	0.00	0.00
14	5/1/2012	0.00	0.00	0.00	0.00
15	5/2/2012	0.00	0.00	0.00	0.00
	Number of values	15	15	15	15
	Mean	0.00	0.00	0.03	0.04
	Standard deviation s_{x0}	0.00	0.01	0.05	0.04
	Detection limit X	**<0,01**	**0.03**	**0.10**	**0.09**

$$s_{xo} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \overline{x}_0)^2}$$

Annex 2 **Dependence of zero point on ambient temperature** **Page 1 of 1**

Manufacturer COMDE-DERENDA

Type APM-2

Serial-No. SN 3 / SN 4

Standards ZP Zero filter

			Cycle 1		Cycle 2		Cycle 3			
SN 3	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
ZP	1	20	0.0	-	0.0	-	0.0	-		
	2	-20	0.0	0.0	0.0	0.0	0.0	0.0		
	3	20	0.0	0.0	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0	0.0	0.0		
SN 4	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
ZP	1	20	0.0	-	0.0	-	0.0	-		
	2	-20	0.2	0.2	0.2	0.2	0.1	0.1		
	3	20	0.0	0.0	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0	0.0	0.0		

Annex 2 **Dependence of zero point on ambient temperature** **Page 2 of 2**

Manufacturer COMDE-DERENDA

Type APM-2

Serial-No. SN 3 / SN 4

Standards ZP Zero filter

			Cycle 1		Cycle 2		Cycle 3			
SN 3	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
ZP	1	20	0.0	-	0.0	-	0.0	-		
	2	-20	0.0	0.0	0.0	0.0	0.0	0.0		
	3	20	0.0	0.0	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0	0.0	0.0		
SN 4	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
ZP	1	20	0.0	-	0.0	-	0.0	-		
	2	-20	0.1	0.1	0.1	0.1	0.1	0.1		
	3	20	0.0	0.0	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0	0.0	0.0		

Annex 3 Dependence of measured value on ambient temperature

Manufacturer Comde-Derenda

Type APM-2

Serial-No. SN 3 / SN 4

Standards ZP Propane test gas

			Cycle 1		Cycle 2		Cycle 3	
SN 3	No.	Temperature [°C]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]
RP	1	20	335.4	-	336.0	-	339.3	-
	2	-20	333.6	-0.5	335.7	-0.1	337.1	-0.6
	3	20	348.2	3.8	347.6	3.5	342.0	0.8
	4	50	335.1	-0.1	345.6	2.9	345.6	1.9
	5	20	330.6	-1.4	330.6	-1.6	332.0	-2.2
SN 4	No.	Temperature [°C]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]
RP	1	20	335.8	-	335.0	-	342.2	-
	2	-20	333.8	-0.6	333.3	-0.5	331.0	-3.3
	3	20	333.0	-0.8	332.6	-0.7	339.5	-0.8
	4	50	334.9	-0.3	342.2	2.1	342.3	0.0
	5	20	331.8	-1.2	339.0	1.2	338.1	-1.2

Annex 4 **Dependence of measured value on mains voltage** **Page 1 of 1**

Manufacturer	Comde-Derenda
Type	APM-2
Serial-No.	SN 3 / SN 4
Standards	ZP Propane test gas

			Cycle 1		Cycle 2		Cycle 3			
SN 3	No.	Mains voltage [V]	Measured value	Dev. [%]	Measured value	Dev. [%]	Measured value	Dev. [%]		
RP	1	230	361.5	-	365.0	-	362.9	-		
	2	210	365.2	1.0	365.9	0.3	364.6	0.5		
	3	230	366.6	1.4	368.1	0.8	367.9	1.4		
	4	245	367.8	1.7	367.8	0.8	367.8	1.3		
	5	230	367.9	1.8	367.0	0.5	365.9	0.8		
SN 4	No.	Mains voltage [V]	Measured value	Dev. [%]	Measured value	Dev. [%]	Measured value	Dev. [%]		
RP	1	230	356.1	-	357.3	-	355.1	-		
	2	210	356.8	0.2	356.1	-0.3	353.2	-0.5		
	3	230	353.7	-0.7	353.9	-0.9	350.8	-1.2		
	4	245	351.5	-1.3	351.8	-1.5	351.5	-1.0		
	5	230	353.7	-0.7	351.8	-1.5	349.9	-1.5		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 1 of 22**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
1	11/19/2012										Zero point	Cologne, winter
2	11/20/2012										Zero point	
3	11/21/2012										Zero point	
4	11/22/2012										Audits	
5	11/23/2012	15.3	15.1	19.6	19.6	77.8	14.1	15.3	17.0	19.2		
6	11/24/2012						12.5	13.6	15.1	17.2		
7	11/25/2012	5.1	5.8	10.8	10.4	51.1	4.0	4.1	5.8	7.1		
8	11/26/2012	6.1	6.9	11.0	11.6	57.4	6.2	6.8	8.1	9.5		
9	11/27/2012	10.9	11.5	18.5	17.6	62.0	10.3	11.2	12.6	14.6		
10	11/28/2012	23.3	23.5	29.0	29.1	80.5	20.5	21.7	23.9	26.3		
11	11/29/2012	9.0	9.3	14.2	14.4	64.0	9.4	9.9	11.0	12.3		
12	11/30/2012	17.8	19.3	24.5	24.3	76.0	18.1	19.7	20.6	23.6		
13	12/1/2012						13.2	14.1	14.8	16.3		
14	12/2/2012	10.0	11.0	14.8	14.6	71.2	10.5	11.0	12.1	13.4		
15	12/3/2012	8.8	9.0	14.1	14.4	62.2	9.4	10.0	11.3	13.0		
16	12/4/2012	8.3	7.6	11.6	11.6	68.3	8.1	8.4	9.6	10.6		
17	12/5/2012	8.7	8.5	12.1	12.5	69.8	8.9	9.3	10.3	11.5		
18	12/6/2012	9.5	10.3	16.5	16.1	60.7	10.6	11.6	12.2	14.4		
19	12/7/2012	13.0	12.8	15.4	15.4	83.8	13.6	14.6	15.8	17.6		
20	12/8/2012						31.5	33.5	34.5	38.0		
21	12/9/2012	5.5	5.8	10.1	8.9	59.5	6.2	6.4	7.9	8.9		
22	12/10/2012	10.6	11.2	14.5	13.5	77.5	11.2	11.7	12.7	14.1		
23	12/11/2012	17.3	17.7	23.6	22.8	75.4	16.3	17.2	18.5	20.7		
24	12/12/2012	18.2	18.5	24.7	24.2	75.1	16.1	17.2	18.0	20.5		
25	12/13/2012	23.4	23.7	29.3	28.2	82.0	22.4	24.4	24.2	27.8		
26	12/14/2012	7.3	6.7	8.9	8.8	79.5	7.6	8.1	8.6	9.4		
27	12/15/2012						3.8	4.1	5.1	5.9		
28	12/16/2012	5.4	5.9	9.7	9.5	58.9	6.2	6.6	7.9	9.0		
29	12/17/2012	6.8	7.2	13.7	13.4	51.9	7.1	7.8	9.6	11.3		
30	12/18/2012	12.9	13.3	20.1	20.5	64.5	13.4	14.4	16.3	18.7		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 2 of 22**

Manufacturer	Comde-Derenda		
Type of instrument	APM-2		PM10 and PM2,5 Measured values in µg/m³ (AMB)
Serial-No..	SN 3 / SN 4		

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
31	12/19/2012	13.4	13.3	18.3	18.0	73.7	13.1	13.6	14.8	16.4		Cologne, winter
32	12/20/2012	11.6	11.6	14.1	13.6	83.8	11.7	12.1	13.0	14.0		
33	12/21/2012	11.7	10.8	18.1	17.8	62.7	13.2	14.2	16.1	18.1		
34	12/22/2012						4.0	4.2	5.3	5.8		
35	12/23/2012						3.5	3.8	4.9	5.7		
36	12/24/2012						6.3	7.1	8.7	10.1		
37	12/25/2012						1.8	2.2	2.8	3.5		
38	12/26/2012						3.2	3.5	5.6	6.5		
39	12/27/2012						8.1	8.8	12.7	14.6		
40	12/28/2012						4.8	5.2	6.1	6.5		
41	12/29/2012						3.6	4.0	4.8	5.3		
42	12/30/2012						3.3	3.6	5.9	6.5		
43	12/31/2012										Power loss	
44	1/1/2013										Power loss	
45	1/2/2013	9.7	9.3	16.1	15.0	60.9	9.6	10.1	11.9	13.1		
46	1/3/2013	11.9	13.1	19.4	18.6	65.6	12.1	12.8	15.9	17.2		
47	1/4/2013	9.5	9.9	13.8	13.0	72.5	9.5	9.9	11.6	12.2		
48	1/5/2013						14.3	15.2	17.4	19.0		
49	1/6/2013	26.7	26.6	37.5	37.4	71.3	23.4	25.2	28.9	31.9		
50	1/7/2013	17.6	19.4	24.6	25.0	74.5	15.8	16.8	18.7	20.5		
51	1/8/2013	13.6	14.7	19.6	20.1	71.4	13.2	13.9	15.5	17.1		
52	1/9/2013	11.6	13.3	18.9	19.7	64.5	11.8	12.3	14.6	16.5		
53	1/10/2013	13.6	14.7	21.9	21.5	65.1	12.8	13.6	15.8	17.9		
54	1/11/2013										Zero point	
55	1/12/2013										Zero point	
56	1/13/2013										Zero point	
57	1/14/2013	24.9	24.8	28.4	29.4	86.0	22.7	23.8	25.5	27.9		
58	1/15/2013	33.4	33.8	36.3	37.1	91.5	31.2	32.6	34.7	37.9		
59	1/16/2013	58.5	58.4	63.7	63.3	92.0	44.8	46.8	52.4	57.1		
60	1/17/2013	55.4	56.2	60.2	59.8	93.0	43.3	45.1	49.9	54.1		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 3 of 22**

Manufacturer Comde-Derenda

Type of instrument APM-2

Serial-No.. SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
61	1/18/2013	17.4	17.5	19.0	18.6	92.7	15.7	16.2	17.2	18.7		Cologne, winter
62	1/19/2013	21.1	21.1	22.6	23.0	92.4	20.0	20.7	22.1	24.2		
63	1/20/2013	29.7	30.0	30.9	31.2	96.2	28.4	29.3	31.9	34.5		
64	1/21/2013	44.9	42.8	45.4	44.8	97.2	40.1	41.4	44.1	47.4		
65	1/22/2013	53.5	54.9			90.5	50.6	52.4	56.0	59.4	Outlier Ref PM10 - not discarded	
66	1/23/2013	62.1	63.2	69.2	68.8	90.8	58.3	60.2	64.8	67.7		
67	1/24/2013	23.6	24.5	27.8	28.1	86.1	20.3	20.9	23.1	23.6		
68	1/25/2013	19.6	19.3	21.2	20.4	93.3	16.3	16.9	18.4	18.9		
69	1/26/2013	26.6	25.9	28.3	28.4	92.5	23.3	23.9	26.0	27.0		
70	1/27/2013	9.1	9.2	15.0	15.0	61.1	8.3	8.4	10.8	12.3		
71	1/28/2013	5.7	5.9	8.9	7.9	68.6	5.3	5.6	6.7	7.6		
72	1/29/2013	3.4	3.9	5.5	4.5	72.0	3.6	4.1	4.6	5.1		
73	1/30/2013	6.4	6.8	15.2	14.8	43.8	3.5	4.1	7.4	8.9		
74	1/31/2013	8.0	8.5	20.3	19.2	41.6	4.8	5.5	9.8	12.2		
75	2/1/2013	9.2	9.4	11.9	10.9	81.4	8.8	9.2	10.9	11.9		
76	2/2/2013						4.3	4.5	7.8	8.8		
77	2/3/2013						7.9	8.1	9.7	10.4		
78	2/4/2013						5.4	5.9	9.2	10.8		
79	2/5/2013										Zero point	
80	2/6/2013										Zero point	
81	2/27/2013										Zero point	Bonn, winter
82	2/28/2013										Zero point	
83	3/1/2013	24.9	23.0	36.3	36.7	65.6	20.8	21.8	27.0	30.0		
84	3/2/2013						25.1	26.1	31.7	35.4		
85	3/3/2013	22.1	23.2	29.3	29.8	76.6	19.1	20.0	22.7	24.9		
86	3/4/2013	19.6	20.5	28.2	28.7	70.2	16.3	17.4	20.3	22.9		
87	3/5/2013	28.4	27.7	40.2	39.9	70.1	23.9	25.6	29.4	32.7		
88	3/6/2013	25.8	24.5	39.3	39.7	63.8	21.1	22.6	26.8	30.3		
89	3/7/2013	28.0	28.3	39.5	39.5	71.2	25.6	27.6	31.5	35.1		
90	3/8/2013	28.8	27.0	35.4	34.8	79.5	27.0	28.8	32.0	34.8		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 4 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
91	3/9/2013						9.9	10.7	12.3	13.5		Bonn, winter
92	3/10/2013	21.8	22.0	23.1	22.3	96.5	25.1	26.1	27.4	29.6		
93	3/11/2013	27.6	28.1	31.2	30.3	90.6	30.7	32.0	33.5	36.5		
94	3/12/2013	15.6	15.6	17.8	17.7	87.9	16.1	17.1	18.0	20.0		
95	3/13/2013	36.7	36.7	50.8	50.0	72.9	31.8	33.5	36.7	40.4		
96	3/14/2013	19.6	19.2	27.5	27.6	70.3	16.9	18.0	20.4	23.0		
97	3/15/2013	22.0	21.5	31.7	31.7	68.7	18.8	20.0	22.7	25.0		
98	3/16/2013						12.0	12.4	14.6	16.0		
99	3/17/2013	7.0	7.4	11.0	10.5	67.2	9.6	10.1	11.0	12.0		
100	3/18/2013	7.7	8.2	17.4	17.2	45.9	8.3	8.9	10.5	11.8		
101	3/19/2013	9.5	9.9	17.1	16.8	57.5	10.5	11.0	12.4	13.6		
102	3/20/2013	21.3	20.9	25.2	24.5	84.7	23.5	24.4	26.5	28.4		
103	3/21/2013	37.5	36.6	46.3	45.9	80.5	35.9	37.7	40.7	44.0		
104	3/22/2013	21.4	21.6	26.0	26.3	82.2	21.5	22.9	24.2	26.6		
105	3/23/2013						23.1	24.4	25.4	27.9		
106	3/24/2013	15.1	15.9	19.7	18.8	80.6	15.3	16.2	17.1	19.2		
107	3/25/2013	20.1	20.6	26.0	25.6	78.9	20.8	22.2	23.7	26.7		
108	3/26/2013	15.7	15.3	21.1	20.4	74.7	14.7	15.7	16.3	19.1		
109	3/27/2013	26.6	25.9	33.3	32.8	79.5	25.1	27.0	28.8	32.4		
110	3/28/2013						46.0	49.0	51.4	56.5		
111	3/29/2013	71.1	69.8	76.5	76.3	92.2	63.6	67.2	70.5	76.8		
112	3/30/2013										Zero point	
113	3/31/2013										Zero point	
114	4/1/2013										Zero point	
115	4/2/2013	20.2	20.2	24.7	25.2	81.0	21.4	22.8	23.9	26.5		
116	4/3/2013	27.2	26.5	31.4	30.8	86.3	28.2	29.8	31.0	34.1		
117	4/4/2013	29.5	29.1	33.5	33.2	88.0	29.0	30.7	32.4	35.1		
118	4/5/2013	25.8	25.4	30.8	30.0	84.1	22.7	24.1	26.0	28.4		
119	4/6/2013						23.0	24.3	25.9	28.3		
120	4/7/2013	23.0	22.8	30.9	30.2	74.9	21.4	23.2	24.6	27.7		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 5 of 22**

Manufacturer Comde-Derenda

Type of instrument APM-2

Serial-No.. SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
121	4/8/2013	26.3	25.1	31.7	31.7	81.0	21.8	23.4	25.7	28.7		Bonn, winter
122	4/9/2013	16.5	16.5	21.6	21.0	77.4	14.6	15.5	17.0	18.6		
123	4/10/2013	12.2	12.2	17.9	17.8	68.4	10.6	11.3	12.8	13.9		
124	4/11/2013	9.4	8.8	15.9	15.7	57.4	7.1	7.6	9.4	9.8		
125	4/12/2013	6.2	6.3	10.4	10.4	60.4	4.6	4.9	6.6	7.1		
126	4/13/2013						5.6	5.9	7.8	8.2		
127	4/14/2013	7.2	6.9	11.9	11.1	61.4	5.0	5.4	7.0	7.6		
128	4/15/2013	18.5	16.8	31.2	30.2	57.3	14.3	15.2	20.6	22.3		
129	4/16/2013	12.7	11.2	21.1	20.7	57.2	10.1	10.5	13.6	14.4		
130	4/17/2013	9.9	9.8	19.5	19.7	50.2	6.6	6.8	10.1	10.8		
131	4/18/2013	9.4	8.7	21.4	21.5	42.2	5.6	5.9	9.9	10.8		
132	4/19/2013	10.3	10.3	21.0	20.8	49.4	8.4	8.8	12.0	12.9		
133	4/20/2013						9.6	10.1	12.7	13.8		
134	4/21/2013	24.4	23.0	36.7	37.6	63.8	16.9	18.1	23.3	25.6		
135	4/22/2013	31.0	29.4	44.7	43.9	68.3	24.1	25.7	30.8	33.9		
136	4/23/2013	11.0	10.4	18.2	18.8	57.6	8.5	8.9	11.4	12.1		
137	4/24/2013	14.3	12.7	24.2	24.4	55.6	11.0	11.7	15.0	16.3		
138	4/25/2013	13.8	12.1	23.3	23.6	55.3	10.4	10.9	14.5	15.8		
139	4/26/2013										Zero point	
140	4/27/2013										Zero point	
141	4/28/2013										Zero point	
142	4/29/2013	14.3	12.9	20.6	21.4	64.9	10.7	11.1	14.0	15.0		
143	4/30/2013						13.0	13.8	17.1	18.5		
144	5/1/2013	16.9	18.2	21.4	22.2	80.7	15.9	16.9	19.3	20.8		
145	5/2/2013						16.0	16.9	20.0	21.7		
146	5/3/2013	23.2	23.4	33.7	34.4	68.5	21.4	22.7	27.5	30.1		
147	5/4/2013	20.2	19.7	30.1	30.6	65.7	16.8	17.7	21.5	23.3		
148	5/5/2013	9.6	9.3	14.0	14.8	65.4	7.5	8.0	9.6	10.2		
149	5/6/2013	14.5	15.0	23.3	22.9	63.9	12.9	13.7	16.5	18.1		
150	5/15/2013										Zero point	Cologne, summer

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 6 of 22**

Manufacturer	Comde-Derenda	
Type of instrument	APM-2	PM10 and PM2,5 Measured values in µg/m³ (AMB)
Serial-No..	SN 3 / SN 4	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
151	5/16/2013										Zero point	Cologne, summer
152	5/17/2013	16.7	17.5	19.9	20.8	84.1	13.3	14.1	17.0	17.7		
153	5/18/2013						13.0	13.7	15.2	16.6		
154	5/19/2013						15.7	16.6	19.7	21.1		
155	5/20/2013	9.1	10.0	11.6	12.5	79.2	8.6	9.0	11.1	11.7		
156	5/21/2013	5.8	6.3	8.0	8.9	72.0	6.0	6.4	7.6	8.0		
157	5/22/2013	6.5	6.9	13.0	13.1	51.3	6.4	7.1	9.8	10.6		
158	5/23/2013	8.6	9.3	11.6	12.7	73.8	8.1	8.8	10.3	11.1		
159	5/24/2013	8.2	9.3	12.9	13.3	66.8	8.5		10.1		SN4 no data recording cause unknown	
160	5/25/2013						9.8		12.4			
161	5/26/2013	9.5	10.0	19.5	18.9	50.8	9.1		13.1			
162	5/27/2013	16.8	16.8	24.3	23.8	69.9	16.1	17.6	19.7	20.9		
163	5/28/2013	8.4	8.3	12.5	12.5	66.5	8.5	8.8	10.1	10.7		
164	5/29/2013						7.4	7.7	9.2	9.7		
165	5/30/2013						13.5	14.3	16.4	17.3		
166	5/31/2013						13.5	14.3	16.9	18.5		
167	6/1/2013						11.7	12.4	15.6	17.1		
168	6/2/2013	5.5	6.1	13.0	12.8	45.0	6.1	6.4	8.3	9.1		
169	6/3/2013	8.5	8.5	16.5	16.9	50.9	7.8	8.4	10.5	11.8		
170	6/4/2013	11.8	10.8	21.6	21.2	53.0	10.4	10.6	13.5	14.5		
171	6/5/2013	9.3	9.3	15.9	15.1	60.1	8.7	9.0	10.8	11.6		
172	6/6/2013	11.6	11.3	17.4	18.2	64.1	9.8	9.9	12.0	12.7		
173	6/7/2013	15.3	15.4	23.5	23.0	66.1	13.9	14.0	17.1	18.1		
174	6/8/2013						13.6	14.4	17.4	19.0		
175	6/9/2013	12.6	12.1	20.5	18.7	63.0	12.9	13.5	15.9	17.2		
176	6/10/2013	16.6	16.7	31.1	29.5	55.0	16.7	17.9	22.2	24.6		
177	6/11/2013	14.4	14.3	25.6	24.8	56.8	15.9	16.7	20.1	22.2		
178	6/12/2013	6.6	5.8	15.2	14.1	42.5	6.3	6.8	10.7	10.7		
179	6/13/2013	5.3	4.6	11.2	10.5	45.5	4.4	4.9	6.8	7.7		
180	6/14/2013	6.6	7.1	12.6	12.3	55.0	5.7	6.3	7.5	8.8		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 7 of 22**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
181	6/15/2013	5.7	5.8	12.7	12.9	45.0	4.9	5.5	6.9	8.2		Cologne, summer
182	6/16/2013	8.1	8.0	18.3	17.6	44.9	6.8	7.5	9.3	10.8		
183	6/17/2013	13.3	13.3	23.3	22.1	58.4	11.5	12.3	14.8	16.7		
184	6/18/2013	16.9	16.7	26.9	26.1	63.5	16.6	17.7	21.4	24.1		
185	6/19/2013			46.8	45.1		33.0	35.7	40.6	45.6	Ref. PM2,5 - stability criteria EN 14907 not met	
186	6/20/2013	7.9	8.1	14.2	13.2	58.6	11.5	12.5	14.9	16.7		
187	6/21/2013	4.7	4.9	8.5	8.3	57.5	5.3	5.7	6.6	7.4		
188	6/22/2013	4.0	4.7	5.3	5.1	83.9	3.3	3.7	4.2	4.8		
189	6/23/2013	4.9	5.5	7.7	7.6	68.6	3.9	4.4	5.5	6.4		
190	6/24/2013	9.8	11.1	16.2	15.7	65.3	9.4	9.9	12.0	13.3		
191	6/25/2013	6.8	7.4	11.2	12.3	60.5	6.1	6.8	8.3	9.4		
192	6/26/2013	9.6	10.0	14.4	13.7	69.8	8.9	9.3	10.9	11.6		
193	6/27/2013	9.8	9.8	14.4	13.7	69.7	9.3	10.0	11.6	12.7		
194	6/28/2013	9.7	10.5	12.3	13.2	79.1	10.6	11.7	13.1	14.2		
195	6/29/2013										Zero point	
196	6/30/2013										Zero point	
197	7/1/2013	8.9	10.6	17.1	16.7	57.8	9.6	10.1	12.0	13.3		
198	7/2/2013	7.8	8.6	13.9	13.1	60.8	8.7	9.0	10.3	11.0		
199	7/3/2013	5.6	6.9	11.8	11.8	53.2	6.0	6.5	8.3	9.3		
200	7/4/2013	7.8	9.2	15.6	14.8	56.1	9.2	9.6	11.1	12.1		
201	7/5/2013			23.8	23.1		15.0	16.0	18.6	20.6	Outlier Ref. PM2,5	
202	7/6/2013	13.1	14.5	18.1	17.6	77.4	14.0	14.3	16.3	17.3		
203	7/7/2013	11.3	13.1	16.5	16.4	74.2	10.8	11.0	12.3	13.1		
204	7/8/2013	12.3	13.2	18.1	18.2	70.2	10.7	11.5	12.9	14.3		
205	7/9/2013	13.6	14.7	23.5	23.4	60.3	11.2	12.1	14.9	16.8		
206	7/10/2013	10.1	9.6	18.4	17.8	54.4	8.5	8.7	11.5	12.5		
207	7/11/2013	17.5	17.9				17.2	18.6	22.1	24.5	Outlier Ref. PM10	
208	7/12/2013	16.8	16.8	28.9	26.8	60.3	16.0	17.1	20.5	22.9		
209	7/13/2013	19.5	19.5	26.6	24.9	75.9	18.3	19.5	21.5	23.4		
210	7/14/2013						17.0	18.2	20.3	22.6		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 8 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
211	7/30/2013	6.5	6.6	13.7	13.1	49.0	4.9	4.7	7.6	7.7		Rodenkirchen, summer
212	7/31/2013	6.6	6.6	12.0	12.3	54.1	6.0	5.4	8.0	7.7		
213	8/1/2013	8.5	8.6	14.4	15.2	57.7	7.5	6.8	9.6	9.4		
214	8/2/2013	12.0	12.9	20.8	22.9	56.9	10.3	9.9	13.4	13.4		
215	8/3/2013						7.9	7.4	9.9	9.8		
216	8/4/2013	7.1	9.2	14.1	15.0	55.7	7.1	6.6	9.0	8.8		
217	8/5/2013	10.3	10.4	20.2	22.3	48.6	8.8	7.9	12.1	11.6		
218	8/6/2013	9.2	8.7	18.5	19.0	47.6	8.5	7.9	11.2	10.9		
219	8/7/2013	8.8	8.9	15.0	15.1	59.0	9.1	8.7	11.5	11.3		
220	8/8/2013	11.1	10.5	18.8	18.5	58.1	10.4	10.5	12.8	13.1		
221	8/9/2013	10.7	10.6	18.7	19.1	56.3	10.1	10.1	12.9	13.0		
222	8/10/2013						8.1	8.2	10.8	11.1		
223	8/11/2013	4.9	4.9	12.6	12.3	39.5	5.7	5.7	7.7	7.7		
224	8/12/2013	8.0	7.7	18.6	17.6	43.4	7.1	7.3	9.8	10.0		
225	8/13/2013	7.3	6.8	16.5	17.1	41.7	6.9	6.7	9.7	9.8		
226	8/14/2013	9.6	9.0	23.1	24.9	38.8	8.2	7.9	12.1	12.4		
227	8/15/2013	8.5	8.7	19.2	18.6	45.6	8.3	8.2	11.3	11.7		
228	8/16/2013	11.5	11.5	22.2	22.5	51.4	9.9	9.4	13.2	13.3		
229	8/17/2013						6.6	5.7	8.5	7.9		
230	8/18/2013	4.6	5.0	10.7	10.1	46.1	4.5	4.4	6.9	6.9		
231	8/19/2013	6.4	7.1	14.1	14.0	48.3	6.7	6.6	9.0	9.2		
232	8/20/2013	10.7	11.4	19.5	18.9	57.6	11.0	10.6	13.4	13.5		
233	8/21/2013	12.0	12.4	18.8	18.0	66.4	13.1	12.6	15.5	15.6		
234	8/22/2013	15.6	16.0	25.4	25.7	61.9	16.4	16.0	20.3	20.4		
235	8/23/2013	13.6	14.5	22.9	23.0	61.3	15.2	14.8	18.5	18.6		
236	8/24/2013						19.7	19.2	24.9	24.7		
237	8/25/2013	23.4	23.6	32.7	31.0	73.6	20.3	20.4	28.6	29.6		
238	8/26/2013	10.8	10.9	19.2	19.3	56.4	10.6	10.6	13.4	13.9		
239	8/27/2013	12.7	12.5	22.0	20.8	58.8	12.6	12.4	15.7	16.4		
240	8/28/2013	14.1	13.5	22.9	23.5	59.5	15.9	15.7	19.9	20.8		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 9 of 22**

Manufacturer	Comde-Derenda		
Type of instrument	APM-2		PM10 and PM2,5 Measured values in µg/m³ (AMB)
Serial-No..	SN 3 / SN 4		

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
241	8/29/2013	16.3	17.1	26.7	27.2	61.9	18.9	18.4	23.3	23.8		Rodenkirchen, summer
242	8/30/2013	16.6	16.2	27.5	29.5	57.7	17.8	17.4	21.9	22.6		
243	8/31/2013						7.9	8.0	11.5	12.5		
244	9/1/2013	9.7	7.5	18.9	19.6	44.5	6.1	6.2	9.0	10.0		
245	9/2/2013	10.1	9.5	21.2	23.1	44.3	8.4	8.4	11.6	13.0		
246	9/3/2013	13.8	12.3	23.1	24.4	55.0	12.4	12.2	15.7	16.6		
247	9/4/2013	8.9	8.5	14.5	15.3	58.2	9.6	9.2	11.2	11.3		
248	9/5/2013	11.2	10.2	16.2	19.0	60.8	9.5	8.6	11.4	11.1		
249	9/6/2013	19.3	18.5	30.7	33.2	59.1	17.7	16.9	22.0	22.6		
250	9/7/2013	16.6	15.5	24.2	24.9	65.6	14.5	14.3	18.4	19.2		
251	9/8/2013						12.1	13.5	14.6	16.7		
252	9/9/2013	6.7	6.8	11.1	11.7	59.3	5.7	6.7	7.3	8.4		
253	9/10/2013	6.5	6.3	10.9	11.1	58.3	6.1	6.4	7.5	7.8		
254	9/11/2013						10.0	10.0	12.1	12.7		
255	9/12/2013	15.1	13.6	23.0	24.0	60.9	11.8	11.7	14.3	15.3		
256	9/13/2013	8.3	8.4	14.4	14.5	57.6	7.9	7.5	9.4	9.5		
257	9/14/2013						4.1	4.0	5.9	6.3		
258	9/15/2013	6.9	6.8	14.7	15.3	45.5	5.4	5.0	7.3	7.4		
259	9/16/2013	6.6	6.6	14.5	14.6	45.4	4.5	4.3	6.8	7.0		
260	9/17/2013	6.1	6.2	12.4	12.8	48.8	4.6	4.4	6.7	7.0		
261	9/18/2013	13.5	12.4	21.7	22.5	58.4	10.3	10.0	12.8	13.3		
262	9/19/2013	8.3	8.8	16.4	17.8	50.0	6.9	6.6	9.1	9.3		
263	9/20/2013	9.4	9.6	20.7	20.7	45.9	8.2	8.1	10.6	11.3		
264	9/21/2013										Zero point	
265	1/13/2014	12.9	13.6	18.2	18.9	71.5	13.3	12.6	17.2	15.7		Cologne, winter 2014 validation campaign
266	1/14/2014	10.8	11.2	15.5	15.0	72.3	12.5	11.8	15.0	14.1		
267	1/15/2014	5.5	5.7	8.0	8.7	66.9	9.1	7.9	10.4	9.0		
268	1/16/2014	3.1	3.6	6.4	7.1	50.0	6.8	5.5	9.6	7.8		
269	1/17/2014	4.6	5.2	8.9	8.6	56.0	7.3	5.8	9.4	8.2		
270	1/18/2014						12.3	11.5	13.8	12.9		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 10 of 22**

Manufacturer	Comde-Derenda	
Type of instrument	APM-2	PM10 and PM2,5 Measured values in µg/m³ (AMB)
Serial-No..	SN 3 / SN 4	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
271	1/19/2014	14.5	14.2	16.8	17.3	84.2	17.3	15.7	19.6	17.7		Cologne, winter 2014 validation campaign
272	1/20/2014	15.6	15.3	18.9	19.9	79.7	18.4	16.9	22.9	20.4		
273	1/21/2014	24.2	24.6	30.8	31.1	78.7	22.9	22.5	30.1	27.8		
274	1/22/2014	18.4	18.8	23.0	23.5	80.0	19.6	18.8	24.5	22.2		
275	1/23/2014	10.9	11.4	15.2	16.3	70.9	12.1	11.8	15.7	16.3		
276	1/24/2014	18.7	19.3	28.1	28.9	66.6	19.7	19.7	27.5	28.9		
277	1/25/2014						11.2	10.3	15.1	15.1		
278	1/26/2014	4.4	4.4	11.4	12.0	37.8	6.0	5.5	11.5	11.6		
279	1/27/2014	2.9	3.5	6.7	7.1	46.7	5.8	4.3	8.1	7.3		
280	1/28/2014	6.3	6.7	10.9	10.6	60.4	8.3	7.7	10.6	10.6		
281	1/29/2014	16.0	16.6	19.2	19.7	83.8	16.3	16.2	19.3	20.1		
282	1/30/2014	35.7	36.0	41.6	42.3	85.4	36.7	36.9	43.3	45.1		
283	1/31/2014	29.8	29.0	35.0	34.9	84.1	29.4	29.5	35.0	36.5		
284	2/1/2014						8.5	7.0	9.7	8.7		
285	2/2/2014	8.6	7.9	18.1	17.5	46.3	9.6	9.1	17.6	18.0		
286	2/3/2014	18.7	18.0	22.0	21.5	84.5	18.7	18.7	22.2	23.2		
287	2/4/2014						13.8	13.3	17.3	17.3		
288	2/5/2014	4.4	3.4	8.0	8.2	48.6	6.5	5.8	8.9	8.7		
289	2/6/2014	2.9	3.1	9.8	9.1	32.0	5.6	3.8	9.0	8.1		
290	2/7/2014										Zero point	
291	2/8/2014										Zero point	
292	2/9/2014										Zero point	
293	2/10/2014	9.8	8.8	12.9	13.1	71.4	10.9	10.2	13.6	13.6		
294	2/11/2014	4.5	3.8	9.6	8.0	47.6	6.1	5.0	8.3	7.9		
295	2/12/2014	4.5	3.8	8.2	7.9	51.3	5.7	4.3	9.0	8.1		
296	2/13/2014	4.8	4.3	10.3	10.0	44.8	5.7	4.9	9.4	9.2		
297	2/14/2014						4.8	4.5	7.3	7.5		
298	2/15/2014						4.9	3.4	7.5	6.9		
299	2/16/2014	5.2	4.9	8.8	9.2	56.2	6.5	5.7	9.3	9.1		
300	2/17/2014	8.0	7.0	12.7	12.5	59.7	9.1	8.6	12.5	12.3		

Manufacturer Comde-Derenda

Type of instrument APM-2

Serial-No.. SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
301	2/18/2014	14.5	13.8	19.8	19.6	71.7	14.9	14.0	19.9	19.7		Cologne, winter 2014 validation campaign
302	2/19/2014	9.6	8.9	13.2	14.2	67.4	11.1	10.6	13.6	13.7		
303	2/20/2014	4.3	4.4	6.6	6.2	67.5	6.7	6.4	8.0	8.1		
304	2/21/2014	4.8	5.0	7.8	7.8	63.2	7.3	6.6	9.7	9.1		
305	2/22/2014	4.2	5.0	4.7	5.4	90.9	7.0	5.8	7.8	6.9		
306	2/23/2014	5.6	6.6	7.1	7.0	87.0	7.7	7.4	8.5	8.6		
307	2/24/2014	9.3	9.3	13.7	12.7	70.6	9.5	8.7	12.6	12.5		
308	2/25/2014	9.0	8.6	12.8	12.1	70.5	9.1	8.9	11.6	12.0		
309	2/26/2014	11.3	11.3	19.4	17.3	61.7	12.0	11.0	17.8	17.4		
310	2/27/2014	7.5	8.2	12.0	10.4	70.3	8.6	8.1	11.9	12.1		
311	2/28/2014	7.7	7.3	10.3	9.9	74.3	8.3	7.7	10.5	10.4		
312	3/1/2014	12.1	12.4	14.7	14.7	83.5	13.2	12.5	15.7	15.8		
313	3/2/2014	16.8	16.9	18.3	19.6	88.6	16.0	16.1	18.7	19.5		
314	3/3/2014	6.8	6.9	9.9	11.8	63.0	9.1	8.5	11.2	11.3		
315	3/4/2014	19.5	17.6	25.6	24.3	74.4	19.3	18.8	24.8	25.2		
316	3/5/2014	30.8	31.2	43.5	43.7	71.0	28.2	27.7	41.4	42.0		
317	3/6/2014	36.5	35.6	44.2	43.5	82.2	29.4	29.5	38.1	39.7		
318	3/7/2014	43.6	44.0	56.7	55.5	78.0	37.1	38.4	48.9	50.9		
319	3/8/2014	42.8	41.4	49.7	50.0	84.4	34.1	33.8	42.7	44.1		
320	3/9/2014	23.2	21.4	28.1	27.2	80.7	19.2	18.7	26.4	26.4		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 12 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
1	11/19/2012	-	-						Zero point	Cologne, winter
2	11/20/2012	-	-						Zero point	
3	11/21/2012	-	-						Zero point	
4	11/22/2012	-	-						Audits	
5	11/23/2012	-	-	20.2	20.3	-	17.6	19.9		
6	11/24/2012	-	-			-	15.9	18.1		
7	11/25/2012	-	-	11.2	10.9	-	6.1	7.4		
8	11/26/2012	-	-	11.5	12.2	-	8.5	10.0		
9	11/27/2012	-	-	19.2	18.4	-	13.2	15.3		
10	11/28/2012	-	-	30.0	30.2	-	24.9	27.5		
11	11/29/2012	-	-	14.6	14.8	-	11.3	12.8		
12	11/30/2012	-	-	24.7	24.7	-	21.0	24.1		
13	12/1/2012	-	-			-	15.1	16.7		
14	12/2/2012	-	-	15.1	15.0	-	12.3	13.7		
15	12/3/2012	-	-	14.5	14.8	-	11.6	13.5		
16	12/4/2012	-	-	12.0	12.1	-	10.0	11.1		
17	12/5/2012	-	-	12.3	12.8	-	10.5	11.8		
18	12/6/2012	-	-	16.7	16.3	-	12.4	14.6		
19	12/7/2012	-	-	15.4	15.5	-	15.9	17.7		
20	12/8/2012	-	-			-	34.1	37.6		
21	12/9/2012	-	-	10.4	9.1	-	8.1	9.2		
22	12/10/2012	-	-	14.6	13.7	-	12.9	14.3		
23	12/11/2012	-	-	23.4	22.7	-	18.4	20.7		
24	12/12/2012	-	-	24.6	24.3	-	18.1	20.6		
25	12/13/2012	-	-	29.7	28.7	-	24.7	28.4		
26	12/14/2012	-	-	9.3	9.2	-	9.1	10.0		
27	12/15/2012	-	-			-	5.4	6.2		
28	12/16/2012	-	-	10.1	9.9	-	8.3	9.4		
29	12/17/2012	-	-	14.2	13.9	-	10.0	11.9		
30	12/18/2012	-	-	20.5	21.0	-	16.8	19.2		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 13 of 22**

Manufacturer	Comde-Derenda	PM10 and PM2,5
Type of instrument	APM-2	Measured values in µg/m³ (STD)
Serial-No..	SN 3 / SN 4	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
31	12/19/2012	-	-	18.5	18.3	-	15.1	16.7		Cologne, winter
32	12/20/2012	-	-	14.3	13.9	-	13.3	14.3		
33	12/21/2012	-	-	18.5	18.4	-	16.6	18.7		
34	12/22/2012	-	-			-	5.5	6.0		
35	12/23/2012	-	-			-	5.2	6.0		
36	12/24/2012	-	-			-	9.2	10.8		
37	12/25/2012	-	-			-	2.9	3.7		
38	12/26/2012	-	-			-	5.9	6.8		
39	12/27/2012	-	-			-	13.2	15.2		
40	12/28/2012	-	-			-	6.3	6.8		
41	12/29/2012	-	-			-	5.0	5.5		
42	12/30/2012	-	-			-	6.1	6.8		
43	12/31/2012	-	-			-			Power loss	
44	1/1/2013	-	-			-			Power loss	
45	1/2/2013	-	-	16.4	15.3	-	12.2	13.4		
46	1/3/2013	-	-	19.8	19.1	-	16.3	17.7		
47	1/4/2013	-	-	14.0	13.3	-	11.8	12.5		
48	1/5/2013	-	-			-	17.7	19.4		
49	1/6/2013	-	-	38.2	38.4	-	29.6	32.7		
50	1/7/2013	-	-	25.0	25.7	-	19.1	21.1		
51	1/8/2013	-	-	20.0	20.6	-	15.9	17.5		
52	1/9/2013	-	-	19.2	20.2	-	15.0	16.9		
53	1/10/2013	-	-	22.3	22.0	-	16.2	18.4		
54	1/11/2013	-	-			-			Zero point	
55	1/12/2013	-	-			-			Zero point	
56	1/13/2013	-	-			-			Zero point	
57	1/14/2013	-	-	28.4	29.5	-	25.6	28.0		
58	1/15/2013	-	-	36.5	37.6	-	35.1	38.4		
59	1/16/2013	-	-	63.6	63.6	-	52.5	57.4		
60	1/17/2013	-	-	59.9	59.9	-	49.9	54.2		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 14 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
61	1/18/2013	-	-	19.2	18.9	-	17.5	19.0		Cologne, winter
62	1/19/2013	-	-	22.9	23.4	-	22.5	24.6		
63	1/20/2013	-	-	31.5	32.0	-	32.8	35.5		
64	1/21/2013	-	-	45.8	45.8	-	45.2	48.7		
65	1/22/2013	-	-			-	57.2	60.6	Outlier Ref PM10 - not discarded	
66	1/23/2013	-	-	69.6	69.6	-	65.6	68.7		
67	1/24/2013	-	-	27.7	28.1	-	23.1	23.7		
68	1/25/2013	-	-			-	18.4	19.0		
69	1/26/2013	-	-	28.5	28.7	-	26.3	27.4		
70	1/27/2013	-	-	15.3	15.4	-	11.1	12.6		
71	1/28/2013	-	-	9.2	8.2	-	6.9	7.9		
72	1/29/2013	-	-	5.8	4.8	-	4.8	5.4		
73	1/30/2013	-	-	15.8	15.6	-	7.7	9.3		
74	1/31/2013	-	-	21.0	20.0	-	10.2	12.7		
75	2/1/2013	-	-			-	11.4	12.5		
76	2/2/2013	-	-			-	8.0	9.0		
77	2/3/2013	-	-			-	10.0	10.7		
78	2/4/2013	-	-			-	9.6	11.3		
79	2/5/2013	-	-			-			Zero point	
80	2/6/2013	-	-			-			Zero point	
81	2/27/2013	-	-			-			Zero point	Bonn, winter
82	2/28/2013	-	-			-			Zero point	
83	3/1/2013	-	-	36.6	37.1	-	27.3	30.4		
84	3/2/2013	-	-			-	32.0	35.8		
85	3/3/2013	-	-	29.5	30.2	-	23.0	25.2		
86	3/4/2013	-	-	28.9	29.7	-	20.9	23.6		
87	3/5/2013	-	-	41.8	41.8	-	30.8	34.3		
88	3/6/2013	-	-	41.5	42.3	-	28.6	32.4		
89	3/7/2013	-	-	41.9	42.3	-	33.9	37.7		
90	3/8/2013	-	-	37.8	37.4	-	34.6	37.6		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 15 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
91	3/9/2013	-	-			-	13.1	14.4		Bonn, winter
92	3/10/2013	-	-	23.6	22.9	-	28.2	30.5		
93	3/11/2013	-	-	31.5	30.8	-	34.0	37.1		
94	3/12/2013	-	-	17.9	17.9	-	18.2	20.2		
95	3/13/2013	-	-	51.3	50.9	-	37.2	41.0		
96	3/14/2013	-	-	27.5	27.9	-	20.5	23.2		
97	3/15/2013	-	-	32.0	32.3	-	23.1	25.5		
98	3/16/2013	-	-			-	15.1	16.6		
99	3/17/2013	-	-	11.4	11.0	-	11.5	12.6		
100	3/18/2013	-	-	18.2	18.1	-	11.1	12.5		
101	3/19/2013	-	-	17.7	17.5	-	13.0	14.2		
102	3/20/2013	-	-	25.8	25.2	-	27.2	29.1		
103	3/21/2013	-	-	46.4	46.3	-	41.0	44.4		
104	3/22/2013	-	-	26.4	26.8	-	24.7	27.1		
105	3/23/2013	-	-			-	25.7	28.3		
106	3/24/2013	-	-	19.9	19.1	-	17.3	19.5		
107	3/25/2013	-	-	26.2	25.9	-	24.0	27.1		
108	3/26/2013	-	-	21.4	20.8	-	16.6	19.5		
109	3/27/2013	-	-	33.9	33.6	-	29.5	33.2		
110	3/28/2013	-	-			-	52.9	58.1		
111	3/29/2013	-	-	78.1	77.4	-	71.8	78.4		
112	3/30/2013	-	-			-			Zero point	
113	3/31/2013	-	-			-			Zero point	
114	4/1/2013	-	-			-			Zero point	
115	4/2/2013	-	-	25.2	25.8	-	24.5	27.2		
116	4/3/2013	-	-	31.9	31.5	-	31.7	34.8		
117	4/4/2013	-	-	34.3	34.2	-	33.4	36.2		
118	4/5/2013	-	-	31.5	30.8	-	26.7	29.1		
119	4/6/2013	-	-			-	26.3	28.8		
120	4/7/2013	-	-	31.7	31.2	-	25.4	28.6		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 16 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
121	4/8/2013	-	-	32.9	33.1	-	26.9	30.0		Bonn, winter
122	4/9/2013	-	-	22.6	22.2	-	18.0	19.7		
123	4/10/2013	-	-	18.7	18.8	-	13.6	14.7		
124	4/11/2013	-	-	16.9	16.9	-	10.1	10.6		
125	4/12/2013	-	-	11.0	11.1	-	7.0	7.5		
126	4/13/2013	-	-			-	8.2	8.7		
127	4/14/2013	-	-	12.6	11.9	-	7.5	8.2		
128	4/15/2013	-	-	33.0	32.3	-	22.1	23.9		
129	4/16/2013	-	-	22.4	22.2	-	14.6	15.5		
130	4/17/2013	-	-	20.9	21.2	-	10.9	11.7		
131	4/18/2013	-	-	22.6	22.9	-	10.6	11.5		
132	4/19/2013	-	-	21.7	21.7	-	12.5	13.4		
133	4/20/2013	-	-			-	13.2	14.2		
134	4/21/2013	-	-	38.2	39.4	-	24.4	26.8		
135	4/22/2013	-	-	46.8	46.4	-	32.6	35.8		
136	4/23/2013	-	-	19.0	19.8	-	12.0	12.8		
137	4/24/2013	-	-	25.7	26.0	-	16.0	17.4		
138	4/25/2013	-	-	24.9	25.4	-	15.7	17.1		
139	4/26/2013	-	-			-			Zero point	
140	4/27/2013	-	-			-			Zero point	
141	4/28/2013	-	-			-			Zero point	
142	4/29/2013	-	-	21.5	22.6	-	14.7	15.8		
143	4/30/2013	-	-			-	17.9	19.3		
144	5/1/2013	-	-	22.4	23.4	-	20.4	22.0		
145	5/2/2013	-	-			-	21.4	23.2		
146	5/3/2013	-	-	35.6	36.7	-	29.4	32.2		
147	5/4/2013	-	-	31.7	32.5	-	22.9	24.8		
148	5/5/2013	-	-	14.8	15.7	-	10.2	10.8		
149	5/6/2013	-	-	24.9	24.7	-	17.9	19.6		
150	5/15/2013	-	-			-			Zero point	Cologne, summer

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
151	5/16/2013	-	-			-			Zero point	Cologne, summer
152	5/17/2013	-	-	20.9	21.9	-	18.0	18.8		
153	5/18/2013	-	-			-	16.2	17.7		
154	5/19/2013	-	-			-	21.4	23.0		
155	5/20/2013	-	-	12.2	13.2	-	11.8	12.4		
156	5/21/2013	-	-	8.4	9.4	-	8.0	8.6		
157	5/22/2013	-	-	13.5	13.7	-	10.3	11.0		
158	5/23/2013	-	-	12.0	13.1	-	10.8	11.6		
159	5/24/2013	-	-	13.4	13.8	-	10.6		SN4 no data recording	
160	5/25/2013	-	-			-	13.1		cause	
161	5/26/2013	-	-	20.3	19.8	-	13.7		unknown	
162	5/27/2013	-	-	25.8	25.3	-	21.1	22.5		
163	5/28/2013	-	-	13.6	13.5	-	11.1	11.8		
164	5/29/2013	-	-			-	9.7	10.3		
165	5/30/2013	-	-			-	17.6	18.6		
166	5/31/2013	-	-			-	18.2	19.9		
167	6/1/2013	-	-			-	16.4	17.9		
168	6/2/2013	-	-	13.6	13.4	-	8.7	9.5		
169	6/3/2013	-	-	17.2	17.6	-	11.0	12.3		
170	6/4/2013	-	-	22.9	22.4	-	14.4	15.5		
171	6/5/2013	-	-	17.1	16.2	-	11.7	12.6		
172	6/6/2013	-	-	18.8	19.6	-	13.1	13.8		
173	6/7/2013	-	-	25.5	24.9	-	18.8	19.8		
174	6/8/2013	-	-			-	19.1	20.8		
175	6/9/2013	-	-	21.8	20.0	-	17.1	18.5		
176	6/10/2013	-	-	33.0	31.3	-	23.7	26.3		
177	6/11/2013	-	-	27.6	26.7	-	21.8	24.0		
178	6/12/2013	-	-	16.4	15.2	-	11.7	11.7		
179	6/13/2013	-	-	11.9	11.2	-	7.3	8.3		
180	6/14/2013	-	-	13.4	13.0	-	8.0	9.4		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 18 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No.: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
181	6/15/2013	-	-	13.5	13.8	-	7.4	8.8		Cologne, summer
182	6/16/2013	-	-	19.6	18.8	-	10.1	11.6		
183	6/17/2013	-	-	25.5	24.2	-	16.4	18.4		
184	6/18/2013	-	-	29.9	28.8	-	24.0	27.0		
185	6/19/2013	-	-	51.9	49.8	-	45.5	51.1	Ref. PM2,5 - stability criteria	
186	6/20/2013	-	-	15.4	14.3	-	16.2	18.2	EN 14907 not met	
187	6/21/2013	-	-	9.0	8.9	-	7.2	8.0		
188	6/22/2013	-	-	5.7	5.5	-	4.6	5.2		
189	6/23/2013	-	-	8.2	8.1	-	5.9	6.8		
190	6/24/2013	-	-	17.0	16.5	-	12.7	14.0		
191	6/25/2013	-	-	11.6	12.8	-	8.6	9.8		
192	6/26/2013	-	-	15.0	14.4	-	11.4	12.2		
193	6/27/2013	-	-	15.1	14.3	-	12.1	13.4		
194	6/28/2013	-	-	12.9	14.0	-	13.8	15.0		
195	6/29/2013	-	-			-			Zero point	
196	6/30/2013	-	-			-			Zero point	
197	7/1/2013	-	-	18.4	17.9	-	13.0	14.4		
198	7/2/2013	-	-	15.2	14.2	-	11.4	12.1		
199	7/3/2013	-	-	12.6	12.6	-	8.9	10.0		
200	7/4/2013	-	-	16.7	15.9	-	12.0	13.1		
201	7/5/2013	-	-	25.4	24.6	-	19.9	22.0	Outlier Ref. PM2,5	
202	7/6/2013	-	-	19.4	18.9	-	17.7	18.8		
203	7/7/2013	-	-	17.7	17.6	-	13.4	14.2		
204	7/8/2013	-	-	19.5	19.6	-	14.0	15.6		
205	7/9/2013	-	-	25.5	25.3	-	16.3	18.3		
206	7/10/2013	-	-	19.6	19.0	-	12.4	13.5		
207	7/11/2013	-	-			-	23.4	26.0	Outlier Ref. PM10	
208	7/12/2013	-	-	30.6	28.4	-	21.9	24.4		
209	7/13/2013	-	-	28.3	26.4	-	23.0	25.0		
210	7/14/2013	-	-			-	21.8	24.3		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 19 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
211	7/30/2013	-	-	14.7	14.1	-	8.2	8.3		Rodenkirchen, summer
212	7/31/2013	-	-	12.9	13.2	-	8.7	8.4		
213	8/1/2013	-	-	15.8	16.6	-	10.6	10.4		
214	8/2/2013	-	-	23.2	25.3	-	15.1	15.0		
215	8/3/2013	-	-			-	10.7	10.7		
216	8/4/2013	-	-	15.3	16.1	-	9.8	9.6		
217	8/5/2013	-	-	22.3	24.4	-	13.4	12.8		
218	8/6/2013	-	-	20.1	20.6	-	12.2	11.9		
219	8/7/2013	-	-	16.2	16.3	-	12.4	12.3		
220	8/8/2013	-	-	20.0	19.6	-	13.7	14.0		
221	8/9/2013	-	-	20.0	20.4	-	13.9	14.0		
222	8/10/2013	-	-			-	11.5	11.8		
223	8/11/2013	-	-	13.5	13.2	-	8.3	8.3		
224	8/12/2013	-	-	20.0	18.8	-	10.5	10.8		
225	8/13/2013	-	-	17.5	18.0	-	10.3	10.4		
226	8/14/2013	-	-	24.4	26.3	-	12.8	13.1		
227	8/15/2013	-	-	20.5	19.9	-	12.2	12.6		
228	8/16/2013	-	-	24.2	24.3	-	14.4	14.5		
229	8/17/2013	-	-			-	9.3	8.6		
230	8/18/2013	-	-	11.5	10.9	-	7.5	7.5		
231	8/19/2013	-	-	14.9	14.8	-	9.5	9.8		
232	8/20/2013	-	-	20.4	19.8	-	14.4	14.2		
233	8/21/2013	-	-	19.9	19.0	-	17.0	16.6		
234	8/22/2013	-	-	27.3	27.5	-	21.9	22.1		
235	8/23/2013	-	-	24.8	24.8	-	20.1	20.2		
236	8/24/2013	-	-			-	26.9	26.6		
237	8/25/2013	-	-	34.8	33.1	-	30.6	31.8		
238	8/26/2013	-	-	20.5	20.6	-	14.3	14.9		
239	8/27/2013	-	-	23.5	22.2	-	17.9	17.6		
240	8/28/2013	-	-	24.3	24.9	-	22.8	22.2		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 20 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
241	8/29/2013	-	-	28.5	28.9	-	26.8	25.5		Rodenkirchen, summer
242	8/30/2013	-	-	29.3	31.4	-	23.8	24.3		
243	8/31/2013	-	-			-	12.2	13.2		
244	9/1/2013	-	-	19.9	20.7	-	9.5	10.6		
245	9/2/2013	-	-	22.6	24.4	-	12.4	13.8		
246	9/3/2013	-	-	24.5	25.8	-	18.2	17.7		
247	9/4/2013	-	-	15.6	16.4	-	12.2	12.3		
248	9/5/2013	-	-	17.8	20.8	-	12.6	12.3		
249	9/6/2013	-	-	33.6	36.2	-	24.3	24.9		
250	9/7/2013	-	-	25.7	26.6	-	22.1	20.6		
251	9/8/2013	-	-			-	19.5	17.6		
252	9/9/2013	-	-	11.7	12.4	-	8.9	9.0		
253	9/10/2013	-	-	11.5	11.8	-	9.2	8.3		
254	9/11/2013	-	-			-	14.8	13.5		
255	9/12/2013	-	-	24.3	25.3	-	18.8	16.3		
256	9/13/2013	-	-	15.3	15.5	-	11.1	10.2		
257	9/14/2013	-	-			-	7.3	6.8		
258	9/15/2013	-	-	15.6	16.3	-	9.1	8.0		
259	9/16/2013	-	-	15.3	15.5	-	8.1	7.4		
260	9/17/2013	-	-	13.2	13.7	-	8.9	7.5		
261	9/18/2013	-	-	23.0	23.9	-	18.3	14.2		
262	9/19/2013	-	-	17.4	18.9	-	10.9	9.9		
263	9/20/2013	-	-	21.8	21.8	-	13.1	11.9		
264	9/21/2013	-	-			-			Zero point	
265	1/13/2014	-	-	18.8	19.3	-	17.8	16.3		Cologne, winter 2014 validation campaign
266	1/14/2014	-	-	16.0	15.3	-	15.6	14.6		
267	1/15/2014	-	-	8.3	8.9	-	10.7	9.4		
268	1/16/2014	-	-	6.7	7.3	-	10.1	8.2		
269	1/17/2014	-	-	9.4	8.9	-	9.9	8.6		
270	1/18/2014	-	-			-	14.5	13.5		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 21 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
271	1/19/2014	-	-	17.5	17.7	-	20.5	18.4		Cologne, winter 2014 validation campaign
272	1/20/2014	-	-	19.4	20.2	-	23.5	21.0		
273	1/21/2014	-	-	31.5	31.4	-	30.8	28.5		
274	1/22/2014	-	-	23.3	23.5	-	24.9	22.6		
275	1/23/2014	-	-	15.5	16.4	-	16.1	16.6		
276	1/24/2014	-	-	28.6	29.0	-	28.0	29.5		
277	1/25/2014	-	-			-	15.5	15.5		
278	1/26/2014	-	-	11.8	12.3	-	12.0	12.1		
279	1/27/2014	-	-	6.9	7.2	-	8.4	7.6		
280	1/28/2014	-	-	11.3	10.8	-	11.0	11.0		
281	1/29/2014	-	-	19.7	20.0	-	19.8	20.6		
282	1/30/2014	-	-	42.5	42.7	-	44.4	46.2		
283	1/31/2014	-	-	36.3	35.8	-	36.5	37.9		
284	2/1/2014	-	-			-	10.1	9.0		
285	2/2/2014	-	-	18.5	17.6	-	18.0	18.4		
286	2/3/2014	-	-	22.6	21.9	-	22.9	23.9		
287	2/4/2014	-	-			-	17.9	18.0		
288	2/5/2014	-	-	8.3	8.5	-	9.3	9.2		
289	2/6/2014	-	-	10.3	9.5	-	9.6	8.6		
290	2/7/2014	-	-			-			Zero point	
291	2/8/2014	-	-			-			Zero point	
292	2/9/2014	-	-			-			Zero point	
293	2/10/2014	-	-	13.5	13.5	-	14.3	14.2		
294	2/11/2014	-	-	10.0	8.2	-	8.7	8.2		
295	2/12/2014	-	-	8.6	8.1	-	9.4	8.5		
296	2/13/2014	-	-	10.7	10.2	-	9.8	9.6		
297	2/14/2014	-	-			-	7.7	7.9		
298	2/15/2014	-	-			-	8.0	7.3		
299	2/16/2014	-	-	9.1	9.4	-	9.7	9.4		
300	2/17/2014	-	-	13.0	12.7	-	12.9	12.8		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 22 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
301	2/18/2014	-	-	20.5	20.1	-	20.7	20.5		Cologne, winter 2014 validation campaign
302	2/19/2014	-	-	13.6	14.8	-	14.2	14.3		
303	2/20/2014	-	-	6.9	6.4	-	8.5	8.5		
304	2/21/2014	-	-	8.0	7.9	-	10.0	9.4		
305	2/22/2014	-	-	4.8	5.5	-	8.0	7.1		
306	2/23/2014	-	-	7.3	7.1	-	8.7	8.9		
307	2/24/2014	-	-	14.2	13.2	-	13.2	13.1		
308	2/25/2014	-	-	13.4	12.5	-	12.1	12.6		
309	2/26/2014	-	-	19.9	17.6	-	18.3	17.9		
310	2/27/2014	-	-	12.4	10.6	-	12.3	12.5		
311	2/28/2014	-	-	10.8	10.2	-	11.0	10.9		
312	3/1/2014	-	-	15.3	15.0	-	16.4	16.5		
313	3/2/2014	-	-	19.1	20.3	-	19.6	20.5		
314	3/3/2014	-	-	10.4	12.3	-	11.8	11.9		
315	3/4/2014	-	-	26.5	25.0	-	25.9	26.3		
316	3/5/2014	-	-	44.0	43.7	-	41.9	42.5		
317	3/6/2014	-	-	45.0	43.8	-	38.9	40.6		
318	3/7/2014	-	-	58.4	56.7	-	50.6	52.6		
319	3/8/2014	-	-	51.3	51.2	-	44.2	45.7		
320	3/9/2014	-	-	29.1	27.9	-	27.4	27.5		

Annex 6 **Ambient conditions at the field test sites** **Page 1 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
1	11/19/2012	Cologne, winter						
2	11/20/2012		No weather data available					
3	11/21/2012							
4	11/22/2012		8.2	1013	79.5	0.6	150	0.0
5	11/23/2012		8.5	1010	88.3	0.1	147	9.3
6	11/24/2012		11.6	1005	78.5	0.9	156	0.3
7	11/25/2012		8.8	1004	70.3	1.4	161	0.3
8	11/26/2012		8.9	997	83.3	0.3	150	5.9
9	11/27/2012		7.5	998	81.2	0.1	125	0.3
10	11/28/2012		6.0	997	81.3	1.8	84	0.0
11	11/29/2012		4.0	999	81.0	1.0	80	0.0
12	11/30/2012		1.6	1005	83.8	0.1	157	0.0
13	12/1/2012		2.9	1003	83.1	0.7	156	5.1
14	12/2/2012		3.9	1006	82.3	1.3	146	0.3
15	12/3/2012		3.7	997	87.7	0.5	158	7.2
16	12/4/2012		4.5	993	84.3	1.0	114	5.7
17	12/5/2012		2.1	999	85.7	0.8	120	4.2
18	12/6/2012		0.9	1005	79.9	0.7	151	0.0
19	12/7/2012		-2.6	1001	89.4	0.0	108	0.0
20	12/8/2012		-2.6	1016	86.2	0.0	125	0.9
21	12/9/2012		4.0	1002	87.0	1.8	149	16.1
22	12/10/2012		1.9	1010	81.4	2.6	78	1.8
23	12/11/2012		-0.2	1018	74.8	0.8	128	0.0
24	12/12/2012		-0.5	1010	71.4	0.5	136	0.0
25	12/13/2012		0.9	1000	75.6	0.5	148	0.0
26	12/14/2012		7.1	988	82.4	1.3	157	4.2
27	12/15/2012		8.7	995	78.6	1.2	173	4.7
28	12/16/2012		7.2	997	85.2	0.4	151	7.4
29	12/17/2012		7.2	999	85.4	0.1	141	3.0
30	12/18/2012		6.2	1011	88.1	0.0	145	0.9

Annex 6 **Ambient conditions at the field test sites** **Page 2 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
31	12/19/2012	Cologne, winter	4.2	1014	85.6	0.3	154	0.0
32	12/20/2012		2.8	1003	85.8	1.4	150	7.2
34	12/21/2012		6.0	1007	91.2	0.0	153	2.1
34	12/22/2012		8.7	1001	89.0	1.0	148	25.7
35	12/23/2012		10.6	1001	87.5	0.8	139	8.4
36	12/24/2012		11.8	995	76.0	0.7	155	2.4
37	12/25/2012		9.4	996	77.1	2.1	162	4.2
38	12/26/2012		9.1	1000	76.1	2.3	165	4.2
39	12/27/2012		7.3	1004	86.2	0.5	129	9.8
40	12/28/2012		8.4	1015	85.1	0.5	157	1.8
41	12/29/2012		10.4	1005	72.7	2.2	168	0.3
42	12/30/2012		8.6	1009	72.5	2.6	171	3.3
43	12/31/2012		9.9	1000	71.3	3.3	177	2.1
44	1/1/2013		6.1	1006	82.0	0.7	143	3.0
45	1/2/2013		7.5	1020	79.6	0.8	155	1.8
46	1/3/2013		10.6	1026	88.3	0.6	126	2.4
47	1/4/2013		9.1	1027	89.3	0.7	120	0.9
48	1/5/2013		8.4	1025	86.1	0.3	126	0.0
49	1/6/2013		9.1	1022	86.6	0.4	115	0.0
50	1/7/2013		8.2	1020	80.0	0.3	143	0.0
51	1/8/2013		7.6	1017	78.6	0.3	141	0.0
52	1/9/2013		5.8	1010	87.0	0.2	136	6.3
53	1/10/2013		4.0	1006	80.2	0.7	129	2.4
54	1/11/2013		-1.4	1011	78.3	0.0	153	0.0
55	1/12/2013		-1.5	1010	70.1	0.1	141	0.0
56	1/13/2013		-0.6	1009	70.0	0.2	145	0.0
57	1/14/2013		-2.5	1003	77.5	0.6	140	0.0
58	1/15/2013		-1.5	999	87.5	0.1	139	0.0
59	1/16/2013		-2.1	1006	84.8	0.0	87	0.0
60	1/17/2013		-2.0	1009	84.7	0.2	118	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 3 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
61	1/18/2013	Cologne, winter	-1.2	997	75.2	0.9	147	0.0
62	1/19/2013		-3.3	990	73.9	0.7	147	0.0
63	1/20/2013		-0.9	988	84.1	0.0	148	0.0
64	1/21/2013		-0.1	993	84.0	0.0	152	0.0
65	1/22/2013		0.2	999	80.4	0.0	149	0.0
66	1/23/2013		-0.5	1002	78.9	0.2	128	0.6
67	1/24/2013		-1.1	1010	74.4	0.6	126	0.0
68	1/25/2013		-1.9	1008	77.1	1.0	155	0.0
69	1/26/2013		-0.1	1004	81.5	0.9	148	0.6
70	1/27/2013		3.1	999	85.4	0.9	160	10.2
71	1/28/2013		6.9	1004	78.3	1.9	172	9.8
72	1/29/2013		11.9	1001	82.4	2.0	177	4.2
73	1/30/2013		10.9	1005	71.5	2.9	149	4.4
74	1/31/2013		8.6	1004	72.4	2.4	155	5.9
75	2/1/2013		5.0	990	88.1	0.9	127	11.7
76	2/2/2013		3.7	1006	78.8	1.8	94	0.9
77	2/3/2013		5.8	1006	82.0	2.0	144	3.0
78	2/4/2013		7.5	1000	76.2	1.9	149	3.3
79	2/5/2013		2.5	990	79.2	1.0	142	0.9
80	2/6/2013		2.4	997	84.5	0.9	112	5.4
81	2/27/2013	Bonn, winter	2.5	1021	78.9	0.9	185	0.0
82	2/28/2013		4.1	1017	71.8	1.2	250	0.0
83	3/1/2013		3.5	1016	72.0	1.7	249	0.0
84	3/2/2013		3.0	1015	67.4	1.2	238	0.0
85	3/3/2013		3.1	1014	72.8	0.5	196	0.0
86	3/4/2013		6.6	1007	57.8	1.4	140	0.0
87	3/5/2013		8.5	999	56.5	1.2	136	0.0
88	3/6/2013		11.5	993	48.5	0.4	143	0.0
89	3/7/2013		12.3	990	67.5	0.5	144	2.1
90	3/8/2013		13.7	990	72.1	1.4	138	1.5

Annex 6 **Ambient conditions at the field test sites** **Page 4 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
91	3/9/2013	Bonn, winter	10.6	991	72.2	1.2	178	3.6
92	3/10/2013		1.6	993	81.8	3.6	273	2.4
93	3/11/2013		-1.4	996	78.7	1.9	241	0.0
94	3/12/2013		-3.4	995	83.9	2.0	276	0.0
95	3/13/2013		-1.2	999	72.8	1.1	224	0.3
96	3/14/2013		-1.3	1004	75.3	1.1	209	2.1
97	3/15/2013		2.3	1006	58.8	1.0	132	2.1
98	3/16/2013		5.3	998	49.0	3.4	131	0.0
99	3/17/2013		4.7	988	78.3	2.2	131	0.9
100	3/18/2013		6.6	985	60.3	0.7	131	0.0
101	3/19/2013		5.8	991	74.5	0.6	157	1.2
102	3/20/2013		2.6	999	85.8	1.9	240	13.2
103	3/21/2013		0.6	1010	78.8	1.0	229	0.3
104	3/22/2013		2.9	1006	63.4	3.2	146	0.0
105	3/23/2013		1.1	1005	56.8	4.2	146	0.0
106	3/24/2013		1.0	1005	42.8	3.3	153	0.0
107	3/25/2013		0.9	1004	49.0	2.6	153	0.0
108	3/26/2013		1.6	1003	44.1	2.3	168	0.0
109	3/27/2013		2.6	1001	49.5	2.0	148	0.0
110	3/28/2013		3.0	999	58.9	1.2	243	0.0
111	3/29/2013		0.4	999	77.8	1.1	271	1.5
112	3/30/2013		1.8	1000	68.9	1.3	271	0.0
113	3/31/2013		1.7	1003	68.2	1.1	269	0.0
114	4/1/2013		3.2	1001	52.9	1.5	190	0.0
115	4/2/2013		3.6	1003	52.2	1.8	201	0.0
116	4/3/2013		3.0	1005	58.0	1.8	158	0.0
117	4/4/2013		4.4	1001	60.5	1.8	166	0.0
118	4/5/2013		3.8	1003	67.8	1.6	267	0.0
119	4/6/2013		3.6	1012	73.9	1.7	221	0.3
120	4/7/2013		6.4	1008	51.4	0.7	174	0.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
121	4/8/2013	Bonn, winter	7.0	996	63.9	1.4	130	0.9
122	4/9/2013		8.3	992	78.0	1.2	133	1.8
123	4/10/2013		9.7	996	77.3	1.4	154	6.0
124	4/11/2013		13.0	991	69.6	1.3	169	6.0
125	4/12/2013		12.2	997	69.0	1.1	154	4.4
126	4/13/2013		13.9	1011	56.8	1.4	152	0.6
127	4/14/2013		18.3	1011	57.0	1.5	136	0.0
128	4/15/2013		17.5	1011	67.0	1.5	214	2.7
129	4/16/2013		18.4	1011	54.4	0.9	149	0.0
130	4/17/2013		18.7	1009	54.3	0.6	141	0.0
131	4/18/2013		15.6	1009	46.2	3.1	210	0.0
132	4/19/2013		11.4	1017	57.7	3.5	260	0.0
134	4/20/2013		10.3	1018	51.5	3.3	274	0.0
134	4/21/2013		11.1	1009	57.4	1.1	253	0.0
135	4/22/2013		13.2	1009	46.5	1.4	217	0.0
136	4/23/2013		13.7	1014	63.6	1.7	187	0.0
137	4/24/2013		17.9	1016	56.5	1.0	167	0.0
138	4/25/2013		20.0	1010	51.5	0.4	146	0.0
139	4/26/2013		11.9	1000	77.3	2.2	230	9.9
140	4/27/2013		7.8	1003	70.3	3.2	293	0.0
141	4/28/2013		9.2	1007	68.3	0.7	169	0.0
142	4/29/2013		12.0	1010	56.1	1.9	209	0.0
143	4/30/2013		11.8	1014	57.9	1.0	214	0.0
144	5/1/2013		14.6	1011	62.8	0.9	173	0.3
145	5/2/2013		16.5	1009	60.4	1.1	200	0.0
146	5/3/2013		16.0	1007	60.0	1.5	253	0.0
147	5/4/2013		15.7	1011	54.5	2.4	238	0.0
148	5/5/2013		16.4	1013	55.9	1.3	190	0.0
149	5/6/2013		19.8	1008	50.0	0.6	192	0.0
150	5/15/2013	Cologne, summer	No weather data available					

Annex 6 **Ambient conditions at the field test sites** **Page 6 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
151	5/16/2013	Cologne, summer	No weather data available					
152	5/17/2013		9.9	997	86.2	0.7	173	0.6
153	5/18/2013		12.1	1001	74.2	0.1	140	0.0
154	5/19/2013		17.1	998	64.4	1.5	203	12.1
155	5/20/2013		11.4	1001	83.5	0.3	172	3.3
156	5/21/2013		12.7	1002	78.2	1.4	185	21.3
157	5/22/2013		8.5	1004	79.4	1.4	172	12.7
158	5/23/2013		6.3	1001	80.7	0.9	205	1.5
159	5/24/2013		8.4	1004	67.0	0.2	149	0.0
160	5/25/2013		10.5	1005	71.3	1.9	176	9.8
161	5/26/2013		9.7	1003	79.2	2.7	195	6.5
162	5/27/2013		14.1	1000	61.6	0.9	170	0.0
163	5/28/2013		18.0	993	58.8	1.3	166	0.9
164	5/29/2013		9.2	996	89.4	0.6	164	25.2
165	5/30/2013		13.9	1000	68.4	0.4	196	0.3
166	5/31/2013		16.1	1002	70.0	2.3	197	0.0
167	6/1/2013		11.6	1011	76.2	2.2	187	0.0
168	6/2/2013		13.7	1017	54.1	2.4	213	0.0
169	6/3/2013		13.2	1018	58.9	2.0	195	0.0
170	6/4/2013		16.3	1012	63.2	0.8	189	0.0
171	6/5/2013		20.1	1010	53.6	0.2	172	0.0
172	6/6/2013		21.1	1011	51.4	0.2	182	0.0
173	6/7/2013		23.0	1010	51.4	0.3	186	0.0
174	6/8/2013		20.8	1005	60.2	1.1	163	0.0
175	6/9/2013		15.9	1002	71.7	1.0	199	2.4
176	6/10/2013		15.1	1006	70.0	0.5	193	0.0
177	6/11/2013		19.8	1009	57.4	0.2	176	0.0
178	6/12/2013		21.2	1008	66.3	0.3	151	0.3
179	6/13/2013		16.2	1008	77.3	1.4	158	20.4
180	6/14/2013		15.8	1009	65.6	0.1	200	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 7 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
181	6/15/2013	Cologne, summer	16.8	1006	60.6	1.1	172	0.0
182	6/16/2013		18.1	1007	61.0	0.3	159	0.0
183	6/17/2013		23.6	1005	64.7	0.2	186	0.6
184	6/18/2013		28.2	1005	57.4	0.2	181	0.0
185	6/19/2013		27.2	1003	64.4	1.1	190	0.0
186	6/20/2013		19.7	1003	79.5	0.4	187	32.4
187	6/21/2013		17.9	1006	73.8	0.7	155	2.7
188	6/22/2013		18.4	1004	67.4	1.0	172	2.4
189	6/23/2013		16.0	1006	69.7	1.6	176	1.5
190	6/24/2013		13.7	1014	76.2	1.8	163	0.3
191	6/25/2013		13.0	1019	68.8	0.9	232	0.0
192	6/26/2013		13.6	1018	71.0	0.7	197	11.2
193	6/27/2013		12.6	1014	77.9	0.4	191	8.9
194	6/28/2013		13.7	1010	89.5	0.2	173	22.5
195	6/29/2013		13.8	1014	74.0	1.1	222	0.0
196	6/30/2013		17.6	1012	67.3	0.5	163	0.0
197	7/1/2013		19.4	1008	68.3	0.4	189	0.0
198	7/2/2013		21.8	1003	59.2	0.2	179	0.9
199	7/3/2013		16.9	1005	87.7	0.1	179	12.7
200	7/4/2013		20.4	1015	68.6	0.6	187	0.0
201	7/5/2013		19.9	1021	73.4	0.3	186	0.0
202	7/6/2013		22.9	1020	61.9	0.2	147	0.0
203	7/7/2013		23.6	1021	54.0	0.7	174	0.0
204	7/8/2013		24.0	1019	55.0	0.8	156	0.0
205	7/9/2013		23.4	1014	55.6	0.8	207	0.0
206	7/10/2013		19.1	1012	61.2	2.0	191	0.0
207	7/11/2013		14.8	1014	73.1	0.4	174	0.0
208	7/12/2013		16.8	1014	68.2	0.7	184	0.0
209	7/13/2013		18.0	1015	66.5	0.5	196	0.0
210	7/14/2013		No weather data available					

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
211	7/30/2013	Rodenkirchen, summer	18.2	1006	80.0	2.4	201	7.3
212	7/31/2013		20.1	1006	75.8	3.4	233	0.0
213	8/1/2013		24.0	1004	62.5	2.9	117	0.0
214	8/2/2013		27.8	1000	48.6	3.4	128	2.7
215	8/3/2013		23.1	1006	64.3	3.3	230	0.0
216	8/4/2013		20.5	1009	64.3	1.6	122	0.0
217	8/5/2013		22.8	1004	62.3	2.6	128	0.1
218	8/6/2013		21.6	1003	62.9	2.7	213	0.0
219	8/7/2013		19.5	999	80.7	2.9	175	1.2
220	8/8/2013		16.8	1006	82.9	2.4	233	0.7
221	8/9/2013		17.9	1008	73.5	1.8	174	0.0
222	8/10/2013		17.3	1008	71.8	3.0	241	0.0
223	8/11/2013		17.0	1007	62.9	2.5	199	0.0
224	8/12/2013		16.9	1004	75.3	2.3	202	0.4
225	8/13/2013		15.5	1007	73.7	2.9	217	0.0
226	8/14/2013		14.5	1011	75.3	1.8	161	0.0
227	8/15/2013		17.2	1010	73.1	2.0	151	0.0
228	8/16/2013		20.9	1005	59.1	2.4	167	0.0
229	8/17/2013		21.4	1003	65.8	2.1	226	0.0
230	8/18/2013		19.6	1001	81.0	3.2	174	7.8
231	8/19/2013		16.9	1005	83.0	3.2	263	0.5
232	8/20/2013		14.3	1016	78.9	1.6	154	0.0
234	8/21/2013		15.5	1013	70.6	1.7	141	0.0
234	8/22/2013		18.2	1008	65.3	1.8	154	0.0
235	8/23/2013		20.3	1005	62.3	2.4	128	0.0
236	8/24/2013		17.8	1000	80.0	2.7	135	5.9
237	8/25/2013		16.2	1000	96.4	1.6	224	2.5
238	8/26/2013		16.1	1003	81.8	1.7	141	0.0
239	8/27/2013		17.1	1003	69.7	1.7	142	0.0
240	8/28/2013		15.7	1007	78.3	1.6	166	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
241	8/29/2013	Rodenkirchen, summer	17.0	1010	72.2	1.8	146	0.0
242	8/30/2013		17.1	1008	72.8	1.8	189	0.0
243	8/31/2013		16.4	1009	81.1	2.7	244	2.0
244	9/1/2013		13.9	1015	70.5	2.9	256	0.0
245	9/2/2013		17.1	1013	70.7	3.5	269	0.0
246	9/3/2013		17.2	1015	82.2	1.6	145	0.0
247	9/4/2013		20.5	1010	70.6	2.0	112	0.0
248	9/5/2013		23.6	1002	61.5	3.6	126	0.0
249	9/6/2013		23.7	998	60.2	3.6	166	0.0
250	9/7/2013		17.9	1005	88.0	2.2	225	21.3
251	9/8/2013		14.0	1007	94.6	2.5	244	2.1
252	9/9/2013		14.0	1005	80.5	2.8	186	2.7
253	9/10/2013		12.8	1001	81.3	5.0	255	9.2
254	9/11/2013		12.8	1001	91.5	3.2	270	5.8
255	9/12/2013		13.5	1004	92.0	2.5	277	7.2
256	9/13/2013		15.2	1008	84.4	2.0	194	1.0
257	9/14/2013		15.3	1001	91.0	3.1	214	3.8
258	9/15/2013		13.7	999	79.4	2.3	280	8.1
259	9/16/2013		12.8	990	72.3	4.3	238	0.0
260	9/17/2013		9.9	991	81.7	3.8	184	5.8
261	9/18/2013		11.7	988	92.8	2.7	270	1.2
262	9/19/2013		12.3	1000	79.4	2.7	225	1.8
263	9/20/2013		13.8	1004	83.7	2.9	248	0.0
264	9/21/2013		12.9	1014	83.8	1.2	165	0.0
265	1/13/2014	Cologne, winter 2014 validation campaign	6.8	1002	82.5	0.0	210	0.0
266	1/14/2014		6.3	1001	77.9	0.3	203	0.0
267	1/15/2014		5.3	998	86.2	0.3	205	3.9
268	1/16/2014		7.8	993	80.2	0.2	220	0.0
269	1/17/2014		8.2	994	72.4	0.3	209	0.3
270	1/18/2014		6.5	992	75.3	0.7	202	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
271	1/19/2014	Cologne, winter 2014 validation campaign	5.7	994	80.7	0.2	202	0.0
272	1/20/2014		3.8	1000	83.9	0.3	135	0.0
273	1/21/2014		4.0	1005	87.1	0.0	186	0.0
274	1/22/2014		2.7	1006	84.8	0.1	203	0.0
275	1/23/2014		3.8	1004	87.2	0.2	193	8.0
276	1/24/2014		4.1	1010	86.2	0.0	188	0.3
277	1/25/2014		5.0	1004	79.5	1.1	208	6.5
278	1/26/2014		5.1	991	79.6	0.8	207	18.9
279	1/27/2014		4.9	990	75.6	0.8	214	0.3
280	1/28/2014		3.8	992	73.6	0.6	204	0.0
281	1/29/2014		2.6	996	71.0	1.1	198	0.0
282	1/30/2014		2.5	1000	72.6	0.2	194	0.0
283	1/31/2014		5.7	996	70.7	0.6	204	0.3
284	2/1/2014		5.5	997	81.6	0.5	214	3.6
285	2/2/2014		4.2	1008	76.5	0.5	207	0.0
286	2/3/2014		4.9	1001	77.9	0.7	203	0.0
287	2/4/2014		5.9	998	75.1	0.3	204	0.0
288	2/5/2014		7.4	992	73.8	1.2	209	0.0
289	2/6/2014		10.2	989	66.1	1.6	210	5.1
290	2/7/2014		7.6	991	72.7	2.4	216	7.7
291	2/8/2014		7.7	984	70.0	1.9	219	0.6
292	2/9/2014		5.9	989	67.2	1.7	221	0.0
293	2/10/2014		5.5	990	75.2	0.3	205	1.8
294	2/11/2014		6.7	997	70.1	1.1	217	2.4
295	2/12/2014		7.1	994	68.5	1.7	224	0.3
296	2/13/2014		5.2	992	80.2	0.5	201	8.0
297	2/14/2014		8.6	992	74.6	1.4	217	9.5
298	2/15/2014		10.0	995	65.2	3.0	210	1.5
299	2/16/2014		7.4	1004	71.7	0.8	220	0.6
300	2/17/2014		4.2	1008	82.8	0.0	212	0.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
301	2/18/2014	Cologne, winter 2014 validation campaign	7.4	1005	76.0	0.1	214	1.8
302	2/19/2014		8.3	1006	77.5	0.3	208	0.0
303	2/20/2014		9.7	999	78.3	0.9	209	5.4
304	2/21/2014		5.8	1002	77.2	0.6	207	0.9
305	2/22/2014		5.5	1010	76.2	0.7	211	1.8
306	2/23/2014		7.3	1011	70.4	0.5	206	0.0
307	2/24/2014		12.9	1005	53.2	0.5	203	0.0
308	2/25/2014		No weather data available					
309	2/26/2014							
310	2/27/2014							
311	2/28/2014		6.6	994	75.3	0.3	199	0.0
312	3/1/2014		5.8	995	78.1	0.1	223	0.6
313	3/2/2014		6.1	990	69.9	0.7	199	0.0
314	3/3/2014		6.2	988	71.5	0.6	187	0.0
315	3/4/2014		7.9	1002	70.6	0.1	199	0.0
316	3/5/2014		4.6	1018	81.8	0.2	146	0.0
317	3/6/2014		7.6	1020	67.2	0.2	191	0.0
318	3/7/2014		11.1	1021	63.3	0.1	178	0.0
319	3/8/2014		12.4	1022	56.2	0.5	202	0.0
320	3/9/2014		13.1	1020	46.8	0.3	164	0.0

Appendix 2

Filter weighing procedure

A.1 Carrying out the weighing

All weighings are done in an air-conditioned weighing room. Ambient conditions are 20 °C ±1 °C and 50 % ±5 % relative humidity, which conforms to the requirements of Standard EN 14907.

The filters used in the field test are weighed manually. In order to condition the filters (including control filters), they are placed on sieves to avoid overlap.
The specifications for pre- and post-weighing are specified beforehand and conform to the Standard.

Before sampling = pre-weighing	After sampling = post-weighing
Conditioning 48 h + 2 h	Conditioning 48 h + 2 h
Filter weighing	Filter weighing
Re-conditioning 24 h +2 h	Re-conditioning 24 h + 2 h
Filter weighing and immediate packaging	Filter weighing

The balance is always ready for use. An internal calibration process is started prior to each weighing series. The standard weight of 200 mg is weighed as reference and the boundary conditions are noted down if nothing out of the ordinary results from the calibration process. Deviations of prior weighings conform to the Standard and do not exceed 20 µg (refer to Figure 1). All six control filters are weighed afterwards and a warning is displayed for control filters with deviations > 40 µg during evaluation. These control filters are not used for post-weighing. Instead, the first three acceptable control filters are used while the others remain in the protective jar in order to replace a defective or deviating filter, if necessary. Figure 2 shows an exemplary process over a period of more than four months.

All filters which display a difference of more than 40 µg between the first and second weighing are excluded from the pre-weighing process. Filters exhibiting deviations of more than 60 µg are not considered for evaluation after post-weighing, as conforming to standards.

Weighed filters are packed in separate polystyrene jars for transport and storage. These jars remain closed until the filter is inserted. Virgin filters can be stored in the weighing room for up to 28 days before sampling. Another pre-weighing is carried out if this period is exceeded.

Sampled filters can be stored for up to 15 days at a temperature of 23 °C or less. The filters are stored at 7 °C in a refrigerator.

A2 Filter evaluation

The filters are evaluated with the help of a corrective term in order to minimize relative mass changes caused by the weighing room conditions.

Equation:

$$Dust = MF_{post} – (M_{Tara} \times (MKon_{post} / MKon_{pre})) \quad (F1)$$

$MKon_{pre}$ = mean mass of the 3 control filters after 48 h and 72 h pre-weighing

$MKon_{post}$ = mean mass of the 3 control filters after 48 h and 72 h post-weighing

M_{Tara} = mean mass of the filter after 48 h and 72 h pre-weighing

MF_{post} = mean mass of the loaded filter after 48 h and 72 h post-weighing

Dust = corrected dust mass of the filter

This shows that the method becomes independent from weighing room conditions due to the corrective calculation. Influence due to the water content of the filter mass between virgin and loaded filter can be controlled and do not change the dust content of sampled filters. Hence, point 9.3.2.5 of EN 14907 is fulfilled.

The example of the standard weight between November 2008 and February 2009 shows that the permissible difference of max. 20 µg from the previous measurement is not exceeded.

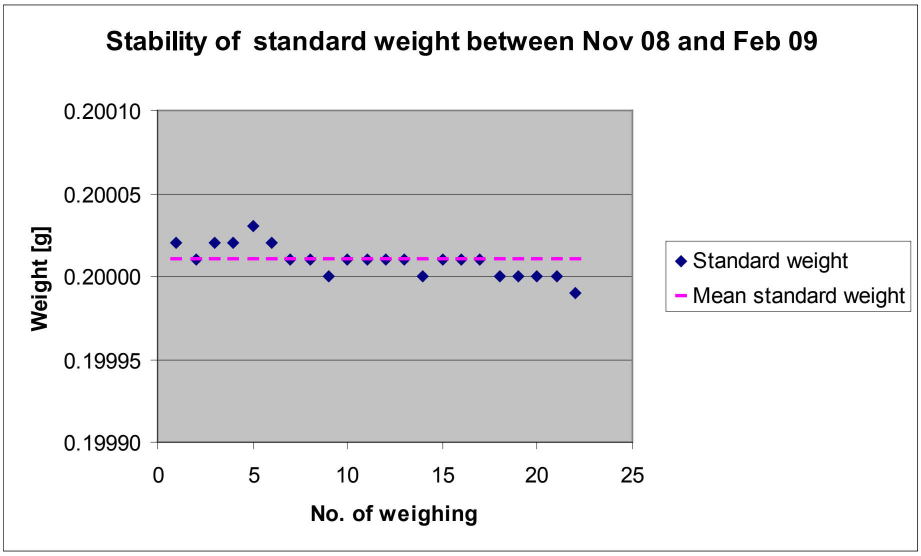

Figure 1: Stability of standard weight

Table 1: Stability of standard weight

Date	Weighing No.	Standard weight	Difference to the previous weighing
		g	µg
12.11.2008	1	0.20002	
13.11.2008	2	0.20001	-10
10.12.2008	3	0.20002	10
11.12.2008	4	0.20002	0
17.12.2008	5	0.20003	10
18.12.2008	6	0.20002	-10
07.01.2009	7	0.20001	-10
08.01.2009	8	0.20001	0
14.01.2009	9	0.20000	-10
15.01.2009	10	0.20001	10
21.01.2009	11	0.20001	0
22.01.2009	12	0.20001	0
29.01.2009	13	0.20001	0
30.01.2009	14	0.20000	-10
04.02.2008	15	0.20001	10
05.02.2009	16	0.20001	0
11.02.2009	17	0.20001	0
12.02.2009	18	0.20000	-10
18.02.2009	19	0.20000	0
19.02.2009	20	0.20000	0
26.02.2009	21	0.20000	0
27.02.2009	22	0.19999	-10

Marked in yellow = average value

Marked in green = lowest value

Marked in blue = highest value

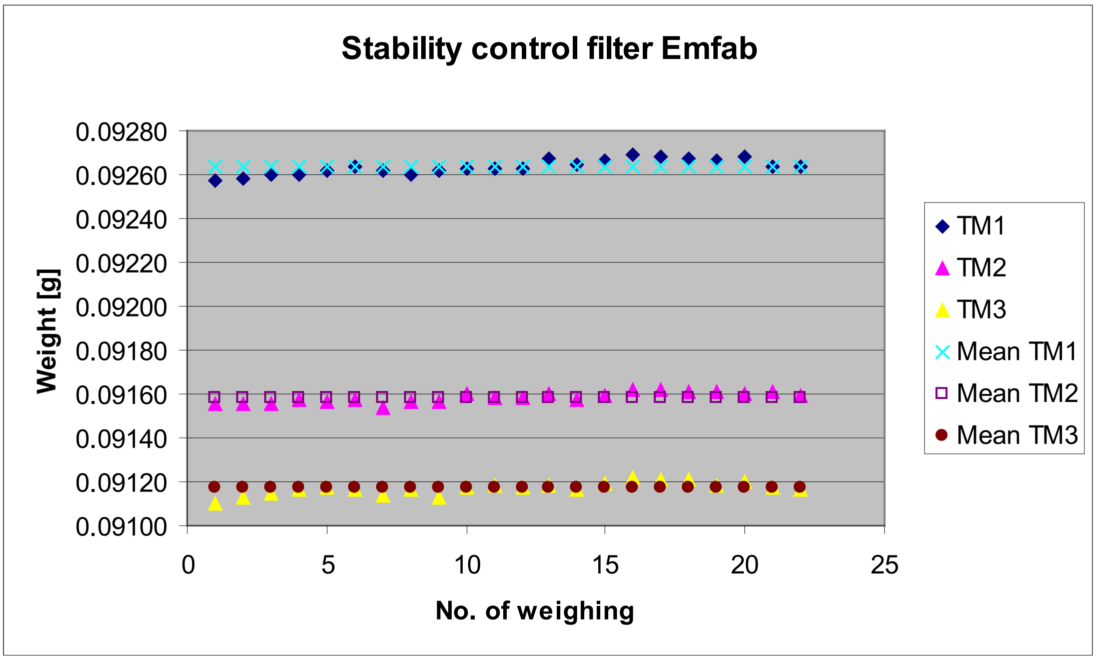

Figure 2: Stability of the control filters

Table 2: Stability of the control filters

	Control filter no.		
Weighing no.	TM1	TM2	TM3
1	0.09257	0.09155	0.09110
2	0.09258	0.09155	0.09113
3	0.09260	0.09155	0.09115
4	0.09260	0.09157	0.09116
5	0.09262	0.09156	0.09117
6	0.09264	0.09157	0.09116
7	0.09262	0.09154	0.09114
8	0.09260	0.09156	0.09116
9	0.09262	0.09156	0.09113
10	0.09263	0.09160	0.09117
11	0.09263	0.09158	0.09118
12	0.09263	0.09158	0.09117
13	0.09267	0.09160	0.09118
14	0.09265	0.09157	0.09116
15	0.09266	0.09159	0.09119
16	0.09269	0.09162	0.09122
17	0.09268	0.09162	0.09121
18	0.09267	0.09161	0.09121
19	0.09266	0.09161	0.09118
20	0.09268	0.09160	0.09120
21	0.09264	0.09161	0.09117
22	0.09264	0.09159	0.09116
Mean value	0.09264	0.09158	0.09117
Standard deviation.	3.2911E-05	2.4937E-05	2.8558E-05
Rel. standard deviation.	0.036	0.027	0.031
Median	0.09264	0.09158	0.09117
Lowest value	0.09257	0.09154	0.09110
Highest value	0.09269	0.09162	0.09122

Marked in yellow = average value

Marked in green = lowest value

Marked in blue = highest value

Appendix 3

Manual

Instruction Manual

Air Pollution Monitor 2 (APM-2)

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Table of Contents

1. Introduction

This instruction manual is intended to provide a systematic and comprehensive introduction to the features, functions and operation of the sampling system. This manual also contains a number of important safety warnings. Please read this manual completely and carefully so that you will be able to make use of the system's many functions and do so both safely and efficiently. Please note that details in the description of the device and in the illustrations may deviate from the properties found in your own unit.

1.1. Symbols and Typography

In the interest of making the text clearer and more understandable, the following symbols and typographic conventions are used.

The following apply to sections that deal with the parameterization and control of the device by way of the control unit:

- Elements that can be clicked or selected (e.g. menu items) are highlighted in blue
- Other words appearing in software screens are **boldfaced**
- Instructions regarding elements to be selected in sequence sometimes use arrows in the interest of brevity (e.g. Settings → Language → English)

The following apply to safety information:

⚠ **DANGER!**	This symbol indicates risk to life, serious injury and/or considerable property damage if the appropriate safety measures are not taken
⚠ **WARNING!**	This symbol indicates risk of lesser injury and property damage if the appropriate safety measures are not taken
WARNING!	without a warning triangle indicates a risk to property if the appropriate safety measures are not taken
CAUTION!	indicates that undesirable results or states could occur if the appropriate notes are not observed
NOTE:	indicates important information or emphasizes a part of the documentation to which particular attention must be paid

1.2. Intended Use

The sampling system may be used only for the purposes specified in this manual and only in conjunction with devices and components recommended and approved by the Comde-Derenda GmbH.

1.3. Operating Environment

The device is designed for operation at temperatures of from -20°C to +50°C. In the case of extended exposure to strong sunlight in conjunction with very high air temperatures (upwards of about 35°C), the system is to be set up beneath a self-supporting roof with an opening through which the air intake tube passes. The APM-2 is designed for outdoor use and may be operated without rain protection or the like.

1.4. Electromagnetic Compatibility

This is a Class A unit and may cause radio interference in residential areas. In this event the operator may be required to implement and pay for appropriate abatement measures. The device satisfies the requirements of the Electromagnetic Compatibility (EMC) Directive and harmonized European standards. Every modification to the system may have an effect on EMC characteristics.

1.5. Scope of Delivery

Included in the delivery are:

- 1 each Basic device APM-2
- 1 each Air intake tube (length 500 mm, diameter 12 mm)
- 1 each Impactor inlet PM_{10}
- 1 each Serial cable for connection to a PC
- 2 each SD memory card
- 1 each USB card reader
- 1 each Instruction manual
- 1 each Calibration record
- 1 each Set of keys for the equipment

2. Safety Instructions

This unit was engineered and tested in accordance with DIN EN 61010-1:2002-08 (Safety requirements for electrical equipment for measurement, control and laboratory use). It left the factory in perfect working condition. In order to maintain this condition and to ensure hazard-free operation please be absolutely sure to observe the following safety notes. Disregarding these warnings or noncompliance with these notes could results in fatalities, severe bodily injury and/or significant property damage. Also observe local safety requirements that govern dealings with electrical and electronic equipment carrying line voltage. Although the device was manufactured in accordance with recognized safety regulations, hazards or adverse effects for the unit or other property could arise during use.

Only suitably qualified personnel may work on this unit. This personnel shall be thoroughly familiar with all the safety notes and with the installation, operation and maintenance procedures contained in this instruction manual. Safe and fault-free operation of the unit presumes proper handling and correct installation, operation and maintenance.

This device may be used only for the purpose intended by Comde-Derenda GmbH (see 1.2). Unauthorized modifications and the use of accessories and spare parts not supplied or recommended by Comde-Derenda GmbH can result in property damage and personal injury.

WARNING! If it is to be expected that hazard-free operation is no longer possible, then the device shall be taken out of service and secured against unintentional restarting.

It is to be presumed that non-hazardous operation is no long possible:

- if the electronics unit exhibits visible damage
- if the unit no longer operates or shows obvious deviations from normal operations
- if an electrical connector has been damaged

As long as the unit is connected to the line power supply components carrying electrical voltage may become accessible when covers are opened or other parts are removed.

WARNING!

- The unit must be disconnected from all sources of electrical power prior to starting maintenance or repairs or replacing parts.

- Whenever it is unavoidable to carry out maintenance or repair work on devices that are opened and connected to the power supply, then such work may be carried out only by a qualified employee who is familiar with all the associated hazards.

- Any interruption in the protective ground wire either inside or outside the unit or disconnection of the ground wire may result in the unit becoming dangerous. Any intentional interruption of the ground wire circuit is prohibited!

- The line plug may be connected only to a socket with a protective ground contact. This safety feature may not be counteracted by using an extension cord that does not incorporate a protective ground wire.

3. System Overview

The APM-2 is a measuring device for direct and continuous determination of the suspended particulate matter of the fractions PM_{10} and $PM_{2.5}$ in outside air. The heart of the device is a highly sensitive scattered light photometer. The measuring method applied makes use of the specific physical features of light scattering in microparticles.

3.1. Functional Concept

Outside air is drawn in via a PM_{10} impactor inlet at a volume flow of 3.3 l/min. Particles larger than 10 µm are separated in this impactor inlet. In a virtual impactor the air drawn in is then divided into two partial flows. The aerosol now optionally goes from the axial flow (enrichment mode for recording PM_{10} concentration) or from the side flow (normal mode for recording $PM_{2.5}$ concentration) to the scattered light sensor system via solenoid valves.

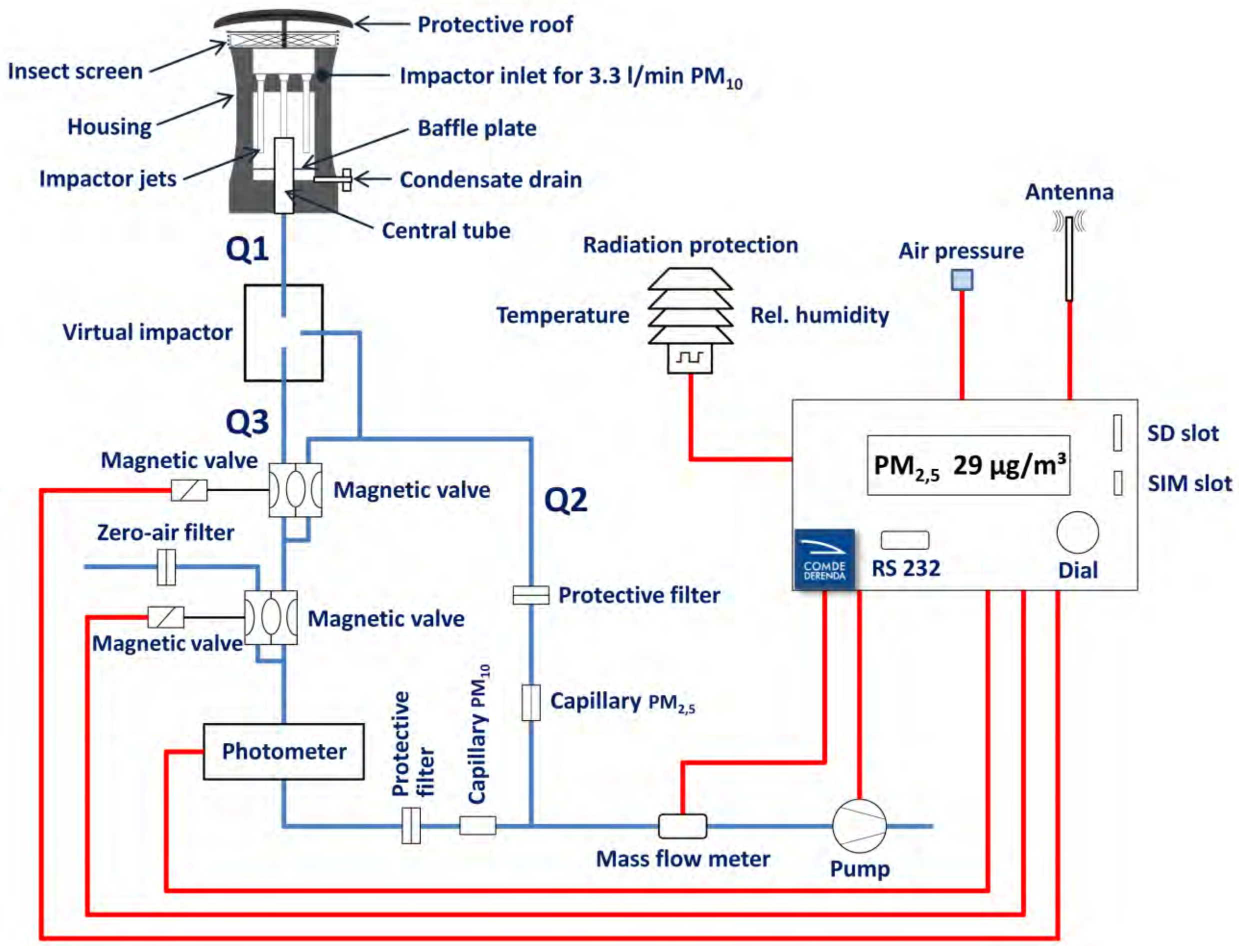


Fig. 1: Overview diagram

The light of a laser diode illuminates there a measurement volume defined by the optical beam path. The light reflected by the aerosol particles within this measurement volume is recorded by the detector positioned at an angle of 90°. The voltage signal generated and then amplified by the detector represents a direct measure for the mass concentration of the aerosol in the measurement volume (0-1000µg/m³). For the zero point adjustment, filtered air is fed to the scattered light sensor via the switching device at periodic intervals. The data determined are stored in the device memory as well as – if provided – on an SD memory card.

Fig. 2: Front side of APM-2

The physics of the light scattering on particulates causes aerosol particles with a diameter on the order of the light wavelength used – based on their mass – to scatter the light the most efficiently. That means they supply the greatest contribution to the signal. The maximum sensitivity for the wavelength of 650 nm used in the device is in a particle size range from 0.5 to 1 µm. Because of this characteristic, there are limits to application of simple scattered light photometry for measurement of the PM_{10} concentration. The measurement signal of a scattered light sensor used in outside air is primarily dominated by the $PM_{2.5}$ fraction.

Based on mass, the complementary coarse fraction $PM_{2.5-10}$ contributes significantly less to the scattered light signal and is therefore underrepresented in the measurement. The sensitivity deficit in the coarse fraction is thus compensated for in the device by a simple process: via selective enrichment of the concentration of the $PM_{2.5-10}$ fraction by a factor of 3.3/0.2=16.5 by means of a virtual impactor (see 3.1.3.), which is connected upstream from the scattered light sensor. Concentration enrichment is equivalent to an increase in sensitivity of the photometry for the $PM_{2.5-10}$ fraction.

The system consists of the following components:

3.1.1. Control Unit

All the system settings are entered at the APM-2 control unit (Fig. 3). The unit has the following elements and functions:

- Main switch used to switch the unit on and off
- Jog dial to select functions and to enter or change parameters
- An illuminated graphic display showing system functions, parameters, data and alarms
- SD memory card slot for automatic storage of sampling data and parameters and for updating the equipment firmware (also for the filter changer unit)

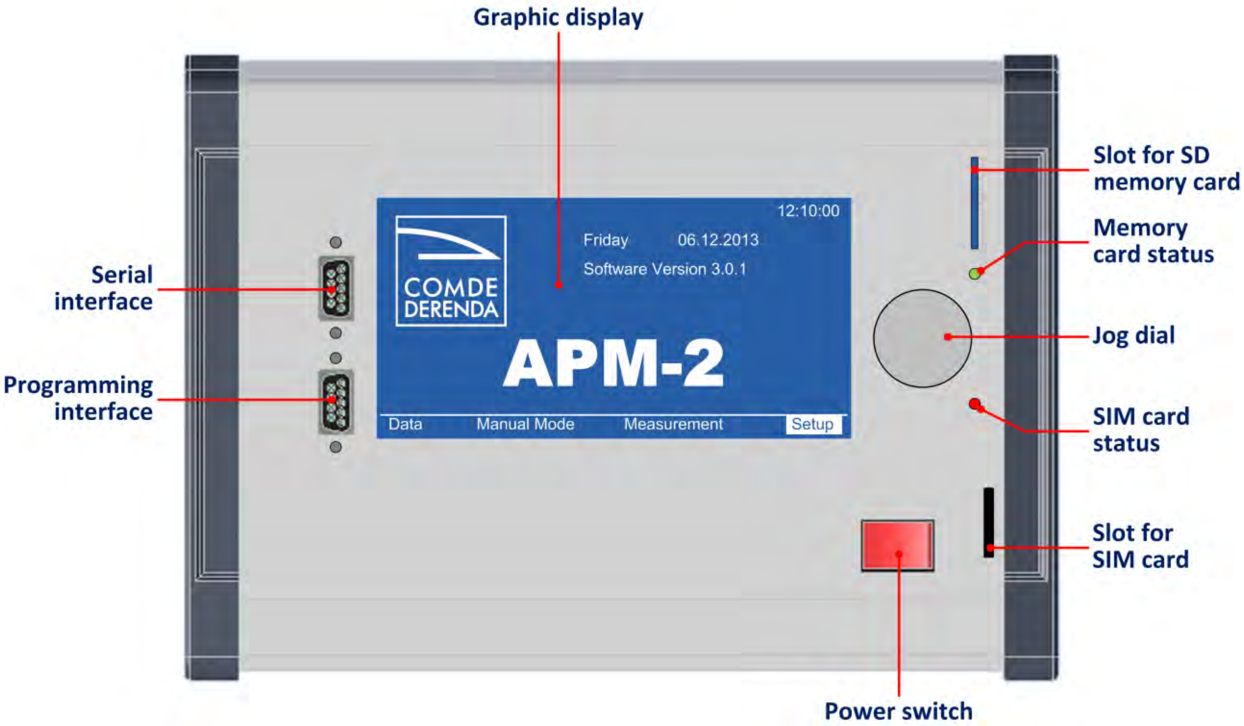


Fig. 3: Control unit

- Programming interface , exclusively for programming purposes; can not be used for data transmission
- Serial interface (RS-232) for data transfer as per the Bayern-Hessen-Protokoll (Bavaria-Hesse protocol)
- Status indicator for the SD memory card:
  - Green = Memory card is on standby
  - Red = Reading from or writing to the memory card
  - Orange = Firmware update being transferred to internal flash memory
  - Dark = No memory card installed
- GSM/GPRS module with SIM card slot for online data transmission via mobile phone network (optional)
- Status indicator for the GSM/GPRS module (slow blink, rapid blink, steady light)

Fig. 4: External sensor

3.1.2. External Sensor

The unit's external sensor (Fig. 4) is used for continuous registration of temperature and relative humidity. The ambient temperature is measured at an accuracy of ±0.5 K in a range of from -40 to +80 °C, relative humidity at an accuracy of ±3 % in a range of from 0 to 100 %.

The sensor is bolted to the unit by way of a mounting bracket (for assembly instruction see 4.3). A shield protects the sensor from direct sunlight and precipitation.

3.1.3. Virtual Impactor

The virtual impactor is located on the top side of housing and is connected to the impactor inlet via the intake tube. The outside air drawn in by means of an integrated pump at 3.3 l/min is divided into two partial flows by the virtual impactor. This division takes place in the area around two jets mounted opposite each other. In this process the side flow (3.1 l/min) is drawn off between the two jets perpendicular to the incoming air flow. Particles that cannot follow the side flow because of their mass inertia extensively maintain their direction of motion and thus enter the smaller axial flow (0.2 l/min). This results in the division into the side flow with exclusively smaller and lighter particles of the $PM_{2.5}$ fraction and the axial flow with a particle size of PM_{10}. The aerosol now goes optionally from the axial flow (enrichment mode) or from the side flow (normal mode) to the scattered light sensor via low-loss switching devices (pinch valves with straight passage). In the enrichment mode the APM-2 thus records the PM_{10} concentration, in normal mode the $PM_{2.5}$ concentration. For zero point adjustment, filtered light is fed to the scattered light sensor via the switching device at periodic intervals.

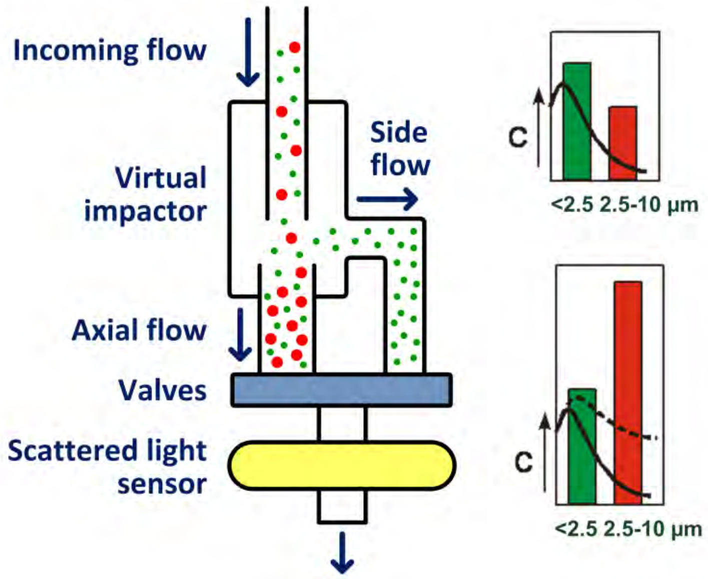


Fig. 5: Functional principle of the virtual impactor

3.1.4. Scattered Light Photometer Unit

The photometer unit consists of an intensity-stabilized laser diode and a semiconductor photodetector. The two components are mounted at an angle of 90° to each other, the unit is thus a single-angle sensor. The light reflected by the particles in a precisely defined measurement volume is recorded by the detector as described in 0. The photodetector then generates a corresponding voltage signal (0-5 V), which is subsequently amplified in a low-noise process.

To rule out temperature dependence of the photometer signal, the photometer is installed in a thermally insulated housing heated with a heating block and temperature-controlled to 40°C.

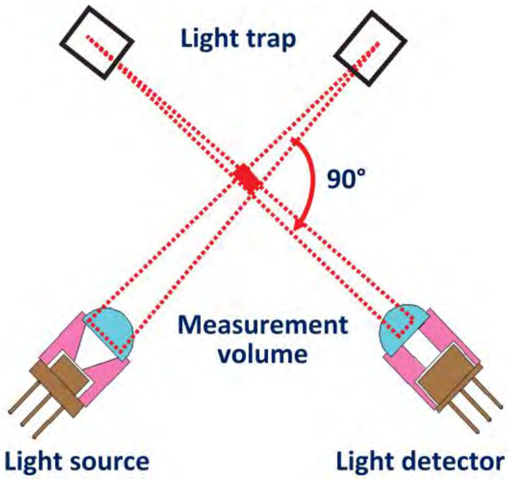


Fig. 6: Functional principle of the photometer unit

3.1.5. Impactor Inlet and Intake Tube

Fig. 7: APM-2 impactor inlet

Particles larger than 10 µm are separated by the PM_{10} impactor inlet (Fig. 7) during intake. In terms of its design it corresponds to the certified Derenda PM_{10} sampling inlet in accordance with DIN EN 12541. It was scaled down from 38.3 l/min to the smaller intake volume flow of 3.3 l/min for application in the APM-2. The impactor inlet is mounted on the intake tube that leads to the virtual impactor on the device roof.

The impactor inlet and the APM-2 are connected to each other via an intake tube made of sturdy stainless steel. The standard length of the tube is 500 mm, on request special lengths are also available. The outside diameter is 12 mm.

4. Assembly and Commissioning

4.1. Transport

The system and its components should be well packed and protected against shipping damage when moving the system to a new location. All the openings have to be closed during transportation in order to protect the device from dirt and grime. The device should be kept in an upright position during transport.

4.2. Intake Tube and Impactor Inlet

The device must be installed at a suitable, level installation site. The components required are the intake tube provided with a diameter of 12 mm and a length of 500 mm and the impactor inlet, which is not included in the scope of supply. To install the components mentioned, proceed as follows:

1. Remove the device and corresponding parts from the transport box and check that the contents are complete (see 1.5.).
2. Slowly and carefully place the intake tube into the intake flange of the virtual impactor from above and check to ensure that the tube is firmly seated.
3. Slowly and carefully place the impactor inlet on the upper end of the intake tube and check to ensure that the inlet is firmly seated (before starting a measurement, lubricate the impact plate of the impactor inlet).

Ensure that the upper and lower parts of the impactor inlet are firmly attached to the housing section.

4.3. External Sensor

The sensor is already screwed to a mounting bracket on delivery. To mount the sensor on the device, proceed as follows:

1. Place the entire unit (protective shield facing up) with the holes of the mounting bracket over the corresponding thread on the housing side.
2. Screw the unit firmly in place using the two knurled nuts provided.
3. Connect the cable of the sensor to the appropriate socket next to the threaded connection using the installed cable plug connector.

NOTE: If the system is used in a measurement container, the external sensor has to be mounted outside the container.

4.4. Connecting and Powering Up the System

1. Connect the power plug to the local power supply.

2. To activate the system, turn on the main power switch, located in the bottom right hand corner, and the line switch at the control unit.

After the unit has been switched on, the display will show the initialization screen for a short period of time. It will be followed by the start screen (Fig. 8). Shown in addition to the date and time of day is the model designation.

3. Read the information in the display at the control unit to determine whether the device has been correctly recognized as “APM-2”.

If the filter changer has not been identified correctly, check the cable connection and, if necessary, get in touch with Comde-Derenda GmbH.

NOTE: Whenever the system is moved to a new location observe an acclimatization period of one hour before sampling so that the external sensor can adjust to the ambient conditions.

4.5. Storage

The following instructions should be followed if the unit is moved or taken out of service for an extended period of time:

- The storage temperature should be in a range of from -10 °C to +60 °C.
- Cover the inlet for the virtual impactor.
- Protect the device’s inlets and outlets against grime.
- It is necessary to avoid both high relative humidity (which could cause condensation in case of a temperature change) and any severe vibration of the unit.

It is advisable to thoroughly clean and maintain the unit before any extended period out of service.

5. Operation and Device Settings

After the device is switched on with the main power and control unit power switches, the APM-2 main menu is shown in the display at the control unit (Fig. 8). The main menu enables access to all system settings and functions. The jog dial on the control unit (see Fig. 3) is used for navigation within the individual menus. Turn the jog dial to change from one menu item to the next and to change the parameter selected. The menu item selected at any given moment is shown inverse or outlined. Press the jog dial to confirm the selection of a menu item or to confirm a modified value.

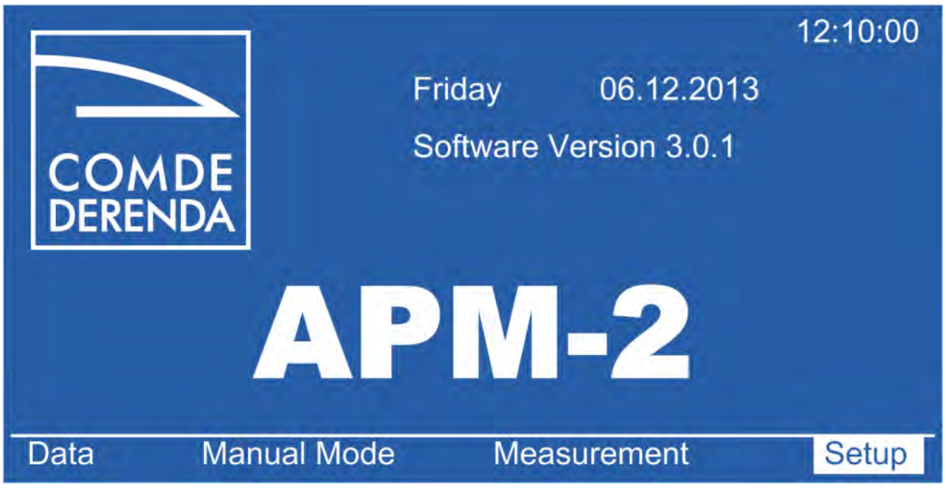


Fig. 8: Start screen with main menu

5.1. Software Design

The software makes possible convenient adaptation of all system settings and exact parameterization for the measurement being planned. See Fig. 10 for a survey of the menu structure implemented in the software. The main menu, which is always shown whenever the unit is switched on, provides access to the submenus described below.

5.1.1. *Setup* Menu

The **Setup** menu (Fig. 9) is used to specify numerous settings at the unit. It contains the following menu items and functions:

- Language: Selecting the language for the equipment software
- Calibration: Verifying the sensitivity of the photometer
- Leaking Test: Leak testing
- Date/time: Setting the date and time of day
- Transfer: Selection and configuration for data transmission
- Contrast: Setting the contrast level for the display screen
- Service: Displaying and adjusting the measured values output by the sensors

- System info: Information on the equipment data
- Administrator: Changing the password and resetting to default settings
- Device Adjustment: Special settings made by the manufacturer
- Measurem. Param.: Setting the particulate fractions to be used for measurement purposes ($PM_{2,5}$, PM_{10} or alternating mode), the target temperature for the heating block, the factors and offsets for the measurement, and the intervals for alternating mode (if selected)

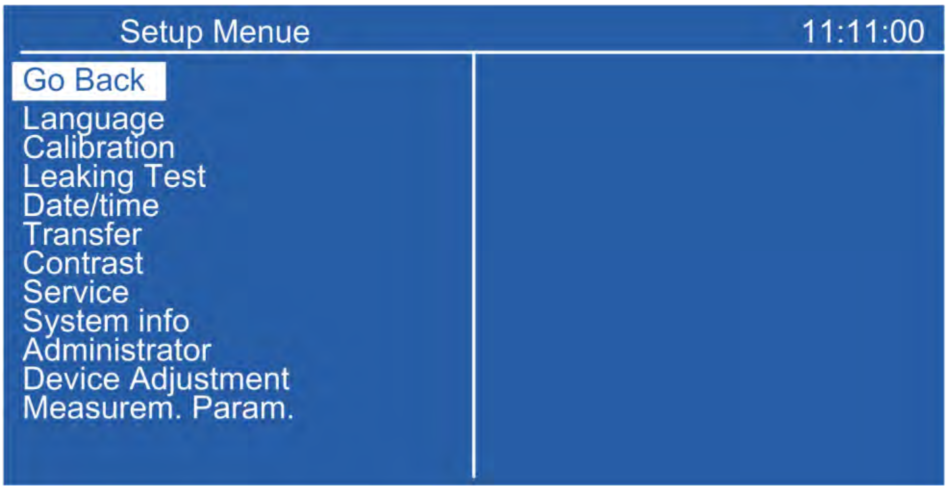


Fig. 9: Setup menu

5.1.2. *Data* Menu

The **Data** menu (Fig. 19) contains all the functions related to the data memory (overview, transmission and deletion of stored data) as well as a display of the capacity utilization of the internal data memory. In addition, this menu provides access to the update functions for the device software. For operation see 8.

5.1.3. *Measurement*

Clicking on this menu item will start the measurements and will control the volume flow correction. For operation see 6.

5.1.4. *Manual Mode* menu

The **Manual Mode** menu (Fig. 21) makes it possible to directly start the functions $PM_{2.5}$ measurement, PM_{10} measurement and flushing manually. The selected functions run without pauses until they are stopped by the user. This menu is primarily designed for service staff to test individual functions of the device. Normal users need it very rarely. For operation see 9.4.

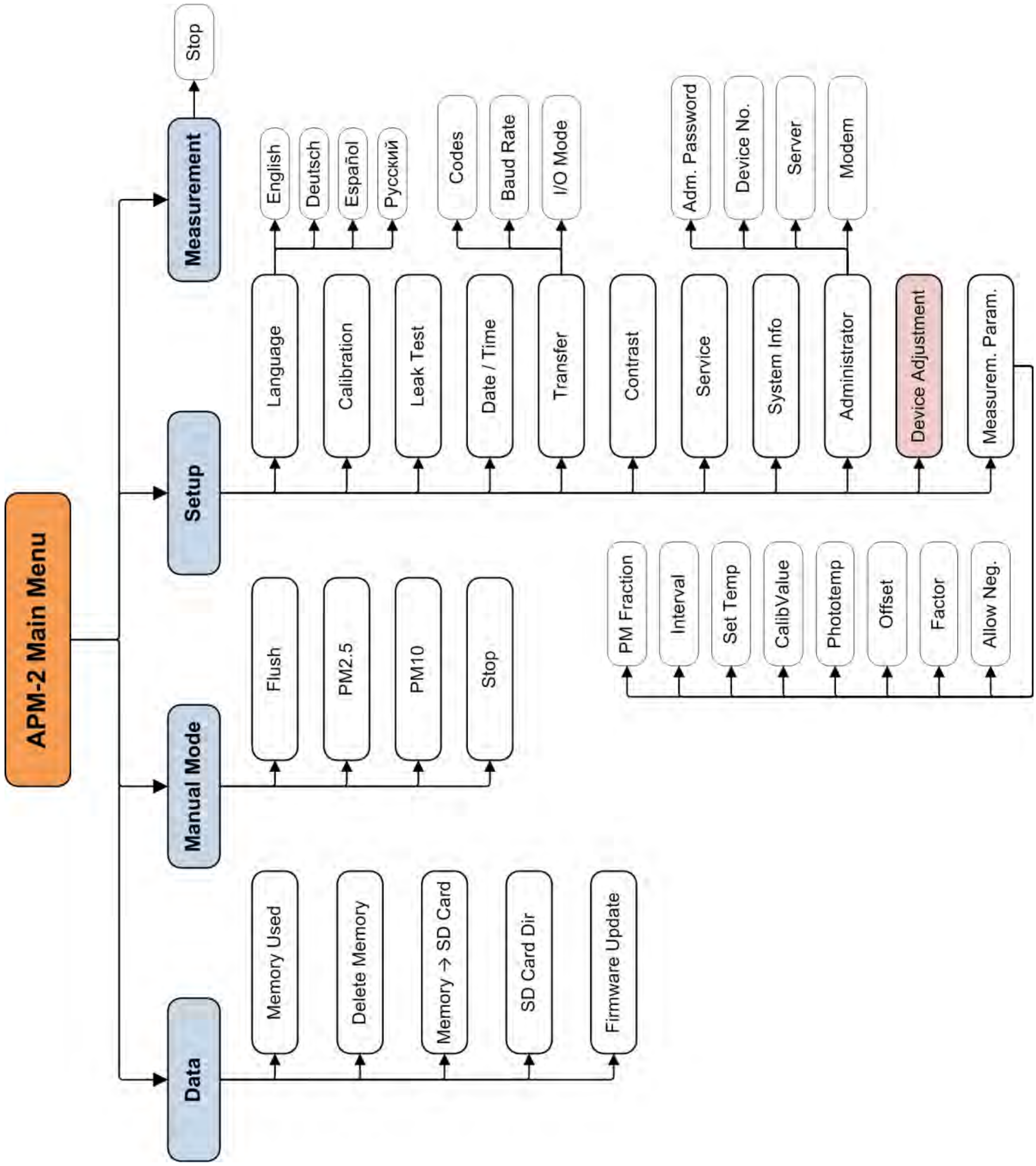


Fig. 10: APM-2 menu structure

5.2. Basic Settings

Certain basic settings will have to be made at the unit before starting the configuration work proper.

5.2.1. Choosing a Language

Follow these instructions to select the language for the operator prompts:

1. Select the Setup item in the main screen and confirm by pressing the jog dial.
2. When in the **Setup** menu select the Language item and confirm this.
3. Turn the jog dial to select the desired language displayed in the right half of the display (English, German, Spanish, Italian and Polish are available at present) and confirm your choice.
4. Confirm the Back menu item to return to the main menu.

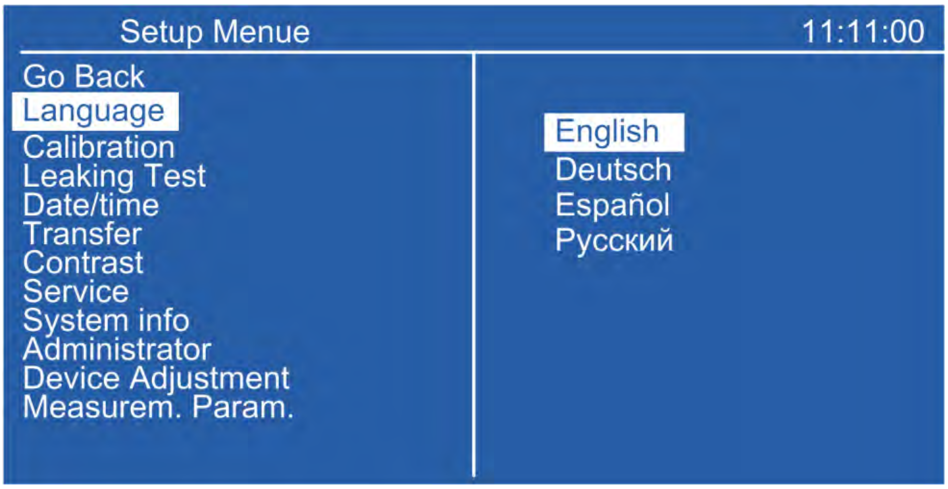


Fig. 11: Language selection

5.2.2. Setting Time of Day and Date

To set the current date and time of day:

1. Select the Setup item in the main screen and confirm by pressing the jog dial.
2. Select Date/time in the **Setup** menu and confirm.
3. Turn the jog dial in order to select the desired value (day, month, year, hour, minute, second) in the **Date/Time** screen (Fig. 12); the selected value will be outlined in each case.
4. To change the selected value press the jog dial – the value is now shown inverse – and turn the dial in the appropriate direction until the desired value is reached.
5. Press the jog dial to confirm the entry.
6. Repeat steps 3 to 5 for all the values to be changed.
7. Select and confirm Set to store the values shown.
8. Select and then confirm Back twice to return to the main menu.

Fig. 12: Setting time and date

5.2.3. Adjusting the Display's Contrast

In order to adjust the contrast in the display:

1. In the main screen select the Setup item and confirm this by pressing the jog dial.
2. In the **Setup** menu select Contrast and confirm your choice.
3. The current contrast value is shown in the right half of the display; turn the jog dial to adjust the contrast as desired, on a scale of from 0 (bright) to 63 (dark), and confirm your selection.
4. Confirm at the Back button to return to the main menu.

5.3. Data Transmission Settings

All the settings affecting data transmission are made in the **Transfer** menu (Fig. 14). Data transmission is effected through the RS-232 serial interface at the control unit.

5.3.1. Choosing the Input/Output Mode

You may choose from two different input/out modes for the serial interface:

1. BH (Bayern-Hessen-Protokoll / Bavaria-Hesse protocol): All measured values with a measured value identifier not equal to "000" will, upon request, be transmitted as per the Bavaria/Hesse protocol. The measured value transmission sequence is sorted in accordance with the measured value identifiers (see 5.3.2).
2. Serial (serial mode): All eight of the recorded measured values (see 5.3.2) and the following additional information will be forwarded via the RS-232 interface to a PC equipped with a terminal emulation program: date; time of day; device type and serial number; event; error (using semicolon as the separator).

Specify the I/O mode as follows:

1. In the main screen, select Setup and press the jog dial to confirm.
2. In the **Setup** menu, select Transfer and confirm your choice.
3. In the **Transfer** menu (Fig. 14) turn the jog dial until the desired mode (BH or Serial) is shown inverse.
4. Press the jog dial to confirm your mode selection.
5. Select Set and confirm to save your settings.

Date	Time	Type	S/N	Flush (mV)	PM2.5 (ug/m3)	PM10 (ug/m3)	Motor-speed (%)	Photometer Temp.('C)	POutside (hPa)	TOutside ('C)	rel. Humidity (%)	Event	Error
08.11.2013	12:02:22	APM-2	0	3081	0	0	0	43,8	1010,4	20	50	Start	ext. Sensor
08.11.2013	12:02:26	APM-2	0	3039	0	0	100	43,7	1010,7	20	50	Stop	ext. Sensor
08.11.2013	12:33:27	APM-2	0	0	0	0	0	40	1010,9	20	50	Start	ext. Sensor
08.11.2013	12:35:00	APM-2	0	3005	0	0	100	40,1	1010,4	20	50	PFlush	ext. Sensor
08.11.2013	12:36:00	APM-2	0	3001	0	0	100	40	1010,9	20	50	Flush	ext. Sensor
08.11.2013	12:38:00	APM-2	0	3001	28	0	67	40,1	1010,7	20	50	PM2.5	ext. Sensor

Fig. 13: Example for the way the measured data are output in serial mode at the interface (corresponds to the log file on the SD card)

5.3.2. Setting Identifier Codes for Individual Parameters

The following 8 measurement parameters can be transferred by the system:

1. Air Flush mV (voltage at photometer during zero air flushing)
2. Concent. PM2.5 µg/m³ ($PM_{2.5}$-concentration in µg/m³)
3. Concent. PM10 µg/m³ (PM_{10}-concentration in µg/m³)
4. Ambient temperature (temperature of the outside air)
5. Relative humidity (humidity of the outside air)
6. Ambient pressure (pressure of the outside air)
7. Photo. temperature (temperature of the photometer)
8. Error (warning message, if temperature and/or volume flow is outside of the tolerance range)

Individual identifier codes can be assigned to each of these parameters in preparation for data transmission in accordance with the Bavaria-Hesse protocol. The code for each parameter comprises three digits. To set the individual codes:

1. When in the **Transfer** menu, turn the jog dial until the numerical code next to the desired parameter (e.g. **Air Flush mV**) is shown outlined in the display, and confirm by pressing the jog dial.
2. Turn the dial to change the code, and press it again once the desired value has been reached.
3. Repeat steps 1 and 2 for all the other parameters.
4. Go to Set and press the jog dial to store the modified codes.
5. Go to Back and press the jog dial to leave the **Transfer** menu.

NOTE: Parameters with code “000” will not be transmitted in BH (Bavaria-Hesse protocol) mode. In Serial mode, all 8 parameters are generally transmitted.

Fig. 14: Tranfer menu

5.3.3. Setting the Baud Rate

The baud rate used for data transmission can be set optionally for 1200, 2400, 4800 or 9600. Make this setting as follows:

1. When in the **Transmission** menu select Baudrate and confirm your choice.
2. Turn the jog dial to change the value (displayed inverse) for the baud rate; press the jog dial to confirm the new value.

5.4. Administrator Settings

In order to access the **Administrator** settings it is necessary first to select Administrator in the **Setup** menu and then to enter the administrator password, digit by digit, and to confirm the entry by selecting OK and pressing on the jog dial (Fig. 15). Then you can make the settings described below in the administrator menu (Fig. 16). The password set at the factory is “0000”.

5.4.1. Editing the Device Number

In addition to the serial number assigned by the manufacturer, you may assign a five-digit device number to the instrument. To set or edit the device number:

1. In the **Setup** menu, select Administrator, enter your password as described above and go to the **Device Number** line.
2. Click on the left-hand digit and change it by turning the jog dial; apply and confirm the change by pressing the jog dial.
3. Edit the other four digits as described in step 2, above.

The device will then automatically store the change. The new device number will be used when using the Bavaria-Hesse protocol.

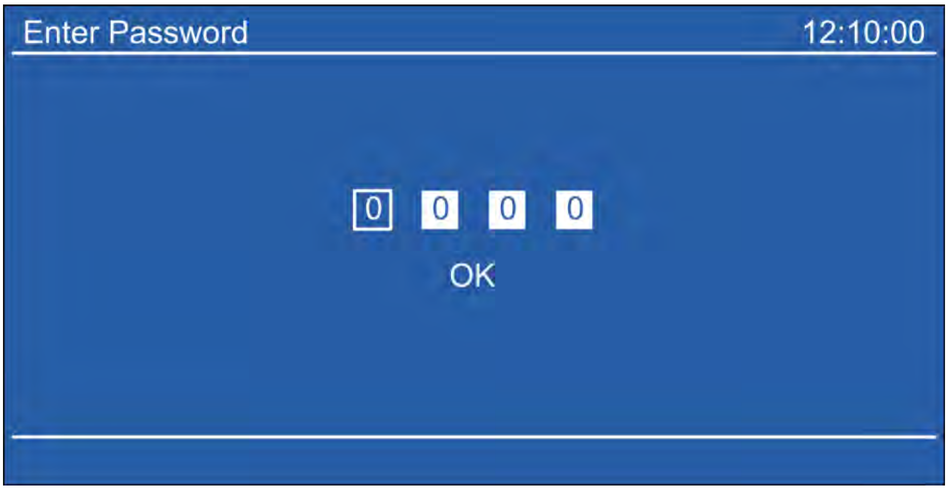


Fig. 15: Password screen

5.4.2. Changing the Administrator Password

Change the four-digit administrator password as follows:

1. When in the **Administrator** menu go to the line Admin-Password.
2. Click on the left-hand digit, turn the jog dial to change it, and confirm the change by pressing on the jog dial.
3. Proceed for the other three digits as described in step 2.

Fig. 16: Administrator menu

5.4.3. Server Settings

In preparation for transmitting the data measured by the APM-2 to a web server via the GSM/GPRS module (available as an option), it is necessary for an authorized web administrator to first install the corresponding software package to the target server. If you have any questions about this, please get in touch with Comde-Derenda. Then, in the **Administrator** menu, enter the server's domain and subdomain names. Do so as described below:

1. Store on an SD card a text (.txt) file, containing as text the designation of the domain / subdomain (e.g. "apm2.derenda.de"). The file must be named: *server.txt*.
2. Mount the card in the SD card drive at the APM-2 control unit.
3. In the **Administrator** menu, click on Server.
4. Answer the query which follows with "**Yes**".

The name of the server will then appear in the **Administrator** menu (see Fig. 16).

5.4.4. Selecting the Modem Type

To select an internal or external modem for data transmission:

1. In the **Administrator** menu, go to the **Modem** line.
2. Turn the jog dial to select either internal or external, and confirm by pressing the jog dial.

5.5. Device Adjustment Menu

The Device Adjustment menu enables authorized service technicians to make changes to specific system settings. This menu is protected by a special password.

6. Parameterizing and Starting a Measurement

After you have carried out the system settings described under 5.2 to 5.4, you can then parameterize and activate the planned measurement. After selecting the desired particulate matter fraction ($PM_{2.5}$, PM_{10} or alternating mode) and, if applicable, the desired interval for alternating mode and the set temperature of the heating block, you can start the measurement. Various data on the measurement are shown in the display during operation.

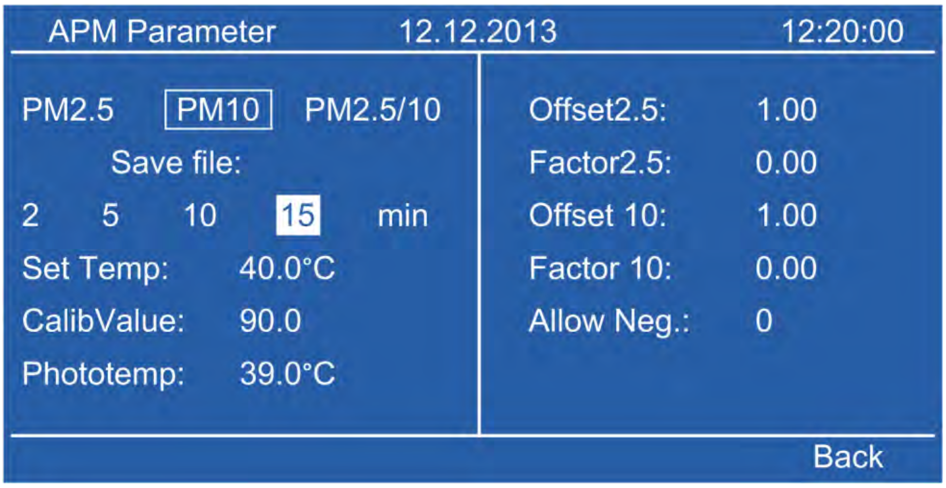


Fig. 17: Measurement parameters in the *APM parameter* menu

In order to access the measurement parameter settings it is necessary first to select Measurem.Param. in the **Setup** menu and then to enter the password, digit by digit, and to confirm the entry by selecting OK and pressing on the jog dial (Fig. 15). Then you can make the settings described below in the APM Parameter menu (Fig. 17). The password set at the factory is “0000”.

6.1. Selecting Particulate Matter Fraction

First of all, you select the particulate matter fraction to be measured. Here you have a choice between $PM_{2.5}$, PM_{10} and alternating measurement of both fractions (alternating mode). To select the fraction to be measured:

1. In the **Setup** menu, select Measurem.Param. and enter your password as described above.
2. In the **APM parameter** menu (Fig. 17), select the desired fraction (2.5, 10 or 2.5/10 for alternating mode) in the top left entry line by turning the jog dial to shift the inversion, and press the jog dial to confirm.

After that, the selected value appears outlined and the selection remains active until it is changed.

6.2. Selecting Interval for Alternating Mode and Storage

If you have selected alternating mode 2.5/10 as the measurement mode, the APM-2 alternately measures the concentration of the particulate matter fractions $PM_{2.5}$ and PM_{10}. The device automatically carries out the necessary zero air flushing for a period of two minutes on an hourly basis. Using the interval setting, you can specify the intervals at which the change between the two fractions should take place. In addition, this setting specifies at what intervals the measurement data are stored in the internal device memory and/or – if provided – on the SD card. To carry out the setting:

1. In the **Setup** menu, select Measurem.Param. and enter your password as described above.
2. In the **APM parameter** menu, select the desired interval (2, 5, 10 or 15 minutes) in the entry line under **Save file** by turning the jog dial to shift the inversion and pressing the jog dial to confirm.

The selected value then appears outlined and the selection remains active until it is changed.

6.3. Selecting the Set Temperature for the Photometer

The photometer unit has to be heated in order to rule out measurement errors (see 3.1.4). In normal cases the target temperature should be set to 40°C because this setting has proven to be appropriate in practice. To modify the value:

1. In the **Setup** menu, select Measurem.Param. and enter your password as described above.
2. In the **APM parameter** menu, turn the jog dial until the value to the right of **Set temp.** is outlined, and press the jog dial.
3. Turn the jog dial to change the value.
4. Press the jog dial again to save the changed value.

The selected value remains active until it is changed.

NOTE: The parameterization options in the APM parameter menu regarding volume flow calibration as well as the factor and offset settings are described in sections 9.5. and 9.8.

6.4. Starting the Measurement

After completing parameterization, start the measurement by calling up the APM-2 main menu; select the Measurement menu item and confirm by pressing on the jog dial. Measurement will commence immediately. After it has started, you will see the **APM Measurement** menu (Fig. 18) in the display.

7. Measurement Procedure

The measurement will not start until the photometer has reached its target temperature. When the measurement starts, first the pump runs up and all device components are activated. The selected measurement program begins after that.

7.1. Flushing with Zero Air

First the photometer unit is flushed with air that has previously flowed through a zero air filter for a period of two minutes. This is necessary for zero point adjustment of the photometer. This zero air flushing is carried out automatically by the device for two minutes in each case at hourly intervals, also in the further course of the measurement. During flushing, the word “**Flush**” will be displayed on the right-hand side of the display.

7.2. Start of the Measurement and the Measurement Menu

The actual measurement starts immediately after the first flushing. You see the **APM Measurement** menu in the display. In addition to date and time, it indicates on the right side the currently measured mass concentration of the selected particulate matter fraction in µg/m³ or, during a flushing operation, the measured voltage value in mV. On the left side of the screen the following values are shown in the two window sections **Measured Values** and **Physical Data**:

- **PM 2.5 avg**: Mean value of the measured mass concentration for $PM_{2.5}$ (if active)
- **PM 10 avg**: Mean value of the measured mass concentration for PM_{10} (if active)
- **Fl. Offset**: Photometer offset, determined during zero air flushing
- **Phototemp**: Temperature at photometer
- **Ext. Temp**: Temperature determined by external sensor
- **Humidity**: Humidity determined by external sensor
- **Pressure**: Air pressure determined by external sensor

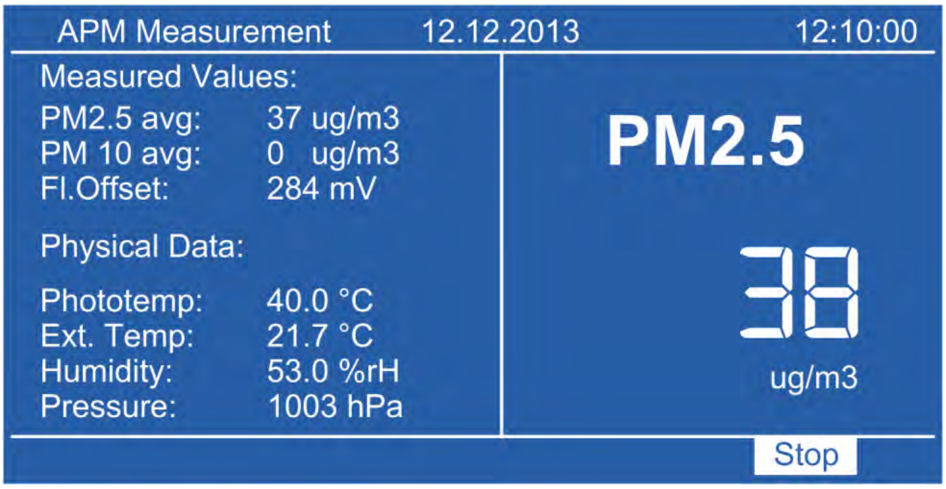


Fig. 18: *APM Measurement* menu

7.3. Aborting the Measurement

To abort an ongoing measurement, select the menu item Stop in the **APM Measurement** menu and press the jog dial to confirm. The measurement is then stopped and the main menu screen is displayed.

8. Data Management

The **Data** menu (Fig. 19) serves to manage the measurement data in internal storage and/or on the SD memory card. You access this menu via the Data menu item in the main screen.

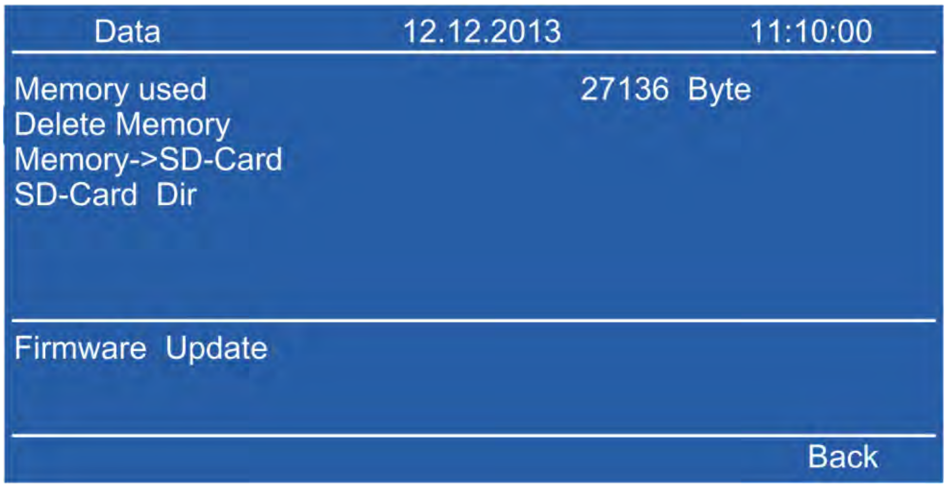


Fig. 19: *Data* menu

Shown at the right in the screen is the memory usage in bytes. The total free capacity of the data memory is 3.5 MB. The following data and parameters for sampling are automatically stored in the unit's memory, individually for each sampling filter:

- **Date, starting time and duration of measurement**
- **Unit model and serial number**
- **Mean mass concentration of the measured particulate matter fraction in µg/m³**
- **% of the maximum pump motor speed**
- **Outside air pressure**
- **Outside air temperature**
- **Photometer temperature**
- **Relative humidity**
- **Any reportable events and errors**

A data record that comprises the information listed above will require 128 bytes. As a consequence, about 27,000 data records can be placed in storage. The system uses a non-volatile ring memory. The data are retained even if the device is switched off. Once the memory is full, the oldest data is overwritten with the new data. Since overwriting works reliably only for a limited number of cycles, the memory should be erased at regular intervals.

If an SD memory card is present in the device, then the data will also be automatically written as a text file (CSV file format) on the SD memory card.

8.1. Storing Data on an SD Memory Card Manually

In additional to ongoing automatic storage, all the data can also be transferred manually from the device memory to an SD memory card. Transfer is in the serial mode, corresponding to normal data output (see 5.3.2). To start data transfer to an SD card, select and confirm menu item Memory → SD Card in the **Data** menu. This function is useful if, for instance, no SD memory card had been mounted in the device during measurement operations.

8.2. Erasing Data Memory

It is recommended that the device memory be erased at regular intervals, e.g. whenever the SD card is replaced. To do so, select and confirm the Erase memory menu item in the **Data** menu and affirm the following confirmation prompt.

8.3. Displaying Data Content of an SD Memory Card

Use the SD card dir command in the **Data** menu to display the data stored on the SD memory card. The .csv files present on the SD card, containing the data for the measurement, can be opened with any PC and can be viewed and edited with a suitable program such as Microsoft Excel®.

NOTE: See 9.1 for information on updating the firmware.

9. Special Functions

Described below are some of the device's functions that are irrelevant to normal operations but which nonetheless may occasionally be required.

9.1. Updating the Firmware

It may occasionally be necessary to update the equipment's operating program. An SD memory card with the software to be installed is required for this purpose. Please apply to Comde-Derenda GmbH to receive the latest version.

CAUTION! Pay attention to compatibility issues: If the parameter records in the old and new versions of the firmware are not identical, then settings may be lost and the proper functioning of the device may be endangered. Please contact Comde-Derenda GmbH prior to updating in order to clarify compatibility questions.

Proceed as follows to update the firmware:

1. Mount the SD memory card with the update file in the SD card slot at the upper right hand corner of the control unit.
2. In the main menu, select the Data menu item and confirm by pressing the jog dial.
3. In the **Data** menu, select the Firmware Update item and confirm your choice.
4. Confirm with Yes the query as to whether you want to proceed with the update.

The update will now be installed. A bar appears, showing the progress of the copying procedure. Once the update has run successfully to completion, the display will show **OK**. The unit will then automatically be reset and restarted.

WARNING! The unit must not be switched off while the software is being upgraded. This would cause data loss, the device could no longer be used and it would have to be returned to the factory for repairs before it could be returned to service.

9.2. System Information

Proceed as follows to call up the system information:

1. Select the Setup menu item in the main screen and confirm your choice by pressing the jog dial.
2. When in the **Setup** menu select the System info item and confirm your choice.

You will see the following information in the **System information** screen:

- **Software-Vers.**: Software release version number
- **Hardware-Vers.**: Hardware version number
- **Series Number**: Device serial number

- **Device Number**: Device number assigned by the user (see 5.4.1)
- **Last Flow Calib.**: Date and time of the most recent calibration of the flow sensor
- **Last Photo Calib.**: Date and time of the most recent service for the photometer
- **Model Number**: GPRS modem type
- **Firmware Rev**: Firmware version for the GPRS modem
- **Network Stat.**: Status of the GSM/GPRS connection
- **IP Address**: IP address of the GPRS connection

See section 9.5.3 for details on calibrating the flow sensor.

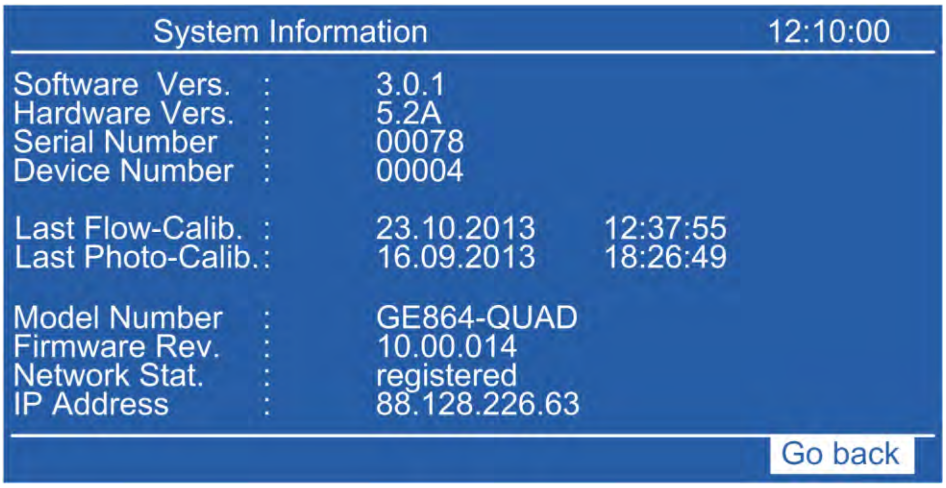


Fig. 20: System Information screen

9.3. Service Menu

The **Service** menu is used primarily to check the sensors and for adjustment and maintenance work carried out by service technicians. This menu will not usually be used in normal operations. You access the **Service** menu from the main screen by selecting Setup → Service.

Shown in the **Service** menu are all measured values reported by the unit's sensors together with the corresponding correction parameters.

9.4. Manual Mode

The **Manual Mode** menu allows you to start individual system functions manually. It is primarily designed for service technicians who want to test individual functions. Manual mode is not suitable for regular measurements of the particulate matter mass concentration because there is no automatic flushing during the measurement. You can call up the following functions via the **Manual Mode** menu:

9.4.1. Flushing

Carry out manual activation of zero air flushing of the photometer unit as follows:

1. Select the Manual Mode menu in the main menu and press the jog dial to confirm.
2. Select the item Flush in the **Manual Mode** menu and confirm.

Flushing starts immediately. During flushing you see the current value of the voltage signal at the photometer on the right side of the display, and left of that the offset voltage value of the photometer determined during flushing. To stop flushing, select and confirm the menu item Stop.

9.4.2. Measuring $PM_{2.5}$ oder PM_{10}

Start a manually activated measurement of $PM_{2.5}$ or PM_{10} particulate matter as follows:

1. Select the Manual Mode menu in the main menu and press the jog dial to confirm.
2. Select the item PM2.5 or PM10 in the **Manual Mode** menu and confirm.

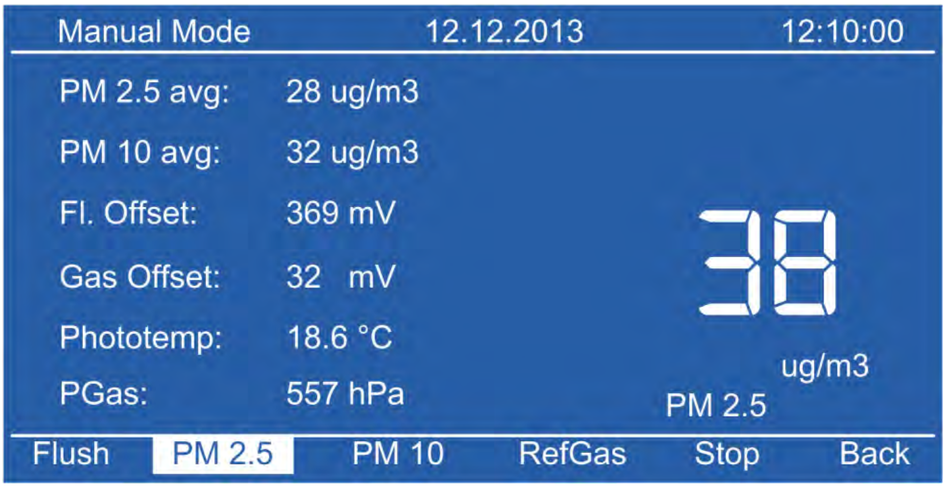


Fig. 21: Manual Mode menu

The measurement starts immediately. The current value of the mass concentration is shown on the right side of the display during the measurement. On the left you see the corresponding mean value for the measurement, which is updated once every second. To stop the measurement, select and confirm the menu item Stop.

9.5. Calibrating the Flow Sensor

For correct measurement operation, the volume flow of the drawn-in air has to be 3.3 l/min during the measurement. When in continuous operation, the flow sensor shall be calibrated once a month. Calibration will require an external flow meter, which is not included in the standard scope of delivery.

9.5.1. Preparing for the Calibration

Prior to calibration of the flow sensor the APM-2 should be run for a period of 15 minutes so it warms up. For this purpose, parameterize and start a measurement. Additionally check the values for outside air temperature (**Ext. Temp**) and air pressure (**Pressure**) indicated on the left side of the **APM Measurement** menu (Fig. 18). If they should deviate from the values of calibrated reference instruments by more than 2 K and 4 mbar respectively, temperature and/or pressure sensors first have to be calibrated/adjusted, see 9.3.

9.5.2. Connecting the external flow meter

1. Remove the impactor inlet by pulling it off the intake tube in an upward direction.
2. Shift the calibration adapter to the upper end of the intake tube and ensure that the adapter is firmly seated.
3. Connect the calibration adapter and the external flow meter using the corresponding hose.

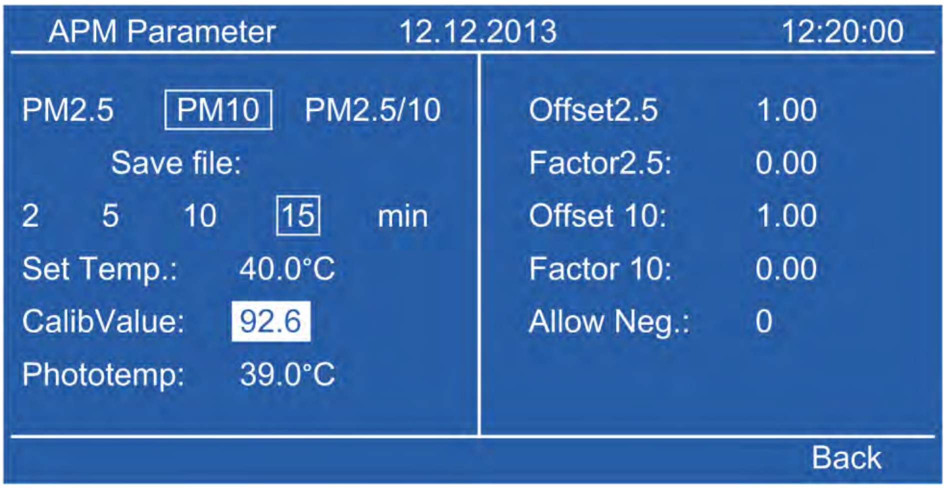


Fig. 22: Adjusting the pump's power setting

9.5.3. Calibrating the Flow Sensor

The calibration process is controlled via the control unit:

1. Select the Setup menu in the main menu and press the jog dial to confirm.
2. In the **Setup** menu, select the Measurement parameter item and confirm your choice.
3. In the **APM Parameter** menu, select the value shown to the right of **CalibValue** so that it is shown outlined and press the jog dial. The value is now shown inverse (Fig. 22).

4. Observe the display of the external flow meter and, if necessary, adjust the pump motor speed by turning the jog dial until the value indicated by the flow meter corresponds exactly to 3.3 l/min. The volume flow correction value also changes accordingly.

5. After the correct value is reached, press the jog dial.

6. To go back to the main menu, select and confirm back.

9.5.4. Checking the Accuracy of the Calibration

After completion of the calibration procedure start a measurement as a test. Please wait until the device automatically changes into the $PM_{2.5}$ or PM_{10} measurement mode. Check the display of the external flow meter for agreement with the set value. In the event of deviations, repeat the calibration as described.

9.6. Inspecting the Photometer

In addition to calibrating the photometer at regular intervals (see 10.3), it is also possible to use a test gas to verify its functioning and sensitivity. You will need optional devices and documentation to carry out the inspection with the test gas. These can be obtained on request from Comde-Derenda GmbH.

9.7. Leak Tightness Test

An automatic leak tightness test is provided in the APM-2 to check the tightness of the system; this is started via the device firmware. This test requires the Comde-Derenda leak test instrument (Fig. 24), available separately.

9.7.1. Sequence for Leak Tightness Testing

Leak testing is started by using the internal pump to create a vacuum of approx. 300 hPa inside the device. Then observe the system to determine whether and the extent to which this pressure rises within the following 5 minutes. The test is considered to have been passed if the pressure rise is less than 290 hPa. Otherwise the system is leaking and will have to be inspected.

The test at the zero air port is optional and intended primarily for use by service technicians.

9.7.2. Leaking Test Menu

The leak test is conducted using the APM-2 control unit. The appropriate menu is called up by selecting Setup → Leaking Test.

Shown in the center of the menu window is the name of the function currently being run and the appropriate progress bar. The following values are shown in the lower section of the window:

- **PGas**: Current vacuum in the system, in hPa
- **Zero air**: Starts the leak test when the leak testing instrument is connected to the zero air port
- **Inlet**: Starts the leak test when the leak testing instrument is connected to the virtual impactor
- **Stop**: Terminates a leak test currently being conducted
- **Back**: Leaves the **Leaking Test** menu

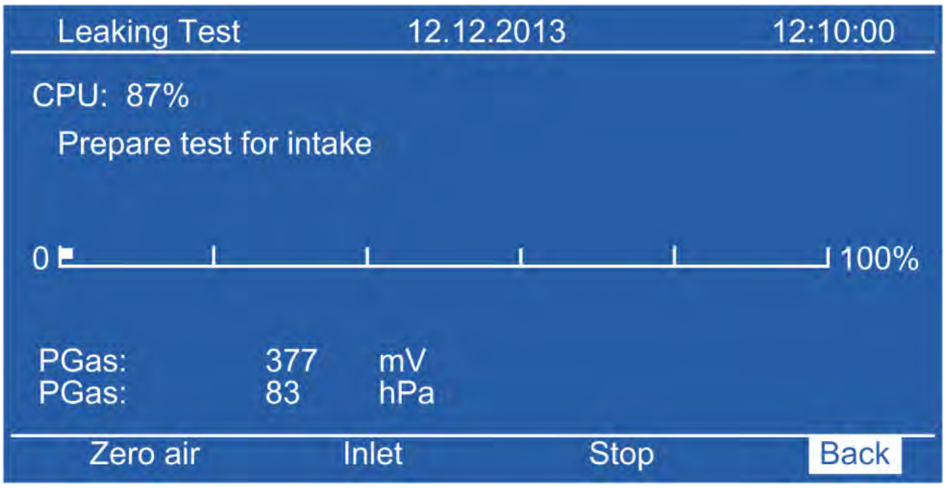


Fig. 23: Leaking Test menu

9.7.3. Conducting the Leak Tightness Test

Follow the instructions below to conduct a leak test.

1. Ensure that the APM-2 is switched off.

2. Remove the impactor head from the APM-2 by pulling it upward and off of the inlet tube above the virtual impactor.

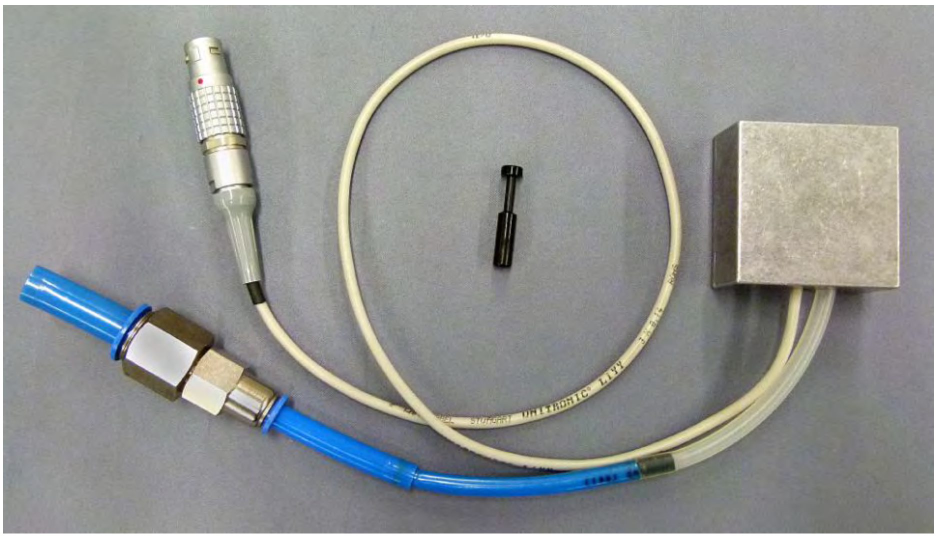


Fig. 24: Leak testing instrument

3. Lift the inlet tube off the virtual impactor.

4. Connect the leak testing instrument (Fig. 24) with the control cable socket on the APM-2. The 7-pole socket is located on the front panel of the APM-2 control unit.

5. Power up the APM-2 by turning on the main switch on the front panel and the switch on the front of the control unit.

6. Disconnect the coarse filter (with tube) from the zero air port on the left-hand side of the unit.

7. Insert the closure plug into the socket at the zero air port.

8. Join the leak testing instrument with the APM-2 by inserting the hose fitting into the virtual impactor inlet port (Fig. 25).

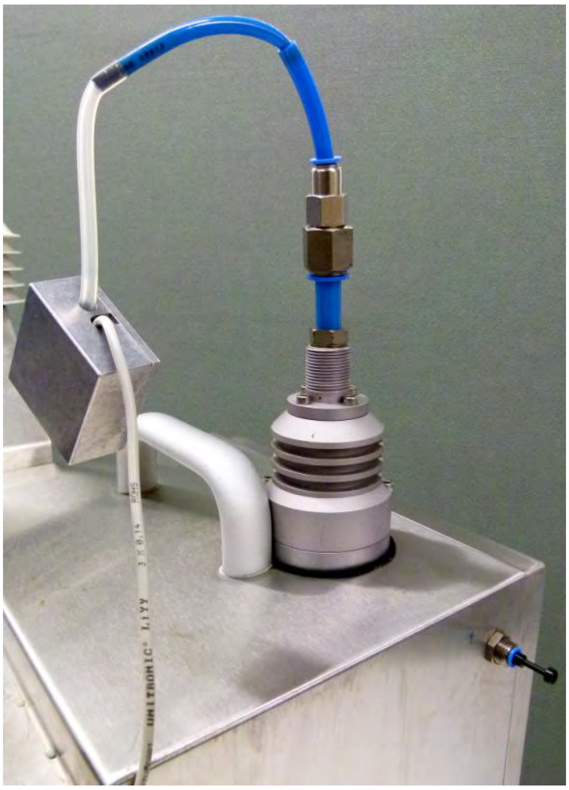


Fig. 25: Connecting the leak testing instrument

9. At the APM-2 control unit, call up the **Leaking Test** menu with menu items Setup → Leaking Test.

10. Click on menu item Inlet to start the automatic testing process.

NOTE: If there is any vacuum in the device at the beginning of the test, then the testing cycle cannot be started. The appropriate message will appear in the display, requesting that the device first be vented. To do so, briefly detach the fitting on the gas hose from the adaptor at the virtual impactor and then reconnect the hose. To begin the test cycle, select and confirm the Start menu item. The leak test is not available in all versions of the device.

The steps in the testing process follow this sequence:

1. **Generating a vacuum**: The message "**Leak test starting**" will appear briefly in the display. The internal pump will generate a vacuum in the APM-2 to a pressure level of approx. 300 hPa.

2. **Testing phase**: The testing phase will commence once the vacuum has been generated. During this period, the vacuum in the system will be monitored continuously by the sensors in the device and shown as the **PGas** value in the display.

3. **Displaying the results**: A tolerance of 290 hPa applies to the rise in pressure. If the pressure during the test phase remains the same or has risen by no more than 290 hPa, then the test is deemed to have been passed. If the pressure has risen by more than 290 hPa, then the test has been failed. The results will be shown accordingly in the display. This concludes the leak test.

To leave the menu after the test, select the Finished menu item and respond to the following confirmation question with Yes. While the test is running, the sequence may be aborted by selecting the Stop menu item; it may be recommenced with Start. If the test is not successful, first attempt to locate and correct the reason for the leak (e.g. a hose that is connected loosely). If this cannot be done, then the device will have to be inspected at the factory. In this case please contact Comde-Derenda GmbH.

9.8. Factor and Offset Settings

In the device the values determined during a measurement are in the form of voltage in mV. The measured value is then converted to µg/m³ by means of correction factors (multiplication). Depending on the measurement situation, it may be necessary to adjust these factors for $PM_{2.5}$ and PM_{10} separately in each case. For this purpose the measurement results are compared to those of a reference device in a measurement series and on this basis the necessary correction factors are calculated mathematically. The values determined by the device regarding offset values can also be adjusted, again separately for $PM_{2.5}$ and PM_{10}. To enter the factor and offset settings, proceed as follows:

1. Select the Setup menu in the main menu and press the jog dial to confirm.
2. In the **Setup** menu, select the Measurement parameter item and confirm your choice.
3. Select the value next to the desired variable (**Factor 2.5**, **Factor 10**, **Offset 2.5** or **Offset 10**) in the right-hand section of the menu so that this value is shown outlined and press the jog dial. The value is now shown inverse.
4. Adjust the value according to the previously calculated values by turning the jog dial and press the jog dial to confirm. The change is thus saved.

9.9. Allowing Negative Measured Values

This function is relevant only for service technicians and is not required in standard operation. The value should, in the normal case, be left at “0”. Change the setting for negative measured values as follows: The change is thus stored.

1. Select the Setup menu in the main menu and press the jog dial to confirm.
2. In the **Setup** menu, select the Measurement parameter item and confirm your choice.
3. Click on the value displayed next to **Allow Neg.** and modify as desired (**0** = negative values not permitted, **1** = negative values permitted).

4. Press the jog dial to confirm. The change is thus saved.

10. Service and Maintenance

10.1. General

The device requires little service. The photometer chamber is cleaned automatically by the device during the measurement operation and should not be opened.

10.2. Internal Filters

The replacement intervals for the filters vary widely, depending on the level of air pollution. In general, the filters should be replaced after six months, at the latest. For the zero air filter, the change in the photometer offset value may be used as an indicator of the loading level. Minor fluctuations in the offset (by a few tens of a mV) are normal. If the offset should, however, rise by several hundred mV, then this is evidence of a clogged or damaged zero air filter. The condition of the filter shall be inspected at regular intervals.

To change the internal filters, switch off the device and disconnect it from the power supply.

The existing filters:

- 1 zero air filter (type Parker Balston)
- 1 photometer outlet filter (type Parker Balston)
- 1 bypass filter (type WIX)
- 1 pump outlet filter (type WIX)

can simply be pulled off the silicone hoses and replaced (see 10.7).

10.3. Photometer Unit

The photometer in the APM-2 shall be calibrated once a year. Do this by sending the photometer in its casing to Comde-Derenda GmbH and by contacting our customer service department.

It will be necessary to replace the photometer after a certain period in service. The photometer is to be changed if either of the following criteria is fulfilled:

- If the total amount of particulate matter collected exceeds 50 mg. This corresponds to a throughput of about 100 µg/m³, continuously over 100 days, or 50 µg/m³, continuously over 200 days, or 10 µg/m³, continuously over 1,000 days.

- If the photometer offset value has risen to more than 2,500 mV.

If one of these events occurs, then please contact Comde-Derenda GmbH. The replacement of the photometer, which may then be necessary, will be carried out by Comde-Derenda GmbH.

10.4. Vacuum Pump

The vacuum pump is powered by a brushless motor and requires no maintenance. The normal service life of the pump, when in continuous operation, is about two years. This period of time may vary, depending on the use. The pump will have to be replaced once it has reached the end of its service life. Should the pump fail, the device will automatically issue the appropriate warning.

10.5. Impactor Inlet

The impactor inlet should be cleaned according to the specific load, but every 28 days at the latest. To do so, pull the inlet off the intake tube and open it. The lubricated baffle plate and the impactor section are inside. The baffle plate can be cleaned with spirit and then recoated with Vaseline or high-vacuum grease (medium). The use of high-vacuum grease (medium) is especially recommended at low ambient temperatures.

You can either blow out the impactor section with compressed air or clean it in an ultrasonic bath.

10.6. Virtual Impactor

The virtual impactor shall be cleaned after 90 days at the latest, with the exact value depending on the amount of loading. For cleaning purposes you need to take off the connecting hoses to the virtual impactor inside the device. Then you can blow out the virtual impactor with compressed air. Once a year you should clean the virtual impactor with spirit or highly volatile alcohol to remove deposits.

10.7. Spare Parts

Item	**Type**	**Part Number**
Zero Air Filter	Parker Balston	D100010
Photometer Outlet Filter	Parker Balston	D100010
Bypass Filter	WIX	D100020
Pump Outlet Filter	WIX	D100020
Brushless Pump	Nitto Kohki	D100093
Pinch Valve	Sirai	D100833
Silicon Hose	Espass	D100823

11. Error Messages

Warnings or error messages may be issued from time to time during operation. Details on the individual reports will be found in the following table. Even after a fault message has been issued, the device will continue to function without any interruption. After a power outage, the device will automatically re-start measurement operations. The measured data recorded up until the power outage occurred will be retained in memory.

Error	**Description**
Error_EXTSENSOR	Warning: External temperature/moisture sensor not connect-ed or faulty
Error_POWERLOSS	Warning following power outage; measurement was restarted after power restored
Error_ENDOFLOG	Warning: Overrun at internal log memory; SD card can no longer store all the malfunctions
Error_RAMCLOCKOVERFLOW	Warning: Overrun at internal log memory (only after restart-ing, if the internal memory is still in an overflow state)
Error_PUMPNOFLOW	Malfunction: Pump creating no measurable flow Check pump: Seized or defective?
Error_NOPHOTOMETER	Malfunction: Photometer values below limit value Check photometer: Is it connected?
Error_HEATINGPHOTO	Malfunction: Photometer chamber not connected correctly Check: Temperature sensor at photometer defective?
Error_PARAMETERCRC	Malfunction: Can appear following a firmware update; be ab-solutely sure to load the factory defaults and calibrate the device Before updating the firmware, be absolutely sure to copy down the old parameters shown in the menu!
Error_MENUITEM	Please notify the manufacturer

12. Bayern-Hessen-Protokoll (Bavaria-Hesse-Protocol)

12.1. Interface Definition "Serial Measuring Instruments"

Being used ever more frequently in pollution measurement networks are intelligent, microprocessor-controlled measurement units fitted as standard equipment with an interface to transfer measurement data, operational status information and error status.

To ensure trouble-free attachment of a wide variety of equipment, a standard interface is described below, similar to the "50-pole data plug" described in the "Standardization Recommendation for Automated Air Quality Control Measurement Networks".

12.2. Interface Specification

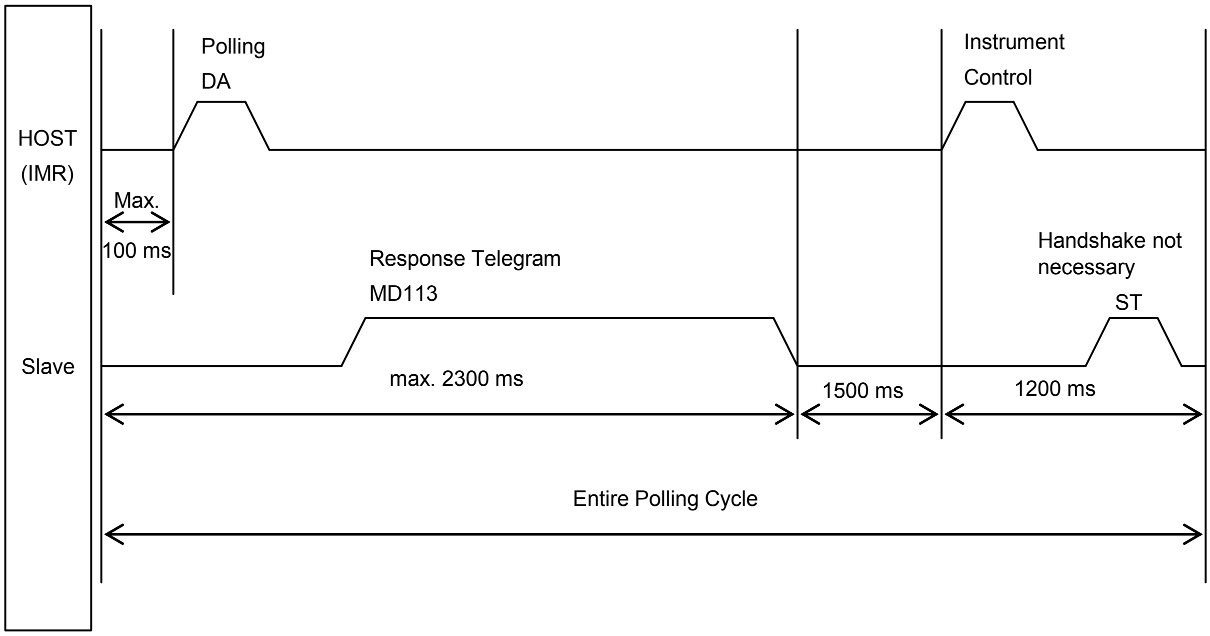
Asynchronous-serial Data Transfer

Baud Rate:	1200 Baud
Data Format:	1 Start Bit
	8 Data Bits
	1 Stop Bit
Handshake:	Full-duplex Operation; Polling Method (MSR = Master)
Connector:	9-pole SUB-D-Connector with the PIN configuration:
	PIN 02: TxD Send Data (Off)
	PIN 03: RxD Receive Data (On)
	PIN 05: GNDGround
Voltage Level:	According to norm V24; not potential-free
	For Data Lines (RxD, TxD):
	-15 to – 3V for logical HIGH
	+3 to + 15V for logical LOW

12.3. Data Transfer

Data transmission (MSR ↔ measurement unit) is effected using standardized blocks, each secured with a block check character (BCC).

The characters transmitted here are taken from the USASCII standard character set (0-9, A-Z); check characters are added to the block to facilitate error detection. Maximum block length at present is 256 characters (including control characters and protocol frame).



12.4. Transfer Protocol

Data transmission between the measurement point and the MSR takes place in accordance with a strict master-slave procedure. The measurement site itself never initiates contact with the MSR.

The MSR transmits commands to the measurement site, which then responds with an answer block. All the commands contain an address, i.e. the measurement unit identifier. The addresses can be used to address either the entire measurement site or individual measurement units at the measurement site.

Response blocks also contain from one to four measurement device identifiers for the purposes of identification and allocation.

See section 12.6 for the definitions of the individual telegrams (message blocks).

Data Protocol Structure:

Byte 001:	STX (Start of Text)
Byte 002-nnn:	<TEXT>; Message Text; max. 120 Characters; USASCII coded
Byte nnn+1:	ETX (End of Text)
Byte nnn+2/3:	BCC (Block Check Character)

The response from the measurement site is always in the same format as that of the command it received.

Data Polling

The data registered at the measurement site are transmitted to the MSR in response to a polling request. A polling data block can be used to query either a single measurement unit or all the measurement units connected at a measurement site.

Data Transmission

The data registered at the site are transferred by way of a response message. Where the measurement site has multiple measurement units, the individual values will all be compiled into a single message.

12.5. Generation of the Block Check Character

The block check character (BCC) is generated by forming, byte by byte, the exclusive-or sum of all the characters transmitted (including STX and ETX), starting at $00. The result byte block (checksum) thus created is transmitted in hexadecimal code wherein the upper nibble of this byte is transmitted as BCC1 and the lower nibble as BCC2.

The ASCII value range of from 0 to 9 and from A to F (capital letters) is permissible for the BCC bytes so that the nibbles can be expressed in hexadecimal notation.

12.6. Telegrams „Serial Measuring Instruments“

In the telegrams cited below the required blanks are depicted with a pound sign (#).

The block control characters and the BCC characters are enclosed in <> for emphasis.

12.6.1. Data Polling of the Measuring Station

Block Identifier: **DA**

Telegram Length: Variable
Telegram Type: Command

Field No.	Start-Byte	Data Format	Description
1	1	<STX>	Start of Text
2	2	DA	Block Identifier
3	4	<ETX>	End of Text
4	5	<BCC1>	Low Nibble BCC
5	6	<BCC2>	High Nibble BCC

12.6.2. Measuring Station Data in Reply to Data Polling

Field No.	Start-Byte	Data Format	Field Description
1	1	<STX>	Start of Text
2	2	MD	Block Identifier
3	4	nn#	Number of Measuring Units
4	7	nnn#	Measuring Unit ID
5	11	±nnnn±ee#	Measured Value
6	20	hh#	Operating Status
7	23	hh#	Error Status
8	26	nnn#	Serial Number
9	30	hhhhhh#	Not Assigned
10	37	nnn#	Measuring Unit #2 ID (optional)
11	41	±nnnn±ee#	Measured Value
12	50	hh#	Operation Status
13	53	hh#	Error Status
14	56	nnn#	Serial Number
15	60	hhhhhh#	Not Assigned
16	67	nnn#	Measuring Unit #3 ID (optional)
17	71	±nnnn±ee#	Measured Value
18	80	hh#	Operating Status
19	83	hh#	Error Status
20	86	nnn#	Serial Number
21	90	hhhhhh#	Not Assigned
22	97	nnn#	Measuring Unit #4 ID (optional)
23	101	±nnnn±ee#	Measured Value
24	110	hh#	Operation Status
25	113	hh#	Error Status
26	116	nnn#	Serial Number
27	120	hhhhhh#	Not Assigned
28	127	<ETX>	End of Text
29	128	<BCC1>	Low Nibble BCC
30	129	<BCC2>	High Nibble BCC

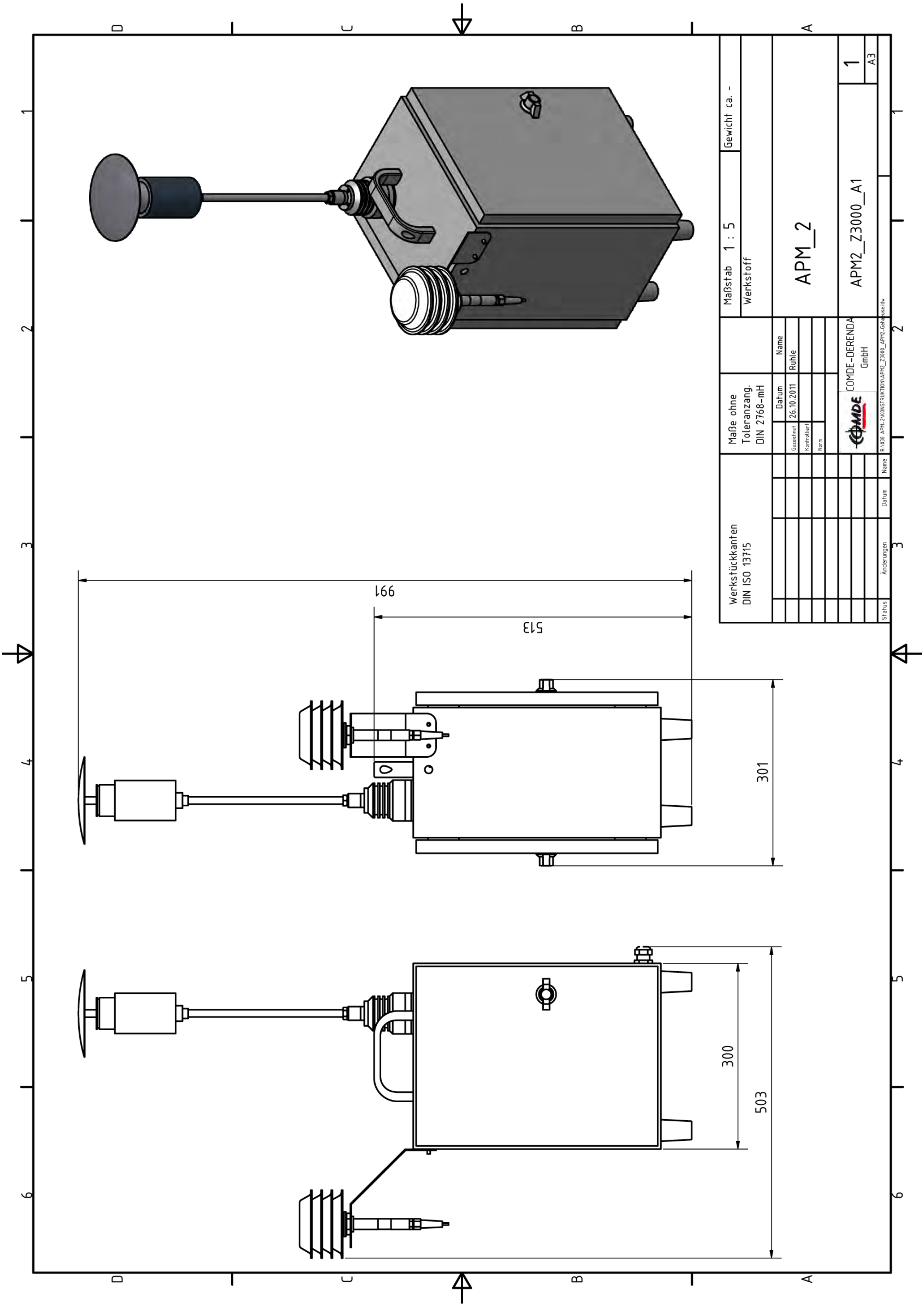
Telegram Identification: **MD**

Telegram Length: Variable
Telegram Type: Response

13. Technical Specifications

Dimensions and Weight (excluding impactor inlet and antenna)	
Width	320 mm
Height	560 mm
Depth	270 mm
Weight	approx. 15 kg
Power Supply	
Supply Voltage	230 V, 50/60 Hz
Microfuse	T 1.25 A
Power Consumption	approx. 80 W
Electronics	
Interface	RS-232
Transfer Protocol	Bayern-Hessen-Protokoll
Additional Data	
Measurement Range	0 … 1000 µg/m³
Resolution	1 µg/m³
Flow Rate	3.3 l/min (controlled)
Sampling time	Continuous
IP Classification	IP 65

14. Dimensional Drawing



15. Index

Ed. 03/2014

TÜV RHEINLAND ENERGY GMBH

ADDENDUM

Addendum to the performance test report for the Air Pollution Monitor 2 (APM-2) ambient air measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM_{10} and $PM_{2.5.}$ TÜV report 936/21219977/A dated 26 March 2014.

TÜV-Report: 936/21253723/A
Cologne, 09 September 2021

www.umwelt-tuv.de

tre-service@de.tuv.com

TÜV Rheinland Energy GmbH and its Ambient Air Quality department in particular
is accredited for the following activities:

- Determination of emissions and ambient air quality affected by air pollutants and odorous substances;
- Inspection of correct installation, function and calibration of continuously operating emission measuring instruments, including data evaluation and remote emission monitoring systems;
- Measurements in combustion chambers;
- Performance testing of measuring systems for continuous monitoring of emissions and ambient air, and of electronic data evaluation and remote emission monitoring systems;
- Determination of the stack height and air quality forecasts for hazardous and odorous substances;
- Determination of emissions and ambient air quality affected by noise and vibration, determination of sound power levels and noise measurements at wind turbines;

according to EN ISO/IEC 17025.

The accreditation has the DAkkS registration number: D-PL-11120-02-00
and covers the scope defined in the appendix to the certificate.

TÜV Rheinland Energy GmbH
D - 51105 Cologne, Am Grauen Stein,
Tel: + 49 (0) 221 806-5200, fax: 0221 806-1349

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1. Summary Overview

On behalf of the company Comde-Derenda GmbH, TÜV Rheinland Energie und Umwelt GmbH (now TÜV Rheinland Energy GmbH) carried out the performance test of the Air Pollution Monitor 2 (APM-2) measuring system for the components suspended particulate matter PM_{10} and $PM_{2.5.}$ in accordance with the following standards.

- VDI Guideline 4202, Part 1 – "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants," dated September 2010 or June 2002 respectively.
- VDI Guideline 4203, part 3 – "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", dated September 2010 or August 2004 respectively.
- European standard EN 12341 "Air Quality - Determination of the PM_{10} fraction of suspended particulate matter - Reference method and field test procedure to demonstrate reference equivalence of measurement methods", German version EN 12341: 1998 (withdrawn)
- European standard EN 12341, "Ambient air - Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter"; German version EN 12341:2014
- European standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005
- Guideline "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version dated January 2010 version

Regarding standard EN 12341:1998 / 2014, it should be noted that the standard was applicable at the time of the original performance test. This is why the standard is cited here for the sake of completeness. Its successor, standard EN 12341:2014 was added to the list.

Based on the specified test principles, the Air Pollution Monitor 2 (APM-2) measuring systems for the components suspended particulate matter PM_{10} and $PM_{2.5}$ have already been performance-tested and announced as follows:

- Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM_{10} and $PM_{2.5,}$ Federal Environment Agency notice of 17 July 2014 (BAnz AT 05.08.2014 B11, chapter III number 2.1) - initial announcement of suitability.
- Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM_{10} and $PM_{2.5,}$ Federal Environment Agency notice of 25 February 2015 (BAnz AT 02.04.2015 B5, chapter IV notification 1) - notification of new location of the output filter.
- Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM_{10} and $PM_{2.5,}$ Federal Environment Agency notice of 18 February 2016 (BAnz AT 14.03.2016 B7, chapter V notification 4) - notification of new software version (3.05.002)
- Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM_{10} and $PM_{2.5,}$ Federal Environment Agency notice of 13 July 2017 (BAnz AT 31.07.2017 B12, chapter II notification 34) - notification of new software version (3.07.002), new buffer bottle to compensate for pressure fluctuations caused by the sampling pump and discontinuation of the optional test method with propane gas.
- Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM_{10} and $PM_{2.5,}$ Federal Environment Agency notice of 27 May 2020 (BAnz AT 31.07.2020 B10, chapter II notification 1) - notification of new software version 3.08.001 and a new hardware version for the input circuit.

Standard EN 16450 “Ambient air — Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2.5}$) has been available since July 2017. This standard, for the first time, harmonises requirements for the performance testing of automated measuring systems for the determination of dust concentrations (PM_{10} and $PM_{2.5}$) on a European level and will form the basis for the approval of such AMS in the future.

This addendum contains an assessment of the measuring system of the type Air Pollution Monitor 2 (APM-2) with regard to compliance with the requirements according to standard EN 16450 (July 2017).

As most of the performance characteristics and performance criteria defined in chapter 7 of standard EN 16450 (July 2017) have been tested and assessed already in the context of the original performance test, the majority of test results can be taken from and/or re-assessed on the basis of the original test report. We were able to re-assess some of the test criteria using data from the original report on performance testing or from tests which have been performed in the context of the controlled development of the AMS in accordance with standard series EN 15267. Only for test items 7.4.4 “Flow rate accuracy", 7.4.8 "Dependence of span on supply voltage" and 7.4.9 "Dependence of reading (measured values) on water vapour concentration" were completely new tests carried out.

New tests for items 6.1 9 Dependence of span on supply voltage (7.4.8) and 6.1 11 Dependence of reading on water vapour concentration (7.4.9) were performed in 2019 with two identical units with the serial numbers SN 20095 and SN 20133.

During the tests in 2019, it became apparent that the AMS in its current set-up could not meet the minimum requirement of test point 6.1 4 Flow rate accuracy (7.4.4) for the targeted ambient temperature range of -20°C to +50°C. As a result, the manufacturer tested and implemented various software approaches to improve the temperature characteristics of the implemented mass flow sensor (temperature compensation), which, due to their significance, were to be evaluated as a type 2 change with respect to the EN 15267-2 standard. These changes were implemented in the software versions 3.10.xxx.

However, since a meaningful qualification of the change "Introduction of temperature compensation for the flow sensor" that could be carried out with reasonable metrological effort was not possible, especially with regard to the potential impact on the historical data sets, the change was completely rejected by Comde-Derenda and all associated changes in the software were withdrawn. The temperature compensation of the flow sensor remains untouched and there is no release for software versions 3.10.xxx.

In order to meet the requirements of the EN 16450 standard [9] in the original set-up of the measuring system, Comde-Derenda decided to carry out the test in a reduced temperature range of -15°C to +40°C. This approach is covered in test item 6.1 4 Flow rate accuracy (7.4.4) by the passage that the test may also be carried out "*....at the minimum and maximum temperatures specified by the manufacturer, if these deviate from the temperatures to be applied as a rule...*".

However, this approach then implies that the proof of compliance with the requirements of the EN 16450 standard for the APM-2 measuring system only applies to an ambient temperature range of -15°C to +40°C.

The new tests for the test point 6.1 4 Flow rate accuracy (7.4.4) for the ambient temperature range of -15°C to +40°C were carried out in August 2021 with two identical units with the serial numbers SN 20123 and SN 20133. The software installed on these units was: 3.11.007.

On its publication, this addendum becomes an integral part of TÜV Rheinland test report no. 936/21219977/A dated 26 March 2014 and will be available at www.qal1.de.

The Air Pollution Monitor 2 (APM-2) measuring systems determine dust concentrations by means of the measuring principle of scattered light measurement with a combination of an intensity-stabilised laser diode and 90° scattered light detection. With the help of a pump, ambient air is sucked over a PM_{10} sampling head and then enters a so-called virtual impactor, in which the sampling stream is divided into 2 partial streams ($PM_{2.5}$ and PM_{10}). In an alternating process with an interval time of 2 minutes, each of the two partial streams reaches the scattered light sensor in turn.

The tests were performed in the laboratory and during a field test lasting several months [10].

The field test, which lasted several months, was carried out at the sites listed in Table 1.

Table 1: Description of the measurement sites

	Cologne Parking lot, winter	Bonn, Crossroads, winter	Cologne Parking lot, summer	Rodenkirchen, Motorway A555 summer
Period	11/2012 – 02/2013	02/2013 – 05/2013	05/2013 – 07/2013	07/2013 – 09/2013
Number of measurement pairs: Test specimens	69	61	54	53
Description	Urban background	Affected by traffic	Urban background	Rural area + motorway
Classification of ambient air pollution	average to high	average to high	low to average	low

During the course of the performance test at that time, the AMS manufacturer continued to optimise the calculation algorithm for the suspended particulate matter measured values. For this purpose, the AMS software had to be revised and a new software version (version 3.0.1) was made available in winter 2014. To validate the now implemented modification of the calculation algorithm in the new AMS software, all measured values from the comparison campaigns were manually converted and evaluated with the new calculation algorithm according to Table 1. In addition, for qualification purposes, a supplementary comparison measurement campaign was carried out at the Cologne site, car park area, with the two test specimens and the new software version (version 3.0.1). Table 2 provides an overview of this. The results of these supplementary tests are presented in chapter 8 “Tests for the validation of the system software 3.0.1” from page 125.

Table 2: Description of the measurement sites (validation campaign 2014)

	Cologne, parking lot, winter
Period	01/2014 – 03/2014
Number of measurement pairs Test specimens	53
Description	Urban background
Classification of ambient air pollution	average to high

The following table provides an overview of the equivalence tests performed.

Table 3: Equivalence test results (raw data)

Comparison campaigns	PM_x	Slope	Axis intercept	All Data sets W_{CM}<25 % Raw data	Calibration yes/no	All Data sets W_{CM}<25% cal. data
4	PM_{10}	0.977	-3.758	23.31%	yes *	13.62%
	$PM_{2,5}$	0.919	0.327	17.87%	yes *	12.64%

* Calibration necessary due to partial non-fulfilment of the requirement for WCM for partial data sets as well as due to significance of slope and/or intercept

1.1 Summary report on test results

Summary of test results in accordance with standard EN 16450 (July 2017)

Performance criterion	Requirement	Test result	Satis-fied	Page
1 Measuring ranges	0 µg/m³ to 1000 µg/m³ as a 24-hour average value 0 µg/m³ to 10,000 µg/m³ as a 1-hour average value, if applicable	The upper limit of the measuring range for the measuring system is 1,000 µg/m³.	yes	52
2 Negative signals	Shall not be suppressed	While the AMS is able to display negative readings directly and via the various outputs, they should not be expected given instrument design and the measurement principle applied.	yes	53
3 Zero level and detection limit (7.4.3)	Zero level: ≤ 2.0 µg/m³ Detection limit: ≤ 2.0 µg/m³	The zero level and the detection limit resulted from the tests of both instruments both for PM10 and PM2.5 and were < 0.15 µg/m³.	yes	54
4 Flow rate accuracy (7.4.4)	≤ 2.0%	The relative difference determined between the mean value of the measurement results for the volume flow at -15°C and +40°C was a maximum of -1.79 %.	yes	56
5 Constancy of sample flow rate (7.4.5)	≤ 2.0% sampling flow (averaged flow) ≤ 5% rated flow (instantaneous flow)	The charts illustrating the constancy of the sample flow rate demonstrate that all measured values determined during sampling deviate from their respective target values by less than ±5%. The deviation of the 24h mean values for the total flow of 3.3 l/min are also significantly smaller than the required ±3 % from the nominal value. The 24h-averages deviate from the nominal values by less then ± 2.0%, all instantaneous values deviate by less than ± 5%.	yes	59
6 Leak tightness of the sampling system (7.4.6)	≤ 2.0% of sample flow rate	The criterion specified by the unit manufacturer for passing the leak test - maximum pressure rise of 290 hPa in 5 minutes - proved to be a suitable parameter for monitoring the unit's leak tightness in the test. The maximum determined leakage rate of 10.4 ml/min is less than 1 % of the nominal flow rate of 3.3 l/min.	yes	62

Performance criterion	**Requirement**	**Test result**	**Satis-fied**	**Page**
7 Dependence of measured value on surrounding temperature (7.4.7)	≤ 2.0 µg/m³	The tested ambient temperature range at the installation site of the AMS was -20 °C to +50 °C. When looking at the values output by the system, a maximum influence of the ambient temperature on the zero point of <0.1 µg/m³ for PM2.5 and of <0.2 µg/m³ for PM10 was determined.	yes	64
8 Dependence of measured value (span) on surrounding temperature (7.4.7)	≤ 5% from the value at the nominal test temperature	The tested ambient temperature range at the installation site of the AMS was -20 °C to +50 °C. No deviations > 2.4 % were determined at the span point.	yes	67
9 Dependence of span on supply voltage (7.4.8)	≤ 5 % from the value at the nominal test voltage	Voltage variations did not cause deviations exceeding -1.3% for PM2.5 and > 1.1 % for PM10, related to the starting value of 230 V.	yes	69
10 Effect of failure of mains voltage	Instrument parameters shall be secured against loss. On return of the mains voltage the instrument shall automatically resume functioning.	Buffering protects all instrument parameters against loss. The AMS is in fault-free operational readiness when the voltage returns and automatically resumes measuring operation after the photometer temperature has stabilised again and after the two-minute zero air purge.	yes	71

Performance criterion	Requirement	Test result	Satis-fied	Page
11 Dependence of reading on water vapour concentration (7.4.9)	≤ 2.0 µg/m³ in zero air	The maximum difference determined between the measured values at 40 % and at 90 % relative humidity was -1.6 µg/m³.	yes	72
12 Zero checks (7.5.3)	Absolute value ≤ 3.0 µg/m³	The maximum absolute measured value at zero was 2.4 µg/m³ for PM2.5 and 2.7 µg/m³ for PM10.	yes	74
13 Recording of operational parameters (7.5.4)	Measuring systems shall be able to provide data of operational states for telemetric transmission of – at minimum – the following parameters: Flow rate pressure drop over sample filter (if relevant) Sampling time Sampling volume (if relevant); Mass concentration of relevant PM fraction(s) Ambient temperature Exterior air pressure Air temperature in measuring section Temperature of sampling inlet if heated inlet is used	The AMS enables comprehensive telemetric control of the measuring system via the serial interface (RS232). The instrument provides operating statuses and all relevant parameters.	yes	77
14 Daily averages (7.5.5)	The AMS shall allow for the formation of daily averages or values.	It is possible to form valid daily averages.	yes	78

Performance criterion	**Requirement**	**Test result**	**Satis-fied**	**Page**
15 Availability (7.5.6)	At least 90%.	Availability was 100 % for SN3 and 98.9 % for SN4.	yes	79
16 Between-AMS uncertainty ubs,AMS (7.5.8.4)	≤ 2.5 µg/m³	At no more than 1.04 µg/m³ for PM2.5 and no more than 2.28 µg/m³ for PM10, the uncertainty between the test specimen ubs remains well below the permissible maximum of 2.5 µg/m³.	yes	82
17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)	≤ 25% at the level of the relevant limit value related to 24-hour average results (if required, after calibration)	Without the need for any correction factors, the determined uncertainties WAMS for PM10 were above the defined expanded relative uncertainty Wdqo of 25 % for particulate matter for all considered data sets except for Cologne, winter 2012/2013 as well as the total data set. The determined uncertainties WAMS were below the defined expanded relative uncertainty Wdqo of 25 % for fine particulate matter for PM2.5 for all data sets considered, with the exception of the comparisons >18 µg/m³ without application of correction factors. Correction factors shall be applied in accordance with item 6.1 17 Use of correction factors/terms .	no	90
17 Use of correction factors/terms (7.5.8.5–7.5.8.8)	After the calibration: ≤ 25% at the level of the relevant limit value related to the 24-hour average results	After the use of correction factors, the candidate systems met the requirements for data quality of air quality monitors for all data sets, both for PM2.5 and for PM10.	yes	113

Performance criterion	**Requirement**	**Test result**	**Satis-fied**	**Page**
18 Maintenance interval (7.5.7)	At least 14 d	The maintenance interval is determined by the maintenance work to be carried out and is 4 weeks.	yes	121
19 Automatic diagnostic check (7.5.4)	Shall be possible for the AMS	All the unit functions listed in the operating manual are available. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages. The monitored parameters, including the automatic hourly zero point check, are recorded during data recording.	yes	122
20 Checks of temperature sensors, pressure and/or humidity sensors	Shall be checked for the AMS to be within the following criteria ± 2 °C ± 1 kPa ± 5 % RH	It is possible to check and adjust the sensors for determining ambient temperature, ambient pressure and relative humidity on site. The deviations of the sensors were within the requirements. Sensors for recording the outdoor temperature, air pressure and relative humidity are easy to check and adjust on site.	yes	123

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2. Task definition

2.1 Nature of the test

On behalf of Comde-Derenda GmbH, a performance test as well as a supplementary test was carried out by TÜV Rheinland Energy GmbH for the Air Pollution Monitor 2 (APM-2) measuring systems.

The Air Pollution Monitor 2 (APM-2) measuring systems for the components suspended particulate matter PM_{10} and $PM_{2.5}$ have already been performance-tested and published in the German Federal Gazette.

This addendum contains an assessment of the measuring systems of the type Air Pollution Monitor 2 (APM-2) with regard to compliance with the requirements according to standard EN 16450 (July 2017).

2.2 Objective

The measuring systems are to measure the content of PM_{10} and $PM_{2.5}$ particulate matter in ambient air in the concentration of range 0 to 1000 µg/m³.

The existing performance test had been carried out on the basis of the latest standards in place at the time of the testing, taking into account the most recent developments.

The test was performed on the basis of the following standards:

- VDI Guideline 4202, Part 1 – "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants," dated September 2010 or June 2002 respectively. [1]
- VDI Guideline 4203, part 3 – "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", dated September 2010 or August 2004 respectively. [2]
- EN 12341 "Air Quality - Determination of the PM_{10} fraction of suspended particulate matter - Reference method and field test procedure to demonstrate reference equivalence of measurement methods", German version EN 12341: 1998, [3]
- European standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005 [4]
- Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version dated January 2010 [5]

Since July 2017, the European standard

- Standard EN 16450 "Ambient air — Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2,5}$), German version EN 16450:2017 [9]

has been available. This standard, for the first time, harmonises requirements for the performance testing of automated measuring systems for the determination of dust concentrations (PM_{10} and $PM_{2.5}$) on a European level and will form the basis for the approval of such AMS in the future.

This addendum contains an assessment of the measuring systems of the type Air Pollution Monitor 2 (APM-2) with regard to compliance with the requirements according to standard EN 16450 (July 2017).

As most of the performance characteristics and performance criteria defined in chapter 7 of standard EN 16450 (July 2017) have been tested and assessed already in the context of the original performance test, the majority of test results can be taken from and/or re-assessed on the basis of the original test report. We were able to re-assess some of the test criteria using data from the original report on performance testing or from tests which have been performed in the context of the controlled development of the AMS in accordance with standard series EN 15267. Only for test items 7.4.4 “Flow rate accuracy", 7.4.8 "Dependence of span on supply voltage" and 7.4.9 "Dependence of reading (measured values) on water vapour concentration" were completely new tests carried out.

On its publication, this addendum becomes an integral part of TÜV Rheinland test report no. 936/21219977/A dated 26 March 2014 and will be available at www.qal1.de.

3. Description of the AMS tested

3.1 Measuring principle

The Air Pollution Monitor 2 (APM-2) measuring system determines the concentrations of suspended particulate matter, PM_{10} and $PM_{2.5,}$ according to the scattered light measuring principle.

The applied measurement method uses the physical characteristics of light scattering by microparticles. The scattered light photometer unit used consists of an intensity-stabilised laser diode and a semiconductor photodetector. Both components are arranged at an angle of 90° to each other, so it is a single-angle scattered light sensor. The light reflected from the particles located in a precisely defined measuring volume is detected by a detector. The photodetector generates a corresponding voltage signal (0-5 V), which is then amplified with low noise and represents a direct measure of the mass concentration of the aerosol in the measurement volume. For zero adjustment, filtered air is fed to the scattered light sensor at periodic intervals via a switching device.

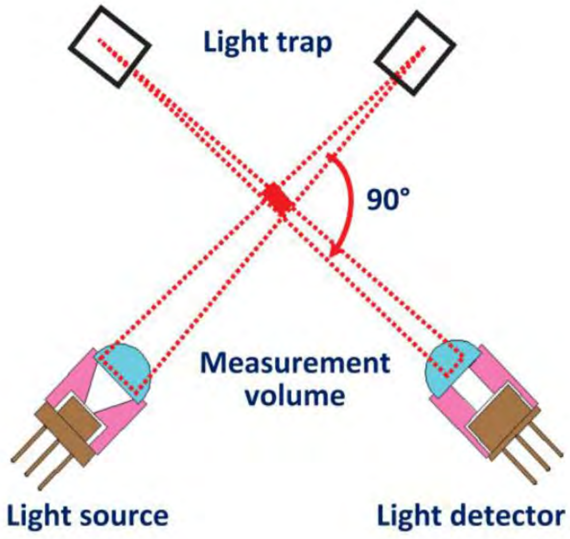

Figure 1: Functional principle photometer unit

In order to eliminate the temperature dependence of the photometer signal, the photometer is installed in thermally insulated housing heated with a heating module and regulated to a temperature of 40 °C.

The physics of light scattering for particles means that aerosol particles with a diameter in the order of magnitude of the light wavelength used - relative to their mass - scatter light most efficiently, i.e. provide the greatest input to the measured signal. For the wavelength of approx. 650 nm used in the system, the maximum sensitivity lies in the particle size range of between 0.5 and 1 µm. Due to these characteristics, there are limits to the use of simple scattered light photometry for measuring PM_{10} concentrations, as the measured signal is primarily dominated by the $PM_{2.5}$ component.

For the measurement of the fraction PM_{10}, the complementary coarse fraction $PM_{2.5}$-$_{10}$ contributes considerably less to the scattered light signal in terms of mass and is therefore underrepresented in the measurement. The sensitivity deficit in the coarse fraction is therefore compensated for in the system via a simple procedure - by selectively enriching the concentration $PM_{2.5-10}$ by a factor of 3.3 / 0.2 = 16.5 by means of a virtual impactor connected upstream of the scattered light sensor. The concentration enrichment is equivalent to an increase in the sensitivity of photometry for the $PM_{2.5-10}$ component.

The virtual impactor is located on the top of the housing and is connected to the impactor head via the intake pipe. The virtual impactor splits the outside air (Q1) drawn in via an integrated pump at 3.3 l/min into two partial flows. The division takes place in the area of two opposing nozzles. The lateral flow Q2 (3.1 l/min) is drawn off between the two nozzles at right angles to the incoming air flow. Particles that cannot follow the lateral flow due to their inertia maintain their direction of movement and thus enter the lower axial flow Q3 (0.2 l/min). This results in the split in the lateral stream with exclusively smaller and lighter particles of the fraction $PM_{2.5}$ and the axial stream with the PM_{10} particle size. Via low-loss switching devices (pinch valves with straight passage), the aerosol now enters the scattered light sensor either from the axial flow (enrichment mode) or from the lateral flow (normal mode). In the enrichment mode, the APM-2 thus detects the PM_{10} concentration, in the normal mode the $PM_{2.5}$ concentration. For zero adjustment, filtered air is supplied to the scattered light sensor at periodic intervals via the switching device.

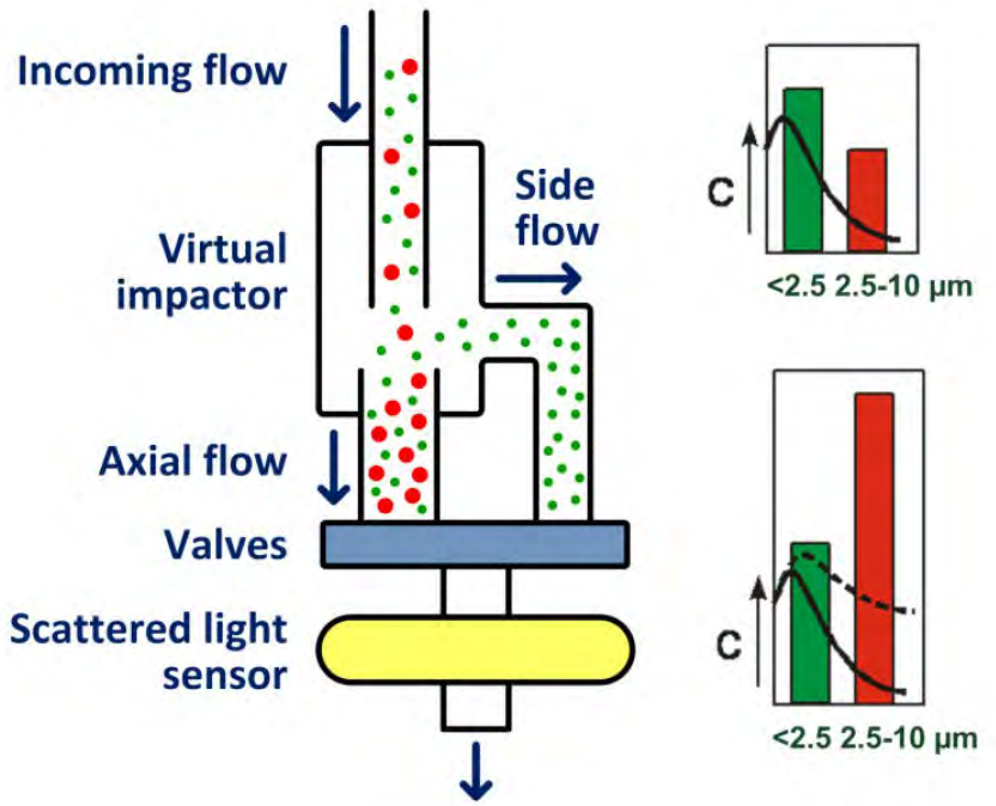

Figure 2: Operating principle of the virtual impactor

3.2 Functioning of the measuring system

The particulate sample passes through the PM_{10} sampling head at a flow rate of 3.3 l/min and enters the sampling tube connecting the sampling head to the virtual impactor. In the virtual impactor, the drawn-in air is divided into two partial flows. Via solenoid valves, the aerosol from the axial stream (enrichment mode for detecting the PM_{10} concentration or from the lateral stream (normal mode for detecting the $PM_{2.5}$ concentration) now reaches the scattered light sensor system, where the actual measurement takes place. Within the scope of the performance test, the measuring system was operated in alternating mode between PM_{10} and $PM_{2.5}$ with a respective interval time of 2 min. Once per hour, a zero air flush was also carried out for approx. two minutes for zero point adjustment - this is indicated in the display with "Flush". The measured data is stored in the unit's memory and - if available - on an SD card.

Figure 3 shows the schematic construction of the APM-2.

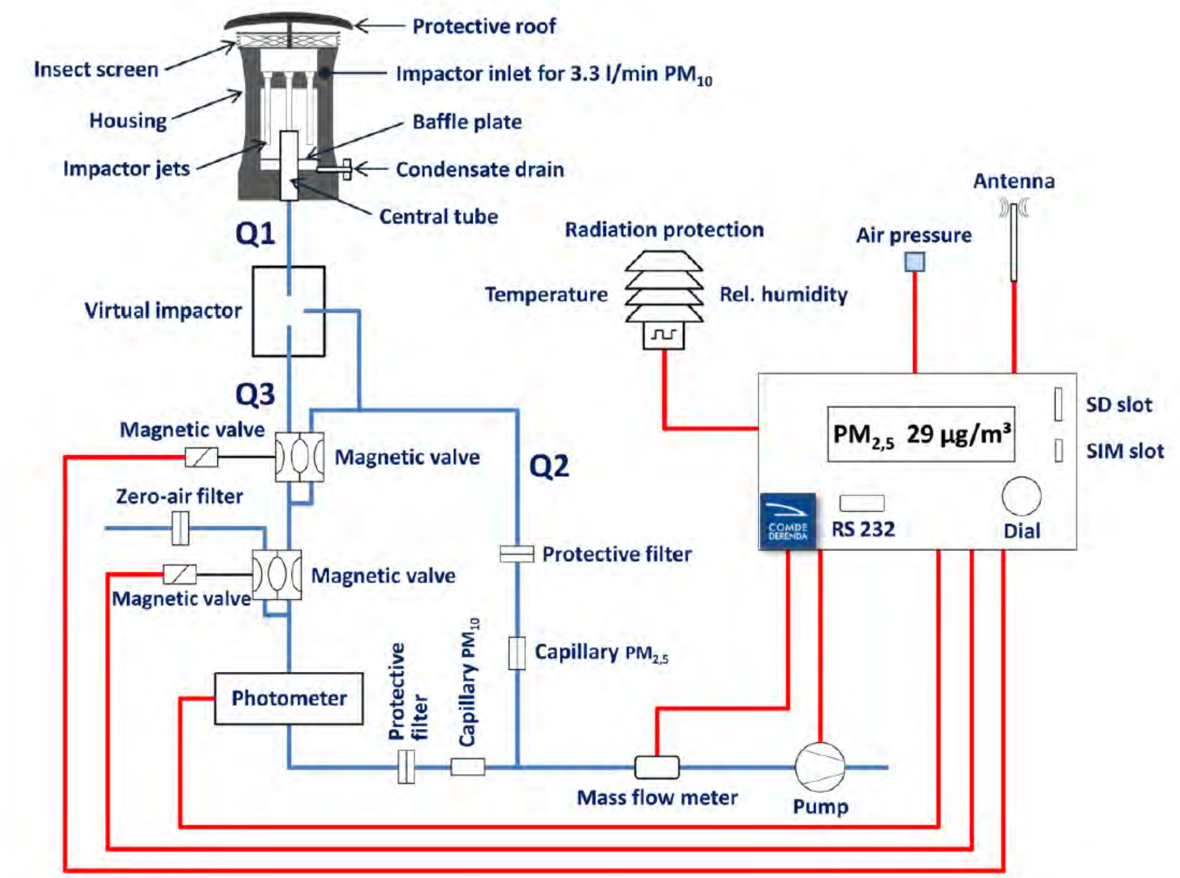

Figure 3: Overview diagram of the APM-2

3.3 AMS scope and set-up

The APM-2 ambient air monitor is based on the measuring principle of scattered light measurement.

The tested AMS consists of the PM_{10} sampling head, the sampling tube, the virtual impactor, the measuring system with operating unit and the scattered light photometer unit, the outdoor sensor as well as the manual in German.

Figure 4: Overview of the overall APM-2 system

Figure 5: PM_{10} sampling head for the APM-2

Figure 6: Virtual impactor for the APM-2

Figure 7: View of the APM-2 (front flap open)

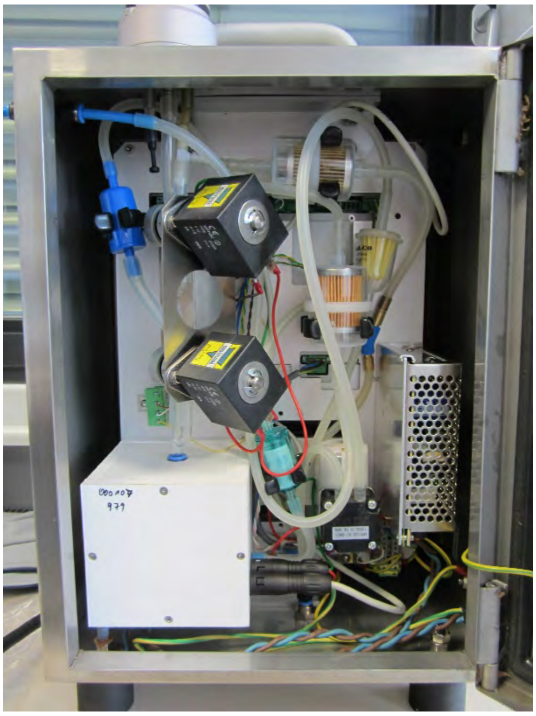

Figure 8: View the APM-2 (rear flap open)

Figure 9: APM-2 measuring systems at a measuring station

The AMS is operated directly via the operating unit with a jog dial (turn-push control) on the front of the system. Measurement data can be stored in the internal memory or on SD card - data transmission via RS232 interface is also possible (serial or Bayern-Hessen protocol). The user can retrieve measurement data and system information, change parameters and perform functionality tests on the measuring system.

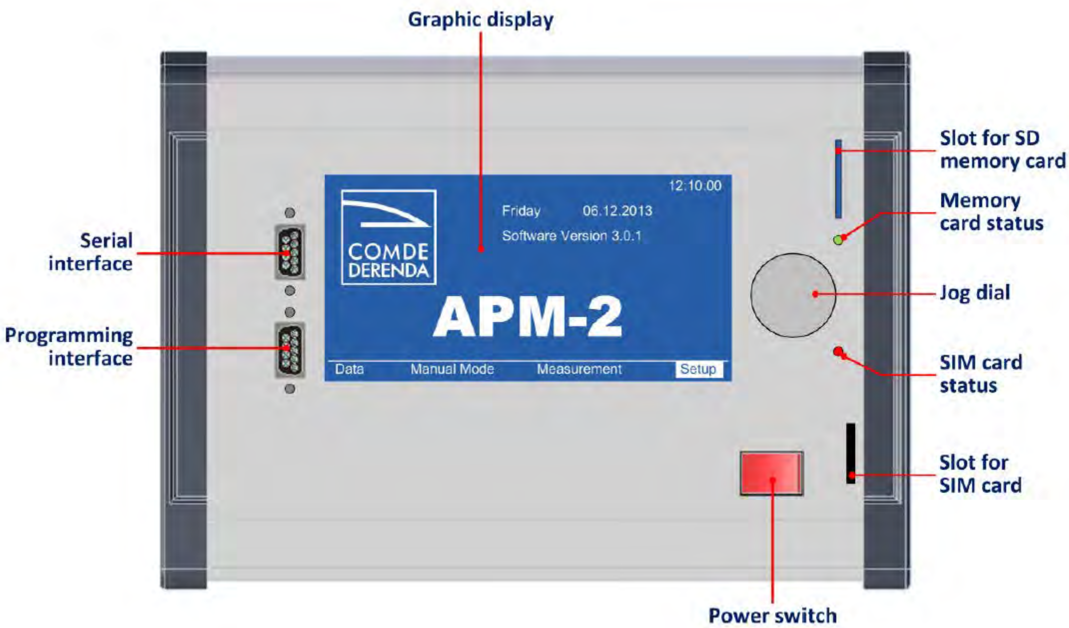

Figure 10: Operating unit

On the top is the main window for the user display - from here you can navigate to the corresponding submenus using the jog dial. Additionally, the current date , the current time and the installed software version are displayed.

Data menu:	This menu contains all functions concerning data storage (internal or SD card). Update functions for the software can also be accessed via this menu.
Manual operation menu:	Here there is the option of starting the $PM_{2.5}$ measurement, PM_{10} measurement and flushing functions manually. The selected functions run until they are cancelled again by the user. This menu is primarily intended for service staff to check functions.
Measurement menu:	Click to start a measurement.
Setup menu:	The "Setup" menu is used to configure the unit settings or to activate the test for checking functions, e.g. language, date/time, checking the sensitivity of the photometer (test gas container test), leak test, data transmission, system information, unit settings (for service, protected with factory password) and measuring parameters ($PM_{2.5}$, PM_{10} or alternating operation, nominal temperature of heating module, interval for alternating operation....).

Figure 11 shows a general overview of the APM-2 menu structure.

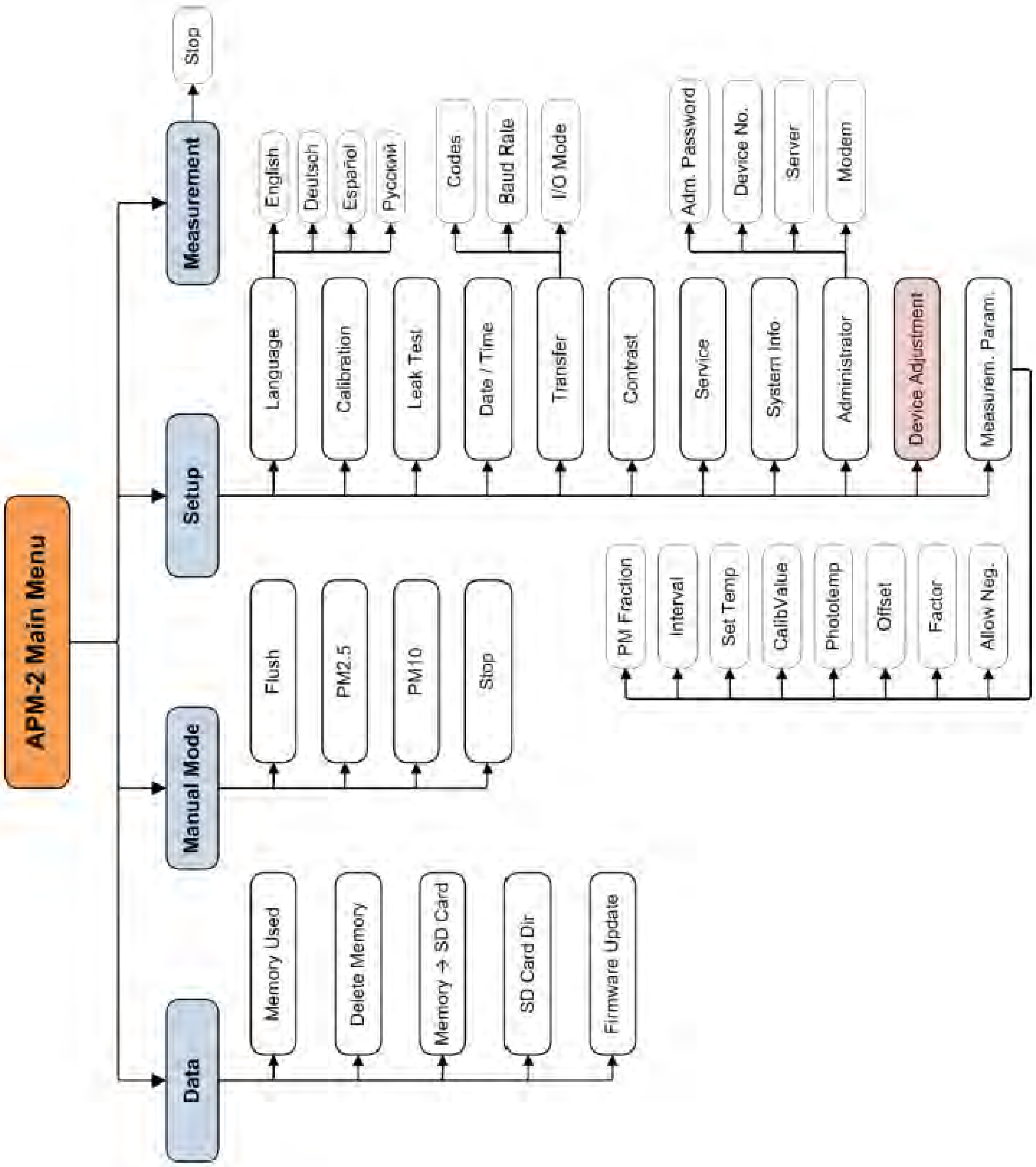

Figure 11: APM-2 menu structure

In addition to direct communication via the jog dial and system display, it is also possible to communicate with the AMS via RS232 (serial interface, Bavaria-Hesse protocol). Measurement data can easily be recorded on a PC via RS232 and terminal software, for example.

Within the scope of the performance test, the measured values were accessed by downloading the measurement data stored on the SD card.

A zero filter is mounted to the instrument inlet for the purpose of external zero checks. The use of this filter allows the provision of PM-free air.

Figure 12: Zero filter

For external verification of the photometer's sensitivity, the following optional test method has been developed by the AMS manufacturer:

By applying propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponding to an aerosol concentration of approx. 70 µg/m³) is generated. The stability of this signal is used as a measure of the stability of the sensitivity. In an analysis of repeatability, a standard deviation of less than 1 % from the average value of the measured values could be determined in 15 measurements (see Table 4), so that the test methodology is sufficiently stable and reproducible in itself.

Table 4 Repeatability test with test gas

Measurement	Time	Measured value [mV]
1	8:48	363
2	8:54	366
3	9:02	370
4	9:09	370
5	9:16	369
6	9:28	368
7	9:33	364
8	9:40	367
9	9:48	365
10	9:57	369
11	10:05	363
12	10:14	372
13	10:22	373
14	10:30	364
15	10:37	370
No. of values		15
Mean value		367.53
Standard deviation s_{x0}		3.25
Detection limit X [% of mean value]		**1.90**

Unfortunately, this test methodology was not available until December 2013, so that the required tests at span point in the laboratory (climatic chamber, mains voltage) could be carried out, however, no long-term drift tests at the span point over the field test duration were done. Since the systems have not shown any drift effects in continual comparison with the standard reference method, this fact should have no bearing on the assessment of the AMS, especially since in future this test point will not be carried out at all in the performance test according to EN 16450 [9]. The method with propane gas is no longer available [15] and is mentioned here because it was used in the laboratory test during the original performance test at test point 6.1 8 Dependence of measured value (span) on surrounding temperature (7.4.7).

Figure 13: Test gas case for checking sensitivity

Figure 14: Test set-up APM-2 + test gas case

A leak test device is available for checking the tightness of the AMS. A vacuum is created in the unit via the unit pump and then the pressure increase is observed over a period of five minutes after the pump is switched off. If the pressure rises >290 hPa, the leak test is considered to have been failed.

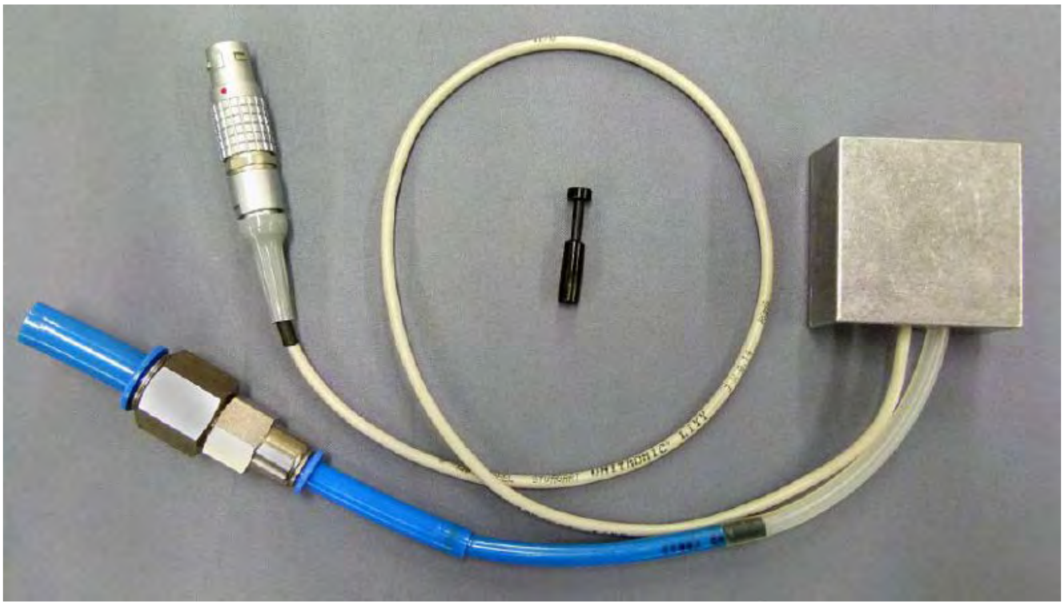

Figure 15: Leak-test apparatus

Table 5 details a number of important instrument specifications for the APM-2.

Table 5: APM-2 technical data (manufacturer's data)

Dimension/weight	**APM-2**
Measuring system	320 x 560 x 270 mm / 15 kg
Sampling tube	0.5 m between inlet and virtual impactor, special lengths are possible on request
Sampling head	PM_{10}, fundamental structure according to EN 12341, scaled down to 3.3 l/min
Power supply	230 V, 50/60 Hz
Power requirement	ca. 80 W
Ambient conditions	
Temperature	-20 to +50 °C
Moisture	Outdoor installation/degree of protection IP65
Sample flow rate (inlet)	3.3 l/min
Virtual Impactor	
Lateral flow	3.1 l/min, $PM_{2.5}$
Axial flow	0.2 l/min, PM_{10}
Aerosol sensor	
Measuring principle	Scattered light measurement, single angle (90°)
Set temperature photometer	40 °C
Measuring range	0 – 1000 µg/m³
Resolution	1 µg/m³
Operating mode	In the PM_{10} and $PM_{2.5}$ performance test in alternating operation at an alternating interval of 2 min, deviating alternating intervals (5,10 and 15 min) as well as the option for single operation PM_{10} or $PM_{2.5}$ are available
Date storage capacity (internal)	3.5 MB corresponds to 27,000 data records, non-volatile ring buffer
Instrument inputs/outputs	1 x SD card for saving the measured values 1 x RS232 interface for communication via serial interface / Bavaria-Hesse protocol 1 x RS232 interface as programming interface (service only)
Status signals/error messages	available (manual chapter 11)

4. Test programme

4.1. General

The original performance test [10] was carried out on two identical units with the serial numbers SN3 and SN4.

The original test comprised a laboratory test to determine the process parameters and a field test lasting several months at various field test sites in Germany.

Within the scope of the original performance test, a continued and controlled development / optimisation of the software up to the then announced version 3.0.1 took place.

After the initial announcement, the software versions 3.05.002, 3.07.02 and 3.08.001 were announced in the following years (see announcement history chapter 1).

New tests for the test items 6.1 9 Dependence of span on supply voltage (7.4.8) and 6.1 11 Dependence of reading on water vapour concentration (7.4.9) were carried out in 2019 with two identical units with the serial numbers SN 20095 and SN 20133.

These units had software 3.09.003 installed at the start of testing in October 2019. In comparison to version 3.08.001, only a few minor changes had been introduced here (type 0).

During the tests in 2019, it became apparent that the AMS in its current set-up could not meet the minimum requirement of test point 6.1 4 Flow rate accuracy (7.4.4) for the targeted ambient temperature range of -20°C to +50°C. As a result, the manufacturer tested and implemented various software approaches to improve the temperature characteristics of the implemented mass flow sensor (temperature compensation), which, due to their significance, were to be evaluated as a type 2 change with respect to the EN 15267-2 standard. These changes were implemented in the software versions 3.10.xxx.

However, since a meaningful qualification of the change "Introduction of temperature compensation for the flow sensor" that could be carried out with reasonable metrological effort was not possible, especially with regard to the potential impact on the historical data sets, the change was completely rejected by Comde-Derenda and all associated changes in the software were withdrawn. The temperature compensation of the flow sensor remains untouched and there is no release for software versions 3.10.xxx.

In order to meet the requirements of the EN 16450 standard [9] in the original set-up of the measuring system, Comde-Derenda decided to carry out the test in a reduced temperature range of -15°C to +40°C. This approach is covered in test item 6.1 4 Flow rate accuracy (7.4.4) by the passage that the test may also be carried out *"....at the minimum and maximum temperatures specified by the manufacturer, if these deviate from the temperatures to be applied as a rule..."*. However, this approach then implies that the proof of compliance with the requirements of the EN 16450 standard only applies to an ambient temperature range of -15°C to +40°C.

The new tests for the test point 6.1 4 Flow rate accuracy (7.4.4) for the ambient temperature range of -15°C to +40°C were carried out in August 2021 with two identical units with the serial numbers SN 20123 and SN 20133. The software installed on these units was: 3.11.007. Compared to version 3.09.003, further minor changes had been introduced here (various type 0 and a positively validated type 1 change).

The software history after version 3.08.001 as well as all software changes from 3.08.001 (last announced version) to 3.11.007 shall be submitted in a separate statement to the relevant body.

Concentrations are indicated as µg/m³ (operating conditions).

This addendum contains an assessment of the APM-2 measuring system with regard to the requirements according to standard EN 16450 [9].

In this report, the heading for each performance criterion cites the requirements according to [9] including its chapter number and wording.

4.2 Laboratory testing

Most of the laboratory testing was carried out in the existing performance test [10]. For the present report, test results were either taken from the previous report or re-assessed. The SN3 and SN4 units were used for this purpose.

Additional new tests had to be carried out for the following test points in 2019:

- Dependence of span on supply voltage
- Dependence of reading on water vapour concentration

The units SN 20095 and SN 20133 were used for this purpose.

For the following test point, an additional new test had to be carried out in 2021:

- Flow rate accuracy

The units SN 20123 and SN 20133 were used for this purpose.

The following devices were used to determine the performance characteristics during the laboratory tests.

- Climatic chamber (temperature range –20°C to +50°C, accuracy better than 1°C).
- Isolating transformer,
- 1 mass flow meter Model 4043 (manufacturer: TSI)
- 1 reference flow meter, type BIOS Met Lab 500 (manufacturer: Mesa Lab)
- Zero filter for external zero checks
- Waste gas chamber for span point check (only dependence of the span on the mains voltage)
- APM-2 (SN 79) as reference unit for checking the dependence of span on the mains voltage.

Measured values at zero point were recorded internally by the system. The stored raw data sets were read out via data download from the SD card.

To check the dependence of span on the mains voltage supply, a so-called smoke chamber was provided by the manufacturer. Beechwood chips are burned in this smoke chamber. The resulting smoke is homogenised in the chamber and can be sampled by 2 test specimens simultaneously.

Chapter 6 summarises the results of the laboratory tests.

4.3 Field test

The field test was carried out as part of the existing performance test [10] and was carried out with 2 identical measuring systems. These were:

Unit 1: SN3
Unit 2: SN4

For the present report, test results were either taken from the previous report or re-assessed. No further testing was required.

The following instruments were used during the field test.

- Measurement container provided by TÜV Rheinland, air-conditioned to ca. 20 °C
- Weather station (WS 500 from ELV Elektronik AG) for recording meteorological parameters such as air temperature, air pressure, air humidity, wind speed, wind direction and rainfall.
- 2 reference measuring systems, LVS3 for PM_{10} in accordance with item 5
- 2 reference measuring systems, LVS3 for $PM_{2.5}$ in accordance with item 5
- 1 gas meter, dry version
- 1 mass flow meter Model 4043 (manufacturer: TSI)
- Measuring system for power consumption; Metratester 5 (manufacturer: Gossen Metrawatt)
- Zero filter for external zero checks

The measured values were recorded by the system storing them on an SD card.

In the field test, two APM-2 systems and two reference units each for $PM_{2.5}$ and PM_{10} ran simultaneously for 24 hours. The reference instrument works intermittently, i.e. the filter must be changed manually after sampling.

Impaction plates of the PM_{10} and $PM_{2.5}$ sampling inlets were cleaned approximately every two weeks during the test period and greased with silicone grease in order to ensure reliable separation of particles. The sampling heads of the test specimens were cleaned approx. every 4 weeks according to the manufacturer's instructions. The sampling head generally has to be cleaned following the manufacturer's instruction taking into account local concentrations of suspended particulate matter.

The flow rates of the tested and the reference instruments were checked before and after the field test as well as before and after each relocation using a dry gas meter or a mass flow controller in each case connected to the instrument's air inlet via a hose line.

Sites of measurement and instrument installation

The measuring systems were installed completely outdoors on the roof of the measuring container during the field test at the Cologne and Bonn sites. The reference systems (LVS3) were also installed completely outdoors on the roof at these locations. The installation of the test specimens and the reference systems at the Rodenkirchen site was carried out on pedestals approx. 0.5 m high.

The field test was performed at the following measurement sites:

Table 6: Field test sites

No.	Measurement site	Period	Description
1	Cologne, winter	11/2012 – 02/2013	Urban background
2	Bonn, crossroads, winter	02/2013 – 05/2013	Affected by traffic
3	Cologne, summer	05/2013 – 07/2013	Urban background
4	Rodenkirchen, summer	07/2013 – 09/2013	Rural area + traffic
5	Cologne, winter*	01/2014 – 03/2014	Urban background

* Validation campaign for software 3.0.1, see chapter 8 Tests for the validation of the system software 3.0.1 from page 125

Figure 16 to Figure 25 show the PM concentrations measured with the reference systems at the field test sites.

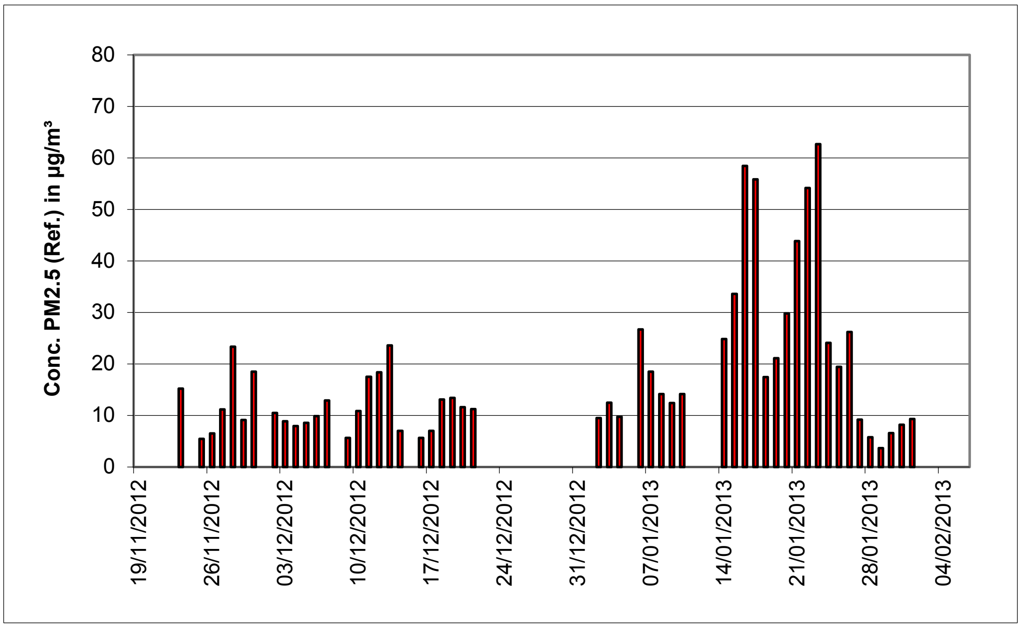

Figure 16: $PM_{2.5}$ concentrations (reference) in Cologne, winter

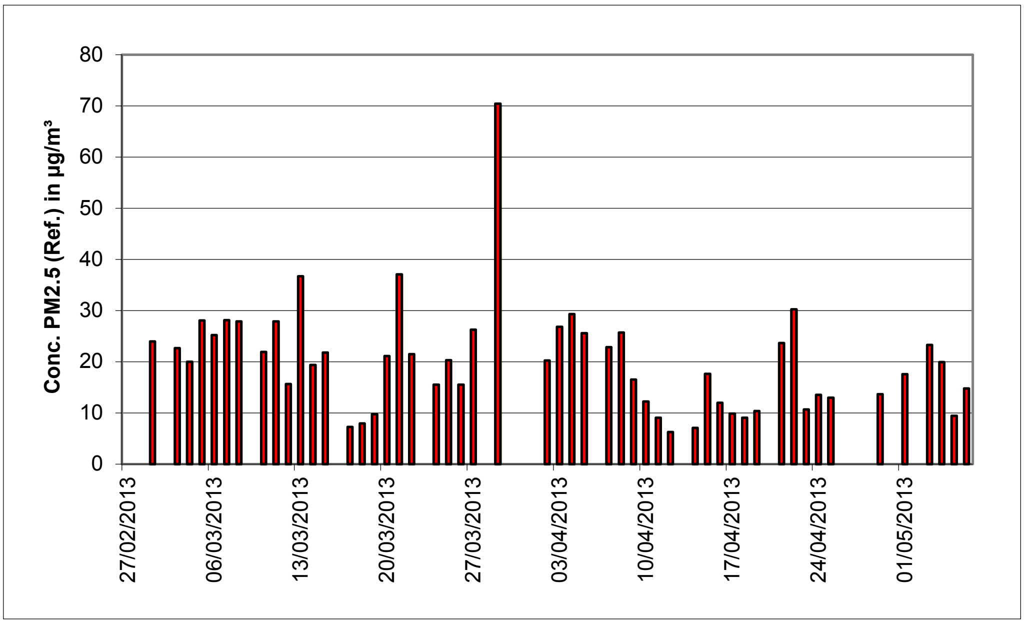

Figure 17: $PM_{2.5}$ concentrations (reference) in Bonn, winter

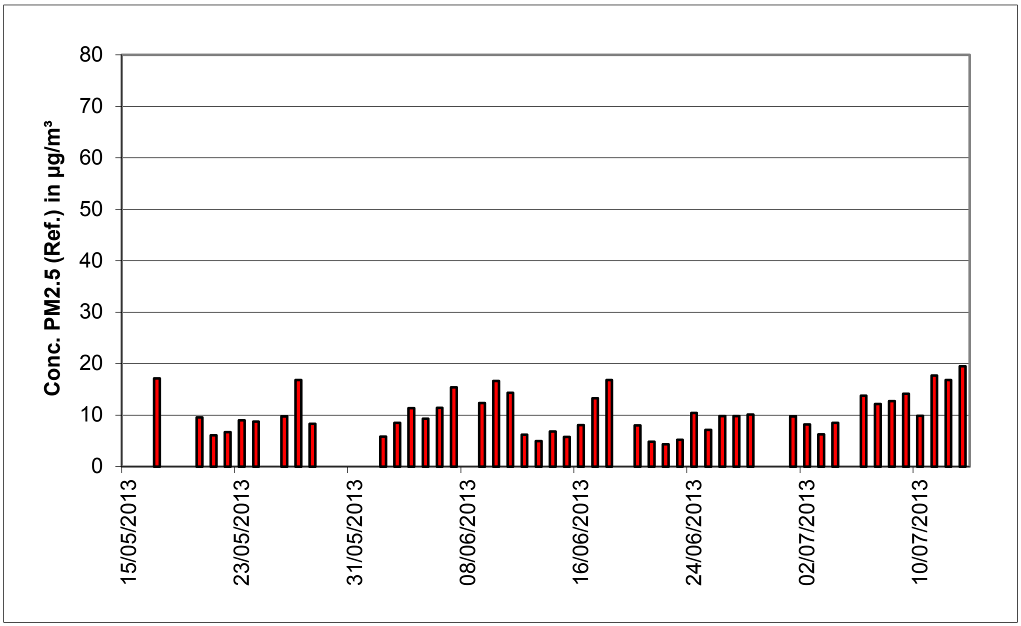

Figure 18: $PM_{2.5}$ concentrations (reference) in Cologne, summer

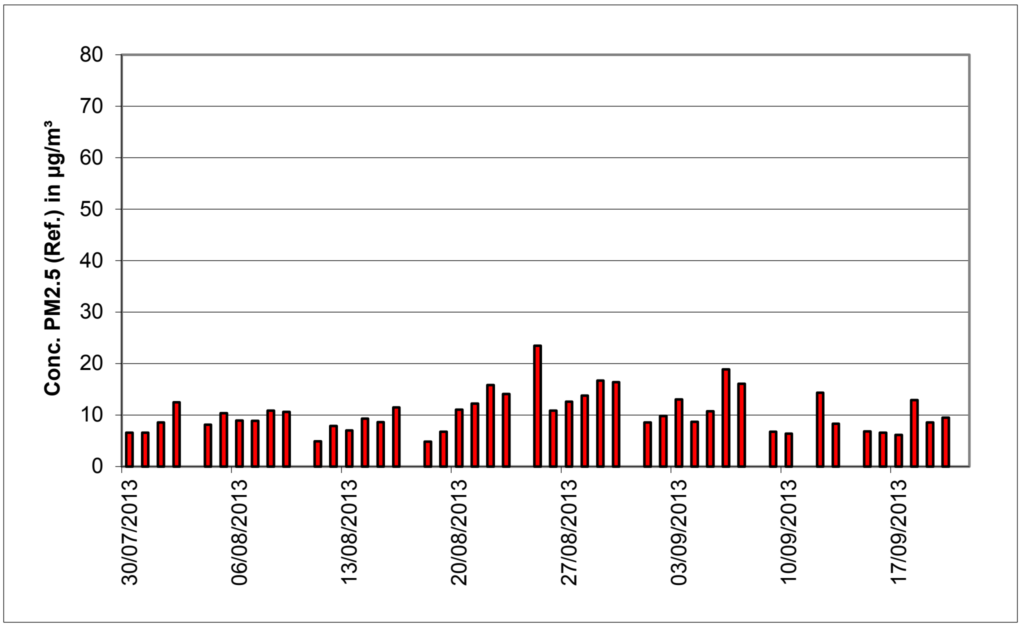

Figure 19: $PM_{2.5}$ concentrations (reference) in Rodenkirchen, summer

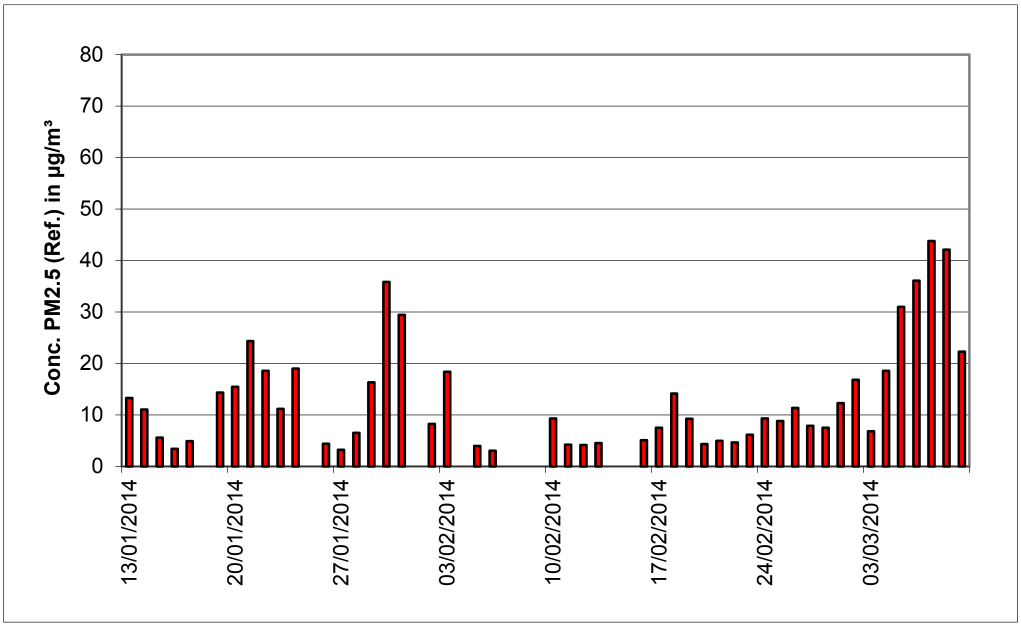

Figure 20: $PM_{2.5}$ concentrations (reference) in Cologne, winter 2014

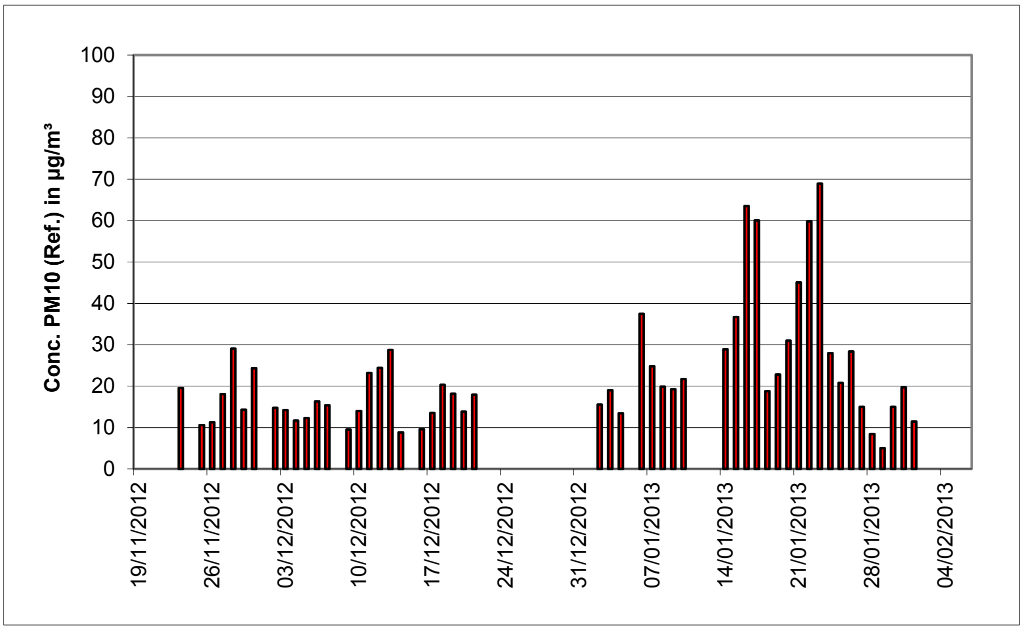

Figure 21: PM_{10} concentrations (reference) in Cologne, winter

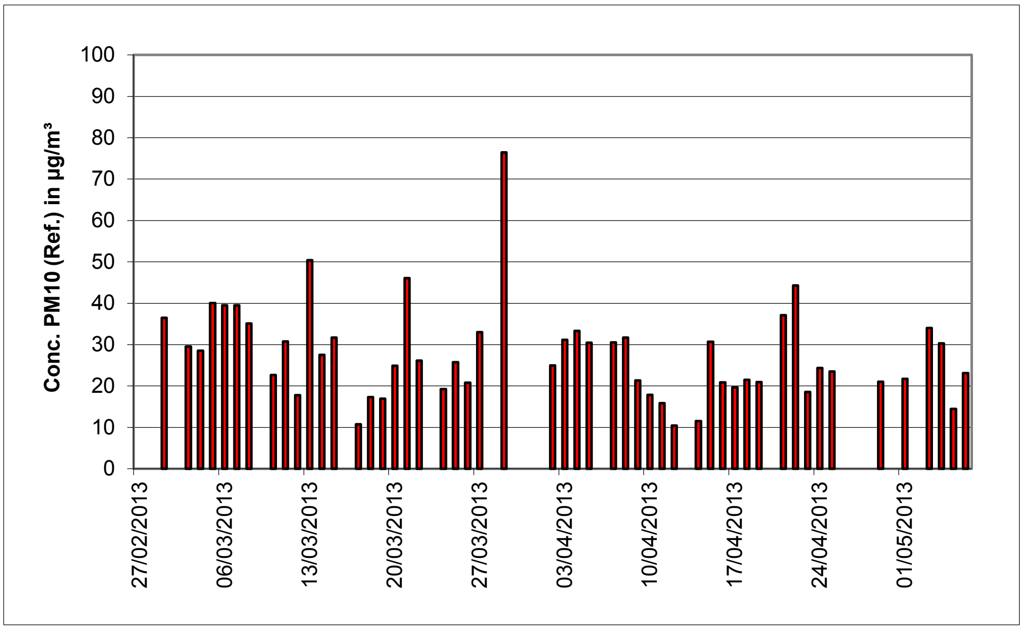

Figure 22: PM_{10} concentrations (reference) in Bonn, winter

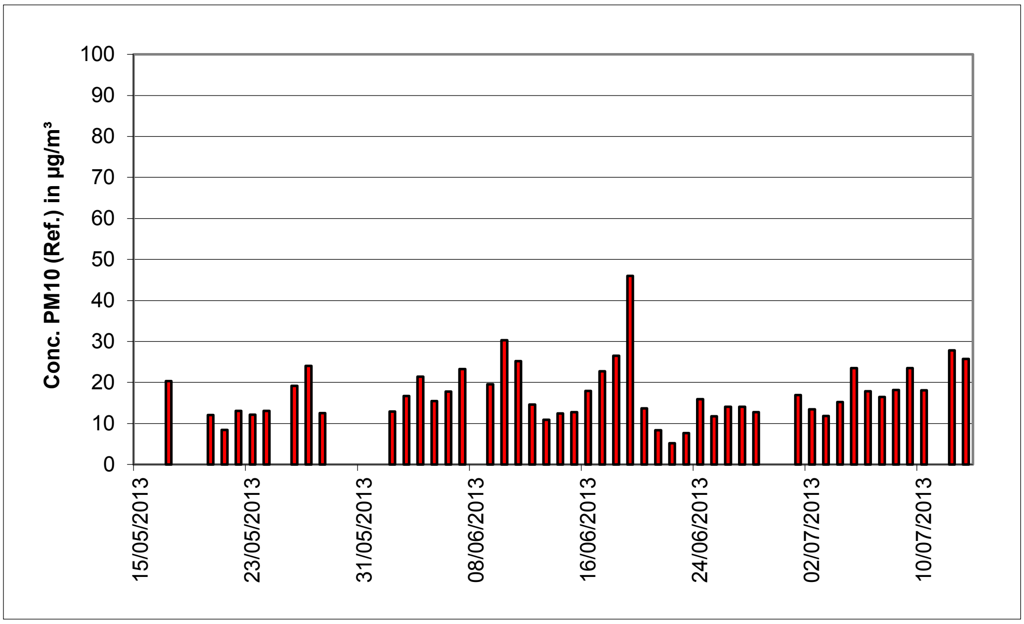

Figure 23: PM_{10} concentrations (reference) in Cologne, summer

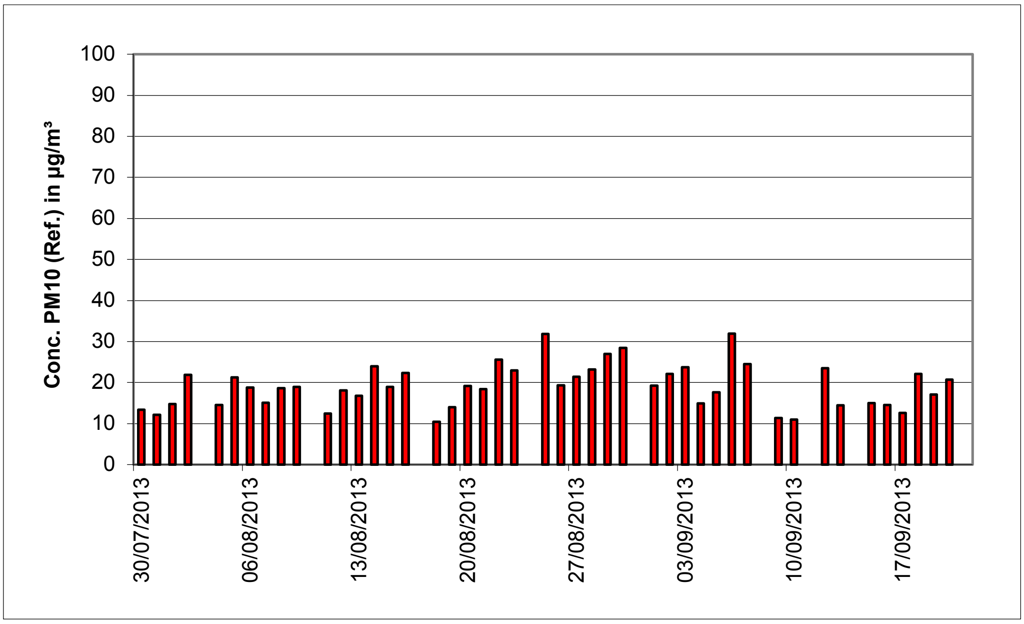

Figure 24: PM_{10} concentrations (reference) in Rodenkirchen, summer

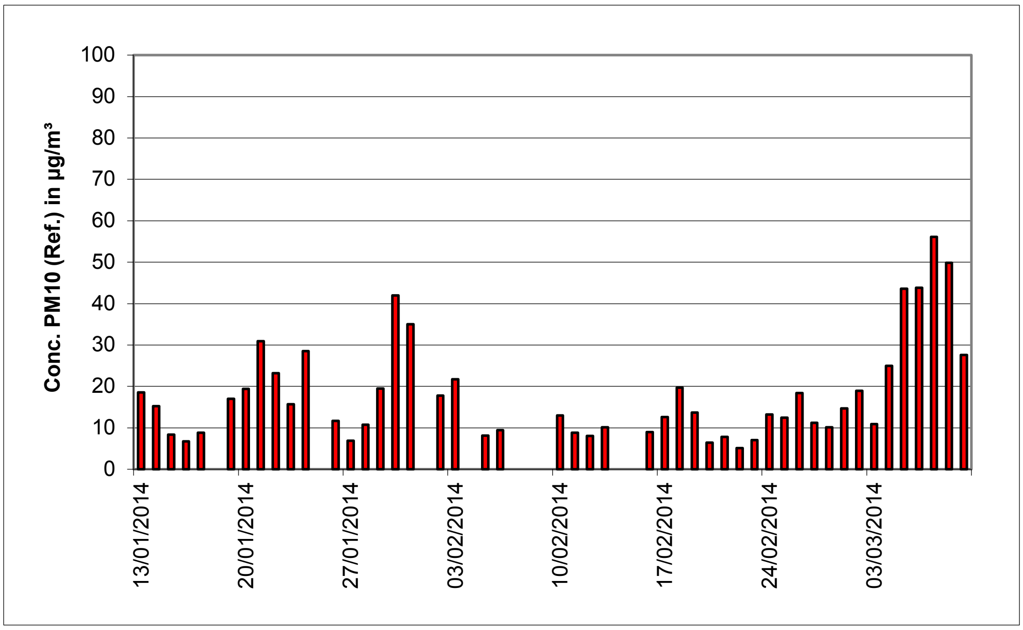

Figure 25: PM_{10} concentrations (reference) in Cologne, winter 2014

The following pictures show the measurement cabinet at the field test sites in Cologne, Bonn and Rodenkirchen.

Figure 26: Field test site Cologne, summer and winter

Figure 27: Field test site Bonn, winter

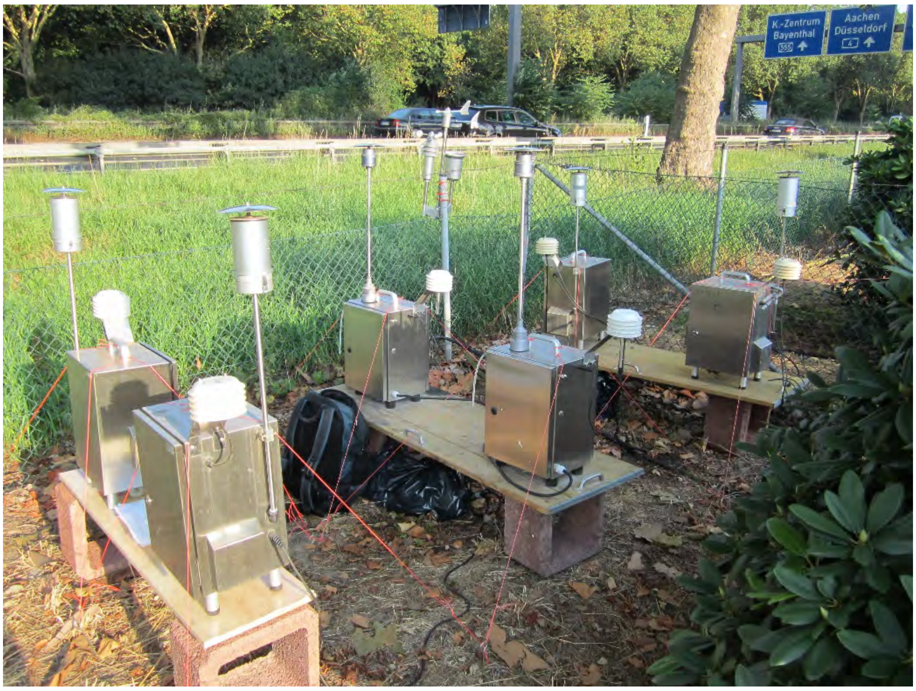

Figure 28: Field test site Rodenkirchen, summer

In addition to the air quality measuring systems for monitoring suspended particulate matter, a data logger for meteorological data was installed at the container/measurement site. Data on air temperature, pressure, humidity, wind speed, wind direction and precipitation were continually measured. 30-minute mean values were recorded.

The construction of the container itself as well as the arrangement of the sampling probes was characterised by the following dimensions:

• Height of cabinet roof:	2.50 m
• Height of the sampling system for test/ Reference system	0.96 m/0.51 m above cabinet roof 3.46 / 3.01 m above ground level
• Height of the wind vane:	4.5 m above ground level

Table 7 contains an overview of the most important meteorological parameters determined during the measurements at the 4 field test sites (+ validation campaign Cologne, winter 2014) as well as an overview of the suspended particulate conditions during the test period. All individual readings can be found in Annex 1 in Appendices 5 and 6.

Table 7: Ambient conditions at the field test sites as daily averages

	Cologne winter	Bonn, winter	Cologne summer	Rodenkirchen, summer	Cologne winter 2014*
Number of measurements PM_{10} reference	52	51	47	45	46
Number of measurements $PM_{2.5}$ reference	52	51	46	45	47
Ratio of $PM_{2.5}$ to PM_{10} [%] Range Average	41.6 – 97.2 73.8	42.2 – 96.5 70.5	42.5 – 84.1 62.2	38.8 – 73.6 54.0	32.0 – 90.9 68.5
Air temperature [°C] Range Average	-3.3 – 11.9 4.6	-3.4 – 20.0 7.9	6.3 – 28.2 16.7	9.9 – 27.8 17.2	2.5 – 13.1 6.5
Air pressure [hPa] Range Average	988 – 1027 1004	985 – 1021 1004	993 – 1021 1008	988 – 1016 1005	984 – 1022 1000
Rel. Humidity [%] Range Average	70.0 – 91.2 81.2	42.8 – 85.8 63.2	51.4 – 89.5 68.4	48.6 – 96.4 75.6	46.8 – 87.2 74.4
Wind speed [m/s] Range Average	0.0 – 3.3 0.9	0.4 – 4.2 1.6	0.1 – 2.7 0.8	1.2 – 5.0 2.6	0.0 – 3.0 0.0
Precipitation rate [mm/d] Range Average	0.0 – 25.7 2.9	0.0 – 13.2 0.9	0.0 – 32.4 3.7	0.0 – 21.3 1.9	0.0 – 18.9 1.7

* Validation campaign for software 3.0.1

Sampling duration

EN 12341 specifies the sampling duration as 24 h. However, longer sampling times are permissible for low concentrations as are shorter times for higher concentrations.

Standard EN 14907 specifies a sampling time of 24 h ± 1 h.

In the field test, a sampling time of 24 h was always set for all units (from 10:00 - 10:00 (Cologne), from 7:00 - 7:00 (Bonn) and from 9:00 - 9:00 (Rodenkirchen)).

Data handling

Prior to their assessment for each field test site, measured value pairs determined from reference values during the field test were submitted to a statistical Grubbs's test for outliers (99%) in order to prevent distortions of the measured results from data, which evidently is implausible. Measured values pairs detected as significant outliers may be expunged from the pool of values as long as the test statistic remains above the critical value. The January 2010 version of the guideline [5] requires that no more than 2.5% of the data pairs be detected and removed as outliers.

In principle, no measured value pairs are expunged for the tested AMS, unless there are justifiable technical reasons for implausible values. During the entire test, no measured values were expunged for the tested AMS.

Table 8 and Table 9 show an overview of the pairs of measured values (reference) detected and removed as significant outliers for each individual site.

The following value pairs have been expunged:

Table 8: Value pairs (reference PM_{10}) discarded from the data set following Grubbs's test

Location	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Cologne, summer	11.07.2013	31.0	28.1

Table 9: Value pairs (reference $PM_{2.5}$) discarded from the data set following Grubbs's test

Location	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Cologne, summer	05.07.2013	14.6	17.4

Filter handling – Mass measurement

The following filters were used during performance testing:

Table 10: Filter materials used

Measuring device	Filter material, type	Manufacturer
Reference devices LVS3	Emfab™, ∅ 47 mm	Pall

Filter handling was performed in compliance with EN 14907.

The methods used for processing and weighing filters and for weighing are described in detail in Annex 2 to this report.

5. Reference Measurement Method

During the field test, the following instruments were used in accordance with EN 12341 and EN 14907:

1. as PM_{10} reference system: Low Volume Sampler LVS3
   Manufacturer: Engineering office Sven Leckel, Leberstraße 63, Berlin, Germany
   Date of manufacture: 2007
   PM_{10} sampling head
2. as $PM_{2.5}$ reference system: Low Volume Sampler LVS3
   Manufacturer: Engineering office Sven Leckel, Leberstraße 63, Berlin, Germany
   Date of manufacture: 2007 and 2010
   $PM_{2.5}$ sampling inlet

During the tests, two reference systems each for $PM_{2.5}$ and PM_{10} were operated in parallel with the flow controlled at 2.3 m³/h. Under normal conditions the accuracy of flow control is < 1% of the nominal flow rate.

For the LVS3 low volume sampler, the rotary vane vacuum pump takes in sample air via the sampling inlet. The volumetric flow is measured between the filter and the vacuum pump with the help of a measuring orifice. The air taken in flows from the pump via a separator for the abrasion of the rotary vane to the air outlet.

After sampling has been completed, the electronics display the sample air volume in standard and operating m³.

The PM_{10} and $PM_{2.5}$ concentrations were determined by dividing the quantity of suspended particulate matter on each filter determined in the laboratory with a gravimetric method by the corresponding throughput of sample air flow as operating m³.

6. Test results

6.1 1 Measuring ranges

The measuring ranges should meet the following requirements:
0 µg/m^3 to 1000 µg/m^3 as a 24-hour average value
0 µg/m^3 to 10,000 µg/m^3 as a 1-hour average value, if applicable

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

It was tested whether the measuring system's upper limit of measurement meets the requirements .

6.4 Evaluation

A measuring range of 0 - 1,000 µg/m³ is set as standard on the measuring system.

6.5 Assessment

The upper limit of the measuring range for the measuring system is 1,000 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 2 Negative signals

Negative signals shall not be suppressed.

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

The possibility of displaying negative signals was tested both in the laboratory and in the field test.

6.4 Evaluation

The measuring system is able to output negative signals both via its display and its data outputs, however, negative measured values did not occur during the test. Given the measuring principle and design of the instrument, negative values are not to be expected.

6.5 Assessment

While the AMS is able to display negative readings directly and via the various outputs, they should not be expected given instrument design and the measurement principle applied.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 3 Zero level and detection limit (7.4.3)

Zero level: ≤ 2.0 µg/m³
Detection limit: ≤ 2.0 µg/m³

6.2 Equipment

Zero filter for zero checks

6.3 Testing

The detection limit was determined for the SN3 and SN4 test units by operating the AMS with zero filters installed at both measuring system inlets. Air free of suspended particulate matter is applied over a period of 15 days for a duration of 24h each.

6.4 Evaluation

The detection limit X is calculated from the standard deviation s_{x0} of the measured values sucking air free from suspended particulate matter through both test specimens. It is equal to the standard deviation of the average x_0 of the measured values x_{0i} multiplied by 3.3 for each test specimen.

$$X = 3.3 \cdot s_{x0} \qquad \text{where} \cdot s_{x0} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

6.5 Assessment

The zero level and the detection limit resulted from the tests of both instruments both for PM_{10} and $PM_{2.5}$ and were < 0.15 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 11: Zero level and detection limit PM_{10}

		Device SN3	Device SN4
Number of values n		15	15
Average of the zero values (Zero level) $\overline{x}_0$	µg/m³	0.004	0.044
Standard deviation of the values s_{x0}	µg/m³	0.014	0.041
Detection limit x	µg/m³	**0.047**	**0.135**

Table 12: Zero level and detection limit $PM_{2.5}$

		Device SN3	Device SN4
Number of values n		15	15
Average of the zero values (Zero level) $\overline{x}_0$	µg/m³	0.000	0.027
Standard deviation of the values s_{x0}	µg/m³	0.000	0.046
Detection limit x	µg/m³	**0.000**	**0.151**

Appendix 1 in the annex contains the individual measured values for the determination of the zero level and detection limit.

6.1 4 Flow rate accuracy (7.4.4)

The relative difference between the mean value of the measurement results for the volumetric flow at two temperatures of the ambient air shall be ≤ 2.0 %.
The determined relative difference between the mean value of the measurement results for the volume flow at two temperatures of the ambient air must meet the following requirements : ≤ 2.0%

- *at 5°C and 40°C for installations in an air-conditioned environment by default*
- *at minimum and maximum temperatures specified by the manufacturer if these deviate from the default temperatures.*

6.2 Equipment

Climatic chamber for the temperature range -15 to +40 °C, reference flow meter according to chapter 4.

6.3 Testing

The APM-2 measuring systems operate with a flow rate of 3.3 l/min regulated to operating conditions.

During the tests in 2019, it became apparent that the AMS in its current set-up could not meet the minimum requirement for the targeted ambient temperature range of -20°C to +50°C. As a result, the manufacturer tested and implemented various software approaches to improve the temperature characteristics of the implemented mass flow sensor (temperature compensation), which, due to their significance, were to be evaluated as a type 2 change with respect to the EN 15267-2 standard. These changes were implemented in the software versions 3.10.xxx.

However, since a meaningful qualification of the change "Introduction of temperature compensation for the flow sensor" that could be carried out with reasonable metrological effort was not possible, especially with regard to the potential impact on the historical data sets, the change was completely rejected by Comde-Derenda and all associated changes in the software were withdrawn. The temperature compensation of the flow sensor remains untouched and there is no release for software versions 3.10.xxx.

In order to meet the requirements even in the original set-up of the measuring system, Comde-Derenda decided to carry out the test in a reduced temperature range of -15°C to +40°C. This approach is covered in test item 6.1 4 Flow rate accuracy (7.4.4) by the passage that the test may also be carried out *"....at the minimum and maximum temperatures specified by the manufacturer, if these deviate from the temperatures to be applied as a rule...".*

However, this approach then implies that the proof of compliance with the requirements of the EN 16450 standard only applies to an ambient temperature range of -15°C to +40°C.

With the help of a reference flow meter, the volume flow was determined for both measuring systems at -15°C and +40°C by 10 measurements over 1 hour. The measurements were performed at equal intervals throughout the measurement period.

6.4 Evaluation

Averages were calculated from the 10 measured values determined at each temperature and deviations from the operating flow rate determined.

6.5 Assessment

The relative difference determined between the mean value of the measurement results for the volume flow at -15°C and +40°C was a maximum of -1.79 %.

Criterion satisfied? yes

6.6 Detailed presentation of test results

The results of the flow measurements at the permissible ambient temperatures are shown in Table 13.

Table 13: Flow rate accuracy at -15 °C and +40 °C

		Instrument SN 20123	Instrument SN 20133
Nominal sample flow rate value	l/min	3.300	3.300
Average at -15 °C	l/min	3.356	3.357
Dev. from nominal value	%	1.70	1.73
Average at 40 °C	l/min	3.241	3.272
Dev. from nominal value	%	-1.79	-0.86

Appexdix 2 in the annex contains the individual measured values for the determination of the flow rate accuracy.

6.1 5 Constancy of sample flow rate (7.4.5)

The instantaneous flow rate and the flow rate averaged over the sampling period shall fulfil the performance requirements below.
≤ 2.0 % of the nominal value of the volume flow (averaged sample flow)
≤ 5 % of the nominal value of the volume flow (instantaneous value of the sample flow)

6.2 Equipment

For this test, an additional reference flow meter in accordance with item 4 was provided.

6.3 Testing

The APM-2 measuring systems operate with a flow rate of 3.3 l/min regulated to operating conditions.

The sample flow rate was calibrated before the first field test and the checked with the help of a mass flow controller at every new field test site and re-adjusted when necessary.

To determine the constancy of the sample flow rate, the flow rate was recorded and evaluated with the help of a mass flow meter over a period of 24h.

6.4 Evaluation

The average, standard deviation as well as the maximum and minimum values were determined from the measured values for the flow rate.

6.5 Assessment

Table 14 presents the results of the flow rate checks performed at every field test site.

Table 14: Results of the sample flow rate test

Flow rate check before:	SN3		SN4	
Field test site:	[l/min]	Dev. from target [%]	[l/min]	Dev. from target [%]
Cologne, winter	3.31	0.3	3.30	0
Bonn, winter	3.32	0.6	3.28	-0.6
Cologne, summer	3.33	0.9	3.29	-0.3
Rodenkirchen, summer	3.36	1.8	3.33	0.9

The charts illustrating the constancy of the sample flow rate demonstrate that all measured values determined during sampling deviate from their respective target values by less than ±5%. The deviation of the 24h mean values for the total flow of 3.3 l/min are also significantly smaller than the required ±3 % from the nominal value.

The 24h-averages deviate from the nominal values by less then ± 2.0%, all instantaneous values deviate by less than ± 5%.

Criterion satisfied? yes

6.6 Detailed presentation of test results for the nominal flow

Table Table 15 lists the characteristics determined for the flow rate. Figure 29 and Figure 30 show the flow rate measurements for the SN3 and SN4 test instruments.

Table 15: Performance characteristics for total flow measurement (24h average), SN3 & SN4

Device	Mean [l/min]	Deviation from nominal [%]	Std. dev. [l/min]	Max [l/min]	Min [l/min]
SN3	3.29	-0.43	0.033	3.45	3.20
SN4	3.31	0.24	0.030	3.37	3.27

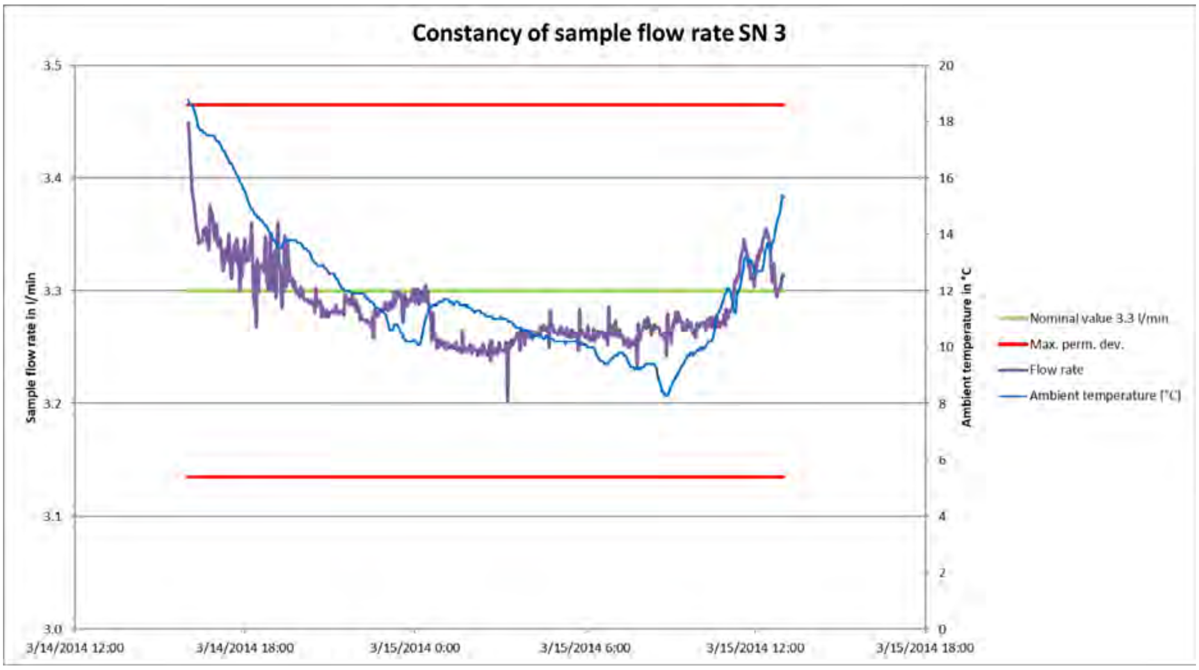

Figure 29: Flow rate for the SN3 test unit

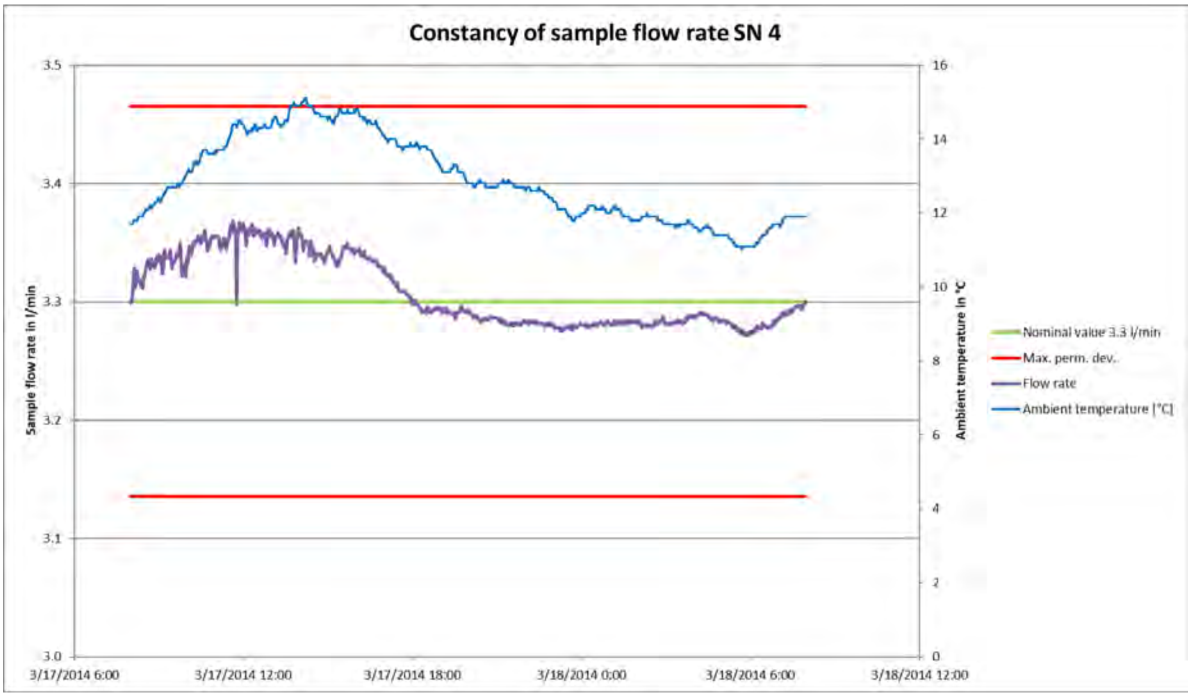

Figure 30: Flow rate for the SN4 test unit

6.1 6 Leak tightness of the sampling system (7.4.6)

Leakage shall not exceed 2.0% of the sample flow rate or else meet the AMS manufacturer's specifications in complying with the required data quality objectives (DQO).

6.2 Equipment

Leak test device.

6.3 Testing

The flow sensor on the APM-2 measuring system is located directly in front of the pump. To determine the leakage rate of the measuring system, a leakage test is carried out in accordance with chapter 9.7 of the manual using a leakage test device provided by the manufacturer. First, a vacuum is created in the unit by the internal pump. Then, over a period of 5 minutes, it is checked whether and to what extent there is a pressure increase in the system. If this pressure increase is >290 hPa, then the unit is leaking and must be checked. System volume is 215 ml. The unit also outputs the leakage rate in ml/min as additional information.

The flow rate is 3.3 l/min, i.e. the maximum permissible leakage rate is 0.033 l/min or 33 ml/min.

It is recommended to check the leak tightness of the measuring system every 3 months using the described procedure.

6.4 Evaluation

The leak test was performed in the laboratory.

The criterion specified by the unit manufacturer for passing the leak test - maximum pressure rise of 290 hPa in 5 minutes - proved to be a suitable parameter for monitoring the unit's leak tightness in the test.

The maximum determined leakage rate of 10.4 ml/min is less than 1 % of the nominal flow rate of 3.3 l/min.

6.5 Assessment

The criterion specified by the unit manufacturer for passing the leak test - maximum pressure rise of 290 hPa in 5 minutes - proved to be a suitable parameter for monitoring the unit's leak tightness in the test. The maximum determined leakage rate of 10.4 ml/min is less than 1 % of the nominal flow rate of 3.3 l/min.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 16 shows the results of the leak tests.

Table 16: Results of the leak tests

Test	SN3		SN4		Max. permissible leak rate in l/min
	Pressure increase in 5 min in hPa	Leak rate in l/min	Pressure increase in 5 min in hPa	Leak rate in l/min	
1	108	8.2	151	10.4	33
2	104	8.0	143	10.1	33
3	102	8.0	139	9.9	33

6.1 7 Dependence of measured value on surrounding temperature (7.4.7)

The differences found shall comply with the performance criteria given below.
Zero point
≤ 2.0 µg/m3

- *between 5°C and 40°C by default, for installations in an air-conditioned environment.*
- *at minimum and maximum temperatures specified by the manufacturer if these deviate from the default temperatures.*

6.2 Equipment

Climatic chamber for the temperature range between -20 and +50 °C; zero filter for the zero point check.

6.3 Testing

The dependence of the zero reading on the surrounding temperature was determined at the following temperatures (within the specifications of the manufacturer):

a) at a nominal temperature $T_{S,n}$ = +20 °C;

b) at a minimum temperature $T_{S,1}$ = -20 °C

c) at a maximum temperature $T_{S,2}$ = +50 °C.

To test the dependence of the zero point on the surrounding temperature, the complete measuring system was operated in a climatic chamber.

Sample air, free of suspended particles, was supplied to the two candidate systems after fitting two zero filters at the AMS inlet in order to perform zero point checks.

The tests were performed in the temperature sequence $T_{S,n}$ — $T_{S,1}$ — $T_{S,n}$ — $T_{S,2}$ — $T_{S,n}$.

Readings were recorded at zero point after an equilibration period of at least 6h for every temperature step (3 readings each).

6.4 Evaluation

Measured values for the concentrations of the individual readings were read and evaluated.

In order to exclude any possible drift due to factors other than temperature, the measurements at $T_{S,n}$ were averaged.

The differences between readings at both extreme temperatures and $T_{S,lab}$ were determined.

6.5 Assessment

The tested ambient temperature range at the installation site of the AMS was -20 °C to +50 °C. When looking at the values output by the system, a maximum influence of the ambient temperature on the zero point of <0.1 µg/m³ for $PM_{2.5}$ and of <0.2 µg/m³ for PM_{10} was determined.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 17: Dependence of the zero point on the surrounding temperature, PM_{10}

Temperature	SN3		SN4	
	Measured value	Deviation to mean value at 20°C	Measured value	Deviation to mean value at 20°C
°C	µg/m³	µg/m³	µg/m³	µg/m³
20	0.0	0.0	0.0	0.0
-20	0.0	0.0	0.2	0.2
20	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
Mean value at 20°C	0.0	-	0.0	-

Table 18: Dependence of the zero point on the surrounding temperature, $PM_{2.5}$

Temperature	SN3		SN4	
	Measured value	Deviation to mean value at 20°C	Measured value	Deviation to mean value at 20°C
°C	µg/m³	µg/m³	µg/m³	µg/m³
20	0.0	0.0	0.0	0.0
-20	0.0	0.0	0.1	0.1
20	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
Mean value at 20°C	0.0	-	0.0	-

Appendix 3 in the annex contains the individual measured results.

6.1 8 Dependence of measured value (span) on surrounding temperature (7.4.7)

The differences found shall comply with the performance criteria given below.
Sensitivity of the measuring system (span):
≤ 5% from the value at the nominal test temperature

- *between 5°C and 40°C by default, for installations in an air-conditioned environment.*
- *at minimum and maximum temperatures specified by the manufacturer if these deviate from the default temperatures.*

6.2 Equipment

Climatic chamber for the temperature range -20 to +50 °C, test gas with propane for span point check.

6.3 Testing

The dependence of AMS sensitivity (span) on the surrounding temperature was determined at the following temperatures (within the specifications of the manufacturer):

a) at a nominal temperature $T_{S,n}$ = +20 °C;

b) at a minimum temperature $T_{S,1}$ = -20 °C

c) at a maximum temperature $T_{S,2}$ = +50 °C.

To test the dependence of the sensitivity of the measuring system (span) on the ambient temperature, the complete measuring equipment was operated in the climate chamber.

The tests were performed in the temperature sequence $T_{S,n}$ — $T_{S,1}$ — $T_{S,n}$ — $T_{S,2}$ — $T_{S,n}$.

Readings were recorded at zero point after an equilibration period of at least 6h for every temperature step (3 readings each).

6.4 Evaluation

The measured values of the respective individual measurements with propane were determined.

In order to exclude any possible drift due to factors other than temperature, the measurements at $T_{S,n}$ were averaged.

The differences between readings at both extreme temperatures and $T_{S,lab}$ were determined.

6.5 Assessment

The tested ambient temperature range at the installation site of the AMS was -20 °C to +50 °C. No deviations > 2.4 % were determined at the span point.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 19: Dependence of sensitivity (propane) on surrounding temperature, SN3 + SN4

Temperature	SN3		SN4	
	Measured value	Deviation to mean value at 20°C	Measured value	Deviation to mean value at 20°C
°C	[mV]	%	[mV]	%
20	336.9	-0.3	337.7	0.4
-20	335.5	-0.7	332.7	-1.1
20	345.9	2.4	335.0	-0.4
50	342.5	1.3	339.8	1.0
20	331.1	-2.0	336.3	0.0
Mean value at 20°C	338.0	-	336.3	-

Appendix 3 in the annex contains the results from 3 individual measurements.

6.1 9 Dependence of span on supply voltage (7.4.8)

The differences found shall comply with the performance criteria given below.
Sensitivity of the measuring system (span):
≤ 5% from the value at the nominal test voltage

6.2 Equipment

Isolating transformer, smoke chamber for span point check.

6.3 Testing

In order to test the dependence of span on supply voltage, supply voltage was reduced to 195 V starting from 230 V, it was then increased to 253 V via an intermediary step of 230 V.

For the span point tests, the test instruments, SN 20095 and SN 20133, were each operated in succession with a third instrument as a reference via the smoke chamber. Beechwood chips are burned in this smoke chamber. The resulting smoke is homogenised in the chamber and can be sampled by 2 test specimens simultaneously.

The voltage was then only varied for the test units and not for the reference unit. The difference to the reference unit was used to calculate the deviations at the various voltage levels.

6.4 Evaluation

At span point, the percentage change of the measured value determined for every step related to the starting point at 230 V was considered.

6.5 Assessment

Voltage variations did not cause deviations exceeding -1.3% for $PM_{2.5}$ and > 1.1 % for PM_{10}, related to the starting value of 230 V.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 21 and Table 20 summarise the test results.

Table 20: Dependence of the measured value on the mains voltage, deviation in %, PM_{10}, SN 20095 + SN 20133

Supply voltage	SN20095		SN20133	
	Measured value	Deviation to start value at 230 V	Measured value	Deviation to start value at 230 V
V	[µg/cm²]	%	[µg/cm²]	%
230	658.2	0.9	693.8	0.5
195	649.1	-0.5	692.8	0.4
230	651.3	-0.2	693.1	0.4
253	659.8	1.1	694.3	0.6
230	648.1	-0.7	683.7	-0.9
Mean value at 230 V	652.5	-	690.2	-

Table 21: Dependence of the measured value on the mains voltage, deviation in %, $PM_{2.5}$, SN 20095 + SN 20133

Supply voltage	SN20095		SN20133	
	Measured value	Deviation to start value at 230 V	Measured value	Deviation to start value at 230 V
V	[µg/cm²]	%	[µg/cm²]	%
230	646.8	0.6	655.7	0.7
195	648.9	1.0	642.8	-1.3
230	643.3	0.1	651.3	0.0
253	649.4	1.0	650.8	0.0
230	637.9	-0.7	646.0	-0.8
Mean value at 230 V	642.7	-	651.0	-

6.1 10 Effect of failure of mains voltage

Instrument parameters shall be secured against loss.
On return of main voltage the instrument shall automatically resume functioning.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

A simulated failure in the mains voltage served to test whether the instrument remained fully functional and reached operation mode on return of the mains voltage.

6.4 Evaluation

In the event of a mains failure, the AMS is again in a ready-to-measure state after the voltage has been restored, the photometer temperature has stabilised and the two-minute zero air purge has taken place.

6.5 Assessment

Buffering protects all instrument parameters against loss. The AMS is in fault-free operational readiness when the voltage returns and automatically resumes measuring operation after the photometer temperature has stabilised again and after the two-minute zero air purge.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 11 Dependence of reading on water vapour concentration (7.4.9)

The largest difference in readings between 40% and 90% relative humidity shall fulfil the performance criterion stated below:
≤ 2.0 µg/m³ in zero air when cycling relative humidity from 40% to 90% and back.

.

6.2 Equipment

Climatic chamber with humidity control for the range 40 % to 90 % relative humidity, zero filter for zero point verification.

6.3 Testing

The dependence of the reading on the water vapour concentration in the sample air was determined by supplying humidified zero air in the range of 40 % to 90 % relative humidity. To this effect, the measuring system was operated in the climatic chamber and the relative humidity of the entire surrounding atmosphere was controlled. For the zero point tests, the test specimens SN 20095 and SN 20133 were supplied with sample air free of suspended dust by mounting zero filters at both device inlets.

After stabilisation of relative humidity and the concentration values, a reading over an 8h-averaging period at 40% relative humidity was recorded. The relative humidity was then raised back to 90% at a rate of 25% per hour. The time needed until an equilibrium was reached (ramp) and the measured value over an averaging time of 8h at 90% relative humidity were recorded. The humidity was then lowered back to 25% at a rate of 40% per h. Again, the time needed until an equilibrium was reached (ramp) and the reading over an averaging time of 8h at 40% relative humidity were recorded.

6.4 Evaluation

The measured value for the zero level of 8-hour individual measurements at stable humidity levels were obtained and assessed. The characteristic concerned is the largest difference in µg/m³ between values in the range of 40% to 90% relative humidity.

6.5 Assessment

The maximum difference determined between the measured values at 40 % and at 90 % relative humidity was -1.6 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 22: Dependence of measured values on water vapour concentration, SN 20095 + SN 20133

rel. Humidity	20095		20133	
	Measured value	Deviation to previous value	Measured value	Deviation to previous value
%	µg/m³	µg/m³	µg/m³	µg/m³
40	0.1	-	1.5	-
90	0.6	0.5	2.1	0.6
40	0.5	-0.1	0.5	-1.6
Maximum deviation	-0.1		-1.6	

6.1 12 Zero checks (7.5.3)

During the tests, the absolute measured value of the AMS shall not exceed the following criterion:
Absolute value ≤ 3.0 µg/m³

6.2 Equipment

Zero filter for zero checks

6.3 Testing

The test was carried out within the framework of the field test over a total period of approx. 10 months (comparison campaign 1-4) or approx. 15 months if the validation campaign in winter 2014 is taken into account.

As part of regular checks about every month (incl. at the beginning and at the end of the tests at each location), the measuring systems were operated with zero filters fitted to the AMS inlets over a period of at least 24h and zero readings were evaluated.

6.4 Evaluation

During the tests, the absolute measured value of the AMS at zero point defined at 3.0 µg/m³ shall not be exceeded.

6.5 Assessment

The maximum absolute measured value at zero was 2.4 µg/m³ for $PM_{2.5}$ and 2.7 µg/m³ for PM_{10}.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 23 and Table 24 list the measured value obtained for the zero point in µg/m³.

Table 23: Zero checks SN3 + SN4, PM_{10}, zero filter

Date	SN3		Date	SN4	
	Measured Value µg/m³	Measured value (absolute) < 3.0 µg/m³		Measured Value µg/m³	Measured value (absolute) < 3.0 µg/m³
11/19/2012	0.0	ok	11/19/2012	0.0	ok
11/20/2012	0.0	ok	11/20/2012	0.0	ok
11/21/2012	0.8	ok	11/21/2012	0.8	ok
1/11/2013	0.7	ok	1/11/2013	0.1	ok
1/12/2013	0.4	ok	1/12/2013	0.0	ok
1/13/2013	1.4	ok	1/13/2013	1.0	ok
2/5/2013	0.1	ok	2/5/2013	0.1	ok
2/6/2013	0.0	ok	2/6/2013	0.2	ok
2/27/2013	1.0	ok	2/27/2013	1.8	ok
2/28/2013	1.4	ok	2/28/2013	2.4	ok
3/30/2013	1.2	ok	3/30/2013	2.0	ok
3/31/2013	1.0	ok	3/31/2013	2.7	ok
4/1/2013	1.1	ok	4/1/2013	2.2	ok
4/26/2013	1.1	ok	4/26/2013	1.2	ok
4/27/2013	1.8	ok	4/27/2013	1.6	ok
4/28/2013	1.9	ok	4/28/2013	1.8	ok
5/15/2013	1.4	ok	5/15/2013	1.7	ok
5/16/2013	1.2	ok	5/16/2013	1.7	ok
6/29/2013	1.6	ok	6/29/2013	2.4	ok
6/30/2013	1.5	ok	6/30/2013	2.2	ok
9/21/2013	1.5	ok	9/21/2013	1.7	ok
07.02.2014*	1.8	ok	2/7/2014	1.3	ok
08.02.2014*	2.4	ok	2/8/2014	1.1	ok
09.02.2014*	1.9	ok	2/9/2014	1.2	ok

* Cologne, Winter 2014

Table 24: Zero checks SN3 + SN4, $PM_{2.5}$, zero filter

Date	SN3		Date	SN4	
	Measured Value µg/m³	Measured value (absolute) < 3.0 µg/m³		Measured Value µg/m³	Measured value (absolute) < 3.0 µg/m³
11/19/2012	0.0	ok	11/19/2012	0.0	ok
11/20/2012	0.0	ok	11/20/2012	0.0	ok
11/21/2012	0.6	ok	11/21/2012	0.6	ok
1/11/2013	0.7	ok	1/11/2013	0.1	ok
1/12/2013	0.3	ok	1/12/2013	0.0	ok
1/13/2013	1.4	ok	1/13/2013	1.0	ok
2/5/2013	0.1	ok	2/5/2013	0.1	ok
2/6/2013	0.0	ok	2/6/2013	0.2	ok
2/27/2013	1.1	ok	2/27/2013	1.7	ok
2/28/2013	1.3	ok	2/28/2013	2.4	ok
3/30/2013	1.2	ok	3/30/2013	2.3	ok
3/31/2013	1.0	ok	3/31/2013	1.7	ok
4/1/2013	0.9	ok	4/1/2013	1.8	ok
4/26/2013	1.1	ok	4/26/2013	1.2	ok
4/27/2013	1.5	ok	4/27/2013	1.6	ok
4/28/2013	1.7	ok	4/28/2013	1.7	ok
5/15/2013	1.3	ok	5/15/2013	1.7	ok
5/16/2013	1.1	ok	5/16/2013	1.6	ok
6/29/2013	1.5	ok	6/29/2013	2.3	ok
6/30/2013	1.5	ok	6/30/2013	2.2	ok
9/21/2013	1.5	ok	9/21/2013	2.0	ok
07.02.2014*	2.0	ok	2/7/2014	1.5	ok
08.02.2014*	2.4	ok	2/8/2014	1.4	ok
09.02.2014*	2.1	ok	2/9/2014	1.4	ok

* Cologne, Winter 2014

6.1 13 Recording of operational parameters (7.5.4)

Measuring systems shall be able to provide data of operational states for telemetric transmission of – at minimum – the following parameters:

- *Flow rate;*
- *Pressure drop over sample filter (if relevant);*
- *Sampling time;*
- *Sampling volume (if relevant);*
- *Mass concentration of relevant PM fraction(s);*
- *Ambient temperature,*
- *Exterior air pressure,*
- *Air temperature in measuring section,*
- *Temperature of the sampling inlet if a heated inlet is used;*

Results of automated/functional checks, where available, shall be recorded.

6.2 Equipment

Computer for data acquisition

6.3 Testing

A PC was connected locally to the AMS via RS232 and the data transfer including the system status was checked. The data is stored internally and can be copied to an SD card.

Remote monitoring is easily possible via appropriate routers or modems.

6.4 Evaluation

The AMS enables comprehensive telemetric monitoring and control of the measuring system via the serial interface (RS232). The instrument provides operating statuses and all relevant parameters. The following data is stored internally and can be copied to an SD card:

- Flow rate
- Mass concentration of the dust fractions concerned with time reference
- Ambient temperature
- Exterior air pressure
- Exterior humidity
- Air temperature in the measuring unit
- Pump output
- Operating status

6.5 Assessment

The AMS enables comprehensive telemetric control of the measuring system via the serial interface (RS232). The instrument provides operating statuses and all relevant parameters.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 14 Daily averages (7.5.5)

The AMS shall allow for the formation of daily averages or values.

6.2 Equipment

For this test, a clock was additionally provided.

6.3 Testing

It was checked whether the measuring system allows the formation of a daily average.

6.4 Evaluation

The APM-2 measuring system switches between the measuring channels for PM_{10} and $PM_{2.5}$ every two minutes. The photometer unit is flushed with zero air once an hour for two minutes.

The results from the field tests show, however, that with this system configuration the comparability of the test samples with the reference method could be demonstrated and the formation of daily average values is thus possible. This also applies to the location at the road junction in Bonn, which is heavily influenced by traffic.

The available collection time per PM fraction is ((60min-2min)/2) = 29 min per hour and thus 48.3 % of the total time.

Thus, the formation of daily averages is ensured.

6.5 Assessment

It is possible to form valid daily averages.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 15 Availability (7.5.6)

The availability of the measuring system shall be at least 90%.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The start and end times at each of the four field test sites marked the start and end time for the availability test. For this purpose, all interruptions to the test, e.g. due to malfunctions or maintenance work, are recorded.

The total time during the field test in which valid measurement data of ambient air concentrations were obtained was used for calculating availability. Time needed for scheduled calibrations and maintenance (cleaning; change of consumables) should not be included.

Availability is calculated as

$$A = \frac{t_{valid} + t_{cal,maint}}{t_{field}}$$

Where:

t_{valid} is the time during which valid data have been collected;

$t_{cal,maint}$ is the time spent for scheduled calibrations and maintenance;

t_{field} is the total duration of the field test.

6.4 Evaluation

Table 25 shows a list of operating, maintenance and malfunction times. The measuring equipment was operated in the field tests (4 comparison campaigns) over a total period of 264 measuring days. This period includes a total of 22 days with zero filter operation or equipment checks as part of the performance test (see also Appendix 5).

Outages due to external influences that cannot be blamed on the unit were registered on 31.12.2012 and on 01.01.2013 (power failure). The externally-caused outages reduced the total time of operation to 262 measuring days.

The following errors in functioning were observed:

SN3:

No instrument malfunctions were observed.

SN4:

Between 24.05.2013 and 26.05.2013 there was no data recording on SN4 for unknown reasons - thus there were three days of outage here.

No further errors in functioning were observed:

Regular maintenance of the sampling heads, regular checking of the flow rates (or tightness) lead to downtimes of 0.5 to approx. 1 hour. Affected daily average values were not discarded in these cases.

6.5 Assessment

Availability was 100 % for SN3 and 98.9 % for SN4.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 25: Determination of the availability

		Instrument 1 (SN3)	Instrument 2 (SN4)
Operation time	d	262	262
Outage time	d	0	3
Maintenance time inkl. zero filter	d	22	22
Actual operating time:	d	240	237
Availability	%	100	98.9

6.1 Method used for equivalence testing (7.5.8.4 & 7.5.8.8)

Standard EN 16450 [9] requires compliance with the following five criteria:

1. Of the full data set, at least 20% of the concentration values (determined with the reference method) shall be greater than 28 µg/m³ for PM_{10} and 17 µg/m³ for $PM_{2.5}$. When due to low concentration levels, the criteria for 20 % of results to be greater than 28 µg/m3 for PM_{10}, or to be greater than 17 µg/m3 for $PM_{2.5}$ cannot be obtained, a minimum of 32 data points higher than these thresholds is considered sufficient.
2. Between-AMS uncertainty shall remain below 2.5 µg/m³ for the overall data and for data sets with data larger than/equal to 30 µg/m³ PM_{10} and 18 µg/m³ $PM_{2.5}$.
3. The uncertainty between reference systems shall not exceed 2.0 µg/m³.
4. The expanded uncertainty (W_{CM}) is calculated at 50 µg/m³ for PM_{10} and at 30 µg/m³ for $PM_{2.5}$ for every individual test specimen and checked against the average of the reference method. For each of the following cases, the expanded uncertainty shall not exceed 25%:
   - Full data set:
   - datasets representing PM concentrations greater than/equal to 30 µg/m³ for PM_{10}, or concentrations greater than/equal to 18 µg/m³ for $PM_{2.5}$, provided that the set contains 40 or more valid data pairs
   - Datasets for each individual site
5. Preconditions for acceptance of the full dataset are that the slope b is insignificantly different from 1: $|b-1| \leq 2 \cdot u(b)$ and the intercept a is insignificantly different from 0: $|a| \leq 2 \cdot u(a)$. If these preconditions are not met, the candidate method may be calibrated using the values obtained for slope and/or intercept.

The following chapters address the issue of verifying compliance with the five criteria.

Chapter 6.1 16 Between-AMS uncertainty $u_{bs,AMS}$ (7.5.8.4) addresses verification of criteria 1 and 2.

Verification of criteria 3, 4 and 5 is reported on in chapter 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)

Chapter 6.1 17 Use of correction factors/terms (7.5.8.5–7.5.8.8) contains an assessment for the case that criterion 5 is not complied with without applying correction factors.

6.1 16 Between-AMS uncertainty $u_{bs,AMS}$ (7.5.8.4)

The between-AMS uncertainty u_{bs} shall be ≤ 2.5 µg/m³.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The test was performed as part of the field test with four separate comparison campaigns. Different seasons as well as different concentrations of $PM_{2.5}$ and PM_{10} were taken into consideration.

Of the entire data set, at least 20 % of the concentration values determined with the reference method should be greater than 17 µg/m³ for $PM_{2.5}$ or greater than 28 µg/m³ for PM_{10}. Should this not be assured because of low concentration levels, a minimum of 32 value pairs is considered sufficient.

For each comparison campaign, at least 40 valid value pairs were determined. Of the full data set (4 comparisons, for PM_{10}: 195 valid measured value pairs for SN3, 193 valid measured value pairs for SN4; for $PM_{2.5}$: 194 valid measured value pairs for SN3, 192 valid measured value pairs for SN4), a total of 28.6 % of the measured values are above the upper assessment threshold of 17 µg/m³ for $PM_{2.5}$ and a total of 20.7 % of the measured values are above the upper assessment threshold of 28 µg/m³ for PM_{10}. The concentrations measured were related to the ambient conditions.

6.4 Evaluation

Chapter 7.5.8.4 of standard EN 16450 specifies that:

The between-AMS uncertainty u_{bs} shall be ≤ 2.5 µg/m³. A between-AMS uncertainty > 2.5 µg/m^3 is an indication of unsuitable performance of one or both instruments, and equivalence should not be stated.

Uncertainty is determined for:

- All comparisons together (complete data set)
- 1 data set with measured values ≥ 18 µg/m³ for $PM_{2.5}$ (basis: averages reference measurement)
- 1 data set with measured values ≥ 30 µg/m³ for PM_{10} (basis: averages reference measurement)

The between-AMS uncertainty u_{bs} is calculated from the differences of all daily averages (24h-values) of the AMS which are operated simultaneously as:

$$u_{bs,AMS}^2 = \frac{\sum_{i=1}^{n}(y_{i,1} - y_{i,2})^2}{2n}$$

Where: $y_{i,1}$ and $y_{i,2}$ = Results of the parallel measurements of individual 24h-values i
n = Number of 24h-values

6.5 Assessment

At no more than 1.04 µg/m³ for $PM_{2.5}$ and no more than 2.28 µg/m³ for PM_{10}, the uncertainty between the test specimen u_{bs} remains well below the permissible maximum of 2.5 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 26 and Table 27 list the calculated values for the between-AMS uncertainties u_{bs}. Corresponding charts are provided in Figure 31 to Figure 42.

Table 26: Between-AMS uncertainty $u_{bs,AMS}$ for $PM_{2.5}$

Location	Number of measurements	Uncertainty $u_{bs,AMS}$
		µg/m³
All locations	**192**	**0.65**
Classification via reference values		
Values ≥ 18 µg/m³	**49**	**1.04**

Table 27: Between-AMS uncertainty $u_{bs,AMS}$ for PM_{10}

Location	Number of measurements	Uncertainty $u_{bs,AMS}$
		µg/m³
All locations	**193**	**1.27**
Classification via reference values		
Values ≥ 30 µg/m³	**33**	**2.28**

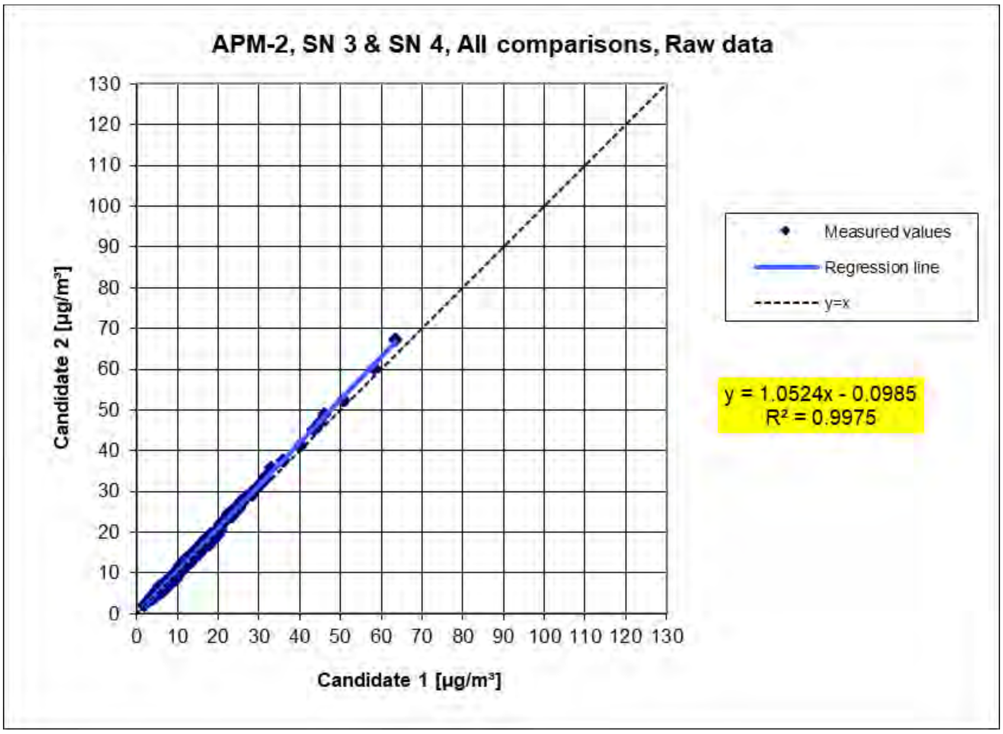

Figure 31: Result of the parallel measurements with the test instruments SN3 / SN4, measured component $PM_{2.5}$, all locations

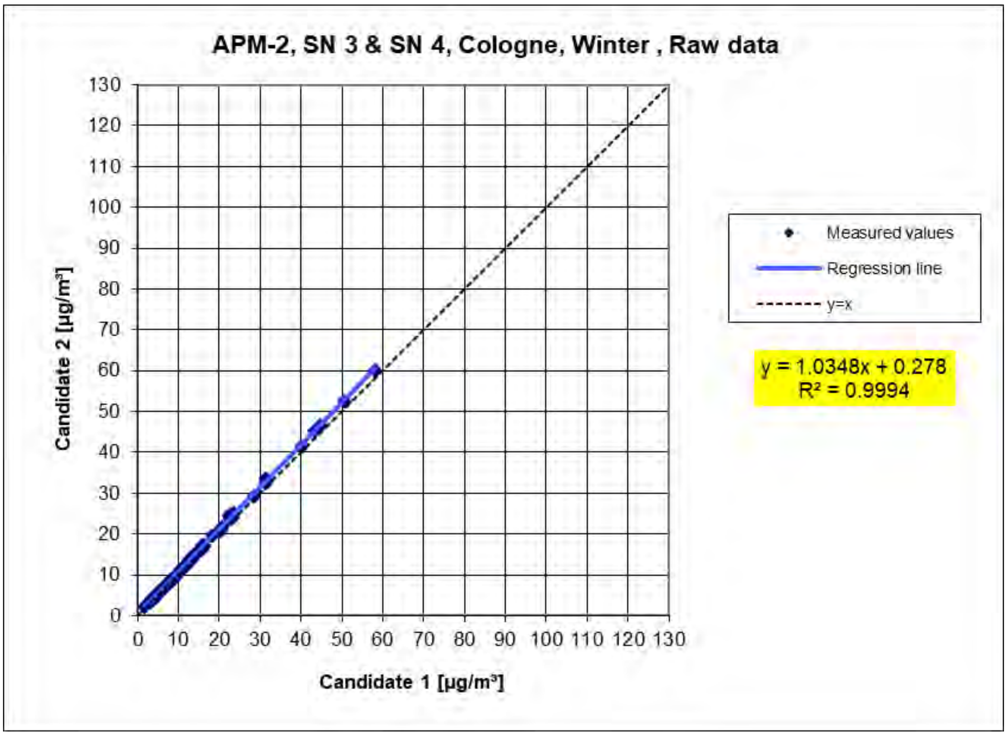

Figure 32: Result of the parallel measurements with the test instruments SN3 / SN4, measured component $PM_{2.5,}$ Cologne, winter

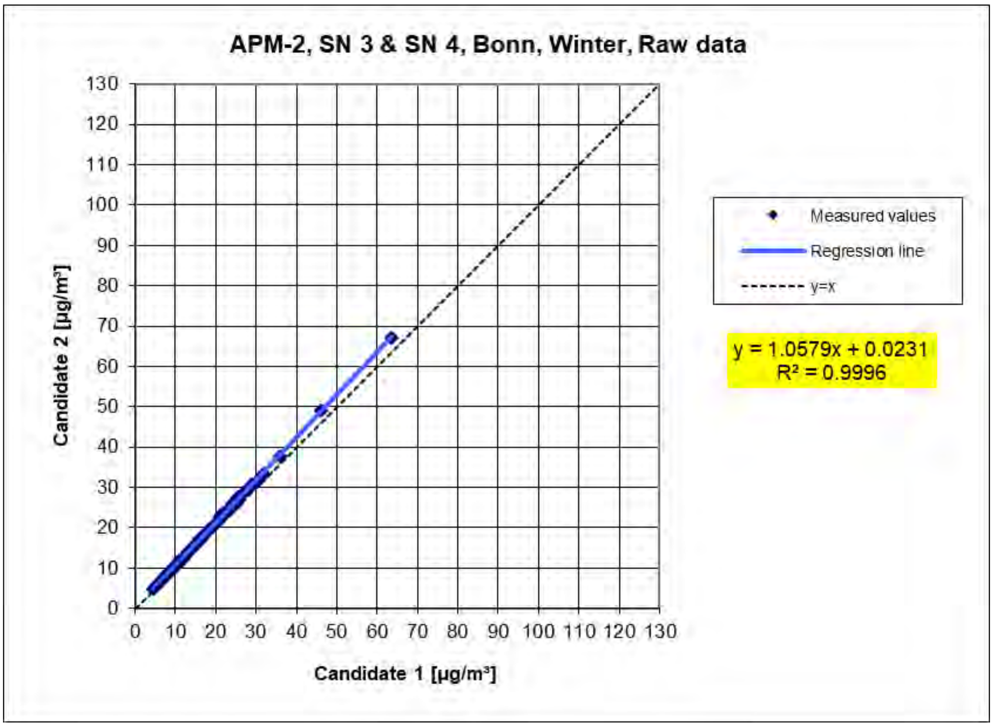

Figure 33: Result of the parallel measurements with the test instruments SN3 / SN4, measured component $PM_{2.5}$, Bonn, winter

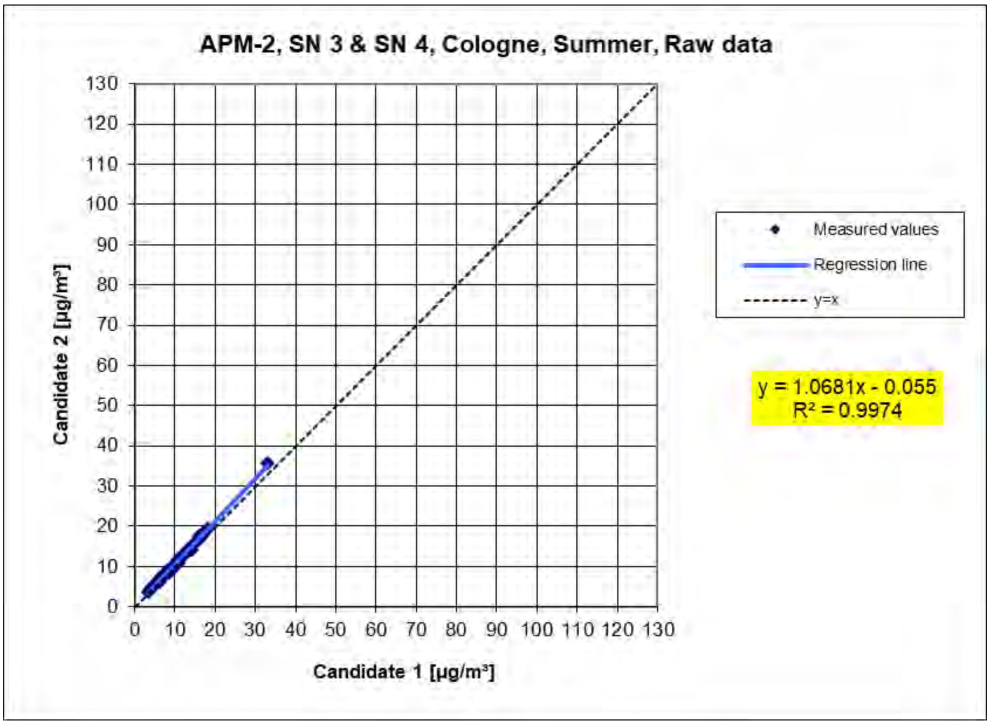

Figure 34: Result of the parallel measurements with the test instruments SN3 / SN4, measured component $PM_{2,5}$, Cologne, summer

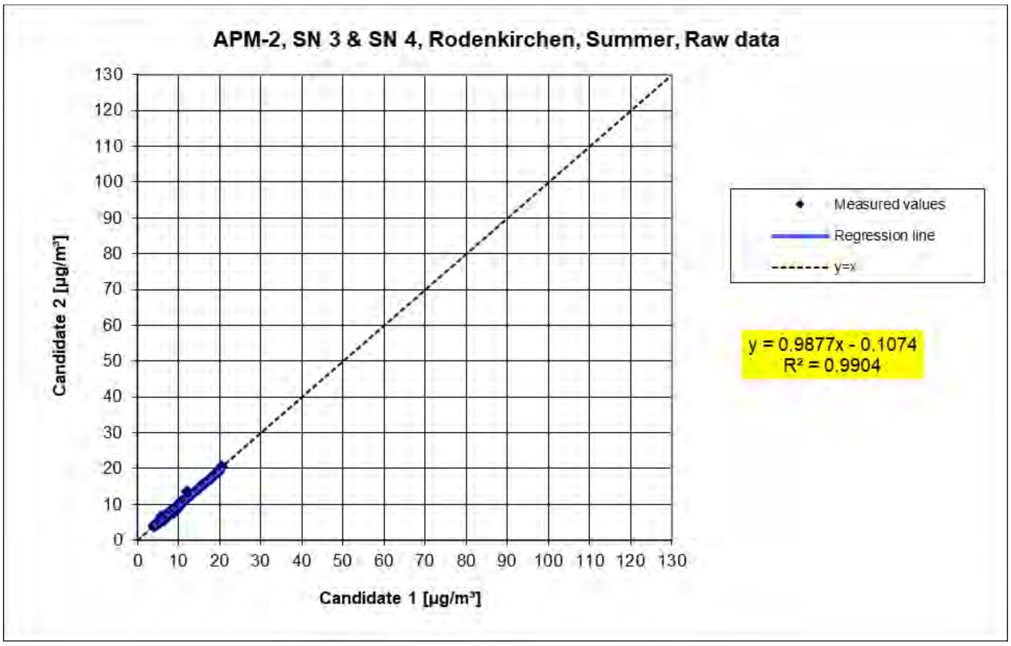

Figure 35: Result of the parallel measurements with the test instruments SN3 / SN4, measured component $PM_{2.5}$, Rodenkirchen, summer

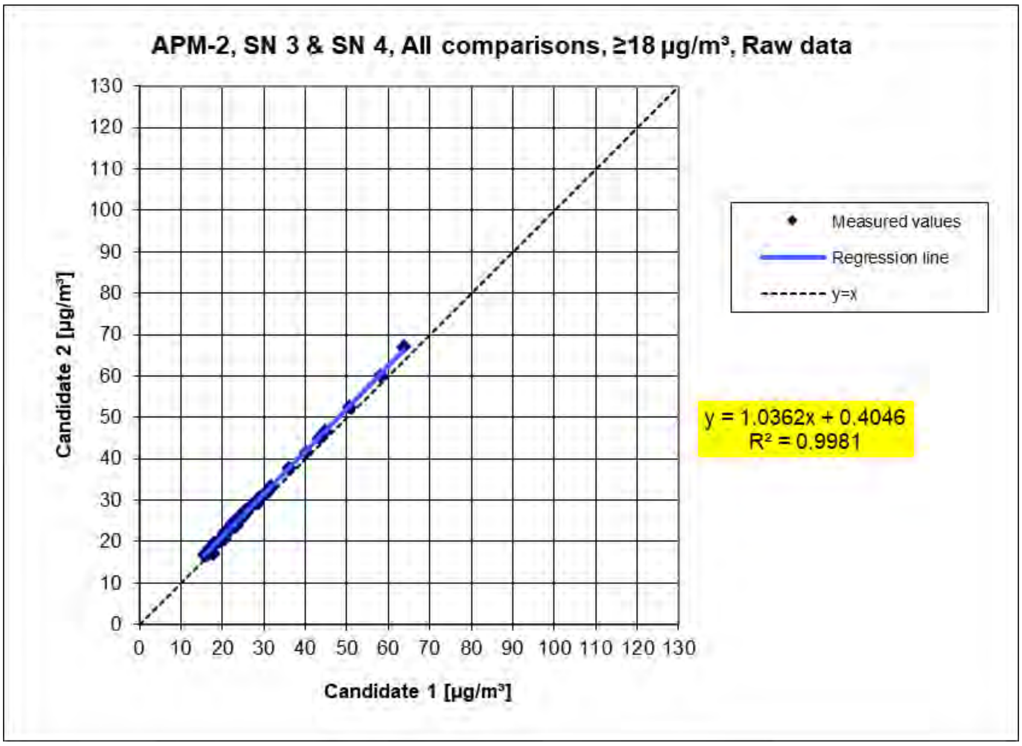

Figure 36: Result of the parallel measurements with the test instruments SN3 / SN4, measured component $PM_{2.5}$, all locations, values ≥ 18 µg/m³

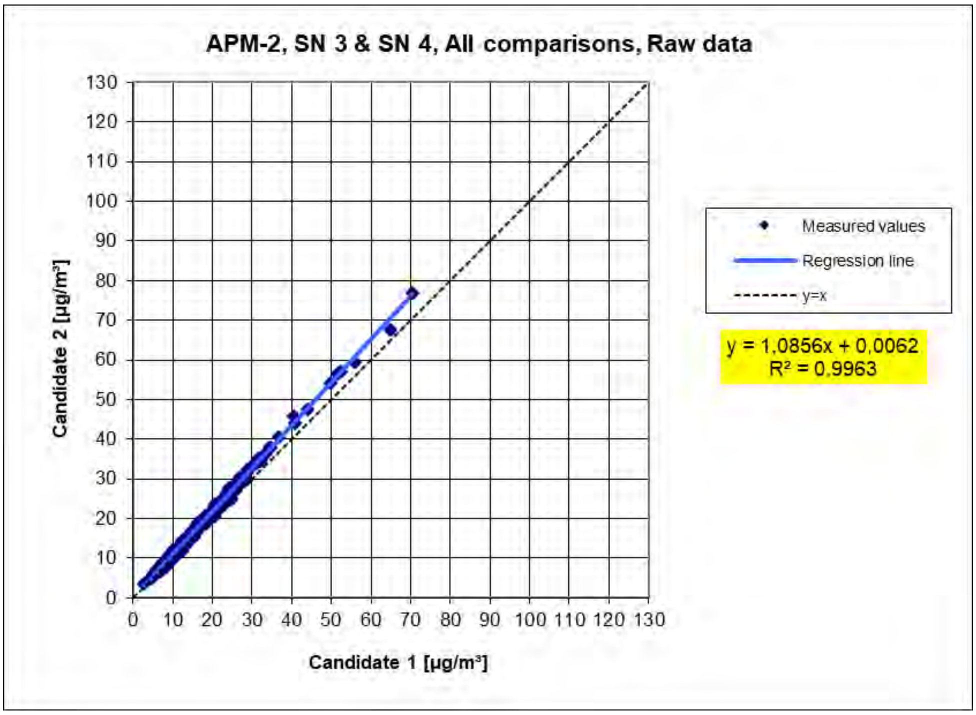

Figure 37: Result of the parallel measurements with the test instruments SN3 / SN4, measured component PM_{10}, all field test sites

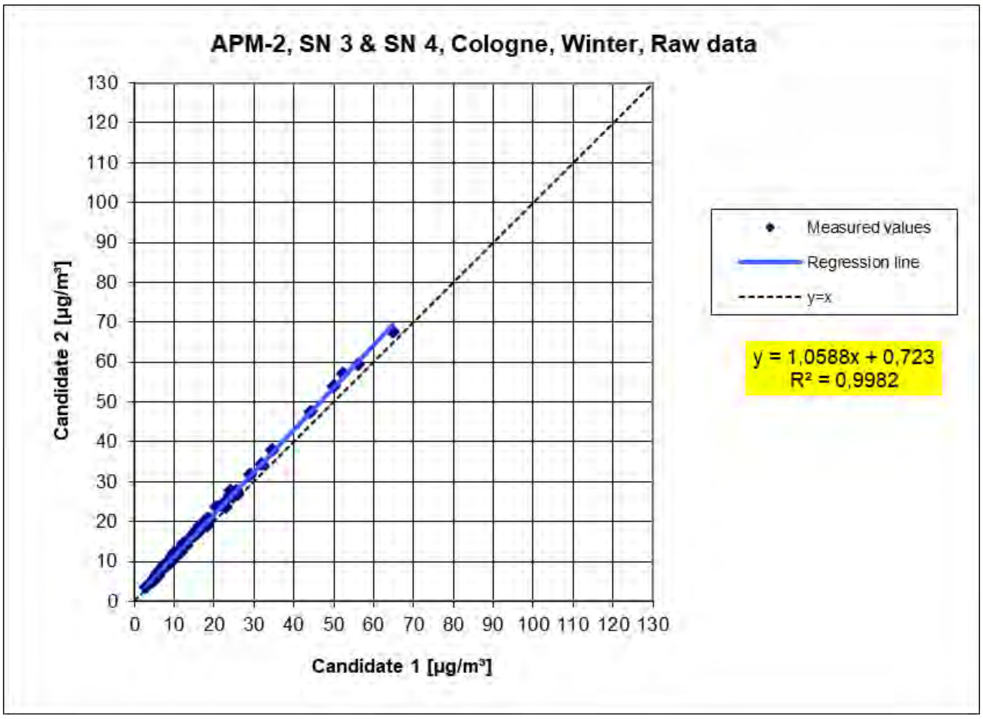

Figure 38: Result of the parallel measurements with the test instruments SN3 / SN4, measured component PM_{10}, Cologne, winter

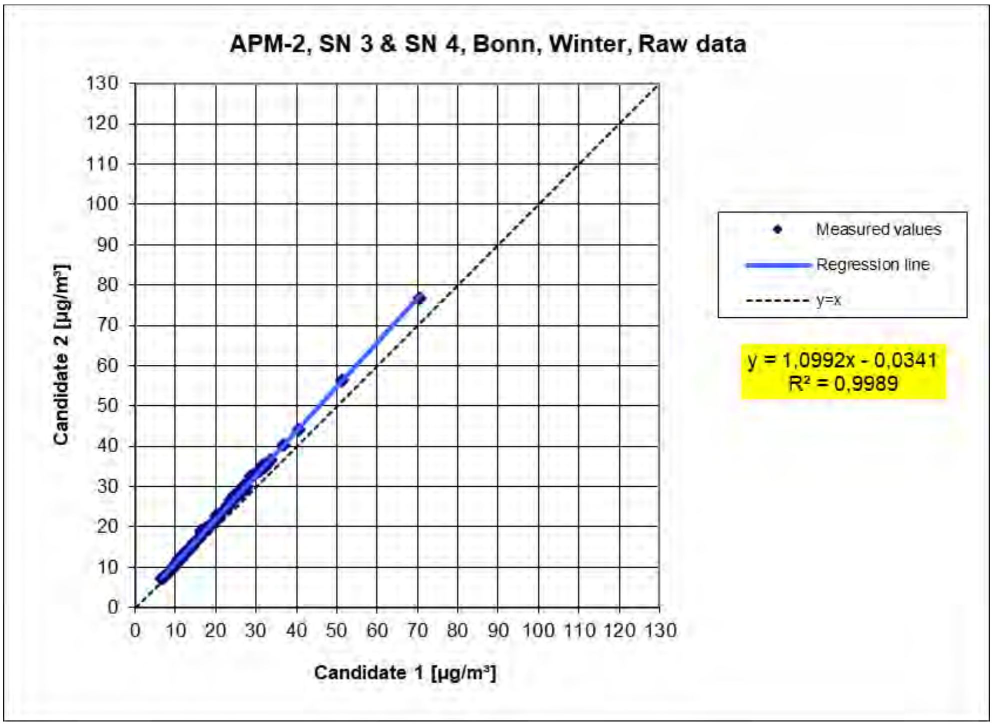

Figure 39: Result of the parallel measurements with the test instruments SN3 / SN4, measured component PM_{10}, Bonn, winter

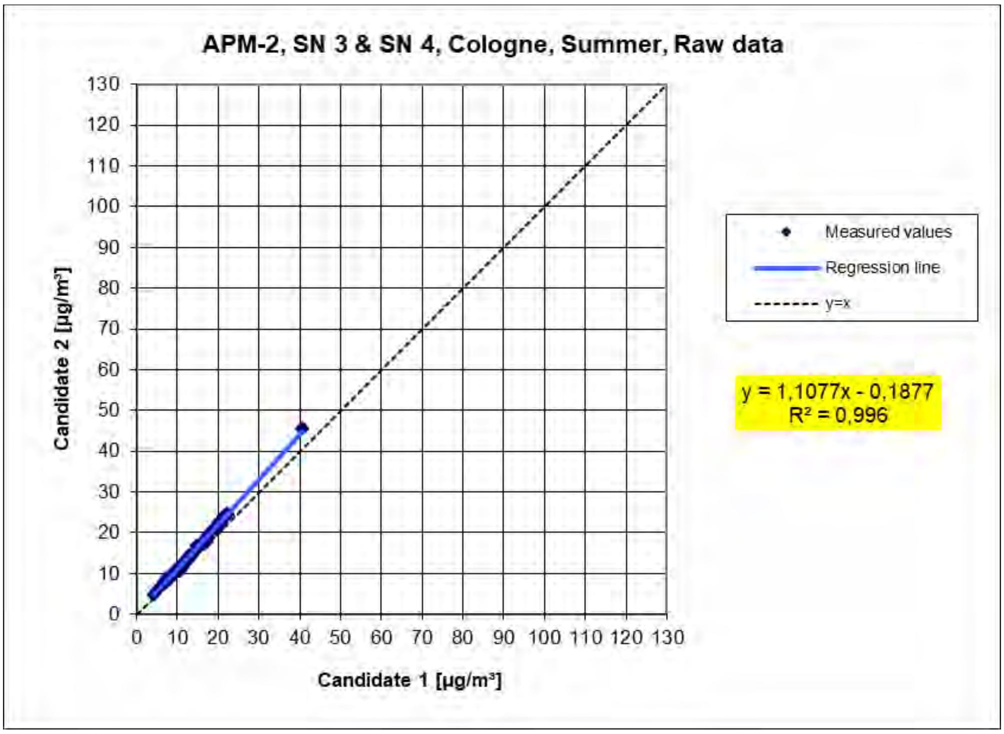

Figure 40: Result of the parallel measurements with the test instruments SN3 / SN4, measured component PM_{10}, Cologne, summer

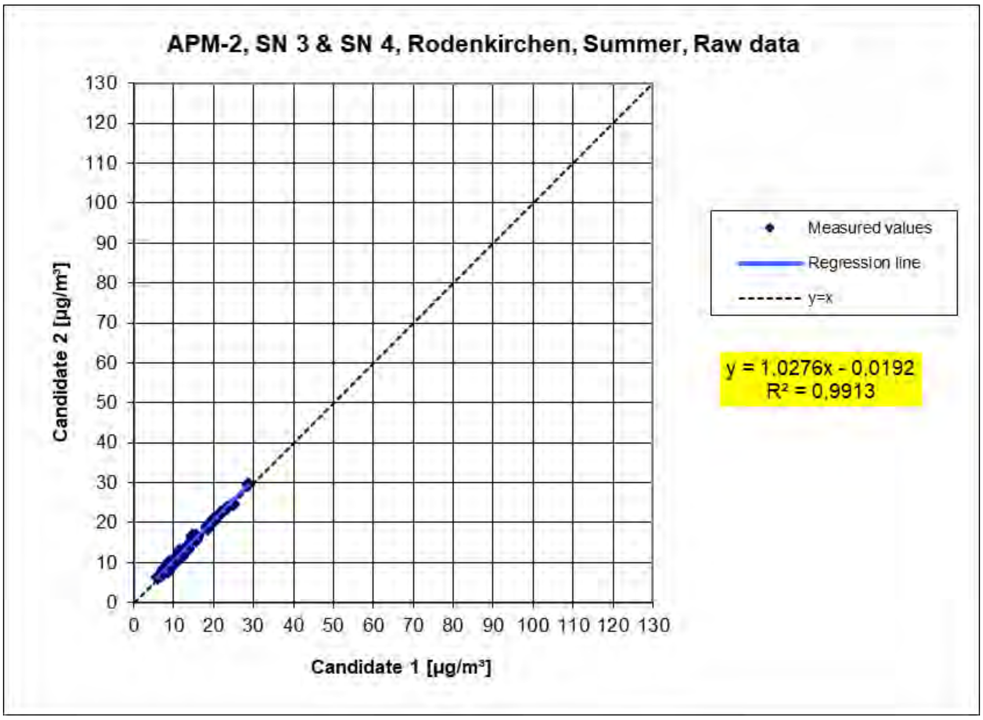

Figure 41: Result of the parallel measurements with the test instruments SN3 / SN4, measured component PM_{10}, Rodenkirchen, summer

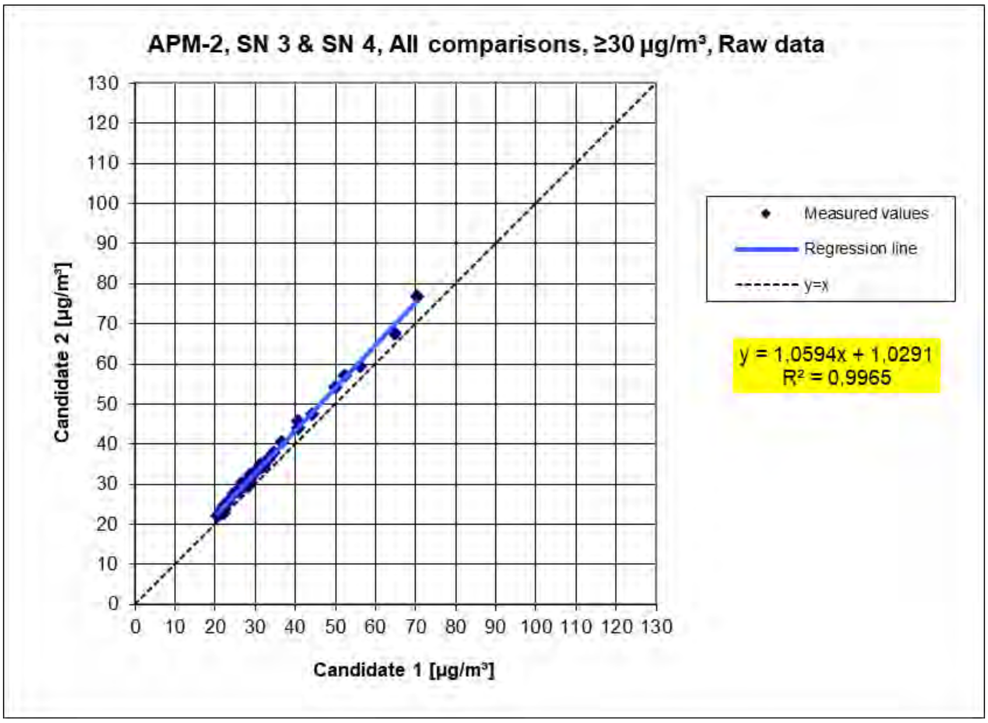

Figure 42: Result of the parallel measurements with the test instruments SN3 / SN4, measured component PM_{10}, all field test sites, values ≥ 30 µg/m³

6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)

The expanded uncertainty shall be ≤ 25% at the level of the relevant limit value related to the 24-hour average results – after a calibration where necessary.

6.2 Equipment

Additional equipment as described in chapter 5 of this report was used for this test.

6.3 Testing

The test was performed as part of the field test with four separate comparison campaigns. Different seasons as well as different concentrations of $PM_{2.5}$ and PM_{10} were taken into consideration.

Of the entire data set, at least 20 % of the concentration values determined with the reference method should be greater than 17 µg/m³ for $PM_{2.5}$ or greater than 28 µg/m³ for PM_{10}. Should this not be assured because of low concentration levels, a minimum of 32 value pairs is considered sufficient.

For each comparison campaign, at least 40 valid value pairs were determined. Of the full data set (4 comparisons, for PM_{10}: 195 valid measured value pairs for SN3, 193 valid measured value pairs for SN4; for $PM_{2.5}$: 194 valid measured value pairs for SN3, 192 valid measured value pairs for SN4), a total of 28.6 % of the measured values are above the upper assessment threshold of 17 µg/m³ for $PM_{2.5}$ and a total of 20.7 % of the measured values are above the upper assessment threshold of 28 µg/m³ for PM_{10}. The concentrations measured were related to the ambient conditions.

6.4 Evaluation

[EN 16450, 7.5.8.3]

Before calculating the expanded uncertainty of the test specimens, uncertainties were established between the simultaneously operated reference measuring systems (u_{ref})

Uncertainties between the simultaneously operated reference measuring systems $u_{bs,RM}$ were established similar to the between-AMS uncertainties and shall be ≤ 2.0 µg/m³.

Results of the evaluation are summarised in section 6.6.

[EN 16450, 7.5.8.5 & 7.5.8.6]

In order to assess comparability of the tested instruments y with the reference method x, a linear relationship $y_i = a + bx_i$ between the measured values of both methods is assumed. The association between the means of the reference systems and each individual test specimen to be assessed is established by means of orthogonal regression.

The regression is calculated for:

- All sites or comparisons respectively together
- Every location or comparison separately
- 1 data set with measured values $PM_{2.5}$ ≥ 18 µg/m³ (basis: averages of reference measurement)
- 1 data set with measured values PM_{10} ≥ 30 µg/m³ (basis: averages of reference measurement)

For further assessment, the uncertainty u_{c_s} resulting from a comparison of the test specimens with the reference method is described in the following equation which defines u_{CR} as a function of the fine dust concentration x_i.

$$u_{yi}^2 = \frac{RSS}{(n-2)} - u_{RM}{}^2 + [a + (b-1)L]^2$$

Where RSS is the sum of the (relative) residuals from orthogonal regression

u_{RM} = random uncertainty of the reference method; u_{RM} is calculated as $u_{bs,RM}/\sqrt{2}$, where $u_{bs,RM}$ is the between RM uncertainty of two reference instruments operated in parallel.

The algorithms for calculating axis intercept a and slope b as well as their variance by means of orthogonal regression are described in detail in the annex to [9].

The sum of (relative) residuals RSS is calculated according to the following equation:

$$RSS = \sum_{i=1}^{n} (y_i - a - bx_i)^2$$

Uncertainty u_{CR} is calculated for:

- All sites or comparisons respectively together
- Every location or comparison separately
- 1 data set with measured values $PM_{2.5}$ ≥ 18 µg/m³ (basis: averages of reference measurement)
- 1 data set with measured values PM_{10} ≥ 30 µg/m³ (basis: averages of reference measurement)

The Guideline states the following prerequisite for accepting the full data set:

- The slope be is insignificantly different from 1: $|b-1| \leq 2 \cdot u(b)$

and

- The axis intercept a is insignificantly different from 0: $|a| \leq 2 \cdot u(a)$, where u(a) and u(b) describe the standard uncertainty of the slope and the axis intercept calculated as the square root of the variance. If the prerequisites are not met, it is possible to calibrate the measuring systems in accordance with section 9.7 of the Guideline (also see 6.1 17 Use of correction factors/terms). The calibration may only be performed for the full data set.

[EN 16450, 7.5.8.7] For all data sets the combined relative uncertainty of the AMS $w_{c,CM}$ is calculated from a combination of contributions from 9.5.3.1 and 9.5.3.2 in accordance with the following equation:

$$w_{AMS}^2 = \frac{u_{yi=L}^2}{L^2}$$

For each data set the uncertainty w_{AMS} is calculated at a level of L = 30 µg/m³ for $PM_{2.5}$ as well as L = 50 µg/m³ for PM_{10}.

[EN 16450 7.5.8.8] For each data set the expanded relative uncertainty of the results measured with the test specimen is calculated by multiplying w_{AMS} by an coverage factor k according to the following equation:

$$W_{AMS} = k \cdot w_{AMS}$$

In practice, k is specified at k=2 for large n.

[Item 9.6]

The largest resulting uncertainty W_{AMS} is compared and assessed against the criteria for data quality of air quality measurements in accordance with EU Directive [8]. Two situations are conceivable:

1. $W_{AMS} \leq W_{dqo}$ → The test is deemed equivalent to the reference method.
2. $W_{AMS} > W_{dqo}$ → The tested instrument is not deemed equivalent to the reference method.

The expanded relative uncertainty W_{dqo} specified is 25% [8].

7.5 Assessment

Without the need for any correction factors, the determined uncertainties W_{AMS} for PM_{10} were above the defined expanded relative uncertainty W_{dqo} of 25 % for particulate matter for all considered data sets except for Cologne, winter 2012/2013 as well as the total data set. The determined uncertainties W_{AMS} were below the defined expanded relative uncertainty W_{dqo} of 25 % for fine particulate matter for $PM_{2.5}$ for all data sets considered, with the exception of the comparisons >18 µg/m³ without application of correction factors. Correction factors shall be applied in accordance with item 6.1 17 Use of correction factors/terms .

Criterion satisfied? no

Table 28 and Table 29 show an overview of all results of the equivalence test for $PM_{2.5}$ and PM_{10}. Where a criterion was not satisfied, the corresponding line is marked in red.

Table 28: APM-2 equivalence test for $PM_{2.5}$

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0,55**	**µg/m³**			
Uncertainty between Candidates	**0,65**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**192**				
Slope b	**0,919**	**significant**			
Uncertainty of b	**0,012**				
Ordinate intercept a	**0,327**	**not significant**			
Uncertainty of a	**0,216**				
Expanded meas. uncertainty W_{CM}	**17,87**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0,63**	**µg/m³**			
Uncertainty between Candidates	**1,04**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**49**				
Slope b	**0,887**				
Uncertainty of b	**0,030**				
Ordinate intercept a	**1,248**				
Uncertainty of a	**0,937**				
Expanded meas. uncertainty W_{CM}	**22,12**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017				
Candidate	APM-2	SN	SN 3 & SN 4	
		Limit value	30	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	0,54	µg/m³		
Uncertainty between Candidates	0,65	µg/m³		
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0,855		0,883	
Uncertainty of b	0,017		0,018	
Ordinate intercept a	1,068		1,387	
Uncertainty of a	0,389		0,400	
Expanded meas. uncertainty W_{CM}	24,69	%	18,29	%
Bonn, Winter				
Uncertainty between Reference	0,62	µg/m³		
Uncertainty between Candidates	0,88	µg/m³		
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	0,952		1,007	
Uncertainty of b	0,029		0,029	
Ordinate intercept a	-0,834		-0,849	
Uncertainty of a	0,649		0,666	
Expanded meas. uncertainty W_{CM}	20,75	%	15,09	%
Cologne, Summer				
Uncertainty between Reference	0,53	µg/m³		
Uncertainty between Candidates	0,57	µg/m³		
	SN 3		SN 4	
Number of data pairs	46		44	
Slope b	0,966		1,019	
Uncertainty of b	0,041		0,045	
Ordinate intercept a	-0,221		-0,174	
Uncertainty of a	0,453		0,508	
Expanded meas. uncertainty W_{CM}	10,88	%	8,28	%
Rodenkirchen, Summer				
Uncertainty between Reference	0,52	µg/m³		
Uncertainty between Candidates	0,33	µg/m³		
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	1,053		1,037	
Uncertainty of b	0,046		0,047	
Ordinate intercept a	-1,230		-1,320	
Uncertainty of a	0,519		0,521	
Expanded meas. uncertainty W_{CM}	8,14	%	7,93	%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0,63	µg/m³		
Uncertainty between Candidates	1,04	µg/m³		
	SN 3		SN 4	
Number of data pairs	49		49	
Slope b	0,871		0,904	
Uncertainty of b	0,030		0,031	
Ordinate intercept a	1,046		1,438	
Uncertainty of a	0,921		0,96	
Expanded meas. uncertainty W_{CM}	25,16	%	19,85	%
All comparisons				
Uncertainty between Reference	0,55	µg/m³		
Uncertainty between Candidates	0,65	µg/m³		
	SN 3		SN 4	
Number of data pairs	194		192	
Slope b	0,896	significant	0,943	significant
Uncertainty of b	0,012		0,012	
Ordinate intercept a	0,382	not significant	0,267	not significant
Uncertainty of a	0,209		0,225	
Expanded meas. uncertainty W_{CM}	21,25	%	15,07	%

Results for testing the five criteria from chapter 6.1 Method used for equivalence testing were as follows:

Criterion 1: More than 20% of the data exceed 17 µg/m³.

Criterion 2: Between-AMS uncertainty of the AMS tested did not exceed 2.5 µg/m³.

Criterion 3: Uncertainty between reference instruments did not exceed 2.0 µg/m³.

Criterion 4: All expanded uncertainties except for the comparisons >18 µg/m³ were below 25 %.

Criterion 5: For both tested systems, the slope determined when assessing the full data set is significantly higher than allowed.

Additional: The slope determined for the full data set regarding both test specimens combined was at 0.919, the axis intercept was at 0.327 at a total expanded uncertainty of 17.87%.

Table 29: APM-2 equivalence test for PM_{10}

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0,58**	**µg/m³**			
Uncertainty between Candidates	**1,27**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**193**				
Slope b	**0,977**	**not significant**			
Uncertainty of b	**0,020**				
Ordinate intercept a	**-3,758**	**significant**			
Uncertainty of a	**0,502**				
Expanded measured uncertainty WCM	**23,31**	**%**			
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0,72**	**µg/m³**			
Uncertainty between Candidates	**2,28**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**33**				
Slope b	**1,035**				
Uncertainty of b	**0,063**				
Ordinate intercept a	**-6,432**				
Uncertainty of a	**2,681**				
Expanded measured uncertainty WCM	**25,96**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	**0,54**	**µg/m³**			
Uncertainty between Candidates	**1,38**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**52**			**52**	
Slope b	**0,931**			**0,982**	
Uncertainty of b	**0,023**			**0,022**	
Ordinate intercept a	**-2,007**			**-1,290**	
Uncertainty of a	**0,611**			**0,582**	
Expanded measured uncertainty W_{CM}	**23,75**	**%**		**12,40**	**%**
Bonn, Winter					
Uncertainty between Reference	**0,38**	**µg/m³**			
Uncertainty between Candidates	**1,72**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**51**			**51**	
Slope b	**0,943**			**1,043**	
Uncertainty of b	**0,049**			**0,054**	
Ordinate intercept a	**-4,224**			**-4,829**	
Uncertainty of a	**1,477**			**1,604**	
Expanded measured uncertainty W_{CM}	**32,59**	**%**		**20,69**	**%**
Cologne, Summer					
Uncertainty between Reference	**0,60**	**µg/m³**			
Uncertainty between Candidates	**1,06**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**47**			**45**	
Slope b	**0,852**			**0,954**	
Uncertainty of b	**0,039**			**0,043**	
Ordinate intercept a	**-1,667**			**-2,156**	
Uncertainty of a	**0,733**			**0,809**	
Expanded measured uncertainty W_{CM}	**36,94**	**%**		**19,56**	**%**
Rodenkirchen, Summer					
Uncertainty between Reference	**0,76**	**µg/m³**			
Uncertainty between Candidates	**0,43**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**45**			**45**	
Slope b	**0,944**			**0,983**	
Uncertainty of b	**0,063**			**0,063**	
Ordinate intercept a	**-5,390**			**-5,818**	
Uncertainty of a	**1,252**			**1,258**	
Expanded measured uncertainty W_{CM}	**33,90**	**%**		**28,19**	**%**
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0,72**	**µg/m³**			
Uncertainty between Candidates	**2,28**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**33**			**33**	
Slope b	**1,003**			**1,068**	
Uncertainty of b	**0,062**			**0,065**	
Ordinate intercept a	**-6,650**			**-6,252**	
Uncertainty of a	**2,639**			**2,74**	
Expanded measured uncertainty W_{CM}	**31,49**	**%**		**21,63**	**%**
All comparisons					
Uncertainty between Reference	**0,58**	**µg/m³**			
Uncertainty between Candidates	**1,27**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**195**			**193**	
Slope b	**0,935**	**significant**		**1,020**	**not significant**
Uncertainty of b	**0,019**			**0,022**	
Ordinate intercept a	**-3,552**	**significant**		**-3,981**	**significant**
Uncertainty of a	**0,474**			**0,531**	
Expanded measured uncertainty W_{CM}	**29,74**	**%**		**17,87**	**%**

Results for testing the five criteria from chapter 6.1 Method used for equivalence testing were as follows:

Criterion 1: More than 38 valid value pairs exceed 28 µg/m³.

Criterion 2: Between-AMS uncertainty of the AMS tested did not exceed 2.5 µg/m³.

Criterion 3: Uncertainty between reference instruments did not exceed 2.0 µg/m³.

Criterion 4: All expanded uncertainties are above 25 % with the exception of Cologne, winter 2012/2013 and the overall data set.

Criterion 5: In the evaluation of the total data set, the intercept of both test specimens and the slope of SN 3 are significantly larger than permitted.

Additional: The slope determined for the full data set regarding both test specimens combined was at 0.977, the axis intercept was at -3.758 at a total expanded uncertainty of 23.31%.

The January 2010 version of the Guideline does not specify clearly which axis intercept and which slope to use for correcting test specimens if a test specimen does not meet the requirements for equivalence testing. After double-checking with the chair of the EU working group responsible for issuing the Guideline (Mr Theo Hafkenscheid), we decided to apply the requirements of the November 2005 version of the Guideline and to use the slope and the intercept determined by means of orthogonal regression for the full data set. These are listed for each criterion under “Additional”

According to Table 28, a correction of the slope for $PM_{2.5}$ must therefore be made due to the determined significance. Given the significance determined for PM_{10} for both sets of candidate systems as illustrated in Table 29, the slope and axis intercept had to be corrected. This is why chapter 6.1 17 Use of correction factors/terms contains an additional assessment for which the corresponding calibration factor was applied to the data sets.

For $PM_{2.5}$:

The slope for the entire data set is 0.919. This is why chapter 6.1 17 Use of correction factors/terms contains an additional assessment for which the corresponding calibration factor was applied to the data sets.

For PM_{10}:

The slope for the entire data set is 0.977. The intercept for the full data set is -3.758. This is why chapter 6.1 17 Use of correction factors/terms contains an additional assessment for which the corresponding calibration factors were applied to the data sets.

For compliant monitoring, the revised version of the January 2010 Guideline and standard EN 16450 require continuous random checks of a certain number of instruments in a measurement grid and specify the number of measurement sites to be checked as a function of the expanded uncertainty of a measuring system. The operator of the measurement grid or the competent authority of a member state is responsible for compliant implementation. However, TÜV Rheinland recommends that the expanded uncertainty of the overall data set (here: uncorrected raw data) is used for this purpose. Namely, 17.87 % for $PM_{2.5}$, which in turn would require an annual check at 4 measurement locations, and 23.31 % for PM_{10}, which in turn would require an annual check at 5 measurement locations (Guideline [5], Chapter 9.9.2, Table 6 and EN 16450 [9], Chapter 8.6.2, Table 5) As a result of the necessary use of calibration factors, this assessment should be based on the evaluation of the corrected data sets (see chapter 6.1 17 Use of correction factors/terms).

6.6 Detailed presentation of test results

Table 30 and Table 31 provide an overview of the between-RM uncertainties $u_{bs,RM}$ determined during the field tests.

Table 30: Between RM uncertainty $u_{bs,RM}$ for $PM_{2.5}$

Reference instruments	Location	Number of measurements	Uncertainty u_{bs}
No.			µg/m³
1 / 2	Cologne, winter	52	0.54
1 / 2	Bonn, winter	51	0.62
1 / 2	Cologne, summer	46	0.53
1 / 2	Rodenkirchen, summer	45	0.52
1 / 2	All locations	194	0.55

Table 31: Between RM uncertainty $u_{bs,RM}$ for PM_{10}

Reference instruments	Location	Number of measurements	Uncertainty u_{bs}
No.			µg/m³
1 / 2	Cologne, winter	52	0.54
1 / 2	Bonn, winter	51	0.38
1 / 2	Cologne, summer	47	0.60
1 / 2	Rodenkirchen, summer	33	0.76
1 / 2	All locations	195	0.58

At all sites, between-RM uncertainty $u_{bs,RM}$ was < 2.0 µg/m³.

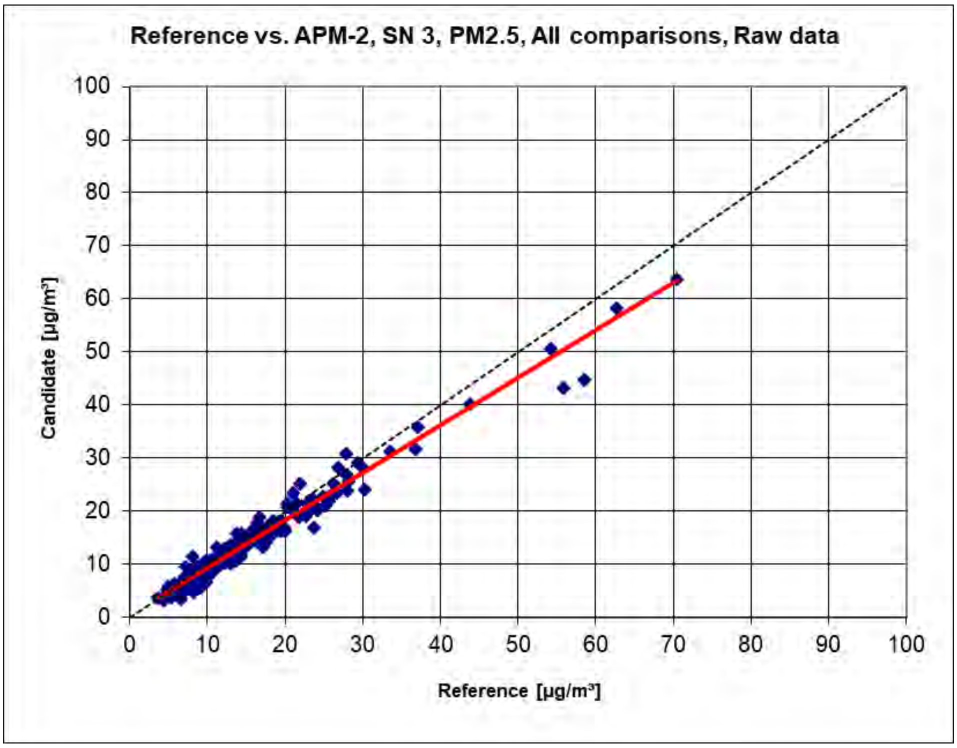

Figure 43: Reference vs. test instrument, SN3, for $PM_{2.5}$, all locations

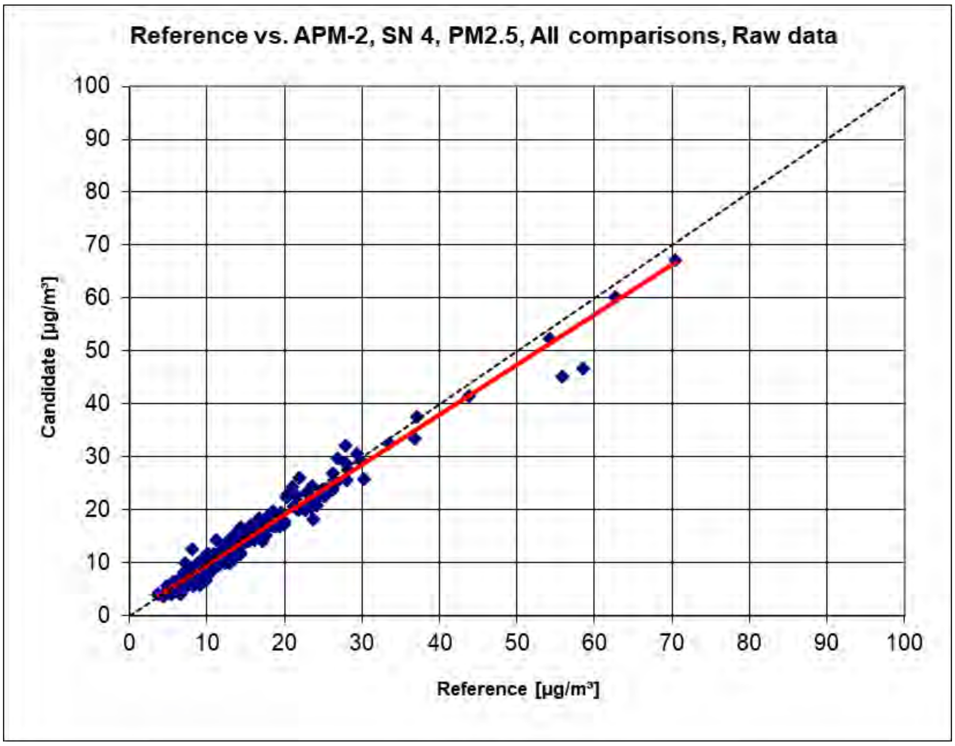

Figure 44: Reference vs. test instrument, SN4, for $PM_{2.5}$, all locations

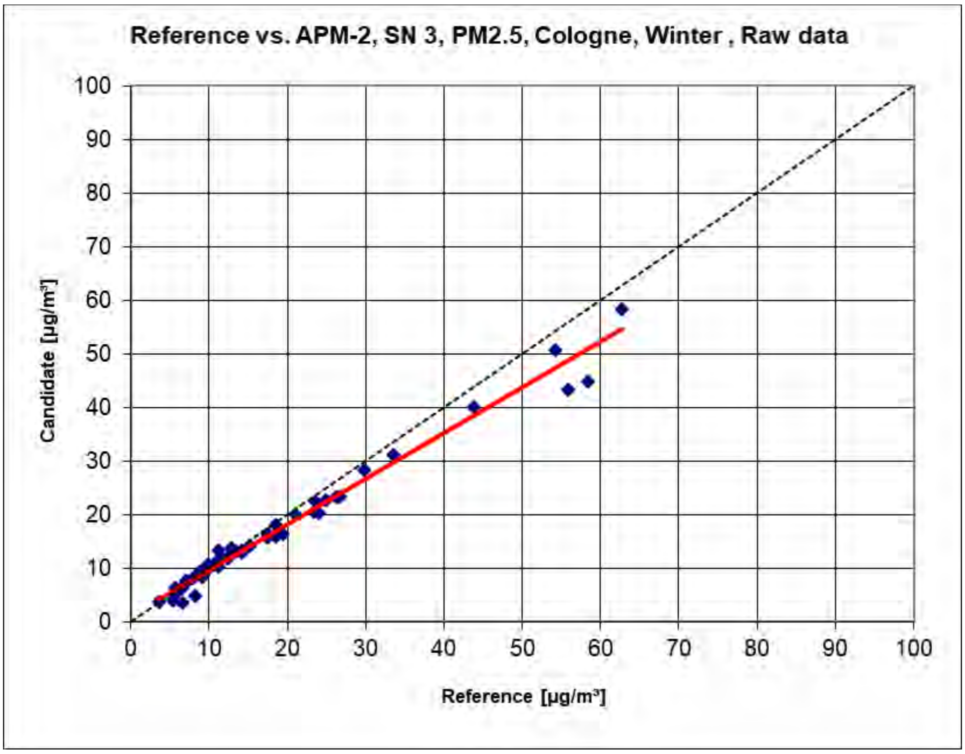

Figure 45: Reference vs. test instrument, SN3, for $PM_{2.5}$, Cologne, winter

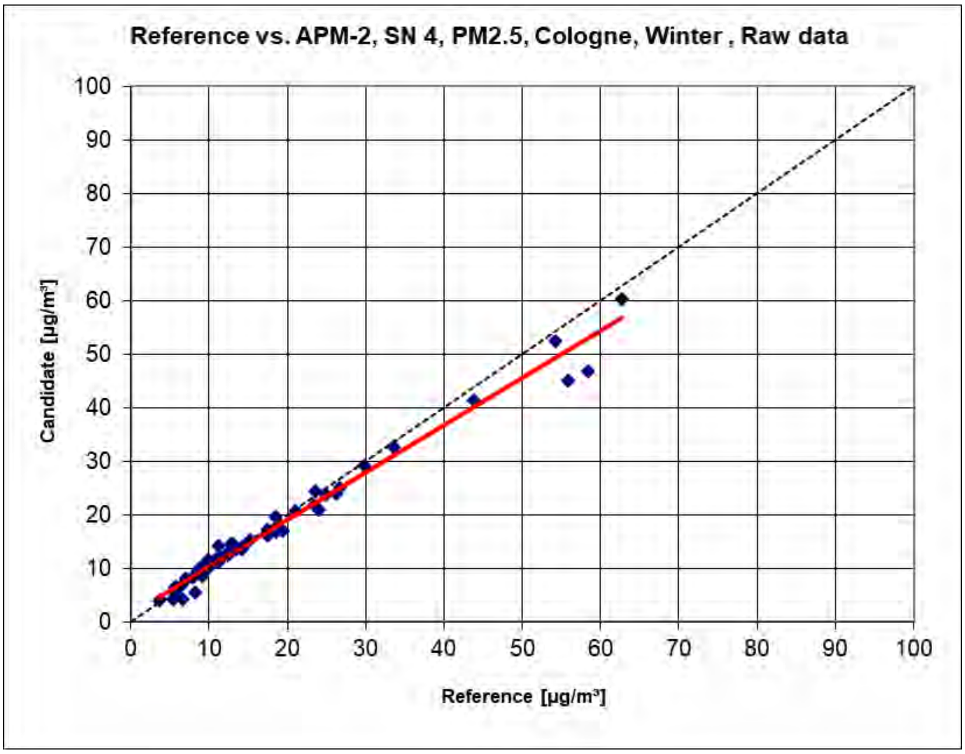

Figure 46: Reference vs. test instrument, SN4, for $PM_{2.5}$, Cologne, winter

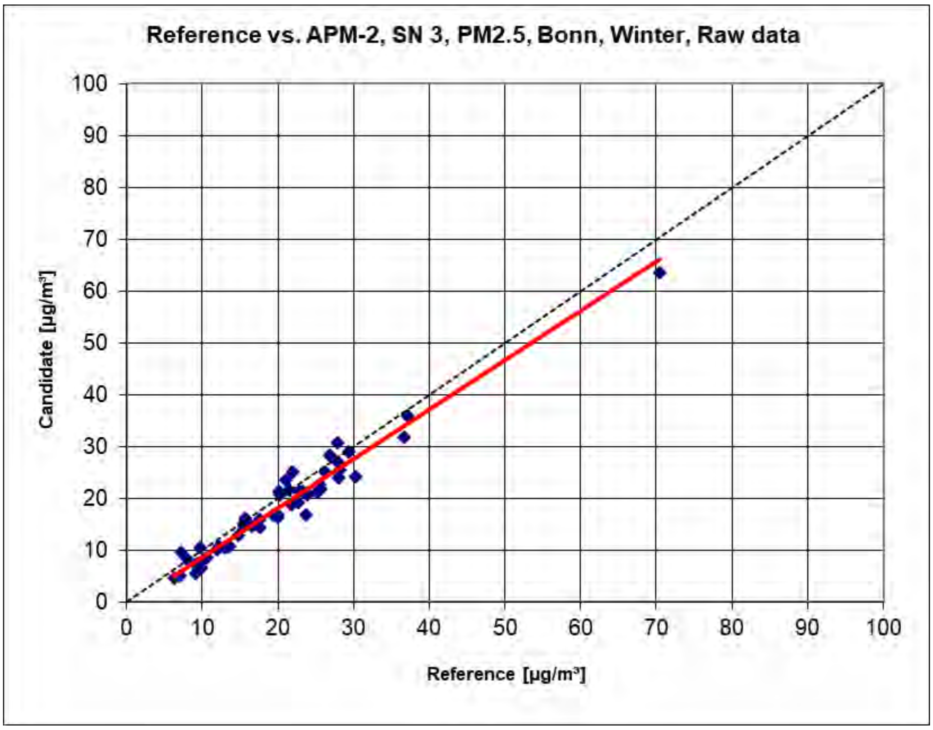

Figure 47: Reference vs. test instrument, SN3, for $PM_{2.5}$, Bonn, winter

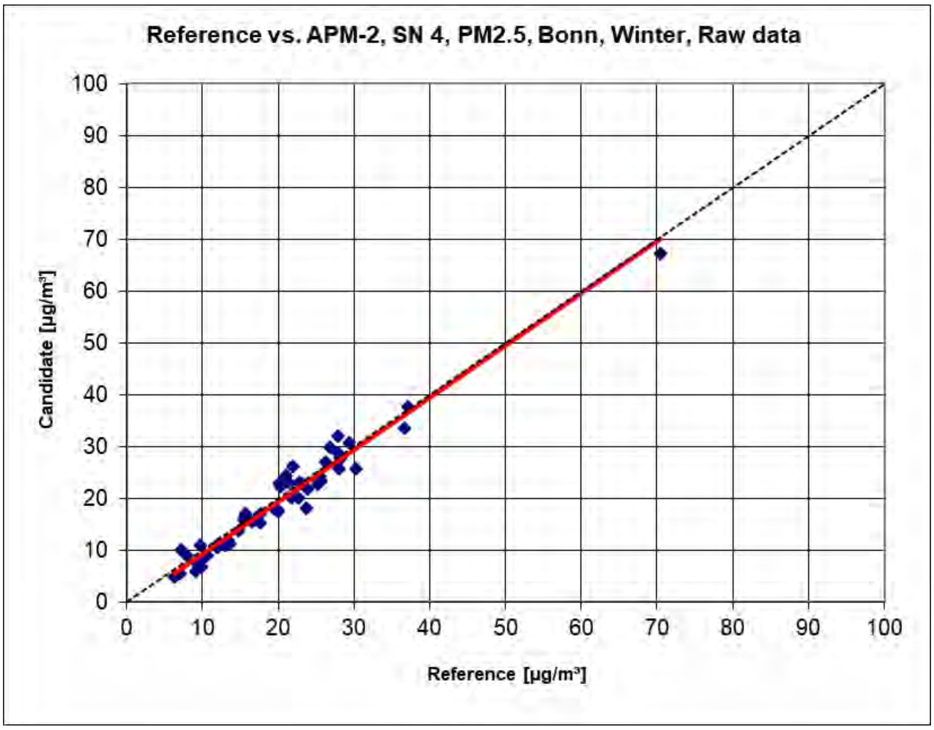

Figure 48: Reference vs. test instrument, SN4, for $PM_{2.5}$, Bonn, winter

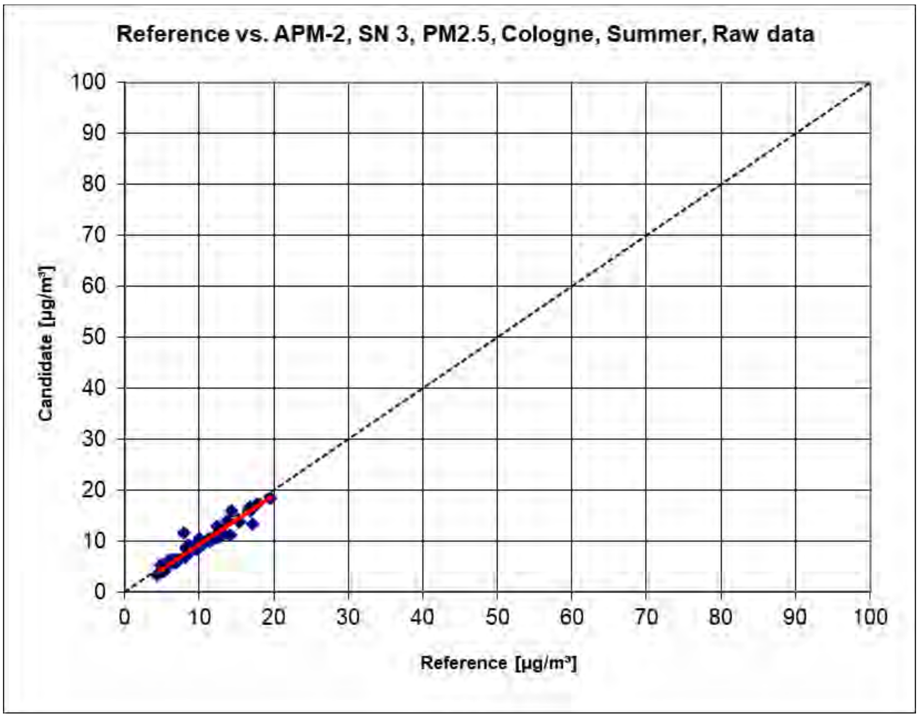

Figure 49: Reference vs. test instrument, SN3, for $PM_{2.5}$, Cologne, summer

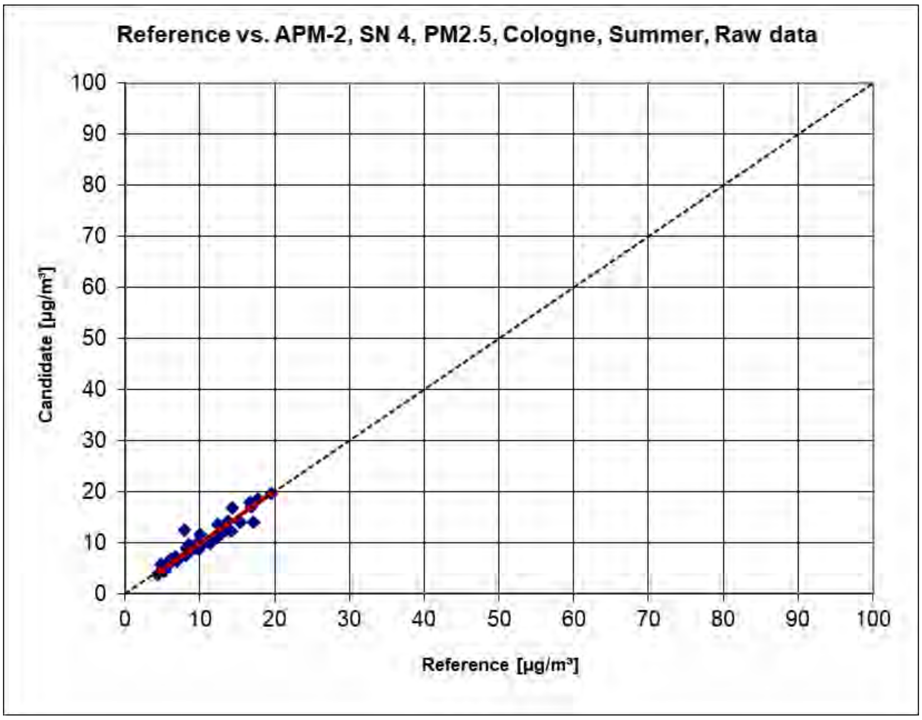

Figure 50: Reference vs. test instrument, SN4, for $PM_{2.5}$, Cologne, summer

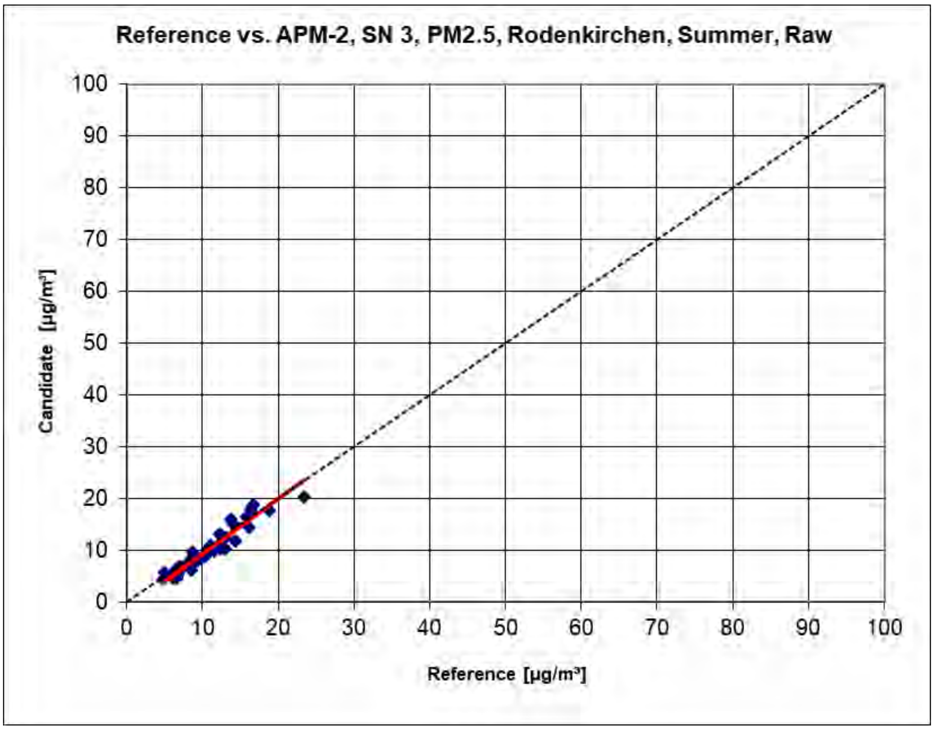

Figure 51: Reference vs. test instrument, SN3, for $PM_{2.5}$, Rodenkirchen, summer

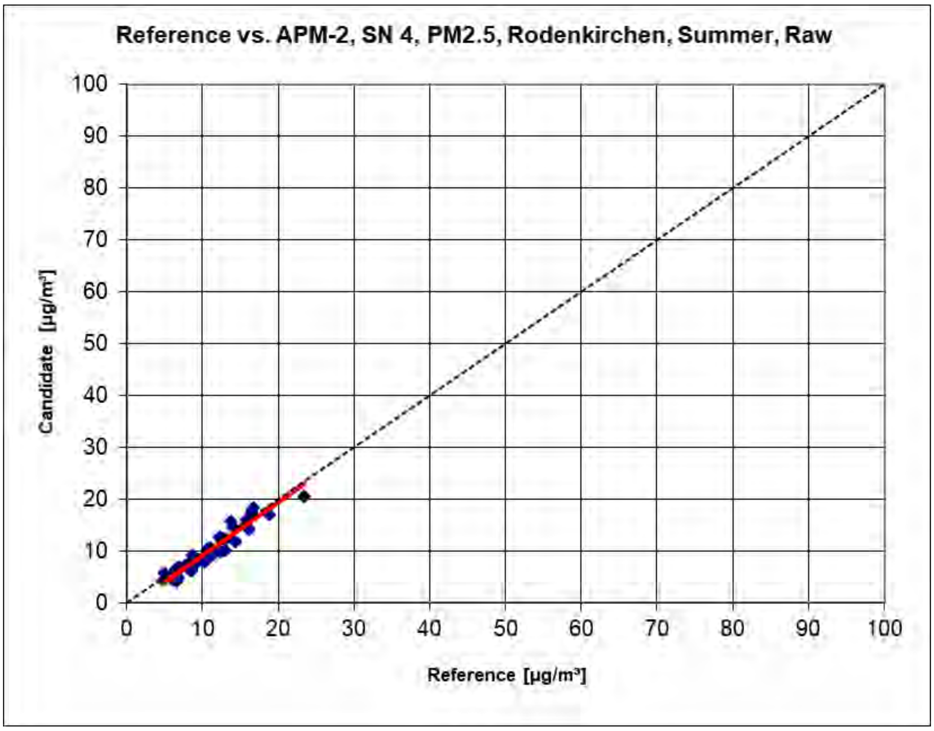

Figure 52: Reference vs. test instrument, SN4, for $PM_{2.5}$, Rodenkirchen, summer

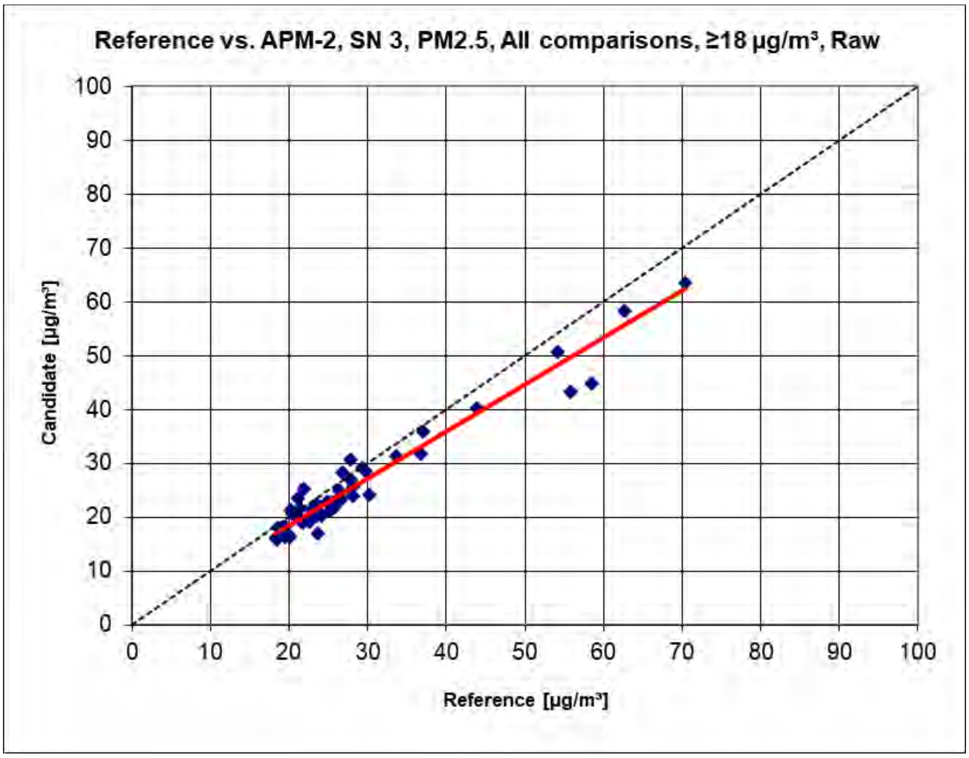

Figure 53: Reference vs. test instrument, SN3, for $PM_{2.5}$, values ≥ 18 µg/m³

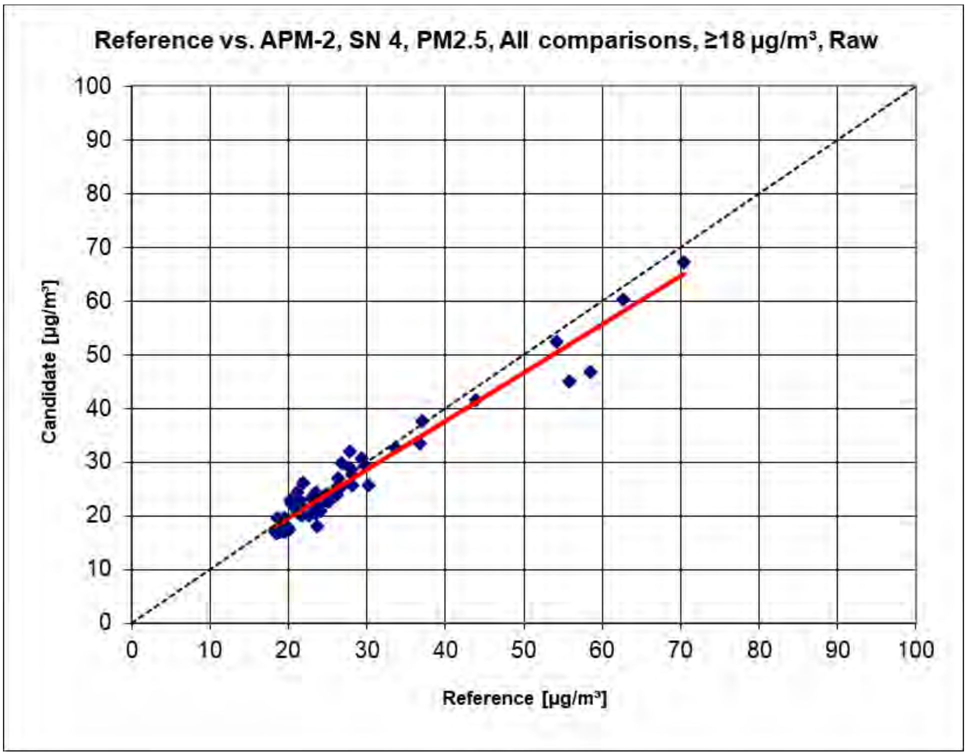

Figure 54: Reference vs. test instrument, SN4, for $PM_{2.5}$, values ≥ 18 µg/m³

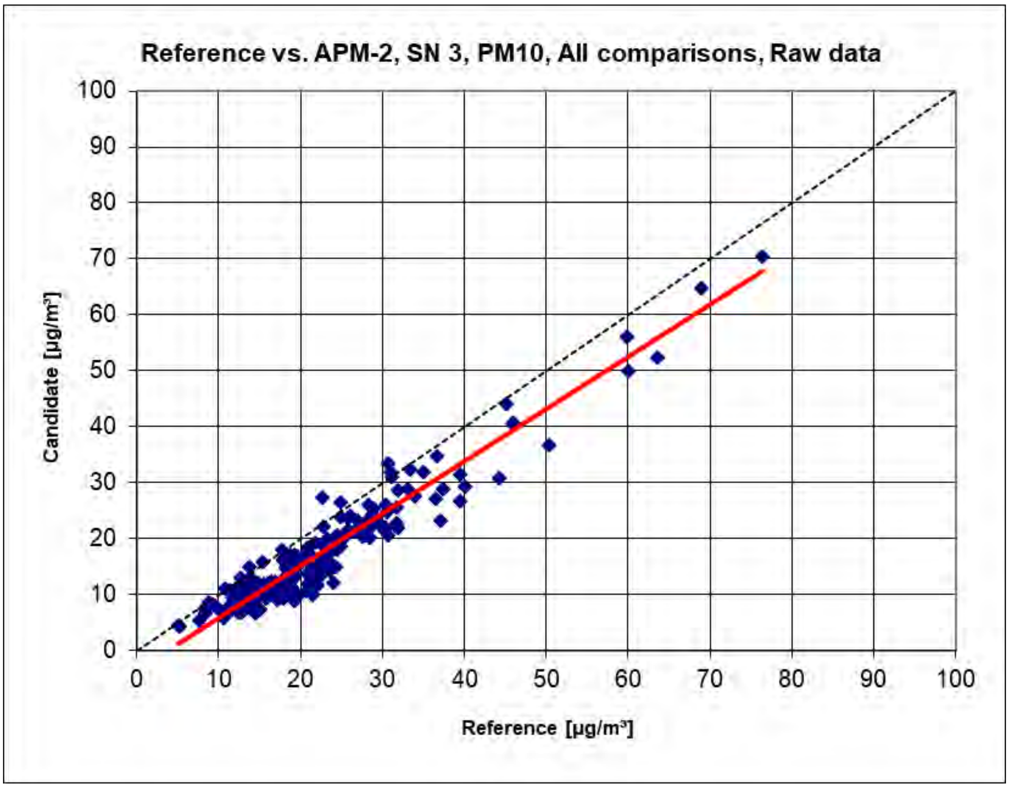

Figure 55: Reference vs. test instrument, SN3, for PM_{10}, all locations

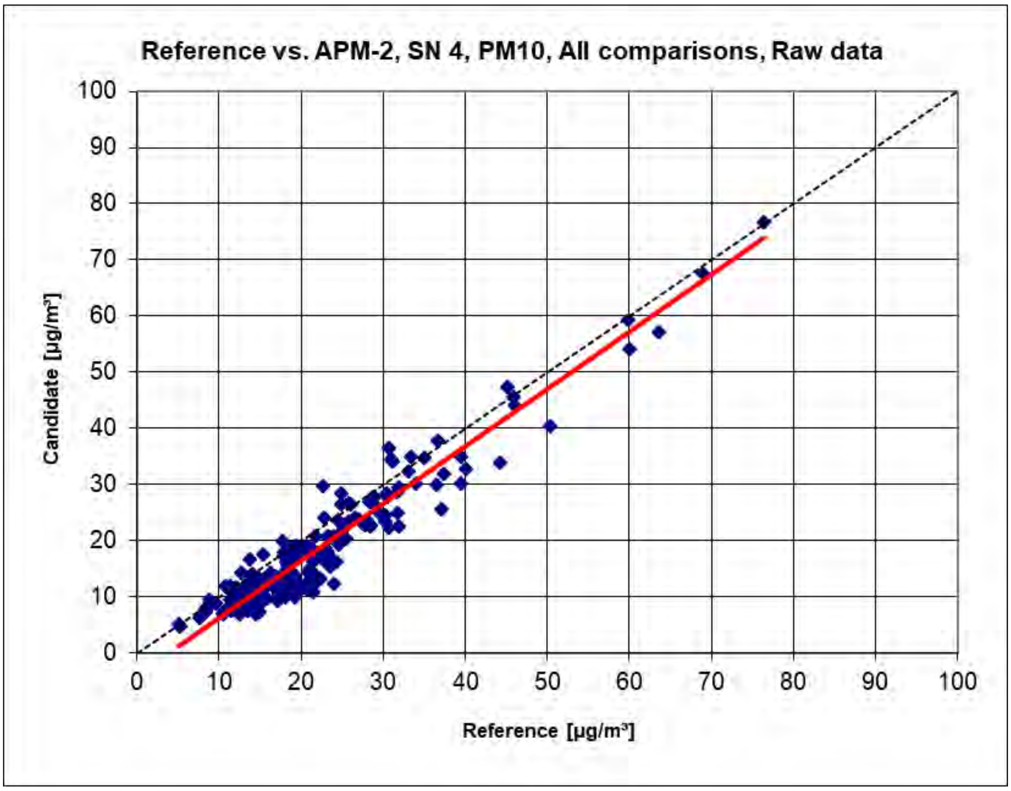

Figure 56: Reference vs. test instrument, SN4, for PM_{10}, all locations

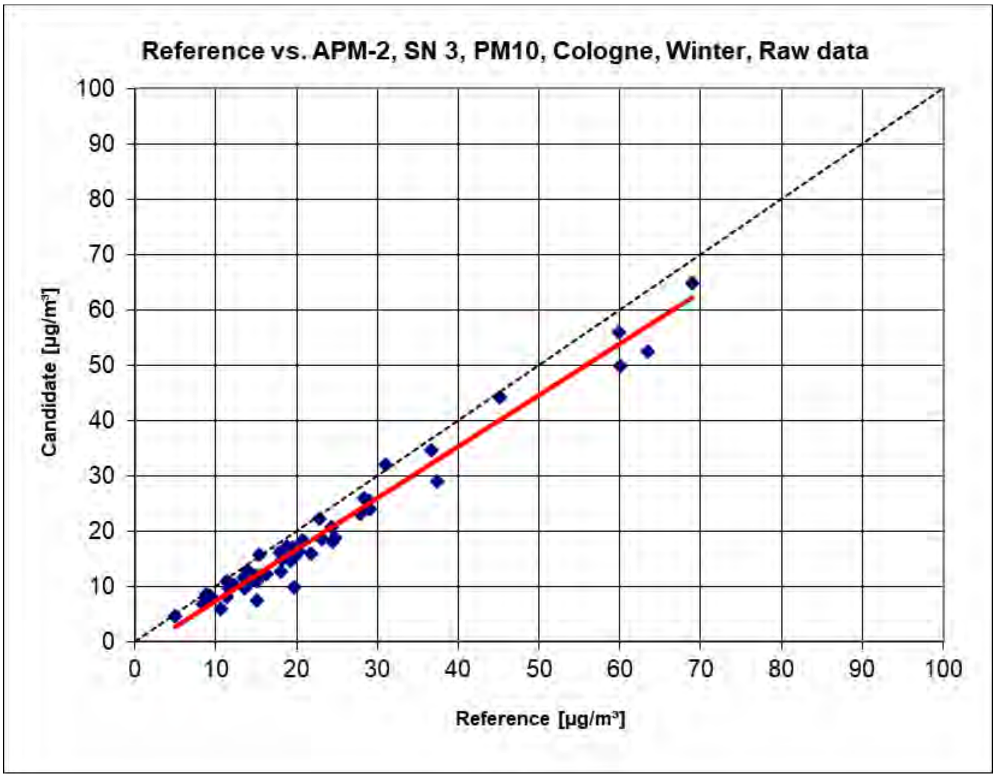

Figure 57: Reference vs. test instrument, SN3, for PM_{10}, Cologne, winter

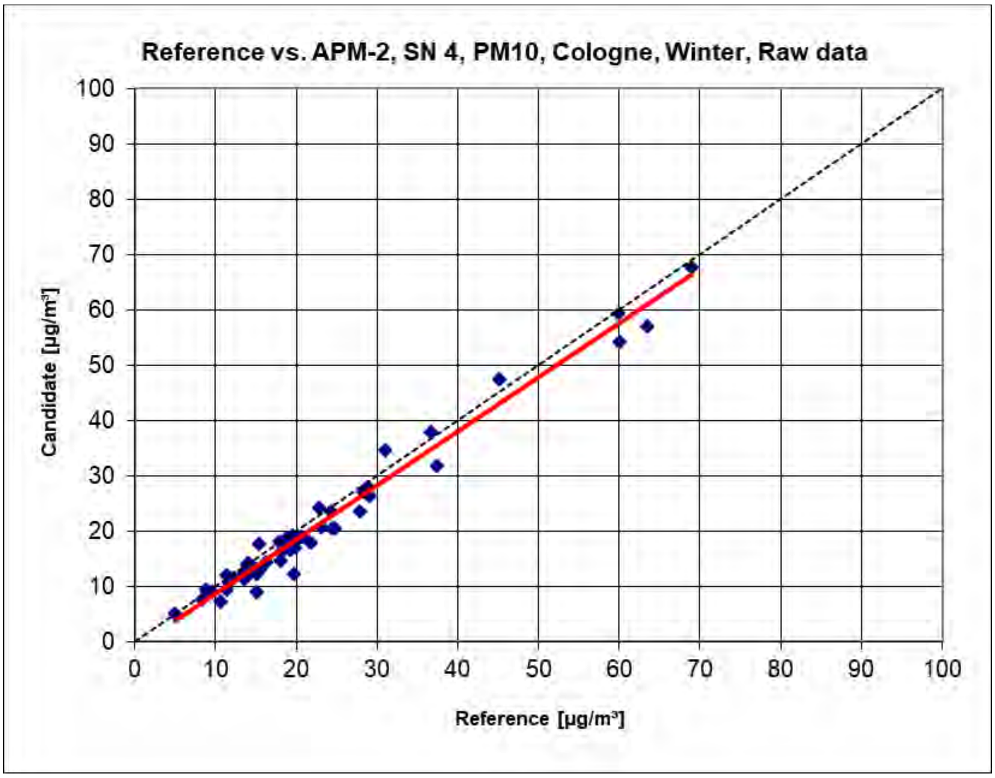

Figure 58: Reference vs. test instrument, SN4, for PM_{10}, Cologne, winter

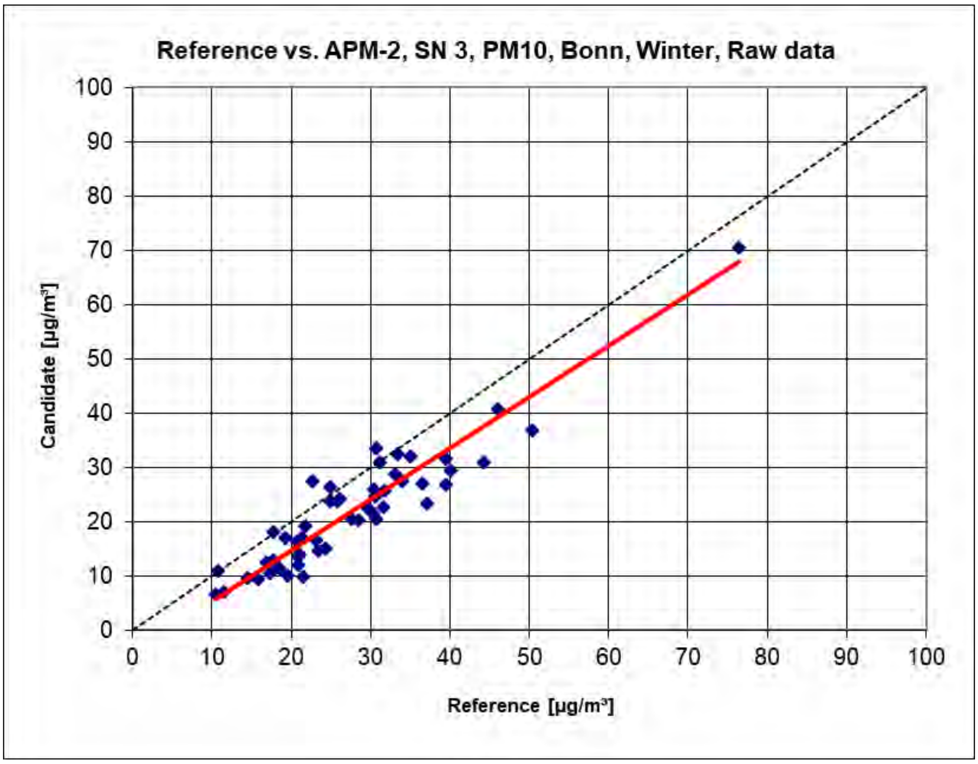

Figure 59: Reference vs. test instrument, SN3, for PM_{10}, Bonn, winter

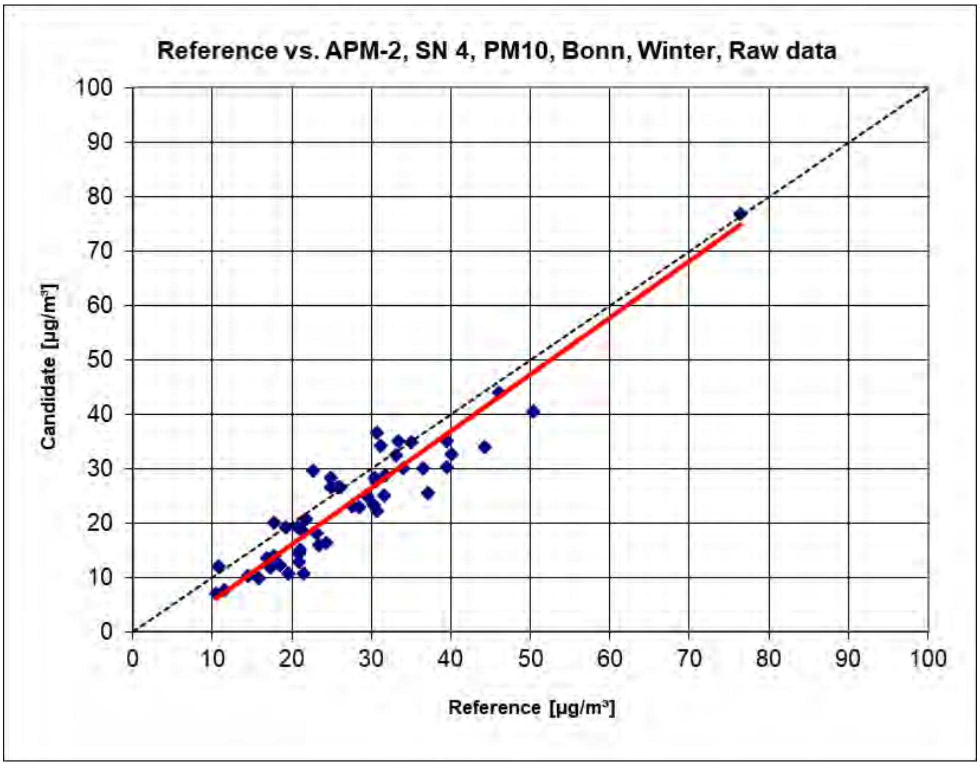

Figure 60: Reference vs. test instrument, SN4, for PM_{10}, Bonn, winter

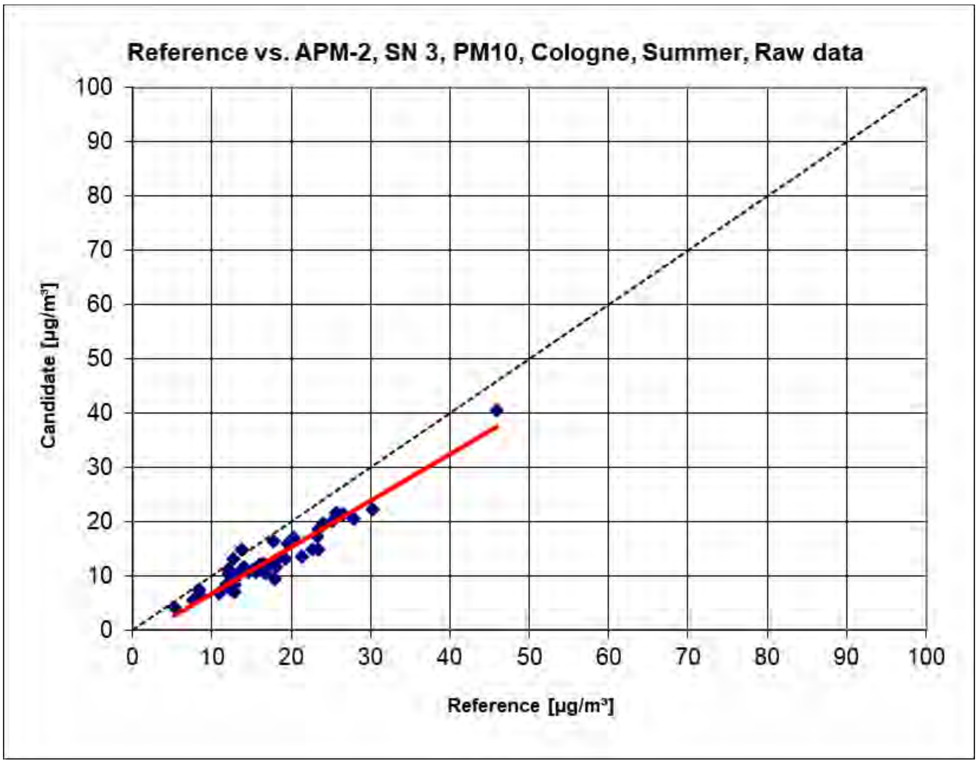

Figure 61: Reference vs. test instrument, SN3, for PM_{10}, Cologne, summer

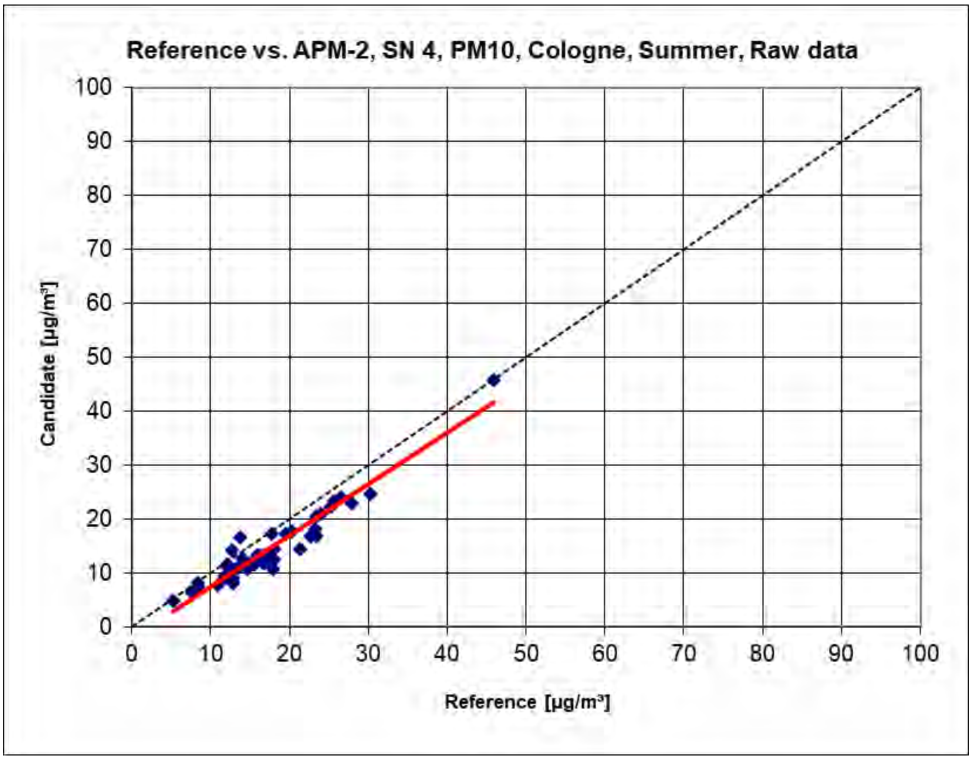

Figure 62: Reference vs. test instrument, SN4, for PM_{10}, Cologne, summer

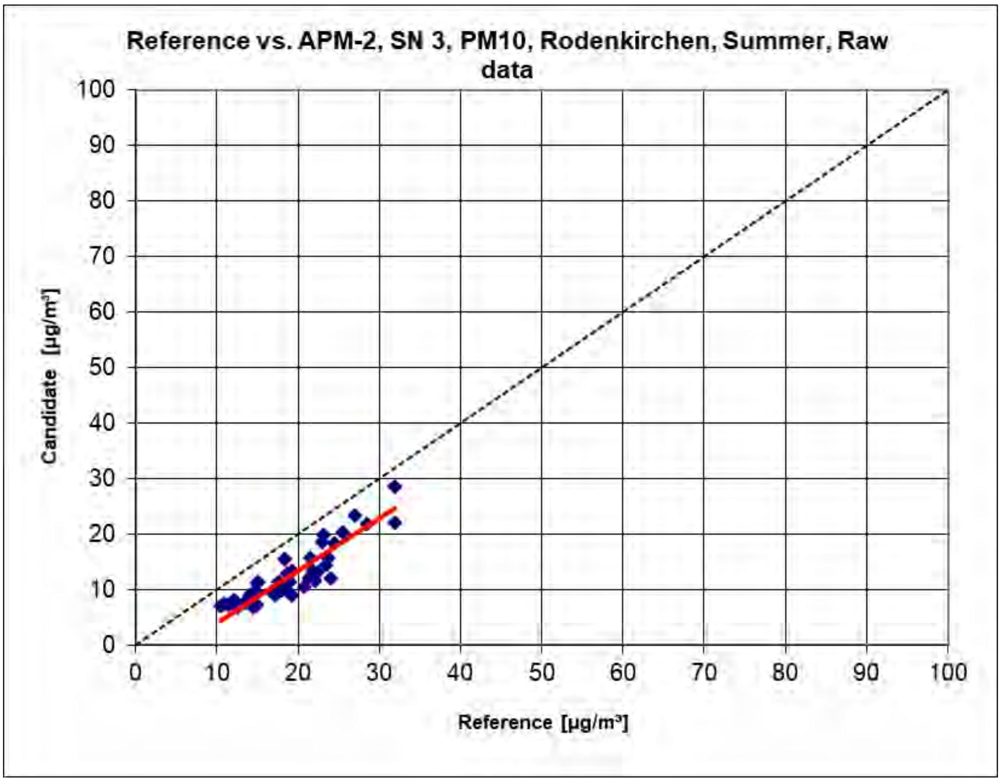

Figure 63: Reference vs. test instrument, SN3, for PM_{10}, Rodenkirchen, summer

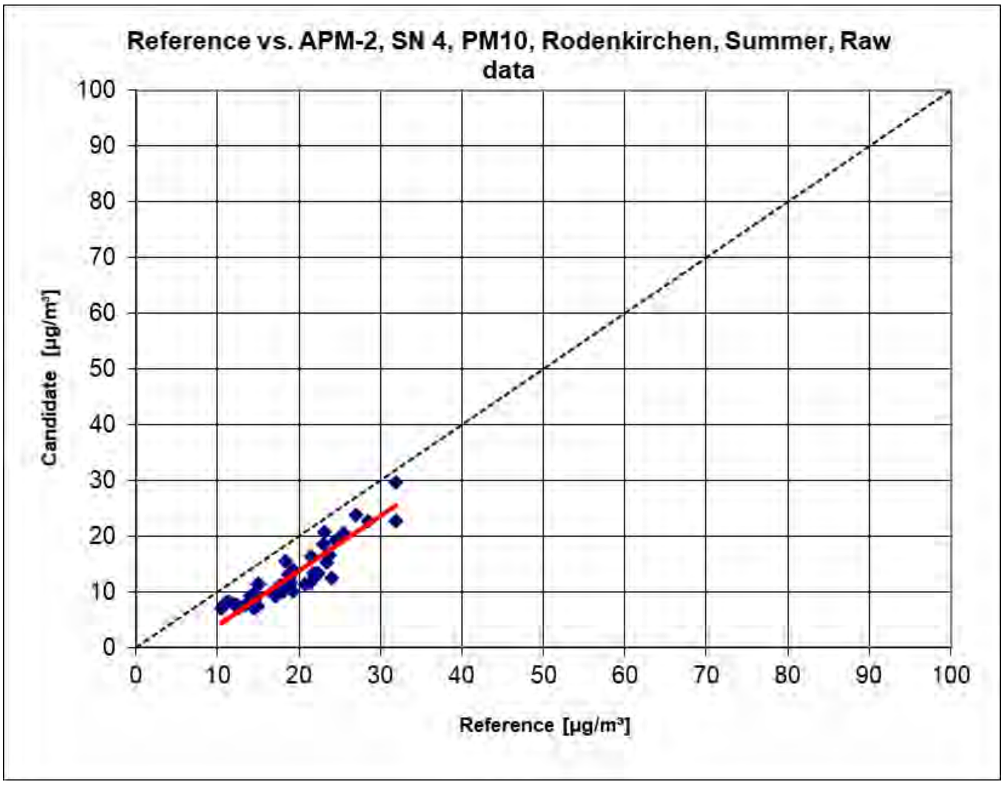

Figure 64: Reference vs. test instrument, SN4, for PM_{10}, Rodenkirchen, summer

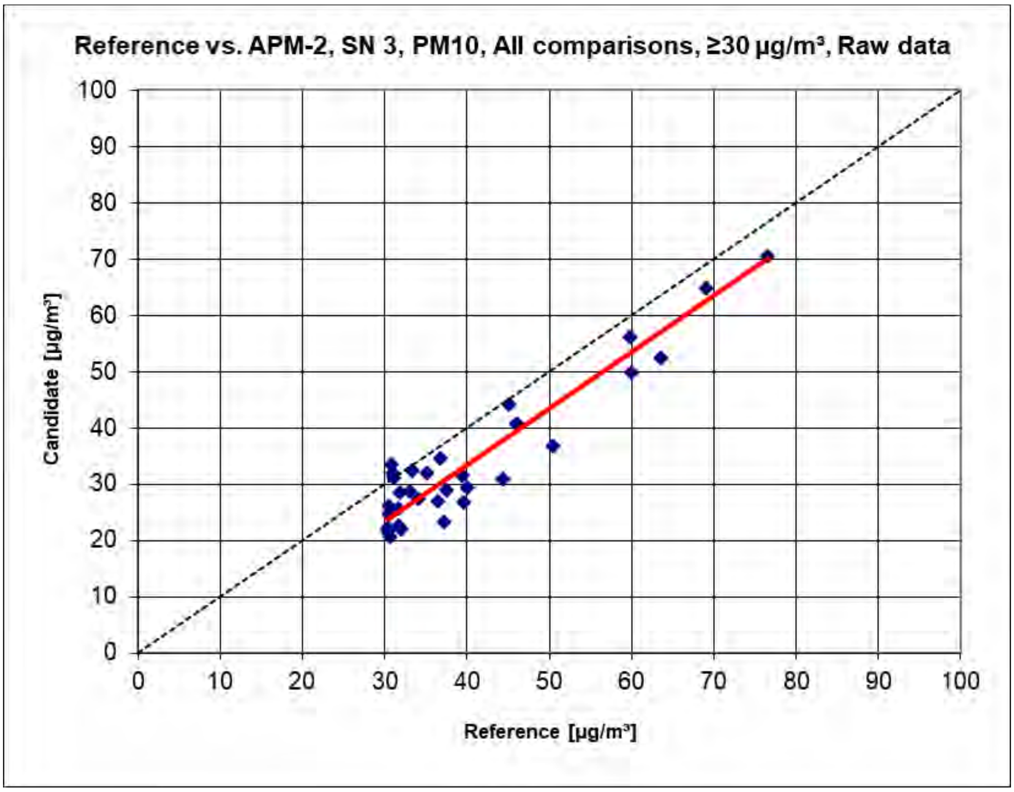

Figure 65: Reference vs. test instrument, SN3, for PM_{10}, values ≥ 30 µg/m³

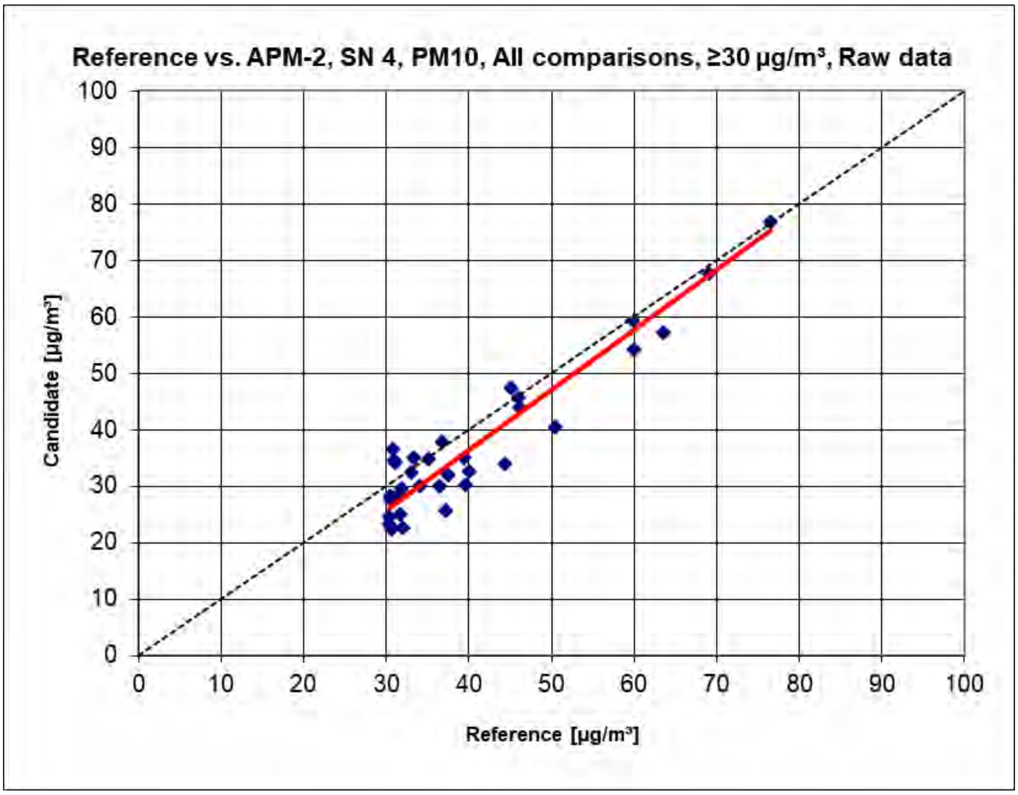

Figure 66: Reference vs. test instrument, SN4, for PM_{10}, values ≥ 30 µg/m³

6.1 17 Use of correction factors/terms (7.5.8.5–7.5.8.8)

Correction factors/terms (=calibration) shall be applied in the event the highest expanded uncertainty calculated for the tested instruments exceeds the relative expanded uncertainty specified under requirements for data quality or the test demonstrates that the slope is significantly different from 1 and/or the ordinate intercept is significantly different from 0.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

See item 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)

6.4 Evaluation

If it emerges from the evaluation of raw data in accordance with 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8) that $W_{AMS} > W_{dqo}$, i.e. the tested instrument is not found to be equivalent with the reference method, then it is permissible to use a correction factor or term which results from the regression equation for the full data set. The corrected values have to meet the requirements for all data sets or sub data sets. Moreover, a correction may also be used for the case that $W_{AMS} \leq W_{dqo}$ in order to improve the accuracy of the tested instruments.

Three different situations may occur:

a) Slope b is not significantly different from 1: $|b-1| \leq 2u(b)$

Axis intercept a is significantly different from 0: $|a| > 2u(a)$

b) Slope b is significantly different from 1: $|b-1| > 2u(b)$

Axis intercept a is not significantly different from 0: $|a| \leq 2u(a)$

b) Slope b is significantly different from 1: $|b-1| > 2u(b)$

Axis intercept a is significantly different from 0: $|a| > 2u(a)$

concerning a)

The value of the axis intercept a may be used as a correction term to correct all input values y_i according to the following equation:

$$y_{i,corr} = y_i - a$$

The corrected values $y_{i,corr}$ may then serve to calculate the following new terms using linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u_{yi,corr}^2 = \frac{RSS}{(n-2)} - u_{RM}^{\;2} + [c + (d-1)L]^2 + u^2(a)$$

where u(a) = uncertainty of the axis intercept a, whose value was used to determine $y_{i,corr}$.

The algorithms for calculating axis intercepts and slopes as well as their variance by means of orthogonal regression are described in detail in the annex to [9].

concerning b)

The value of the slope b may be used as a correction term to correct all input values y_i according to the following equation:

$$y_{i,corr} = \frac{y_i}{b}$$

The corrected values $y_{i,corr}$ may then serve to calculate the following new terms using a new linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u_{yi,corr}^2 = \frac{RSS}{(n-2)} - u_{RM}^{\;2} + [c + (d-1)L]^2 + L^2 u^2(b)$$

where u(b) = uncertainty of the original slope b, whose value was used to determine $y_{i,corr}$.

The algorithms for calculating axis intercepts and slopes as well as their variance by means of orthogonal regression are described in detail in the annex to [9].

concerning c)

The values of the slope b and the axis intercept a may be used as a correction terms to correct all input values y_i according to the following equation:

$$y_{i,corr} = \frac{y_i - a}{b}$$

The corrected values $y_{i,corr}$ may then serve to calculate the following new terms using a new linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{yi,corr} = \frac{RSS}{(n-2)} - u_{RM}{}^2 + \left[c + (d-1)L\right]^2 + L^2 u^2(b) + u^2(a)$$

where u(b) = uncertainty of the original slope b, whose value was used to determine $y_{i,corr}$ and u(a) = uncertainty of the original axis intercept a, whose value was used to determine $y_{i,corr}$.

The algorithms for calculating axis intercepts and slopes as well as their variance by means of orthogonal regression are described in detail in the annex to [9].

The values for $u_{c\_s,corr}$ are then used to calculate the combined relative uncertainty of the AMS after correction in accordance with the following equation:

$$w^2_{AMS,corr} = \frac{u^2_{corr,yi=L}}{L^2}$$

The uncertainty $w_{AMS,corr}$ for the corrected data set is calculated at the 24h limit value using y_i as concentration at the limit value.

The relative expanded uncertainty $W_{AMS,corr}$ is calculated using the following equation:

$$W_{AMS',corr} = k \cdot w_{AMS,corr}$$

In practice, k is specified at k=2 for large n.

The largest resulting uncertainty $W_{AMS,corr}$ is compared and assessed against the criteria for data quality of air quality measurements in accordance with EU Directive [8]. Two situations are conceivable:

1. $W_{AMS,corr} \leq W_{dqo}$ → The tested instrument is deemed equivalent to the reference method.
2. $W_{AMS,corr} > W_{dqo}$ → The tested instrument is not deemed equivalent to the reference method.

The expanded relative uncertainty W_{dqo} specified is 25% [8].

6.5 Assessment

After the use of correction factors, the candidate systems met the requirements for data quality of air quality monitors for all data sets, both for $PM_{2.5}$ and for PM_{10}.

Criterion satisfied? yes

The evaluation of the full data set resulted in a significant slope for $PM_{2.5}$ and a significant slope and intercept for PM_{10}.

For $PM_{2.5}$:

The slope for the entire data set is 0.919. The intercept for the full data set is 0.327 (see Table 28)

For PM_{10}:

The slope for the entire data set is 0.977. The intercept for the full data set is -3.758 (see Table 29)

For the component $PM_{2,5}$, the full data set was corrected in terms of the slope. All data sets were re-evaluated using the corrected values.

For the component PM_{10}, the full data set was corrected in terms of the slope and intercept. All data sets were re-evaluated using the corrected values.

All data sets meet the data quality requirements after correction.

When a measuring system is operated in the context of a measurement grid, the January 2010 version of the Guideline and standard EN 16450 require that the instruments are tested annually at a number of sites which in turn depends on the highest expanded uncertainty determined during equivalence testing. The criterion used for specifying the number of sites for annual testing is grouped into 5% steps (Guideline [4], chapter 9.9.2, Table 6 and/or EN 16450 [9], chapter 8.6.2, Table 5). It should be noted that the highest calculated expanded uncertainty determined for $PM_{2.5}$ and PM_{10} after applying the correction was in the range of 20 % to 25 %.

The operator of the measurement grid or the competent authority of a member state is responsible for compliant implementation of the requirements for regular tests as described above. TÜV Rheinland recommends that the expanded uncertainty of the full data set is used for this purpose, namely 17.87 % ($PM_{2.5}$, uncorrected data set) or 12.64 % ($PM_{2.5}$, data set after slope correction), which in turn would require an annual check at 4 measurement locations (uncorrected) or 3 measurement sites (corrected), and 23.31 % (PM_{10}, uncorrected data set), or 13.62 % (PM_{10}, data set after slope/offset correction), which in turn would require an annual check at 5 measurement sites (uncorrected), or 3 measurement sites (corrected).

6.6 Detailed presentation of test results

Table 32 and Table 33 show the evaluation results of the equivalence test after applying the correction factor to the full data set.

Table 32: Compilation of the results of the equivalence test for $PM_{2.5}$ after slope correction

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0,55**	**µg/m³**			
Uncertainty between Candidates	**0,71**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**192**				
Slope b	**1,001**	**not significant**			
Uncertainty of b	**0,013**				
Ordinate intercept a	**0,335**	**not significant**			
Uncertainty of a	**0,235**				
Expanded meas. uncertainty W_{CM}	**12,64**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0,63**	**µg/m³**			
Uncertainty between Candidates	**1,13**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**49**				
Slope b	**0,967**				
Uncertainty of b	**0,033**				
Ordinate intercept a	**1,292**				
Uncertainty of a	**1,019**				
Expanded meas. uncertainty W_{CM}	**18,70**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017				
Candidate	APM-2	SN	SN 3 & SN 4	
		Limit value	30	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	**0,54**	**µg/m³**		
Uncertainty between Candidates	**0,71**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**52**		**52**	
Slope b	**0,931**		**0,962**	
Uncertainty of b	**0,019**		**0,019**	
Ordinate intercept a	**1,148**		**1,495**	
Uncertainty of a	**0,424**		**0,435**	
Expanded meas. uncertainty W_{CM}	**14,07**	**%**	**13,17**	**%**
Bonn, Winter				
Uncertainty between Reference	**0,62**	**µg/m³**		
Uncertainty between Candidates	**0,96**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**51**		**51**	
Slope b	**1,037**		**1,097**	
Uncertainty of b	**0,031**		**0,032**	
Ordinate intercept a	**-0,948**		**-0,964**	
Uncertainty of a	**0,706**		**0,725**	
Expanded meas. uncertainty W_{CM}	**15,61**	**%**	**20,61**	**%**
Cologne, Summer				
Uncertainty between Reference	**0,53**	**µg/m³**		
Uncertainty between Candidates	**0,62**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**46**		**44**	
Slope b	**1,054**		**1,113**	
Uncertainty of b	**0,044**		**0,049**	
Ordinate intercept a	**-0,279**		**-0,232**	
Uncertainty of a	**0,493**		**0,553**	
Expanded meas. uncertainty W_{CM}	**12,03**	**%**	**22,86**	**%**
Rodenkirchen, Summer				
Uncertainty between Reference	**0,52**	**µg/m³**		
Uncertainty between Candidates	**0,36**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**45**		**45**	
Slope b	**1,150**		**1,133**	
Uncertainty of b	**0,050**		**0,051**	
Ordinate intercept a	**-1,383**		**-1,482**	
Uncertainty of a	**0,565**		**0,567**	
Expanded meas. uncertainty W_{CM}	**22,59**	**%**	**18,94**	**%**
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	**0,63**	**µg/m³**		
Uncertainty between Candidates	**1,13**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**49**		**49**	
Slope b	**0,949**		**0,986**	
Uncertainty of b	**0,032**		**0,034**	
Ordinate intercept a	**1,074**		**1,497**	
Uncertainty of a	**1,002**		**1,05**	
Expanded meas. uncertainty W_{CM}	**18,50**	**%**	**20,36**	**%**
All comparisons				
Uncertainty between Reference	**0,55**	**µg/m³**		
Uncertainty between Candidates	**0,71**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**194**		**192**	
Slope b	**0,976**	**not significant**	**1,027**	**significant**
Uncertainty of b	**0,013**		**0,013**	
Ordinate intercept a	**0,396**	**not significant**	**0,269**	**not significant**
Uncertainty of a	**0,228**		**0,245**	
Expanded meas. uncertainty W_{CM}	**12,25**	**%**	**14,81**	**%**

Table 33: Compilation of the results of the equivalence test for PM_{10} after slope and axis intercept correction

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0,58**	**µg/m³**			
Uncertainty between Candidates	**1,30**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**193**				
Slope b	**1,001**	**not significant**			
Uncertainty of b	**0,021**				
Ordinate intercept a	**-0,023**	**not significant**			
Uncertainty of a	**0,514**				
Expanded measured uncertainty WCM	**13,62**	**%**			
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0,72**	**µg/m³**			
Uncertainty between Candidates	**2,33**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**33**				
Slope b	**1,061**				
Uncertainty of b	**0,065**				
Ordinate intercept a	**-2,800**				
Uncertainty of a	**2,744**				
Expanded measured uncertainty WCM	**18,93**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	**0,54**	**µg/m³**			
Uncertainty between Candidates	**1,41**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**52**			**52**	
Slope b	**0,953**			**1,006**	
Uncertainty of b	**0,023**			**0,022**	
Ordinate intercept a	**1,785**			**2,520**	
Uncertainty of a	**0,625**			**0,596**	
Expanded measured uncertainty W_{CM}	**10,72**	**%**		**15,06**	**%**
Bonn, Winter					
Uncertainty between Reference	**0,38**	**µg/m³**			
Uncertainty between Candidates	**1,76**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**51**			**51**	
Slope b	**0,967**			**1,069**	
Uncertainty of b	**0,051**			**0,055**	
Ordinate intercept a	**-0,523**			**-1,146**	
Uncertainty of a	**1,511**			**1,641**	
Expanded measured uncertainty W_{CM}	**19,26**	**%**		**20,77**	**%**
Cologne, Summer					
Uncertainty between Reference	**0,60**	**µg/m³**			
Uncertainty between Candidates	**1,09**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**47**			**45**	
Slope b	**0,873**			**0,978**	
Uncertainty of b	**0,040**			**0,044**	
Ordinate intercept a	**2,123**			**1,622**	
Uncertainty of a	**0,750**			**0,828**	
Expanded measured uncertainty W_{CM}	**18,99**	**%**		**9,70**	**%**
Rodenkirchen, Summer					
Uncertainty between Reference	**0,76**	**µg/m³**			
Uncertainty between Candidates	**0,44**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**45**			**45**	
Slope b	**0,969**			**1,008**	
Uncertainty of b	**0,065**			**0,065**	
Ordinate intercept a	**-1,719**			**-2,154**	
Uncertainty of a	**1,281**			**1,287**	
Expanded measured uncertainty W_{CM}	**16,54**	**%**		**12,32**	**%**
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0,72**	**µg/m³**			
Uncertainty between Candidates	**2,33**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**33**			**33**	
Slope b	**1,028**			**1,095**	
Uncertainty of b	**0,064**			**0,066**	
Ordinate intercept a	**-3,024**			**-2,618**	
Uncertainty of a	**2,701**			**2,81**	
Expanded measured uncertainty W_{CM}	**19,73**	**%**		**21,11**	**%**
All comparisons					
Uncertainty between Reference	**0,58**	**µg/m³**			
Uncertainty between Candidates	**1,30**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**195**			**193**	
Slope b	**0,958**	**significant**		**1,045**	**significant**
Uncertainty of b	**0,020**			**0,022**	
Ordinate intercept a	**0,190**	**not significant**		**-0,253**	**not significant**
Uncertainty of a	**0,485**			**0,543**	
Expanded measured uncertainty W_{CM}	**15,10**	**%**		**16,44**	**%**

6.1 18 Maintenance interval (7.5.7)

The maintenance interval shall be at least 2 weeks.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

With regard to this minimum requirement, the maintenance tasks required in a specific period and the length of that period for the correct functioning of the measuring system were identified. Furthermore, the results of the drift determination for the zero point (see [10]) were taken into account to determine the maintenance interval.

6.4 Evaluation

Over the entire period of the field test, no unacceptable drift was observed.

The maintenance interval is thus determined by the necessary maintenance works.

During operation times, maintenance is generally limited to contamination and plausibility checks and potential status/error messages.

6.5 Assessment

The maintenance interval is determined by the maintenance work to be carried out and is 4 weeks.Criterion satisfied? yes

6.6 Detailed presentation of test results

The required maintenance work can be found in chapter 10 of the operating manual and chapter 7 Recommendations for use in practice of this report.

6.1 19 Automatic diagnostic check (7.5.4)

Results of automated/functional checks, where available, shall be recorded.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The current operating status of the measuring system is continuously monitored and any issues will be flagged via a series of different error messages. The current state of monitored parameters can be displayed on the instrument itself and is recorded as part of data logging. An error message is flagged if performance characteristics are outside the permissible range of tolerance.

6.4 Evaluation

The instrument provides all features described in the operation manual. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages. The monitored parameters, including the automatic hourly zero point check, are also recorded in the data logging.

6.5 Assessment

All the unit functions listed in the operating manual are available. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages. The monitored parameters, including the automatic hourly zero point check, are recorded during data recording.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 20 Checks of temperature sensors, pressure and/or humidity sensors

The verifiability of temperature sensors, pressure and/or humidity sensors shall be checked for the AMS. Deviations determined shall be within the following criteria:

T ±2 °C
p ±1 kPa
rF ± 5 %

6.2 Equipment

Barometer, thermometer and hygrometer.

6.3 Testing

This minimum requirement serves to verify whether AMS sensors for temperature, pressure and humidity, which are necessary for correct AMS performance, are accessible and can be checked at the field test site location. In the event, checks cannot be performed on-site, this has to be documented.

6.4 Evaluation

The measuring system uses a weather sensor (mounted at the sampling tube below the sample inlet) to record ambient temperature and relative moisture. Air pressure is measured inside the instrument.

Relying on transfer standards, it is easily possible to perform comparison measurements on-site at any time and to adjust the sensors. The sensors' deviations remained within the required ranges.

6.5 Assessment

It is possible to check and adjust the sensors for determining ambient temperature, ambient pressure and relative humidity on site. The deviations of the sensors were within the requirements. Sensors for recording the outdoor temperature, air pressure and relative humidity are easy to check and adjust on site.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

7. Recommendations for use in practice

7.1 Work in the maintenance interval (4 weeks)

The tested measuring systems require regular performance of the following tasks:

- Checking the operational status
  The instrument status can be verified by checking the AMS; alternatively it can be monitored online.
- The sampling head generally needs to be cleaned following the manufacturer's instructions and taking into account local concentrations of suspended particulate matter (approximately every 4 weeks during performance testing).

Apart from that, please take note of the manufacturer's instructions.

7.2 Additional maintenance tasks

In addition to the regular tasks to be performed during the maintenance interval, the following tasks need to be performed.

- A check of the sensors for ambient temperature and ambient pressure should be carried out every 3 months.
- A check of the flow rate should be done every 3 months.
- A leakage check should also be carried out every 3 months as part of the flow rate check.
- The virtual impactor must be cleaned every 3 months at the very latest.
- According to the manufacturer, the internal filters in the unit (zero air filter, photometer output filter, bypass filter and pump output filter) should be replaced after 6 months at very the latest.
- At least once a year, the photometer should be sent to the system manufacturer for recalibration.
- The manufacturer states that the photometer must be completely replaced if:
  The total amount of particulate matter absorbed has exceeded 50 mg (corresponds to approx. 200 days at an average concentration of 50 µg/m³) and/or the photometer offset has risen above 2500 mV.

  After the annual maintenance of the photometer, the AMS shall be calibrated with the gravimetric PM_{10} and $PM_{2.5}$ reference method according to EN 12341 at the measuring site. If possible, a seasonal calibration cycle should be set.
  During the annual basic maintenance, attention should also be paid to cleaning the sampling tube.
- The vacuum pump has a life cycle of approx. 2 years - after reaching the end of the life cycle, the pump must be completely replaced. Should the pump fail an error message will be displayed on the unit.

Further details are provided in the operation manual.

8. Tests for the validation of the system software 3.0.1

In winter 2013/2014, new system software 3.0.1 for the APM-2 measuring system was developed by the manufacturer. This software version included, among other things, an optimisation of the calculation algorithm by introducing a linearity correction for the suspended particulate matter measured values.

Since this change had an influence on the formation of measured values and thus also affected the measured values from the comparative campaigns within the scope of the performance test, the following measures were taken to qualify the new software:

All existing measured values from the 4 past comparison campaigns were manually converted and evaluated with the new calculation algorithm. The results of these investigations are listed under point 6.1 Method used for equivalence testing (7.5.8.4 & 7.5.8.8).

In addition, for qualification purposes, a supplementary comparison measurement campaign was carried out at the Cologne site, car park area, with the two test specimens and the new software version (version 3.0.1). For this purpose, the following test programme was carried out in detail:

- A comparative measurement campaign with at least 40 valid measurement pairs reference vs. test specimen
- Determination of the uncertainty between the test items u_{bs} according to the Guideline
- Calculation of the expanded uncertainty of the test items according to the Guideline
- Use of the correction factors/terms determined under point 6.1 17 Use of correction factors/terms (7.5.8.5–7.5.8.8)
- Recalculation of the equivalence for the 4 data sets from the present performance test + additional data set from the validation campaign "Cologne, winter 2014" according to the approach from point "8.2 Suitability test" of CEN/TS 16450 [9].

The additional comparison campaign was carried out at the Cologne site, car park area, between 13.01.2014 and 09.03.2014. The environmental conditions during the campaign are listed in Table 7. All individual values can be found in Appendices 5 (PM measured values) and 6 (ambient conditions).

A total of 47 measurement pairs were determined for both PM_{10} and $PM_{2.5}$.

The evaluation of the comparative measurements according to EN 16450 [9] leads to the following result:

Table 34: Results of the equivalence test at the Cologne site, winter 2014, SN3 & SN4, measured component $PM_{2.5}$, raw data

Cologne, Winter 2014				
Uncertainty between Reference	0,49	µg/m³		
Uncertainty between Candidates	0,61	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0,813		0,847	
Uncertainty of b	0,019		0,019	
Ordinate intercept a	3,122		2,055	
Uncertainty of a	0,320		0,313	
Expanded meas. uncertainty W_{CM}	18,72	%	18,97	%

Assessment for $PM_{2.5}$:

1. The uncertainty between the test items is 0.61 µg/m³ and is thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.

Table 35: Results of the equivalence test at the Cologne site, winter 2014, SN3 & SN4, measured component PM_{10}, raw data

Cologne, Winter 2014				
Uncertainty between Reference	0,58	µg/m³		
Uncertainty between Candidates	0,72	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0,882		0,927	
Uncertainty of b	0,017		0,017	
Ordinate intercept a	2,073		1,120	
Uncertainty of a	0,380		0,376	
Expanded measured uncertainty W_{CM}	16,34	%	11,59	%

Assessment for PM_{10}:

1. The uncertainty between the test items is 0.72 µg/m³ and is thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.

The correction factors/terms determined in the performance test in point 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8) are then applied to the determined raw data sets.

For $PM_{2.5}$ a correction of the data sets for SN3 and SN4 with the slope of 0.919 (uncertainty of the slope 0.012) is carried out accordingly. Results are as follows:

Table 36: Results of the equivalence test at the Cologne site, winter 2014, SN3 & SN4, measured component $PM_{2.5}$, slope correction of 0.919

Cologne, Winter 2014				
Uncertainty between Reference	0,49	µg/m³		
Uncertainty between Candidates	0,66	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0,886		0,922	
Uncertainty of b	0,021		0,020	
Ordinate intercept a	3,385		2,225	
Uncertainty of a	0,348		0,341	
Expanded meas. uncertainty W_{CM}	9,94	%	9,75	%

Assessment:

1. The expanded uncertainty for the data with the corrected slope 0.919 is smaller than the permissible 25 % for both SN3 and SN4.

For PM_{10}, the data sets for SN 3 and SN 4 with the slope 0.977 (uncertainty of the slope 0.020) and with the intercept -3.758 (uncertainty of the intercept 0.502) are corrected. Results are as follows:

Table 37: Results of the equivalence test at the Cologne site, winter 2014, SN3 & SN4, measured component PM_{10}, slope correction of 0.977, intercept correction of -3.758

Cologne, Winter 2014				
Uncertainty between Reference	0,58	µg/m³		
Uncertainty between Candidates	0,74	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0,903		0,949	
Uncertainty of b	0,018		0,018	
Ordinate intercept a	5,965		4,990	
Uncertainty of a	0,389		0,385	
Expanded measured uncertainty W_{CM}	8,50	%	12,08	%

Assessment:

1. The expanded uncertainty for the data with the corrected slope 0.977 and the corrected intercept -3.758 is smaller than the permissible 25% for both SN3 and SN4.

Finally, according to the approach from point "8. 2 Suitability test" of EN 16450 [9], the corrected data set for Cologne, winter 2014 was included as an additional fifth data set in the original equivalence evaluation from the performance test (see Table 32 for $PM_{2.5}$ and Table 33 for PM_{10}) and it was checked whether the equivalence test criteria were still fulfilled.

Table 38: Results of the equivalence test "Performance Test + Cologne, Winter 2014", SN3 & SN4, measured component $PM_{2.5}$, slope correction of 0.919

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0,54**	**µg/m³**			
Uncertainty between Candidates	**0,70**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**239**				
Slope b	**0,981**	**not significant**			
Uncertainty of b	**0,012**				
Ordinate intercept a	**0,872**	**significant**			
Uncertainty of a	**0,209**				
Expanded meas. uncertainty W_{CM}	**12,65**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0,64**	**µg/m³**			
Uncertainty between Candidates	**1,03**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**61**				
Slope b	**0,953**				
Uncertainty of b	**0,030**				
Ordinate intercept a	**1,663**				
Uncertainty of a	**0,932**				
Expanded meas. uncertainty W_{CM}	**18,34**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
Cologne, Winter					
Uncertainty between Reference	**0,54**	**µg/m³**			
Uncertainty between Candidates	**0,71**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**52**			**52**	
Slope b	**0,931**			**0,962**	
Uncertainty of b	**0,019**			**0,019**	
Ordinate intercept a	**1,148**			**1,495**	
Uncertainty of a	**0,424**			**0,435**	
Expanded meas. uncertainty W_{CM}	**14,07**	**%**		**13,17**	**%**
Bonn, Winter					
Uncertainty between Reference	**0,62**	**µg/m³**			
Uncertainty between Candidates	**0,96**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**51**			**51**	
Slope b	**1,037**			**1,097**	
Uncertainty of b	**0,031**			**0,032**	
Ordinate intercept a	**-0,948**			**-0,964**	
Uncertainty of a	**0,706**			**0,725**	
Expanded meas. uncertainty W_{CM}	**15,61**	**%**		**20,61**	**%**
Cologne, Summer					
Uncertainty between Reference	**0,53**	**µg/m³**			
Uncertainty between Candidates	**0,62**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**46**			**44**	
Slope b	**1,054**			**1,113**	
Uncertainty of b	**0,044**			**0,049**	
Ordinate intercept a	**-0,279**			**-0,232**	
Uncertainty of a	**0,493**			**0,553**	
Expanded meas. uncertainty W_{CM}	**12,03**	**%**		**22,86**	**%**
Rodenkirchen, Summer					
Uncertainty between Reference	**0,52**	**µg/m³**			
Uncertainty between Candidates	**0,36**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**45**			**45**	
Slope b	**1,150**			**1,133**	
Uncertainty of b	**0,050**			**0,051**	
Ordinate intercept a	**-1,383**			**-1,482**	
Uncertainty of a	**0,565**			**0,567**	
Expanded meas. uncertainty W_{CM}	**22,59**	**%**		**18,94**	**%**
Cologne, Winter 2014					
Uncertainty between Reference	**0,49**	**µg/m³**			
Uncertainty between Candidates	**0,66**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**47**			**47**	
Slope b	**0,886**			**0,922**	
Uncertainty of b	**0,021**			**0,020**	
Ordinate intercept a	**3,385**			**2,225**	
Uncertainty of a	**0,348**			**0,341**	
Expanded meas. uncertainty W_{CM}	**9,94**	**%**		**9,75**	**%**
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0,64**	**µg/m³**			
Uncertainty between Candidates	**1,03**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**61**			**61**	
Slope b	**0,935**			**0,972**	
Uncertainty of b	**0,030**			**0,032**	
Ordinate intercept a	**1,602**			**1,689**	
Uncertainty of a	**0,919**			**0,97**	
Expanded meas. uncertainty W_{CM}	**18,16**	**%**		**19,77**	**%**
All comparisons					
Uncertainty between Reference	**0,54**	**µg/m³**			
Uncertainty between Candidates	**0,70**	**µg/m³**			
	SN 3			**SN 4**	
Number of data pairs	**241**			**239**	
Slope b	**0,956**	**significant**		**1,006**	**not significant**
Uncertainty of b	**0,012**			**0,012**	
Ordinate intercept a	**1,030**	**significant**		**0,693**	**significant**
Uncertainty of a	**0,212**			**0,212**	
Expanded meas. uncertainty W_{CM}	**12,88**	**%**		**13,95**	**%**

Table 39: Results of the equivalence test "Performance Test + Cologne, Winter 2014", SN3 & SN4, measured component PM_{10}, slope correction of 0.977, intercept correction of -3.758

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	APM-2		SN	SN 3 & SN 4	
			Limit value	50	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0,58**	**µg/m³**			
Uncertainty between Candidates	**1,22**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**240**				
Slope b	**0,975**	**not significant**			
Uncertainty of b	**0,019**				
Ordinate intercept a	**1,346**	**significant**			
Uncertainty of a	**0,454**				
Expanded measured uncertainty WCM	**14,10**	**%**			
All comparisons, ≥30 µg/m³					
Uncertainty between Reference	**0,68**	**µg/m³**			
Uncertainty between Candidates	**2,17**	**µg/m³**			
	SN 3 & SN 4				
Number of data pairs	**40**				
Slope b	**1,052**				
Uncertainty of b	**0,060**				
Ordinate intercept a	**-2,041**				
Uncertainty of a	**2,563**				
Expanded measured uncertainty WCM	**18,56**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017				
Candidate	APM-2	SN	SN 3 & SN 4	
		Limit value	50	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	**0,54**	**µg/m³**		
Uncertainty between Candidates	**1,41**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**52**		**52**	
Slope b	**0,953**		**1,006**	
Uncertainty of b	**0,023**		**0,022**	
Ordinate intercept a	**1,785**		**2,520**	
Uncertainty of a	**0,625**		**0,596**	
Expanded measured uncertainty W_{CM}	**10,72**	**%**	**15,06**	**%**
Bonn, Winter				
Uncertainty between Reference	**0,38**	**µg/m³**		
Uncertainty between Candidates	**1,76**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**51**		**51**	
Slope b	**0,967**		**1,069**	
Uncertainty of b	**0,051**		**0,055**	
Ordinate intercept a	**-0,523**		**-1,146**	
Uncertainty of a	**1,511**		**1,641**	
Expanded measured uncertainty W_{CM}	**19,26**	**%**	**20,77**	**%**
Cologne, Summer				
Uncertainty between Reference	**0,60**	**µg/m³**		
Uncertainty between Candidates	**1,09**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**47**		**45**	
Slope b	**0,873**		**0,978**	
Uncertainty of b	**0,040**		**0,044**	
Ordinate intercept a	**2,123**		**1,622**	
Uncertainty of a	**0,750**		**0,828**	
Expanded measured uncertainty W_{CM}	**18,99**	**%**	**9,70**	**%**
Rodenkirchen, Summer				
Uncertainty between Reference	**0,76**	**µg/m³**		
Uncertainty between Candidates	**0,44**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**45**		**45**	
Slope b	**0,969**		**1,008**	
Uncertainty of b	**0,065**		**0,065**	
Ordinate intercept a	**-1,719**		**-2,154**	
Uncertainty of a	**1,281**		**1,287**	
Expanded measured uncertainty W_{CM}	**16,54**	**%**	**12,32**	**%**
Cologne, Winter 2014				
Uncertainty between Reference	**0,58**	**µg/m³**		
Uncertainty between Candidates	**0,74**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**47**		**47**	
Slope b	**0,903**		**0,949**	
Uncertainty of b	**0,018**		**0,018**	
Ordinate intercept a	**5,965**		**4,990**	
Uncertainty of a	**0,389**		**0,385**	
Expanded measured uncertainty W_{CM}	**8,50**	**%**	**12,08**	**%**
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	**0,68**	**µg/m³**		
Uncertainty between Candidates	**2,17**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**40**		**40**	
Slope b	**1,024**		**1,083**	
Uncertainty of b	**0,061**		**0,061**	
Ordinate intercept a	**-2,267**		**-1,935**	
Uncertainty of a	**2,595**		**2,58**	
Expanded measured uncertainty W_{CM}	**19,13**	**%**	**20,56**	**%**
All comparisons				
Uncertainty between Reference	**0,58**	**µg/m³**		
Uncertainty between Candidates	**1,22**	**µg/m³**		
	SN 3		**SN 4**	
Number of data pairs	**242**		**240**	
Slope b	**0,937**	**significant**	**1,014**	**not significant**
Uncertainty of b	**0,019**		**0,019**	
Ordinate intercept a	**1,556**	**significant**	**1,086**	**significant**
Uncertainty of a	**0,455**		**0,460**	
Expanded measured uncertainty W_{CM}	**15,53**	**%**	**15,97**	**%**

Summary assessment:

To prove the equivalence of the data between the data from the performance test (comparison campaign 1-4) manually converted with the modified calculation algorithm of software version 3.0.1, and the data determined in practice when using software version 3.0.1, an additional validation campaign "Cologne, Winter 2014" was carried out with software version 3.0.1 on the two test items and the data records obtained were subjected to an equivalence test. The results are as follows:

For $PM_{2.5}$:

1. The uncertainty between the test items is 0.61 µg/m³ and is thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.
3. The expanded uncertainty is smaller than the permissible 25 % for both SN3 and SN4 after applying the correction of the slope of 0.919 (determined in the performance test).
4. The combined evaluation of the four original data sets from the performance test (manually converted and evaluated with the new calculation algorithm) with the additional fifth data set from Cologne, winter 2014 (software version 3.0.1 installed) also leads to the fulfilment of the equivalence criteria according to standard EN 16450 [9].

For PM_{10}:

1. The uncertainty between the test items is 0.72 µg/m³ and is thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.
3. The expanded uncertainty is smaller than the permissible 25 % for both SN3 and SN4 after applying the correction for the slope of 0.977 and the intercept of -3.758 (determined in performance testing).
4. The combined evaluation of the four original data sets from the performance test (manually converted and evaluated with the new calculation algorithm) with the additional fifth data set from Cologne, winter 2014 (software version 3.0.1 installed) also leads to the fulfilment of the equivalence criteria according to standard EN 16450 [9].

Thus, it can be stated that the proof of equivalence of the measuring equipment between the data from the performance test (comparison campaign 1-4) manually converted with the modified calculation algorithm of software version 3.0.1 and the data determined in practice when using software version 3.0.1 could be established and therefore the validation of the current software version 3.0.1 was achieved satisfactorily.

Environmental Protection /
Air Pollution Control

Dipl.-Ing. Guido Baum

Dipl.-Ing. Fritz Hausberg

Cologne, 09 September 2021
936/21253723/A

9. Bibliography

[1] VDI Guideline 4202, Part 1 – "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants," dated June 2002 and September 2010

[2] VDI Guideline 4203, part 3 – "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", dated August 2004 and September 2010

[3] European standard EN 12341 "Air Quality - Determination of the PM_{10} fraction of suspended particulate matter - Reference method and field test procedure to demonstrate reference equivalence of measurement methods", German version EN 12341: 1998

[4] European standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005

[5] Guideline "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version dated January 2010

[6] Operation manual APM-2, version 01/2019

[7] Operation manual LVS3 of 2000

[8] 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

[9] European standard EN 16450 Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM10; PM2.5, German version dated July 2017)

[10] TÜV Rheinland Report No. 936/21219977/A of 26 March 2014; Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM_{10} and $PM_{2.5}$.

[12] European standard EN 12341, Ambient air - Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter; German version EN 12341:2014

[13] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 27 September 2014

[14] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 21 October 2015

[15] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 10 March 2017

[16] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 04 May 2020

2.1 Air Pollution Monitor 2 (APM-2) für Schwebstaub PM_{10} und $PM_{2,5}$

Hersteller:

Comde-Derenda GmbH, Stahnsdorf

Eignung:

Zur kontinuierlichen parallelen Immissionsmessung der PM_{10}- und der $PM_{2,5}$-Fraktion im Schwebstaub im stationären Einsatz

Messbereiche in der Eignungsprüfung:

Komponente	Zertifizierungsbereich	Einheit
PM_{10}	0 – 1 000	µg/m³
$PM_{2,5}$	0 – 1 000	µg/m³

Softwareversion: 3.0.1

Einschränkungen:

Keine

Hinweise:

1. Die Anforderungen gemäß des Leitfadens „Demonstration of Equivalence of Ambient Air Monitoring Methods" werden für die Messkomponenten PM_{10} und $PM_{2,5}$ nach Anwendung der ermittelten Korrekturfaktoren/-termen eingehalten.

Bundesanzeiger
Herausgegeben vom Bundesministerium der Justiz und für Verbraucherschutz
www.bundesanzeiger.de

Bekanntmachung
Veröffentlicht am Dienstag, 5. August 2014
BAnz AT 05.08.2014 B11
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2. Die Anforderungen an die Vergleichbarkeitsprüfung gemäß Richtlinie EN 12341: 1998 für PM_{10} wurden von den Prüflingen nicht eingehalten.
3. Die Langzeitdrift der Empfindlichkeit des Partikelsensors konnte im Rahmen der Feldprüfung nicht ermittelt werden.
4. Die Messeinrichtung kann telemetrisch überwacht, aber nicht gesteuert werden.
5. Die Messeinrichtung ermittelt alternierend die PM_{10}- und die $PM_{2,5}$-Fraktion im Schwebstaub – im Rahmen der Eignungsprüfung erfolgte alle zwei Minuten die Umschaltung zwischen den beiden Fraktionen.
6. Die Messeinrichtung ist mit dem gravimetrischen PM_{10}-Referenzverfahren nach DIN EN 12341 nach Wartung des Photometers am Standort zu kalibrieren. Es ist möglichst ein saisonaler Kalibrierrhythmus einzustellen.
7. Die Messeinrichtung ist mit dem gravimetrischen $PM_{2,5}$-Referenzverfahren nach DIN EN 14907 nach Wartung des Photometers am Standort zu kalibrieren. Es ist möglichst ein saisonaler Kalibrierrhythmus einzustellen.
8. Der Prüfbericht über die Eignungsprüfung ist im Internet unter www.qal1.de einsehbar.

Prüfinstitut: TÜV Rheinland Energie und Umwelt GmbH, Köln

Bericht-Nr.: 936/21219977/A vom 26. März 2014

Figure 67: Initial publication BAnz. AT 05.08.2014 B11, chapter III number 2.1

1 Mitteilung zu der Bekanntmachung des Umweltbundesamtes vom 17. Juli 2014 (BAnz AT 05.08.2014 B11, Kapitel III Nummer 2.1)

Bei der Messeinrichtung Air Pollution Monitor 2 (APM-2) für Schwebstaub PM_{10} und $PM_{2,5}$ der Fa. Comde-Derenda GmbH wurde der Ausgangsfilter von der alten Position nach Pumpe auf die neue Position zwischen Massendurchflusssensor und Pumpe verlegt.

Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 27. September 2014

Figure 68: Notification publication BAnz AT 02.04.2015 B5, chapter IV 1st notification

4 Mitteilung zu den Bekanntmachungen des Umweltbundesamtes vom 17. Juli 2014 (BAnz AT 05.08.2014 B11, Kapitel II Nummer 2.1) und vom 25. Februar 2015 (BAnz AT 02.04.2015 B5, Kapitel IV 1. Mitteilung)

Die neue Softwareversion für die Messeinrichtung APM-2 für Schwebstaub PM_{10} und $PM_{2,5}$ der Fa. Comde-Derenda GmbH lautet:

Softwareversion: 3.05.002

Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 21. Oktober 2015

Figure 69: Notification publication BAnz AT 14.03.2016 B7, chapter V 4th notification

34 Mitteilung zu den Bekanntmachungen des Umweltbundesamtes vom 17. Juli 2014 (BAnz AT 05.08.2014 B11 Kapitel II Nummer 2.1) und vom 18. Februar 2016 (BAnz AT 14.03.2016 B7, Kapitel V 4. Mitteilung)

Die aktuelle Softwareversion für die Immissionsmesseinrichtung Air Pollution Monitor 2 (APM-2) für Schwebstaub PM_{10} und $PM_{2,5}$ der Firma Comde-Derenda GmbH lautet:

3.07.002

Die Messeinrichtung ist jetzt mit einer 500 ml Pufferflasche zur Kompensation von Druckschwankungen durch die Probenahmepumpe ausgestattet.

Die optionale Prüfmethode zur externen Überprüfung der Empfindlichkeit des Photometers durch Aufgabe von Propangas ist nicht mehr verfügbar.

Stellungnahme der TÜV Rheinland Energy GmbH vom 10. März 2017

Figure 70: Notification publication BAnz AT 31.07.2017 B12, chapter II 34th notification

1 Mitteilung zu den Bekanntmachungen des Umweltbundesamtes vom 17. Juli 2014 (BAnz AT 05.08.2014 B11, Kapitel III Nummer 2.1) und vom 13. Juli 2017 (BAnz AT 31.07.2017 B12, Kapitel II, 34. Mitteilung)

Die aktuelle Softwareversion für die Messeinrichtung Air Pollution Monitor 2 (APM-2) für Schwebstaub $PM_{2,5}$ und PM_{10} der Firma Comde-Derenda GmbH lautet:

3.08.001

Für die Eingangsschaltung wird zukünftig der Hardwarestand 5.4 verwendet.

Stellungnahme der TÜV Rheinland Energy GmbH vom 4. Mai 2020

Figure 71: Notification publication BAnz AT 31.07.2020 B10, chapter II 1st notification

10. Annexes

Annex 1 **Measured and calculated values**

- Appendix 1: Zero level and detection limit
- Appendix 2: Flow rate accuracy
- Appendix 3: Temperature dependence of the zero point and sensitivity
- Appendix 4: -
- Appendix 5: Measured values from the field test sites PM_ENVIRO_0011
- Appendix 6: Ambient condition at the field test locations

Annex 2: **Methods used for filter weighing**

Annex 3 **Operation manuals**

Appendix 1 **Zero level and Detection limit** **Page 1 of 2**

Manufacturer	Comde-Derenda GmbH				
Type	APM-2		Standards	ZP	Measured values with zero filter
Serial-No.	SN3 / SN4				

No.	Date	Measured values [µg/m³] SN3	Date	Measured values [µg/m³] SN4
1	18.04.2012	0,1	18.04.2012	0,0
2	19.04.2012	0,0	19.04.2012	0,0
3	20.04.2012	0,0	20.04.2012	0,0
4	21.04.2012	0,0	21.04.2012	0,1
5	22.04.2012	0,0	22.04.2012	0,1
6	23.04.2012	0,0	23.04.2012	0,0
7	24.04.2012	0,0	24.04.2012	0,1
8	25.04.2012	0,0	25.04.2012	0,1
9	26.04.2012	0,0	26.04.2012	0,0
10	27.04.2012	0,0	27.04.2012	0,0
11	28.04.2012	0,0	28.04.2012	0,1
12	29.04.2012	0,0	29.04.2012	0,1
13	30.04.2012	0,0	30.04.2012	0,0
14	01.05.2012	0,0	01.05.2012	0,0
15	02.05.2012	0,0	02.05.2012	0,0
	No. of values	15	No. of values	15
	Mean (Zero level)	0,004	Mean (Zero level)	0,044
	Standard deviation s_{x0}	0,014	Standard deviation s_{x0}	0,041
	Detection limit x	0,047	Detection limit x	0,135

$$s_{xo} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Appendix 1 **Zero level and Detection limit** **Page 2 of 2**

Manufacturer	Comde-Derenda GmbH		
Type	APM-2	Standards	ZP Measured values with zero filter
Serial-No.	SN3 / SN4		

No.	Date	Measured values [µg/m³] SN3	Date	Measured values [µg/m³] SN4
1	18.04.2012	0,0	18.04.2012	0,0
2	19.04.2012	0,0	19.04.2012	0,0
3	20.04.2012	0,0	20.04.2012	0,0
4	21.04.2012	0,0	21.04.2012	0,0
5	22.04.2012	0,0	22.04.2012	0,0
6	23.04.2012	0,0	23.04.2012	0,0
7	24.04.2012	0,0	24.04.2012	0,0
8	25.04.2012	0,0	25.04.2012	0,0
9	26.04.2012	0,0	26.04.2012	0,0
10	27.04.2012	0,0	27.04.2012	0,0
11	28.04.2012	0,0	28.04.2012	0,1
12	29.04.2012	0,0	29.04.2012	0,2
13	30.04.2012	0,0	30.04.2012	0,0
14	01.05.2012	0,0	01.05.2012	0,0
15	02.05.2012	0,0	02.05.2012	0,0
	No. of values	15	No. of values	15
	Mean (Zero level)	0,000	Mean (Zero level)	0,027
	Standard deviation s_{x0}	0,000	Standard deviation s_{x0}	0,046
	Detection limit x	0,000	Detection limit x	0,151

$$s_{xo} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Appendix 2 **Flow rate accuracy** **Page 1 of 1**

Manufacturer Comde-Derenda

Type APM-2

Serial-No. SN 20123 / SN 20133

Nominal flow rate [l/min] 3,3

		SN 20123			SN 20133		
Temperature 1	-15°C	No.	Date/Time	Measured value [l/min]	No.	Date/Time	Measured value [l/min]
		1	20.08.2021 05:25	3,356	1	20.08.2021 05:28	3,373
		2	20.08.2021 05:31	3,363	2	20.08.2021 05:34	3,354
		3	20.08.2021 05:37	3,349	3	20.08.2021 05:40	3,380
		4	20.08.2021 05:43	3,356	4	20.08.2021 05:46	3,370
		5	20.08.2021 05:49	3,359	5	20.08.2021 05:52	3,361
		6	20.08.2021 05:55	3,359	6	20.08.2021 05:58	3,369
		7	20.08.2021 06:01	3,356	7	20.08.2021 06:04	3,378
		8	20.08.2021 06:07	3,355	8	20.08.2021 06:10	3,351
		9	20.08.2021 06:13	3,355	9	20.08.2021 06:16	3,332
		10	20.08.2021 06:19	3,355	10	20.08.2021 06:22	3,304
			Mean	**3,356**		**Mean**	**3,357**

		SN 20123			SN 20133		
Temperature 2	40°C	No.	Date/Time	Measured value [l/min]	No.	Date/Time	Measured value [l/min]
		1	20.08.2021 12:25	3,257	1	20.08.2021 12:28	3,269
		2	20.08.2021 12:31	3,237	2	20.08.2021 12:34	3,270
		3	20.08.2021 12:37	3,247	3	20.08.2021 12:40	3,279
		4	20.08.2021 12:43	3,245	4	20.08.2021 12:46	3,270
		5	20.08.2021 12:49	3,245	5	20.08.2021 12:52	3,273
		6	20.08.2021 12:55	3,247	6	20.08.2021 12:58	3,268
		7	20.08.2021 13:01	3,235	7	20.08.2021 13:04	3,268
		8	20.08.2021 13:07	3,231	8	20.08.2021 13:10	3,271
		9	20.08.2021 13:13	3,233	9	20.08.2021 13:16	3,275
		10	20.08.2021 13:19	3,233	10	20.08.2021 13:22	3,272
			Mean	**3,241**		**Mean**	**3,272**

Appendix 3 Temperature dependence at zero point

Page 1 of 3

Manufacturer Comde-Derenda GmbH

System type APM-2

Serial-No. SN3 / SN4

SN3	No.	Temperature [°C]	Measurement 1 Reading [µg/m³]	Measurement 2 Reading [µg/m³]	Measurement 3 Reading [µg/m³]	Average from 3 measurements [µg/m³]	Average at 20 °C [µg/m³]
ZP	1	20	0.0	0.0	0.0	0.0	0.0
	2	-20	0.0	0.0	0.0	0.0	
	3	20	0.0	0.0	0.0	0.0	
	4	50	0.0	0.0	0.0	0.0	
	5	20	0.0	0.0	0.0	0.0	

SN4	No.	Temperature [°C]	Measurement 1 Reading [µg/m³]	Measurement 2 Reading [µg/m³]	Measurement 3 Reading [µg/m³]	Average from 3 measurements [µg/m³]	Average at 20 °C [µg/m³]
ZP	1	20	0.0	0.0	0.0	0.0	0.0
	2	-20	0.2	0.2	0.1	0.2	
	3	20	0.0	0.0	0.0	0.0	
	4	50	0.0	0.0	0.0	0.0	
	5	20	0.0	0.0	0.0	0.0	

Appendix 3 **Temperature dependence at zero point** **Page 2 of 3**

Manufacturer Comde-Derenda GmbH

System type APM-2

Serial-No. SN3 / SN4

SN3	No.	Temperature [°C]	Measurement 1 Reading [µg/m³]	Measurement 2 Reading [µg/m³]	Measurement 3 Reading [µg/m³]	Average from 3 measurements [µg/m³]	[µg/m³]	Average at 20 °C
ZP	1	20	0.0	0.0	0.0	0.0		0.0
	2	-20	0.0	0.0	0.0	0.0		
	3	20	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0		
SN4	**No.**	**Temperature [°C]**	**Reading [µg/m³]**	**Reading [µg/m³]**	**Reading [µg/m³]**	**Average from 3 measurements [µg/m³]**	**[µg/m³]**	**Average at 20 °C**
ZP	1	20	0.0	0.0	0.0	0.0		0.0
	2	-20	0.1	0.1	0.1	0.1		
	3	20	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0		

Appendix 3 Dependence of span on surrounding temperature Page 3 of 3

Manufacturer Comde-Derenda GmbH

Used test standard Propan

Type APM-2

Serial-No. SN3 / SN4

SN3	No.	Temperature [°C]	Measurement 1 Measured value [mV]	Measurement 2 Measured value [mV]	Meaurement 3 Measured value [mV]	Mean value of 3 measurements [mV]	Mean value at 20°C [mV]
Span	1	20	335,4	336,0	339,3	336,9	338,0
	2	-20	333,6	335,7	337,1	335,5	
	3	20	348,2	347,6	342,0	345,9	
	4	50	335,1	346,7	345,6	342,5	
	5	20	330,6	330,6	332,0	331,1	
SN4	**No.**	**Temperature [°C]**	**Measured value [mV]**	**Measured value [mV]**	**Measured value [mV]**	**Mean value of 3 measurements [mV]**	**Mean value at 20°C [mV]**
Span	1	20	335,8	335,0	342,2	337,7	336,3
	2	-20	333,8	333,3	331,0	332,7	
	3	20	333,0	332,6	339,5	335,0	
	4	50	334,9	342,2	342,3	339,8	
	5	20	331,8	339,0	338,1	336,3	

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 1 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
1	11/19/2012										Zero point	Cologne, winter
2	11/20/2012										Zero point	
3	11/21/2012										Zero point	
4	11/22/2012										Audits	
5	11/23/2012	15.3	15.1	19.6	19.6	77.8	14.1	15.3	17.0	19.2		
6	11/24/2012						12.5	13.6	15.1	17.2		
7	11/25/2012	5.1	5.8	10.8	10.4	51.1	4.0	4.1	5.8	7.1		
8	11/26/2012	6.1	6.9	11.0	11.6	57.4	6.2	6.8	8.1	9.5		
9	11/27/2012	10.9	11.5	18.5	17.6	62.0	10.3	11.2	12.6	14.6		
10	11/28/2012	23.3	23.5	29.0	29.1	80.5	20.5	21.7	23.9	26.3		
11	11/29/2012	9.0	9.3	14.2	14.4	64.0	9.4	9.9	11.0	12.3		
12	11/30/2012	17.8	19.3	24.5	24.3	76.0	18.1	19.7	20.6	23.6		
13	12/1/2012						13.2	14.1	14.8	16.3		
14	12/2/2012	10.0	11.0	14.8	14.6	71.2	10.5	11.0	12.1	13.4		
15	12/3/2012	8.8	9.0	14.1	14.4	62.2	9.4	10.0	11.3	13.0		
16	12/4/2012	8.3	7.6	11.6	11.6	68.3	8.1	8.4	9.6	10.6		
17	12/5/2012	8.7	8.5	12.1	12.5	69.8	8.9	9.3	10.3	11.5		
18	12/6/2012	9.5	10.3	16.5	16.1	60.7	10.6	11.6	12.2	14.4		
19	12/7/2012	13.0	12.8	15.4	15.4	83.8	13.6	14.6	15.8	17.6		
20	12/8/2012						31.5	33.5	34.5	38.0		
21	12/9/2012	5.5	5.8	10.1	8.9	59.5	6.2	6.4	7.9	8.9		
22	12/10/2012	10.6	11.2	14.5	13.5	77.5	11.2	11.7	12.7	14.1		
23	12/11/2012	17.3	17.7	23.6	22.8	75.4	16.3	17.2	18.5	20.7		
24	12/12/2012	18.2	18.5	24.7	24.2	75.1	16.1	17.2	18.0	20.5		
25	12/13/2012	23.4	23.7	29.3	28.2	82.0	22.4	24.4	24.2	27.8		
26	12/14/2012	7.3	6.7	8.9	8.8	79.5	7.6	8.1	8.6	9.4		
27	12/15/2012						3.8	4.1	5.1	5.9		
28	12/16/2012	5.4	5.9	9.7	9.5	58.9	6.2	6.6	7.9	9.0		
29	12/17/2012	6.8	7.2	13.7	13.4	51.9	7.1	7.8	9.6	11.3		
30	12/18/2012	12.9	13.3	20.1	20.5	64.5	13.4	14.4	16.3	18.7		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 2 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
31	12/19/2012	13.4	13.3	18.3	18.0	73.7	13.1	13.6	14.8	16.4		Cologne, winter
32	12/20/2012	11.6	11.6	14.1	13.6	83.8	11.7	12.1	13.0	14.0		
33	12/21/2012	11.7	10.8	18.1	17.8	62.7	13.2	14.2	16.1	18.1		
34	12/22/2012						4.0	4.2	5.3	5.8		
35	12/23/2012						3.5	3.8	4.9	5.7		
36	12/24/2012						6.3	7.1	8.7	10.1		
37	12/25/2012						1.8	2.2	2.8	3.5		
38	12/26/2012						3.2	3.5	5.6	6.5		
39	12/27/2012						8.1	8.8	12.7	14.6		
40	12/28/2012						4.8	5.2	6.1	6.5		
41	12/29/2012						3.6	4.0	4.8	5.3		
42	12/30/2012						3.3	3.6	5.9	6.5		
43	12/31/2012										Power loss	
44	1/1/2013										Power loss	
45	1/2/2013	9.7	9.3	16.1	15.0	60.9	9.6	10.1	11.9	13.1		
46	1/3/2013	11.9	13.1	19.4	18.6	65.6	12.1	12.8	15.9	17.2		
47	1/4/2013	9.5	9.9	13.8	13.0	72.5	9.5	9.9	11.6	12.2		
48	1/5/2013						14.3	15.2	17.4	19.0		
49	1/6/2013	26.7	26.6	37.5	37.4	71.3	23.4	25.2	28.9	31.9		
50	1/7/2013	17.6	19.4	24.6	25.0	74.5	15.8	16.8	18.7	20.5		
51	1/8/2013	13.6	14.7	19.6	20.1	71.4	13.2	13.9	15.5	17.1		
52	1/9/2013	11.6	13.3	18.9	19.7	64.5	11.8	12.3	14.6	16.5		
53	1/10/2013	13.6	14.7	21.9	21.5	65.1	12.8	13.6	15.8	17.9		
54	1/11/2013										Zero point	
55	1/12/2013										Zero point	
56	1/13/2013										Zero point	
57	1/14/2013	24.9	24.8	28.4	29.4	86.0	22.7	23.8	25.5	27.9		
58	1/15/2013	33.4	33.8	36.3	37.1	91.5	31.2	32.6	34.7	37.9		
59	1/16/2013	58.5	58.4	63.7	63.3	92.0	44.8	46.8	52.4	57.1		
60	1/17/2013	55.4	56.2	60.2	59.8	93.0	43.3	45.1	49.9	54.1		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 3 of 22**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
61	1/18/2013	17.4	17.5	19.0	18.6	92.7	15.7	16.2	17.2	18.7		Cologne, winter
62	1/19/2013	21.1	21.1	22.6	23.0	92.4	20.0	20.7	22.1	24.2		
63	1/20/2013	29.7	30.0	30.9	31.2	96.2	28.4	29.3	31.9	34.5		
64	1/21/2013	44.9	42.8	45.4	44.8	97.2	40.1	41.4	44.1	47.4		
65	1/22/2013	53.5	54.9			90.5	50.6	52.4	56.0	59.4	Outlier Ref PM10 - not discarded	
66	1/23/2013	62.1	63.2	69.2	68.8	90.8	58.3	60.2	64.8	67.7		
67	1/24/2013	23.6	24.5	27.8	28.1	86.1	20.3	20.9	23.1	23.6		
68	1/25/2013	19.6	19.3	21.2	20.4	93.3	16.3	16.9	18.4	18.9		
69	1/26/2013	26.6	25.9	28.3	28.4	92.5	23.3	23.9	26.0	27.0		
70	1/27/2013	9.1	9.2	15.0	15.0	61.1	8.3	8.4	10.8	12.3		
71	1/28/2013	5.7	5.9	8.9	7.9	68.6	5.3	5.6	6.7	7.6		
72	1/29/2013	3.4	3.9	5.5	4.5	72.0	3.6	4.1	4.6	5.1		
73	1/30/2013	6.4	6.8	15.2	14.8	43.8	3.5	4.1	7.4	8.9		
74	1/31/2013	8.0	8.5	20.3	19.2	41.6	4.8	5.5	9.8	12.2		
75	2/1/2013	9.2	9.4	11.9	10.9	81.4	8.8	9.2	10.9	11.9		
76	2/2/2013						4.3	4.5	7.8	8.8		
77	2/3/2013						7.9	8.1	9.7	10.4		
78	2/4/2013						5.4	5.9	9.2	10.8		
79	2/5/2013										Zero point	
80	2/6/2013										Zero point	
81	2/27/2013										Zero point	Bonn, winter
82	2/28/2013										Zero point	
83	3/1/2013	24.9	23.0	36.3	36.7	65.6	20.8	21.8	27.0	30.0		
84	3/2/2013						25.1	26.1	31.7	35.4		
85	3/3/2013	22.1	23.2	29.3	29.8	76.6	19.1	20.0	22.7	24.9		
86	3/4/2013	19.6	20.5	28.2	28.7	70.2	16.3	17.4	20.3	22.9		
87	3/5/2013	28.4	27.7	40.2	39.9	70.1	23.9	25.6	29.4	32.7		
88	3/6/2013	25.8	24.5	39.3	39.7	63.8	21.1	22.6	26.8	30.3		
89	3/7/2013	28.0	28.3	39.5	39.5	71.2	25.6	27.6	31.5	35.1		
90	3/8/2013	28.8	27.0	35.4	34.8	79.5	27.0	28.8	32.0	34.8		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 4 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
91	3/9/2013						9.9	10.7	12.3	13.5		Bonn, winter
92	3/10/2013	21.8	22.0	23.1	22.3	96.5	25.1	26.1	27.4	29.6		
93	3/11/2013	27.6	28.1	31.2	30.3	90.6	30.7	32.0	33.5	36.5		
94	3/12/2013	15.6	15.6	17.8	17.7	87.9	16.1	17.1	18.0	20.0		
95	3/13/2013	36.7	36.7	50.8	50.0	72.9	31.8	33.5	36.7	40.4		
96	3/14/2013	19.6	19.2	27.5	27.6	70.3	16.9	18.0	20.4	23.0		
97	3/15/2013	22.0	21.5	31.7	31.7	68.7	18.8	20.0	22.7	25.0		
98	3/16/2013						12.0	12.4	14.6	16.0		
99	3/17/2013	7.0	7.4	11.0	10.5	67.2	9.6	10.1	11.0	12.0		
100	3/18/2013	7.7	8.2	17.4	17.2	45.9	8.3	8.9	10.5	11.8		
101	3/19/2013	9.5	9.9	17.1	16.8	57.5	10.5	11.0	12.4	13.6		
102	3/20/2013	21.3	20.9	25.2	24.5	84.7	23.5	24.4	26.5	28.4		
103	3/21/2013	37.5	36.6	46.3	45.9	80.5	35.9	37.7	40.7	44.0		
104	3/22/2013	21.4	21.6	26.0	26.3	82.2	21.5	22.9	24.2	26.6		
105	3/23/2013						23.1	24.4	25.4	27.9		
106	3/24/2013	15.1	15.9	19.7	18.8	80.6	15.3	16.2	17.1	19.2		
107	3/25/2013	20.1	20.6	26.0	25.6	78.9	20.8	22.2	23.7	26.7		
108	3/26/2013	15.7	15.3	21.1	20.4	74.7	14.7	15.7	16.3	19.1		
109	3/27/2013	26.6	25.9	33.3	32.8	79.5	25.1	27.0	28.8	32.4		
110	3/28/2013						46.0	49.0	51.4	56.5		
111	3/29/2013	71.1	69.8	76.5	76.3	92.2	63.6	67.2	70.5	76.8		
112	3/30/2013										Zero point	
113	3/31/2013										Zero point	
114	4/1/2013										Zero point	
115	4/2/2013	20.2	20.2	24.7	25.2	81.0	21.4	22.8	23.9	26.5		
116	4/3/2013	27.2	26.5	31.4	30.8	86.3	28.2	29.8	31.0	34.1		
117	4/4/2013	29.5	29.1	33.5	33.2	88.0	29.0	30.7	32.4	35.1		
118	4/5/2013	25.8	25.4	30.8	30.0	84.1	22.7	24.1	26.0	28.4		
119	4/6/2013						23.0	24.3	25.9	28.3		
120	4/7/2013	23.0	22.8	30.9	30.2	74.9	21.4	23.2	24.6	27.7		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 5 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
121	4/8/2013	26.3	25.1	31.7	31.7	81.0	21.8	23.4	25.7	28.7		Bonn, winter
122	4/9/2013	16.5	16.5	21.6	21.0	77.4	14.6	15.5	17.0	18.6		
123	4/10/2013	12.2	12.2	17.9	17.8	68.4	10.6	11.3	12.8	13.9		
124	4/11/2013	9.4	8.8	15.9	15.7	57.4	7.1	7.6	9.4	9.8		
125	4/12/2013	6.2	6.3	10.4	10.4	60.4	4.6	4.9	6.6	7.1		
126	4/13/2013						5.6	5.9	7.8	8.2		
127	4/14/2013	7.2	6.9	11.9	11.1	61.4	5.0	5.4	7.0	7.6		
128	4/15/2013	18.5	16.8	31.2	30.2	57.3	14.3	15.2	20.6	22.3		
129	4/16/2013	12.7	11.2	21.1	20.7	57.2	10.1	10.5	13.6	14.4		
130	4/17/2013	9.9	9.8	19.5	19.7	50.2	6.6	6.8	10.1	10.8		
131	4/18/2013	9.4	8.7	21.4	21.5	42.2	5.6	5.9	9.9	10.8		
132	4/19/2013	10.3	10.3	21.0	20.8	49.4	8.4	8.8	12.0	12.9		
133	4/20/2013						9.6	10.1	12.7	13.8		
134	4/21/2013	24.4	23.0	36.7	37.6	63.8	16.9	18.1	23.3	25.6		
135	4/22/2013	31.0	29.4	44.7	43.9	68.3	24.1	25.7	30.8	33.9		
136	4/23/2013	11.0	10.4	18.2	18.8	57.6	8.5	8.9	11.4	12.1		
137	4/24/2013	14.3	12.7	24.2	24.4	55.6	11.0	11.7	15.0	16.3		
138	4/25/2013	13.8	12.1	23.3	23.6	55.3	10.4	10.9	14.5	15.8		
139	4/26/2013										Zero point	
140	4/27/2013										Zero point	
141	4/28/2013										Zero point	
142	4/29/2013	14.3	12.9	20.6	21.4	64.9	10.7	11.1	14.0	15.0		
143	4/30/2013						13.0	13.8	17.1	18.5		
144	5/1/2013	16.9	18.2	21.4	22.2	80.7	15.9	16.9	19.3	20.8		
145	5/2/2013						16.0	16.9	20.0	21.7		
146	5/3/2013	23.2	23.4	33.7	34.4	68.5	21.4	22.7	27.5	30.1		
147	5/4/2013	20.2	19.7	30.1	30.6	65.7	16.8	17.7	21.5	23.3		
148	5/5/2013	9.6	9.3	14.0	14.8	65.4	7.5	8.0	9.6	10.2		
149	5/6/2013	14.5	15.0	23.3	22.9	63.9	12.9	13.7	16.5	18.1		
150	5/15/2013										Zero point	Cologne, summer

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 6 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
151	5/16/2013										Zero point	Cologne, summer
152	5/17/2013	16.7	17.5	19.9	20.8	84.1	13.3	14.1	17.0	17.7		
153	5/18/2013						13.0	13.7	15.2	16.6		
154	5/19/2013						15.7	16.6	19.7	21.1		
155	5/20/2013	9.1	10.0	11.6	12.5	79.2	8.6	9.0	11.1	11.7		
156	5/21/2013	5.8	6.3	8.0	8.9	72.0	6.0	6.4	7.6	8.0		
157	5/22/2013	6.5	6.9	13.0	13.1	51.3	6.4	7.1	9.8	10.6		
158	5/23/2013	8.6	9.3	11.6	12.7	73.8	8.1	8.8	10.3	11.1		
159	5/24/2013	8.2	9.3	12.9	13.3	66.8	8.5		10.1		SN4 no data recording	
160	5/25/2013						9.8		12.4		cause	
161	5/26/2013	9.5	10.0	19.5	18.9	50.8	9.1		13.1		unknown	
162	5/27/2013	16.8	16.8	24.3	23.8	69.9	16.1	17.6	19.7	20.9		
163	5/28/2013	8.4	8.3	12.5	12.5	66.5	8.5	8.8	10.1	10.7		
164	5/29/2013						7.4	7.7	9.2	9.7		
165	5/30/2013						13.5	14.3	16.4	17.3		
166	5/31/2013						13.5	14.3	16.9	18.5		
167	6/1/2013						11.7	12.4	15.6	17.1		
168	6/2/2013	5.5	6.1	13.0	12.8	45.0	6.1	6.4	8.3	9.1		
169	6/3/2013	8.5	8.5	16.5	16.9	50.9	7.8	8.4	10.5	11.8		
170	6/4/2013	11.8	10.8	21.6	21.2	53.0	10.4	10.6	13.5	14.5		
171	6/5/2013	9.3	9.3	15.9	15.1	60.1	8.7	9.0	10.8	11.6		
172	6/6/2013	11.6	11.3	17.4	18.2	64.1	9.8	9.9	12.0	12.7		
173	6/7/2013	15.3	15.4	23.5	23.0	66.1	13.9	14.0	17.1	18.1		
174	6/8/2013						13.6	14.4	17.4	19.0		
175	6/9/2013	12.6	12.1	20.5	18.7	63.0	12.9	13.5	15.9	17.2		
176	6/10/2013	16.6	16.7	31.1	29.5	55.0	16.7	17.9	22.2	24.6		
177	6/11/2013	14.4	14.3	25.6	24.8	56.8	15.9	16.7	20.1	22.2		
178	6/12/2013	6.6	5.8	15.2	14.1	42.5	6.3	6.8	10.7	10.7		
179	6/13/2013	5.3	4.6	11.2	10.5	45.5	4.4	4.9	6.8	7.7		
180	6/14/2013	6.6	7.1	12.6	12.3	55.0	5.7	6.3	7.5	8.8		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 7 of 22**

Manufacturer Comde-Derenda

Type of instrument APM-2

Serial-No.. SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
181	6/15/2013	5.7	5.8	12.7	12.9	45.0	4.9	5.5	6.9	8.2		Cologne, summer
182	6/16/2013	8.1	8.0	18.3	17.6	44.9	6.8	7.5	9.3	10.8		
183	6/17/2013	13.3	13.3	23.3	22.1	58.4	11.5	12.3	14.8	16.7		
184	6/18/2013	16.9	16.7	26.9	26.1	63.5	16.6	17.7	21.4	24.1		
185	6/19/2013			46.8	45.1		33.0	35.7	40.6	45.6	Ref. PM2,5 - stability criteria	
186	6/20/2013	7.9	8.1	14.2	13.2	58.6	11.5	12.5	14.9	16.7	EN 14907 not met	
187	6/21/2013	4.7	4.9	8.5	8.3	57.5	5.3	5.7	6.6	7.4		
188	6/22/2013	4.0	4.7	5.3	5.1	83.9	3.3	3.7	4.2	4.8		
189	6/23/2013	4.9	5.5	7.7	7.6	68.6	3.9	4.4	5.5	6.4		
190	6/24/2013	9.8	11.1	16.2	15.7	65.3	9.4	9.9	12.0	13.3		
191	6/25/2013	6.8	7.4	11.2	12.3	60.5	6.1	6.8	8.3	9.4		
192	6/26/2013	9.6	10.0	14.4	13.7	69.8	8.9	9.3	10.9	11.6		
193	6/27/2013	9.8	9.8	14.4	13.7	69.7	9.3	10.0	11.6	12.7		
194	6/28/2013	9.7	10.5	12.3	13.2	79.1	10.6	11.7	13.1	14.2		
195	6/29/2013										Zero point	
196	6/30/2013										Zero point	
197	7/1/2013	8.9	10.6	17.1	16.7	57.8	9.6	10.1	12.0	13.3		
198	7/2/2013	7.8	8.6	13.9	13.1	60.8	8.7	9.0	10.3	11.0		
199	7/3/2013	5.6	6.9	11.8	11.8	53.2	6.0	6.5	8.3	9.3		
200	7/4/2013	7.8	9.2	15.6	14.8	56.1	9.2	9.6	11.1	12.1		
201	7/5/2013			23.8	23.1		15.0	16.0	18.6	20.6	Outlier Ref. PM2,5	
202	7/6/2013	13.1	14.5	18.1	17.6	77.4	14.0	14.3	16.3	17.3		
203	7/7/2013	11.3	13.1	16.5	16.4	74.2	10.8	11.0	12.3	13.1		
204	7/8/2013	12.3	13.2	18.1	18.2	70.2	10.7	11.5	12.9	14.3		
205	7/9/2013	13.6	14.7	23.5	23.4	60.3	11.2	12.1	14.9	16.8		
206	7/10/2013	10.1	9.6	18.4	17.8	54.4	8.5	8.7	11.5	12.5		
207	7/11/2013	17.5	17.9				17.2	18.6	22.1	24.5	Outlier Ref. PM10	
208	7/12/2013	16.8	16.8	28.9	26.8	60.3	16.0	17.1	20.5	22.9		
209	7/13/2013	19.5	19.5	26.6	24.9	75.9	18.3	19.5	21.5	23.4		
210	7/14/2013						17.0	18.2	20.3	22.6		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 8 of 22**

Manufacturer	Comde-Derenda	
Type of instrument	APM-2	PM10 and PM2,5 Measured values in µg/m³ (AMB)
Serial-No..	SN 3 / SN 4	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
211	7/30/2013	6.5	6.6	13.7	13.1	49.0	4.9	4.7	7.6	7.7		Rodenkirchen, summer
212	7/31/2013	6.6	6.6	12.0	12.3	54.1	6.0	5.4	8.0	7.7		
213	8/1/2013	8.5	8.6	14.4	15.2	57.7	7.5	6.8	9.6	9.4		
214	8/2/2013	12.0	12.9	20.8	22.9	56.9	10.3	9.9	13.4	13.4		
215	8/3/2013						7.9	7.4	9.9	9.8		
216	8/4/2013	7.1	9.2	14.1	15.0	55.7	7.1	6.6	9.0	8.8		
217	8/5/2013	10.3	10.4	20.2	22.3	48.6	8.8	7.9	12.1	11.6		
218	8/6/2013	9.2	8.7	18.5	19.0	47.6	8.5	7.9	11.2	10.9		
219	8/7/2013	8.8	8.9	15.0	15.1	59.0	9.1	8.7	11.5	11.3		
220	8/8/2013	11.1	10.5	18.8	18.5	58.1	10.4	10.5	12.8	13.1		
221	8/9/2013	10.7	10.6	18.7	19.1	56.3	10.1	10.1	12.9	13.0		
222	8/10/2013						8.1	8.2	10.8	11.1		
223	8/11/2013	4.9	4.9	12.6	12.3	39.5	5.7	5.7	7.7	7.7		
224	8/12/2013	8.0	7.7	18.6	17.6	43.4	7.1	7.3	9.8	10.0		
225	8/13/2013	7.3	6.8	16.5	17.1	41.7	6.9	6.7	9.7	9.8		
226	8/14/2013	9.6	9.0	23.1	24.9	38.8	8.2	7.9	12.1	12.4		
227	8/15/2013	8.5	8.7	19.2	18.6	45.6	8.3	8.2	11.3	11.7		
228	8/16/2013	11.5	11.5	22.2	22.5	51.4	9.9	9.4	13.2	13.3		
229	8/17/2013						6.6	5.7	8.5	7.9		
230	8/18/2013	4.6	5.0	10.7	10.1	46.1	4.5	4.4	6.9	6.9		
231	8/19/2013	6.4	7.1	14.1	14.0	48.3	6.7	6.6	9.0	9.2		
232	8/20/2013	10.7	11.4	19.5	18.9	57.6	11.0	10.6	13.4	13.5		
233	8/21/2013	12.0	12.4	18.8	18.0	66.4	13.1	12.6	15.5	15.6		
234	8/22/2013	15.6	16.0	25.4	25.7	61.9	16.4	16.0	20.3	20.4		
235	8/23/2013	13.6	14.5	22.9	23.0	61.3	15.2	14.8	18.5	18.6		
236	8/24/2013						19.7	19.2	24.9	24.7		
237	8/25/2013	23.4	23.6	32.7	31.0	73.6	20.3	20.4	28.6	29.6		
238	8/26/2013	10.8	10.9	19.2	19.3	56.4	10.6	10.6	13.4	13.9		
239	8/27/2013	12.7	12.5	22.0	20.8	58.8	12.6	12.4	15.7	16.4		
240	8/28/2013	14.1	13.5	22.9	23.5	59.5	15.9	15.7	19.9	20.8		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 9 of 22**

Manufacturer	Comde-Derenda	PM10 and PM2,5
Type of instrument	APM-2	Measured values in µg/m³ (AMB)
Serial-No..	SN 3 / SN 4	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
241	8/29/2013	16.3	17.1	26.7	27.2	61.9	18.9	18.4	23.3	23.8		Rodenkirchen, summer
242	8/30/2013	16.6	16.2	27.5	29.5	57.7	17.8	17.4	21.9	22.6		
243	8/31/2013						7.9	8.0	11.5	12.5		
244	9/1/2013	9.7	7.5	18.9	19.6	44.5	6.1	6.2	9.0	10.0		
245	9/2/2013	10.1	9.5	21.2	23.1	44.3	8.4	8.4	11.6	13.0		
246	9/3/2013	13.8	12.3	23.1	24.4	55.0	12.4	12.2	15.7	16.6		
247	9/4/2013	8.9	8.5	14.5	15.3	58.2	9.6	9.2	11.2	11.3		
248	9/5/2013	11.2	10.2	16.2	19.0	60.8	9.5	8.6	11.4	11.1		
249	9/6/2013	19.3	18.5	30.7	33.2	59.1	17.7	16.9	22.0	22.6		
250	9/7/2013	16.6	15.5	24.2	24.9	65.6	14.5	14.3	18.4	19.2		
251	9/8/2013						12.1	13.5	14.6	16.7		
252	9/9/2013	6.7	6.8	11.1	11.7	59.3	5.7	6.7	7.3	8.4		
253	9/10/2013	6.5	6.3	10.9	11.1	58.3	6.1	6.4	7.5	7.8		
254	9/11/2013						10.0	10.0	12.1	12.7		
255	9/12/2013	15.1	13.6	23.0	24.0	60.9	11.8	11.7	14.3	15.3		
256	9/13/2013	8.3	8.4	14.4	14.5	57.6	7.9	7.5	9.4	9.5		
257	9/14/2013						4.1	4.0	5.9	6.3		
258	9/15/2013	6.9	6.8	14.7	15.3	45.5	5.4	5.0	7.3	7.4		
259	9/16/2013	6.6	6.6	14.5	14.6	45.4	4.5	4.3	6.8	7.0		
260	9/17/2013	6.1	6.2	12.4	12.8	48.8	4.6	4.4	6.7	7.0		
261	9/18/2013	13.5	12.4	21.7	22.5	58.4	10.3	10.0	12.8	13.3		
262	9/19/2013	8.3	8.8	16.4	17.8	50.0	6.9	6.6	9.1	9.3		
263	9/20/2013	9.4	9.6	20.7	20.7	45.9	8.2	8.1	10.6	11.3		
264	9/21/2013										Zero point	
265	1/13/2014	12.9	13.6	18.2	18.9	71.5	13.3	12.6	17.2	15.7		Cologne, winter 2014 validation campaign
266	1/14/2014	10.8	11.2	15.5	15.0	72.3	12.5	11.8	15.0	14.1		
267	1/15/2014	5.5	5.7	8.0	8.7	66.9	9.1	7.9	10.4	9.0		
268	1/16/2014	3.1	3.6	6.4	7.1	50.0	6.8	5.5	9.6	7.8		
269	1/17/2014	4.6	5.2	8.9	8.6	56.0	7.3	5.8	9.4	8.2		
270	1/18/2014						12.3	11.5	13.8	12.9		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 10 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
271	1/19/2014	14.5	14.2	16.8	17.3	84.2	17.3	15.7	19.6	17.7		Cologne, winter 2014 validation campaign
272	1/20/2014	15.6	15.3	18.9	19.9	79.7	18.4	16.9	22.9	20.4		
273	1/21/2014	24.2	24.6	30.8	31.1	78.7	22.9	22.5	30.1	27.8		
274	1/22/2014	18.4	18.8	23.0	23.5	80.0	19.6	18.8	24.5	22.2		
275	1/23/2014	10.9	11.4	15.2	16.3	70.9	12.1	11.8	15.7	16.3		
276	1/24/2014	18.7	19.3	28.1	28.9	66.6	19.7	19.7	27.5	28.9		
277	1/25/2014						11.2	10.3	15.1	15.1		
278	1/26/2014	4.4	4.4	11.4	12.0	37.8	6.0	5.5	11.5	11.6		
279	1/27/2014	2.9	3.5	6.7	7.1	46.7	5.8	4.3	8.1	7.3		
280	1/28/2014	6.3	6.7	10.9	10.6	60.4	8.3	7.7	10.6	10.6		
281	1/29/2014	16.0	16.6	19.2	19.7	83.8	16.3	16.2	19.3	20.1		
282	1/30/2014	35.7	36.0	41.6	42.3	85.4	36.7	36.9	43.3	45.1		
283	1/31/2014	29.8	29.0	35.0	34.9	84.1	29.4	29.5	35.0	36.5		
284	2/1/2014						8.5	7.0	9.7	8.7		
285	2/2/2014	8.6	7.9	18.1	17.5	46.3	9.6	9.1	17.6	18.0		
286	2/3/2014	18.7	18.0	22.0	21.5	84.5	18.7	18.7	22.2	23.2		
287	2/4/2014						13.8	13.3	17.3	17.3		
288	2/5/2014	4.4	3.4	8.0	8.2	48.6	6.5	5.8	8.9	8.7		
289	2/6/2014	2.9	3.1	9.8	9.1	32.0	5.6	3.8	9.0	8.1		
290	2/7/2014										Zero point	
291	2/8/2014										Zero point	
292	2/9/2014										Zero point	
293	2/10/2014	9.8	8.8	12.9	13.1	71.4	10.9	10.2	13.6	13.6		
294	2/11/2014	4.5	3.8	9.6	8.0	47.6	6.1	5.0	8.3	7.9		
295	2/12/2014	4.5	3.8	8.2	7.9	51.3	5.7	4.3	9.0	8.1		
296	2/13/2014	4.8	4.3	10.3	10.0	44.8	5.7	4.9	9.4	9.2		
297	2/14/2014						4.8	4.5	7.3	7.5		
298	2/15/2014						4.9	3.4	7.5	6.9		
299	2/16/2014	5.2	4.9	8.8	9.2	56.2	6.5	5.7	9.3	9.1		
300	2/17/2014	8.0	7.0	12.7	12.5	59.7	9.1	8.6	12.5	12.3		

Annex 5 **Measured values from the field test sites, related to ambient conditions** **Page 11 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (AMB)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
301	2/18/2014	14.5	13.8	19.8	19.6	71.7	14.9	14.0	19.9	19.7		Cologne, winter 2014 validation campaign
302	2/19/2014	9.6	8.9	13.2	14.2	67.4	11.1	10.6	13.6	13.7		
303	2/20/2014	4.3	4.4	6.6	6.2	67.5	6.7	6.4	8.0	8.1		
304	2/21/2014	4.8	5.0	7.8	7.8	63.2	7.3	6.6	9.7	9.1		
305	2/22/2014	4.2	5.0	4.7	5.4	90.9	7.0	5.8	7.8	6.9		
306	2/23/2014	5.6	6.6	7.1	7.0	87.0	7.7	7.4	8.5	8.6		
307	2/24/2014	9.3	9.3	13.7	12.7	70.6	9.5	8.7	12.6	12.5		
308	2/25/2014	9.0	8.6	12.8	12.1	70.5	9.1	8.9	11.6	12.0		
309	2/26/2014	11.3	11.3	19.4	17.3	61.7	12.0	11.0	17.8	17.4		
310	2/27/2014	7.5	8.2	12.0	10.4	70.3	8.6	8.1	11.9	12.1		
311	2/28/2014	7.7	7.3	10.3	9.9	74.3	8.3	7.7	10.5	10.4		
312	3/1/2014	12.1	12.4	14.7	14.7	83.5	13.2	12.5	15.7	15.8		
313	3/2/2014	16.8	16.9	18.3	19.6	88.6	16.0	16.1	18.7	19.5		
314	3/3/2014	6.8	6.9	9.9	11.8	63.0	9.1	8.5	11.2	11.3		
315	3/4/2014	19.5	17.6	25.6	24.3	74.4	19.3	18.8	24.8	25.2		
316	3/5/2014	30.8	31.2	43.5	43.7	71.0	28.2	27.7	41.4	42.0		
317	3/6/2014	36.5	35.6	44.2	43.5	82.2	29.4	29.5	38.1	39.7		
318	3/7/2014	43.6	44.0	56.7	55.5	78.0	37.1	38.4	48.9	50.9		
319	3/8/2014	42.8	41.4	49.7	50.0	84.4	34.1	33.8	42.7	44.1		
320	3/9/2014	23.2	21.4	28.1	27.2	80.7	19.2	18.7	26.4	26.4		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 12 of 22**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
1	11/19/2012	-	-						Zero point	Cologne, winter
2	11/20/2012	-	-						Zero point	
3	11/21/2012	-	-						Zero point	
4	11/22/2012	-	-						Audits	
5	11/23/2012	-	-	20.2	20.3	-	17.6	19.9		
6	11/24/2012	-	-			-	15.9	18.1		
7	11/25/2012	-	-	11.2	10.9	-	6.1	7.4		
8	11/26/2012	-	-	11.5	12.2	-	8.5	10.0		
9	11/27/2012	-	-	19.2	18.4	-	13.2	15.3		
10	11/28/2012	-	-	30.0	30.2	-	24.9	27.5		
11	11/29/2012	-	-	14.6	14.8	-	11.3	12.8		
12	11/30/2012	-	-	24.7	24.7	-	21.0	24.1		
13	12/1/2012	-	-			-	15.1	16.7		
14	12/2/2012	-	-	15.1	15.0	-	12.3	13.7		
15	12/3/2012	-	-	14.5	14.8	-	11.6	13.5		
16	12/4/2012	-	-	12.0	12.1	-	10.0	11.1		
17	12/5/2012	-	-	12.3	12.8	-	10.5	11.8		
18	12/6/2012	-	-	16.7	16.3	-	12.4	14.6		
19	12/7/2012	-	-	15.4	15.5	-	15.9	17.7		
20	12/8/2012	-	-			-	34.1	37.6		
21	12/9/2012	-	-	10.4	9.1	-	8.1	9.2		
22	12/10/2012	-	-	14.6	13.7	-	12.9	14.3		
23	12/11/2012	-	-	23.4	22.7	-	18.4	20.7		
24	12/12/2012	-	-	24.6	24.3	-	18.1	20.6		
25	12/13/2012	-	-	29.7	28.7	-	24.7	28.4		
26	12/14/2012	-	-	9.3	9.2	-	9.1	10.0		
27	12/15/2012	-	-			-	5.4	6.2		
28	12/16/2012	-	-	10.1	9.9	-	8.3	9.4		
29	12/17/2012	-	-	14.2	13.9	-	10.0	11.9		
30	12/18/2012	-	-	20.5	21.0	-	16.8	19.2		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 13 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
31	12/19/2012	-	-	18.5	18.3	-	15.1	16.7		Cologne, winter
32	12/20/2012	-	-	14.3	13.9	-	13.3	14.3		
33	12/21/2012	-	-	18.5	18.4	-	16.6	18.7		
34	12/22/2012	-	-			-	5.5	6.0		
35	12/23/2012	-	-			-	5.2	6.0		
36	12/24/2012	-	-			-	9.2	10.8		
37	12/25/2012	-	-			-	2.9	3.7		
38	12/26/2012	-	-			-	5.9	6.8		
39	12/27/2012	-	-			-	13.2	15.2		
40	12/28/2012	-	-			-	6.3	6.8		
41	12/29/2012	-	-			-	5.0	5.5		
42	12/30/2012	-	-			-	6.1	6.8		
43	12/31/2012	-	-			-			Power loss	
44	1/1/2013	-	-			-			Power loss	
45	1/2/2013	-	-	16.4	15.3	-	12.2	13.4		
46	1/3/2013	-	-	19.8	19.1	-	16.3	17.7		
47	1/4/2013	-	-	14.0	13.3	-	11.8	12.5		
48	1/5/2013	-	-			-	17.7	19.4		
49	1/6/2013	-	-	38.2	38.4	-	29.6	32.7		
50	1/7/2013	-	-	25.0	25.7	-	19.1	21.1		
51	1/8/2013	-	-	20.0	20.6	-	15.9	17.5		
52	1/9/2013	-	-	19.2	20.2	-	15.0	16.9		
53	1/10/2013	-	-	22.3	22.0	-	16.2	18.4		
54	1/11/2013	-	-			-			Zero point	
55	1/12/2013	-	-			-			Zero point	
56	1/13/2013	-	-			-			Zero point	
57	1/14/2013	-	-	28.4	29.5	-	25.6	28.0		
58	1/15/2013	-	-	36.5	37.6	-	35.1	38.4		
59	1/16/2013	-	-	63.6	63.6	-	52.5	57.4		
60	1/17/2013	-	-	59.9	59.9	-	49.9	54.2		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 14 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
61	1/18/2013	-	-	19.2	18.9	-	17.5	19.0		Cologne, winter
62	1/19/2013	-	-	22.9	23.4	-	22.5	24.6		
63	1/20/2013	-	-	31.5	32.0	-	32.8	35.5		
64	1/21/2013	-	-	45.8	45.8	-	45.2	48.7		
65	1/22/2013	-	-			-	57.2	60.6	Outlier Ref PM10 - not discarded	
66	1/23/2013	-	-	69.6	69.6	-	65.6	68.7		
67	1/24/2013	-	-	27.7	28.1	-	23.1	23.7		
68	1/25/2013	-	-			-	18.4	19.0		
69	1/26/2013	-	-	28.5	28.7	-	26.3	27.4		
70	1/27/2013	-	-	15.3	15.4	-	11.1	12.6		
71	1/28/2013	-	-	9.2	8.2	-	6.9	7.9		
72	1/29/2013	-	-	5.8	4.8	-	4.8	5.4		
73	1/30/2013	-	-	15.8	15.6	-	7.7	9.3		
74	1/31/2013	-	-	21.0	20.0	-	10.2	12.7		
75	2/1/2013	-	-			-	11.4	12.5		
76	2/2/2013	-	-			-	8.0	9.0		
77	2/3/2013	-	-			-	10.0	10.7		
78	2/4/2013	-	-			-	9.6	11.3		
79	2/5/2013	-	-			-			Zero point	
80	2/6/2013	-	-			-			Zero point	
81	2/27/2013	-	-			-			Zero point	Bonn, winter
82	2/28/2013	-	-			-			Zero point	
83	3/1/2013	-	-	36.6	37.1	-	27.3	30.4		
84	3/2/2013	-	-			-	32.0	35.8		
85	3/3/2013	-	-	29.5	30.2	-	23.0	25.2		
86	3/4/2013	-	-	28.9	29.7	-	20.9	23.6		
87	3/5/2013	-	-	41.8	41.8	-	30.8	34.3		
88	3/6/2013	-	-	41.5	42.3	-	28.6	32.4		
89	3/7/2013	-	-	41.9	42.3	-	33.9	37.7		
90	3/8/2013	-	-	37.8	37.4	-	34.6	37.6		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 15 of 22**

Manufacturer	Comde-Derenda	
Type of instrument	APM-2	PM10 and PM2,5 Measured values in µg/m³ (STD)
Serial-No..	SN 3 / SN 4	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
91	3/9/2013	-	-			-	13.1	14.4		Bonn, winter
92	3/10/2013	-	-	23.6	22.9	-	28.2	30.5		
93	3/11/2013	-	-	31.5	30.8	-	34.0	37.1		
94	3/12/2013	-	-	17.9	17.9	-	18.2	20.2		
95	3/13/2013	-	-	51.3	50.9	-	37.2	41.0		
96	3/14/2013	-	-	27.5	27.9	-	20.5	23.2		
97	3/15/2013	-	-	32.0	32.3	-	23.1	25.5		
98	3/16/2013	-	-			-	15.1	16.6		
99	3/17/2013	-	-	11.4	11.0	-	11.5	12.6		
100	3/18/2013	-	-	18.2	18.1	-	11.1	12.5		
101	3/19/2013	-	-	17.7	17.5	-	13.0	14.2		
102	3/20/2013	-	-	25.8	25.2	-	27.2	29.1		
103	3/21/2013	-	-	46.4	46.3	-	41.0	44.4		
104	3/22/2013	-	-	26.4	26.8	-	24.7	27.1		
105	3/23/2013	-	-			-	25.7	28.3		
106	3/24/2013	-	-	19.9	19.1	-	17.3	19.5		
107	3/25/2013	-	-	26.2	25.9	-	24.0	27.1		
108	3/26/2013	-	-	21.4	20.8	-	16.6	19.5		
109	3/27/2013	-	-	33.9	33.6	-	29.5	33.2		
110	3/28/2013	-	-			-	52.9	58.1		
111	3/29/2013	-	-	78.1	77.4	-	71.8	78.4		
112	3/30/2013	-	-			-			Zero point	
113	3/31/2013	-	-			-			Zero point	
114	4/1/2013	-	-			-			Zero point	
115	4/2/2013	-	-	25.2	25.8	-	24.5	27.2		
116	4/3/2013	-	-	31.9	31.5	-	31.7	34.8		
117	4/4/2013	-	-	34.3	34.2	-	33.4	36.2		
118	4/5/2013	-	-	31.5	30.8	-	26.7	29.1		
119	4/6/2013	-	-			-	26.3	28.8		
120	4/7/2013	-	-	31.7	31.2	-	25.4	28.6		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 16 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
121	4/8/2013	-	-	32.9	33.1	-	26.9	30.0		Bonn, winter
122	4/9/2013	-	-	22.6	22.2	-	18.0	19.7		
123	4/10/2013	-	-	18.7	18.8	-	13.6	14.7		
124	4/11/2013	-	-	16.9	16.9	-	10.1	10.6		
125	4/12/2013	-	-	11.0	11.1	-	7.0	7.5		
126	4/13/2013	-	-			-	8.2	8.7		
127	4/14/2013	-	-	12.6	11.9	-	7.5	8.2		
128	4/15/2013	-	-	33.0	32.3	-	22.1	23.9		
129	4/16/2013	-	-	22.4	22.2	-	14.6	15.5		
130	4/17/2013	-	-	20.9	21.2	-	10.9	11.7		
131	4/18/2013	-	-	22.6	22.9	-	10.6	11.5		
132	4/19/2013	-	-	21.7	21.7	-	12.5	13.4		
133	4/20/2013	-	-			-	13.2	14.2		
134	4/21/2013	-	-	38.2	39.4	-	24.4	26.8		
135	4/22/2013	-	-	46.8	46.4	-	32.6	35.8		
136	4/23/2013	-	-	19.0	19.8	-	12.0	12.8		
137	4/24/2013	-	-	25.7	26.0	-	16.0	17.4		
138	4/25/2013	-	-	24.9	25.4	-	15.7	17.1		
139	4/26/2013	-	-			-			Zero point	
140	4/27/2013	-	-			-			Zero point	
141	4/28/2013	-	-			-			Zero point	
142	4/29/2013	-	-	21.5	22.6	-	14.7	15.8		
143	4/30/2013	-	-			-	17.9	19.3		
144	5/1/2013	-	-	22.4	23.4	-	20.4	22.0		
145	5/2/2013	-	-			-	21.4	23.2		
146	5/3/2013	-	-	35.6	36.7	-	29.4	32.2		
147	5/4/2013	-	-	31.7	32.5	-	22.9	24.8		
148	5/5/2013	-	-	14.8	15.7	-	10.2	10.8		
149	5/6/2013	-	-	24.9	24.7	-	17.9	19.6		
150	5/15/2013	-	-			-			Zero point	Cologne, summer

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 17 of 22**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
151	5/16/2013	-	-			-			Zero point	Cologne, summer
152	5/17/2013	-	-	20.9	21.9	-	18.0	18.8		
153	5/18/2013	-	-			-	16.2	17.7		
154	5/19/2013	-	-			-	21.4	23.0		
155	5/20/2013	-	-	12.2	13.2	-	11.8	12.4		
156	5/21/2013	-	-	8.4	9.4	-	8.0	8.6		
157	5/22/2013	-	-	13.5	13.7	-	10.3	11.0		
158	5/23/2013	-	-	12.0	13.1	-	10.8	11.6		
159	5/24/2013	-	-	13.4	13.8	-	10.6		SN4 no data recording	
160	5/25/2013	-	-			-	13.1		cause	
161	5/26/2013	-	-	20.3	19.8	-	13.7		unknown	
162	5/27/2013	-	-	25.8	25.3	-	21.1	22.5		
163	5/28/2013	-	-	13.6	13.5	-	11.1	11.8		
164	5/29/2013	-	-			-	9.7	10.3		
165	5/30/2013	-	-			-	17.6	18.6		
166	5/31/2013	-	-			-	18.2	19.9		
167	6/1/2013	-	-			-	16.4	17.9		
168	6/2/2013	-	-	13.6	13.4	-	8.7	9.5		
169	6/3/2013	-	-	17.2	17.6	-	11.0	12.3		
170	6/4/2013	-	-	22.9	22.4	-	14.4	15.5		
171	6/5/2013	-	-	17.1	16.2	-	11.7	12.6		
172	6/6/2013	-	-	18.8	19.6	-	13.1	13.8		
173	6/7/2013	-	-	25.5	24.9	-	18.8	19.8		
174	6/8/2013	-	-			-	19.1	20.8		
175	6/9/2013	-	-	21.8	20.0	-	17.1	18.5		
176	6/10/2013	-	-	33.0	31.3	-	23.7	26.3		
177	6/11/2013	-	-	27.6	26.7	-	21.8	24.0		
178	6/12/2013	-	-	16.4	15.2	-	11.7	11.7		
179	6/13/2013	-	-	11.9	11.2	-	7.3	8.3		
180	6/14/2013	-	-	13.4	13.0	-	8.0	9.4		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 18 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
181	6/15/2013	-	-	13.5	13.8	-	7.4	8.8		Cologne, summer
182	6/16/2013	-	-	19.6	18.8	-	10.1	11.6		
183	6/17/2013	-	-	25.5	24.2	-	16.4	18.4		
184	6/18/2013	-	-	29.9	28.8	-	24.0	27.0		
185	6/19/2013	-	-	51.9	49.8	-	45.5	51.1	Ref. PM2,5 - stability criteria	
186	6/20/2013	-	-	15.4	14.3	-	16.2	18.2	EN 14907 not met	
187	6/21/2013	-	-	9.0	8.9	-	7.2	8.0		
188	6/22/2013	-	-	5.7	5.5	-	4.6	5.2		
189	6/23/2013	-	-	8.2	8.1	-	5.9	6.8		
190	6/24/2013	-	-	17.0	16.5	-	12.7	14.0		
191	6/25/2013	-	-	11.6	12.8	-	8.6	9.8		
192	6/26/2013	-	-	15.0	14.4	-	11.4	12.2		
193	6/27/2013	-	-	15.1	14.3	-	12.1	13.4		
194	6/28/2013	-	-	12.9	14.0	-	13.8	15.0		
195	6/29/2013	-	-			-			Zero point	
196	6/30/2013	-	-			-			Zero point	
197	7/1/2013	-	-	18.4	17.9	-	13.0	14.4		
198	7/2/2013	-	-	15.2	14.2	-	11.4	12.1		
199	7/3/2013	-	-	12.6	12.6	-	8.9	10.0		
200	7/4/2013	-	-	16.7	15.9	-	12.0	13.1		
201	7/5/2013	-	-	25.4	24.6	-	19.9	22.0	Outlier Ref. PM2,5	
202	7/6/2013	-	-	19.4	18.9	-	17.7	18.8		
203	7/7/2013	-	-	17.7	17.6	-	13.4	14.2		
204	7/8/2013	-	-	19.5	19.6	-	14.0	15.6		
205	7/9/2013	-	-	25.5	25.3	-	16.3	18.3		
206	7/10/2013	-	-	19.6	19.0	-	12.4	13.5		
207	7/11/2013	-	-			-	23.4	26.0	Outlier Ref. PM10	
208	7/12/2013	-	-	30.6	28.4	-	21.9	24.4		
209	7/13/2013	-	-	28.3	26.4	-	23.0	25.0		
210	7/14/2013	-	-			-	21.8	24.3		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 19 of 22**

Manufacturer: Comde-Derenda
Type of instrument: APM-2
Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
211	7/30/2013	-	-	14.7	14.1	-	8.2	8.3		Rodenkirchen, summer
212	7/31/2013	-	-	12.9	13.2	-	8.7	8.4		
213	8/1/2013	-	-	15.8	16.6	-	10.6	10.4		
214	8/2/2013	-	-	23.2	25.3	-	15.1	15.0		
215	8/3/2013	-	-			-	10.7	10.7		
216	8/4/2013	-	-	15.3	16.1	-	9.8	9.6		
217	8/5/2013	-	-	22.3	24.4	-	13.4	12.8		
218	8/6/2013	-	-	20.1	20.6	-	12.2	11.9		
219	8/7/2013	-	-	16.2	16.3	-	12.4	12.3		
220	8/8/2013	-	-	20.0	19.6	-	13.7	14.0		
221	8/9/2013	-	-	20.0	20.4	-	13.9	14.0		
222	8/10/2013	-	-			-	11.5	11.8		
223	8/11/2013	-	-	13.5	13.2	-	8.3	8.3		
224	8/12/2013	-	-	20.0	18.8	-	10.5	10.8		
225	8/13/2013	-	-	17.5	18.0	-	10.3	10.4		
226	8/14/2013	-	-	24.4	26.3	-	12.8	13.1		
227	8/15/2013	-	-	20.5	19.9	-	12.2	12.6		
228	8/16/2013	-	-	24.2	24.3	-	14.4	14.5		
229	8/17/2013	-	-			-	9.3	8.6		
230	8/18/2013	-	-	11.5	10.9	-	7.5	7.5		
231	8/19/2013	-	-	14.9	14.8	-	9.5	9.8		
232	8/20/2013	-	-	20.4	19.8	-	14.4	14.2		
233	8/21/2013	-	-	19.9	19.0	-	17.0	16.6		
234	8/22/2013	-	-	27.3	27.5	-	21.9	22.1		
235	8/23/2013	-	-	24.8	24.8	-	20.1	20.2		
236	8/24/2013	-	-			-	26.9	26.6		
237	8/25/2013	-	-	34.8	33.1	-	30.6	31.8		
238	8/26/2013	-	-	20.5	20.6	-	14.3	14.9		
239	8/27/2013	-	-	23.5	22.2	-	17.9	17.6		
240	8/28/2013	-	-	24.3	24.9	-	22.8	22.2		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 20 of 22**

Manufacturer: Comde-Derenda

Type of instrument: APM-2

Serial-No..: SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
241	8/29/2013	-	-	28.5	28.9	-	26.8	25.5		Rodenkirchen, summer
242	8/30/2013	-	-	29.3	31.4	-	23.8	24.3		
243	8/31/2013	-	-			-	12.2	13.2		
244	9/1/2013	-	-	19.9	20.7	-	9.5	10.6		
245	9/2/2013	-	-	22.6	24.4	-	12.4	13.8		
246	9/3/2013	-	-	24.5	25.8	-	18.2	17.7		
247	9/4/2013	-	-	15.6	16.4	-	12.2	12.3		
248	9/5/2013	-	-	17.8	20.8	-	12.6	12.3		
249	9/6/2013	-	-	33.6	36.2	-	24.3	24.9		
250	9/7/2013	-	-	25.7	26.6	-	22.1	20.6		
251	9/8/2013	-	-			-	19.5	17.6		
252	9/9/2013	-	-	11.7	12.4	-	8.9	9.0		
253	9/10/2013	-	-	11.5	11.8	-	9.2	8.3		
254	9/11/2013	-	-			-	14.8	13.5		
255	9/12/2013	-	-	24.3	25.3	-	18.8	16.3		
256	9/13/2013	-	-	15.3	15.5	-	11.1	10.2		
257	9/14/2013	-	-			-	7.3	6.8		
258	9/15/2013	-	-	15.6	16.3	-	9.1	8.0		
259	9/16/2013	-	-	15.3	15.5	-	8.1	7.4		
260	9/17/2013	-	-	13.2	13.7	-	8.9	7.5		
261	9/18/2013	-	-	23.0	23.9	-	18.3	14.2		
262	9/19/2013	-	-	17.4	18.9	-	10.9	9.9		
263	9/20/2013	-	-	21.8	21.8	-	13.1	11.9		
264	9/21/2013	-	-			-			Zero point	
265	1/13/2014	-	-	18.8	19.3	-	17.8	16.3		Cologne, winter 2014 validation campaign
266	1/14/2014	-	-	16.0	15.3	-	15.6	14.6		
267	1/15/2014	-	-	8.3	8.9	-	10.7	9.4		
268	1/16/2014	-	-	6.7	7.3	-	10.1	8.2		
269	1/17/2014	-	-	9.4	8.9	-	9.9	8.6		
270	1/18/2014	-	-			-	14.5	13.5		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 21 of 22**

Manufacturer	Comde-Derenda
Type of instrument	APM-2
Serial-No..	SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
271	1/19/2014	-	-	17.5	17.7	-	20.5	18.4		Cologne, winter 2014 validation campaign
272	1/20/2014	-	-	19.4	20.2	-	23.5	21.0		
273	1/21/2014	-	-	31.5	31.4	-	30.8	28.5		
274	1/22/2014	-	-	23.3	23.5	-	24.9	22.6		
275	1/23/2014	-	-	15.5	16.4	-	16.1	16.6		
276	1/24/2014	-	-	28.6	29.0	-	28.0	29.5		
277	1/25/2014	-	-			-	15.5	15.5		
278	1/26/2014	-	-	11.8	12.3	-	12.0	12.1		
279	1/27/2014	-	-	6.9	7.2	-	8.4	7.6		
280	1/28/2014	-	-	11.3	10.8	-	11.0	11.0		
281	1/29/2014	-	-	19.7	20.0	-	19.8	20.6		
282	1/30/2014	-	-	42.5	42.7	-	44.4	46.2		
283	1/31/2014	-	-	36.3	35.8	-	36.5	37.9		
284	2/1/2014	-	-			-	10.1	9.0		
285	2/2/2014	-	-	18.5	17.6	-	18.0	18.4		
286	2/3/2014	-	-	22.6	21.9	-	22.9	23.9		
287	2/4/2014	-	-			-	17.9	18.0		
288	2/5/2014	-	-	8.3	8.5	-	9.3	9.2		
289	2/6/2014	-	-	10.3	9.5	-	9.6	8.6		
290	2/7/2014	-	-			-			Zero point	
291	2/8/2014	-	-			-			Zero point	
292	2/9/2014	-	-			-			Zero point	
293	2/10/2014	-	-	13.5	13.5	-	14.3	14.2		
294	2/11/2014	-	-	10.0	8.2	-	8.7	8.2		
295	2/12/2014	-	-	8.6	8.1	-	9.4	8.5		
296	2/13/2014	-	-	10.7	10.2	-	9.8	9.6		
297	2/14/2014	-	-			-	7.7	7.9		
298	2/15/2014	-	-			-	8.0	7.3		
299	2/16/2014	-	-	9.1	9.4	-	9.7	9.4		
300	2/17/2014	-	-	13.0	12.7	-	12.9	12.8		

Annex 5 **PM10-Measured values from the field test sites, related to standard conditions [EN 12431]** **Page 22 of 22**

Manufacturer Comde-Derenda

Type of instrument APM-2

Serial-No.. SN 3 / SN 4

PM10 and PM2,5
Measured values in µg/m³ (STD)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
301	2/18/2014	-	-	20.5	20.1	-	20.7	20.5		Cologne, winter 2014 validation campaign
302	2/19/2014	-	-	13.6	14.8	-	14.2	14.3		
303	2/20/2014	-	-	6.9	6.4	-	8.5	8.5		
304	2/21/2014	-	-	8.0	7.9	-	10.0	9.4		
305	2/22/2014	-	-	4.8	5.5	-	8.0	7.1		
306	2/23/2014	-	-	7.3	7.1	-	8.7	8.9		
307	2/24/2014	-	-	14.2	13.2	-	13.2	13.1		
308	2/25/2014	-	-	13.4	12.5	-	12.1	12.6		
309	2/26/2014	-	-	19.9	17.6	-	18.3	17.9		
310	2/27/2014	-	-	12.4	10.6	-	12.3	12.5		
311	2/28/2014	-	-	10.8	10.2	-	11.0	10.9		
312	3/1/2014	-	-	15.3	15.0	-	16.4	16.5		
313	3/2/2014	-	-	19.1	20.3	-	19.6	20.5		
314	3/3/2014	-	-	10.4	12.3	-	11.8	11.9		
315	3/4/2014	-	-	26.5	25.0	-	25.9	26.3		
316	3/5/2014	-	-	44.0	43.7	-	41.9	42.5		
317	3/6/2014	-	-	45.0	43.8	-	38.9	40.6		
318	3/7/2014	-	-	58.4	56.7	-	50.6	52.6		
319	3/8/2014	-	-	51.3	51.2	-	44.2	45.7		
320	3/9/2014	-	-	29.1	27.9	-	27.4	27.5		

Annex 6 **Ambient conditions at the field test sites** **Page 1 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
1	11/19/2012	Cologne, winter						
2	11/20/2012		No weather data available					
3	11/21/2012							
4	11/22/2012		8.2	1013	79.5	0.6	150	0.0
5	11/23/2012		8.5	1010	88.3	0.1	147	9.3
6	11/24/2012		11.6	1005	78.5	0.9	156	0.3
7	11/25/2012		8.8	1004	70.3	1.4	161	0.3
8	11/26/2012		8.9	997	83.3	0.3	150	5.9
9	11/27/2012		7.5	998	81.2	0.1	125	0.3
10	11/28/2012		6.0	997	81.3	1.8	84	0.0
11	11/29/2012		4.0	999	81.0	1.0	80	0.0
12	11/30/2012		1.6	1005	83.8	0.1	157	0.0
13	12/1/2012		2.9	1003	83.1	0.7	156	5.1
14	12/2/2012		3.9	1006	82.3	1.3	146	0.3
15	12/3/2012		3.7	997	87.7	0.5	158	7.2
16	12/4/2012		4.5	993	84.3	1.0	114	5.7
17	12/5/2012		2.1	999	85.7	0.8	120	4.2
18	12/6/2012		0.9	1005	79.9	0.7	151	0.0
19	12/7/2012		-2.6	1001	89.4	0.0	108	0.0
20	12/8/2012		-2.6	1016	86.2	0.0	125	0.9
21	12/9/2012		4.0	1002	87.0	1.8	149	16.1
22	12/10/2012		1.9	1010	81.4	2.6	78	1.8
23	12/11/2012		-0.2	1018	74.8	0.8	128	0.0
24	12/12/2012		-0.5	1010	71.4	0.5	136	0.0
25	12/13/2012		0.9	1000	75.6	0.5	148	0.0
26	12/14/2012		7.1	988	82.4	1.3	157	4.2
27	12/15/2012		8.7	995	78.6	1.2	173	4.7
28	12/16/2012		7.2	997	85.2	0.4	151	7.4
29	12/17/2012		7.2	999	85.4	0.1	141	3.0
30	12/18/2012		6.2	1011	88.1	0.0	145	0.9

Annex 6 **Ambient conditions at the field test sites** **Page 2 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
31	12/19/2012	Cologne, winter	4.2	1014	85.6	0.3	154	0.0
32	12/20/2012		2.8	1003	85.8	1.4	150	7.2
34	12/21/2012		6.0	1007	91.2	0.0	153	2.1
34	12/22/2012		8.7	1001	89.0	1.0	148	25.7
35	12/23/2012		10.6	1001	87.5	0.8	139	8.4
36	12/24/2012		11.8	995	76.0	0.7	155	2.4
37	12/25/2012		9.4	996	77.1	2.1	162	4.2
38	12/26/2012		9.1	1000	76.1	2.3	165	4.2
39	12/27/2012		7.3	1004	86.2	0.5	129	9.8
40	12/28/2012		8.4	1015	85.1	0.5	157	1.8
41	12/29/2012		10.4	1005	72.7	2.2	168	0.3
42	12/30/2012		8.6	1009	72.5	2.6	171	3.3
43	12/31/2012		9.9	1000	71.3	3.3	177	2.1
44	1/1/2013		6.1	1006	82.0	0.7	143	3.0
45	1/2/2013		7.5	1020	79.6	0.8	155	1.8
46	1/3/2013		10.6	1026	88.3	0.6	126	2.4
47	1/4/2013		9.1	1027	89.3	0.7	120	0.9
48	1/5/2013		8.4	1025	86.1	0.3	126	0.0
49	1/6/2013		9.1	1022	86.6	0.4	115	0.0
50	1/7/2013		8.2	1020	80.0	0.3	143	0.0
51	1/8/2013		7.6	1017	78.6	0.3	141	0.0
52	1/9/2013		5.8	1010	87.0	0.2	136	6.3
53	1/10/2013		4.0	1006	80.2	0.7	129	2.4
54	1/11/2013		-1.4	1011	78.3	0.0	153	0.0
55	1/12/2013		-1.5	1010	70.1	0.1	141	0.0
56	1/13/2013		-0.6	1009	70.0	0.2	145	0.0
57	1/14/2013		-2.5	1003	77.5	0.6	140	0.0
58	1/15/2013		-1.5	999	87.5	0.1	139	0.0
59	1/16/2013		-2.1	1006	84.8	0.0	87	0.0
60	1/17/2013		-2.0	1009	84.7	0.2	118	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 3 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
61	1/18/2013	Cologne, winter	-1.2	997	75.2	0.9	147	0.0
62	1/19/2013		-3.3	990	73.9	0.7	147	0.0
63	1/20/2013		-0.9	988	84.1	0.0	148	0.0
64	1/21/2013		-0.1	993	84.0	0.0	152	0.0
65	1/22/2013		0.2	999	80.4	0.0	149	0.0
66	1/23/2013		-0.5	1002	78.9	0.2	128	0.6
67	1/24/2013		-1.1	1010	74.4	0.6	126	0.0
68	1/25/2013		-1.9	1008	77.1	1.0	155	0.0
69	1/26/2013		-0.1	1004	81.5	0.9	148	0.6
70	1/27/2013		3.1	999	85.4	0.9	160	10.2
71	1/28/2013		6.9	1004	78.3	1.9	172	9.8
72	1/29/2013		11.9	1001	82.4	2.0	177	4.2
73	1/30/2013		10.9	1005	71.5	2.9	149	4.4
74	1/31/2013		8.6	1004	72.4	2.4	155	5.9
75	2/1/2013		5.0	990	88.1	0.9	127	11.7
76	2/2/2013		3.7	1006	78.8	1.8	94	0.9
77	2/3/2013		5.8	1006	82.0	2.0	144	3.0
78	2/4/2013		7.5	1000	76.2	1.9	149	3.3
79	2/5/2013		2.5	990	79.2	1.0	142	0.9
80	2/6/2013		2.4	997	84.5	0.9	112	5.4
81	2/27/2013	Bonn, winter	2.5	1021	78.9	0.9	185	0.0
82	2/28/2013		4.1	1017	71.8	1.2	250	0.0
83	3/1/2013		3.5	1016	72.0	1.7	249	0.0
84	3/2/2013		3.0	1015	67.4	1.2	238	0.0
85	3/3/2013		3.1	1014	72.8	0.5	196	0.0
86	3/4/2013		6.6	1007	57.8	1.4	140	0.0
87	3/5/2013		8.5	999	56.5	1.2	136	0.0
88	3/6/2013		11.5	993	48.5	0.4	143	0.0
89	3/7/2013		12.3	990	67.5	0.5	144	2.1
90	3/8/2013		13.7	990	72.1	1.4	138	1.5

Annex 6 **Ambient conditions at the field test sites** **Page 4 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
91	3/9/2013	Bonn, winter	10.6	991	72.2	1.2	178	3.6
92	3/10/2013		1.6	993	81.8	3.6	273	2.4
93	3/11/2013		-1.4	996	78.7	1.9	241	0.0
94	3/12/2013		-3.4	995	83.9	2.0	276	0.0
95	3/13/2013		-1.2	999	72.8	1.1	224	0.3
96	3/14/2013		-1.3	1004	75.3	1.1	209	2.1
97	3/15/2013		2.3	1006	58.8	1.0	132	2.1
98	3/16/2013		5.3	998	49.0	3.4	131	0.0
99	3/17/2013		4.7	988	78.3	2.2	131	0.9
100	3/18/2013		6.6	985	60.3	0.7	131	0.0
101	3/19/2013		5.8	991	74.5	0.6	157	1.2
102	3/20/2013		2.6	999	85.8	1.9	240	13.2
103	3/21/2013		0.6	1010	78.8	1.0	229	0.3
104	3/22/2013		2.9	1006	63.4	3.2	146	0.0
105	3/23/2013		1.1	1005	56.8	4.2	146	0.0
106	3/24/2013		1.0	1005	42.8	3.3	153	0.0
107	3/25/2013		0.9	1004	49.0	2.6	153	0.0
108	3/26/2013		1.6	1003	44.1	2.3	168	0.0
109	3/27/2013		2.6	1001	49.5	2.0	148	0.0
110	3/28/2013		3.0	999	58.9	1.2	243	0.0
111	3/29/2013		0.4	999	77.8	1.1	271	1.5
112	3/30/2013		1.8	1000	68.9	1.3	271	0.0
113	3/31/2013		1.7	1003	68.2	1.1	269	0.0
114	4/1/2013		3.2	1001	52.9	1.5	190	0.0
115	4/2/2013		3.6	1003	52.2	1.8	201	0.0
116	4/3/2013		3.0	1005	58.0	1.8	158	0.0
117	4/4/2013		4.4	1001	60.5	1.8	166	0.0
118	4/5/2013		3.8	1003	67.8	1.6	267	0.0
119	4/6/2013		3.6	1012	73.9	1.7	221	0.3
120	4/7/2013		6.4	1008	51.4	0.7	174	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 5 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
121	4/8/2013	Bonn, winter	7.0	996	63.9	1.4	130	0.9
122	4/9/2013		8.3	992	78.0	1.2	133	1.8
123	4/10/2013		9.7	996	77.3	1.4	154	6.0
124	4/11/2013		13.0	991	69.6	1.3	169	6.0
125	4/12/2013		12.2	997	69.0	1.1	154	4.4
126	4/13/2013		13.9	1011	56.8	1.4	152	0.6
127	4/14/2013		18.3	1011	57.0	1.5	136	0.0
128	4/15/2013		17.5	1011	67.0	1.5	214	2.7
129	4/16/2013		18.4	1011	54.4	0.9	149	0.0
130	4/17/2013		18.7	1009	54.3	0.6	141	0.0
131	4/18/2013		15.6	1009	46.2	3.1	210	0.0
132	4/19/2013		11.4	1017	57.7	3.5	260	0.0
134	4/20/2013		10.3	1018	51.5	3.3	274	0.0
134	4/21/2013		11.1	1009	57.4	1.1	253	0.0
135	4/22/2013		13.2	1009	46.5	1.4	217	0.0
136	4/23/2013		13.7	1014	63.6	1.7	187	0.0
137	4/24/2013		17.9	1016	56.5	1.0	167	0.0
138	4/25/2013		20.0	1010	51.5	0.4	146	0.0
139	4/26/2013		11.9	1000	77.3	2.2	230	9.9
140	4/27/2013		7.8	1003	70.3	3.2	293	0.0
141	4/28/2013		9.2	1007	68.3	0.7	169	0.0
142	4/29/2013		12.0	1010	56.1	1.9	209	0.0
143	4/30/2013		11.8	1014	57.9	1.0	214	0.0
144	5/1/2013		14.6	1011	62.8	0.9	173	0.3
145	5/2/2013		16.5	1009	60.4	1.1	200	0.0
146	5/3/2013		16.0	1007	60.0	1.5	253	0.0
147	5/4/2013		15.7	1011	54.5	2.4	238	0.0
148	5/5/2013		16.4	1013	55.9	1.3	190	0.0
149	5/6/2013		19.8	1008	50.0	0.6	192	0.0
150	5/15/2013	Cologne, summer	No weather data available					

Annex 6 **Ambient conditions at the field test sites** **Page 6 of 11**

No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
151	5/16/2013	Cologne, summer	No weather data available					
152	5/17/2013		9.9	997	86.2	0.7	173	0.6
153	5/18/2013		12.1	1001	74.2	0.1	140	0.0
154	5/19/2013		17.1	998	64.4	1.5	203	12.1
155	5/20/2013		11.4	1001	83.5	0.3	172	3.3
156	5/21/2013		12.7	1002	78.2	1.4	185	21.3
157	5/22/2013		8.5	1004	79.4	1.4	172	12.7
158	5/23/2013		6.3	1001	80.7	0.9	205	1.5
159	5/24/2013		8.4	1004	67.0	0.2	149	0.0
160	5/25/2013		10.5	1005	71.3	1.9	176	9.8
161	5/26/2013		9.7	1003	79.2	2.7	195	6.5
162	5/27/2013		14.1	1000	61.6	0.9	170	0.0
163	5/28/2013		18.0	993	58.8	1.3	166	0.9
164	5/29/2013		9.2	996	89.4	0.6	164	25.2
165	5/30/2013		13.9	1000	68.4	0.4	196	0.3
166	5/31/2013		16.1	1002	70.0	2.3	197	0.0
167	6/1/2013		11.6	1011	76.2	2.2	187	0.0
168	6/2/2013		13.7	1017	54.1	2.4	213	0.0
169	6/3/2013		13.2	1018	58.9	2.0	195	0.0
170	6/4/2013		16.3	1012	63.2	0.8	189	0.0
171	6/5/2013		20.1	1010	53.6	0.2	172	0.0
172	6/6/2013		21.1	1011	51.4	0.2	182	0.0
173	6/7/2013		23.0	1010	51.4	0.3	186	0.0
174	6/8/2013		20.8	1005	60.2	1.1	163	0.0
175	6/9/2013		15.9	1002	71.7	1.0	199	2.4
176	6/10/2013		15.1	1006	70.0	0.5	193	0.0
177	6/11/2013		19.8	1009	57.4	0.2	176	0.0
178	6/12/2013		21.2	1008	66.3	0.3	151	0.3
179	6/13/2013		16.2	1008	77.3	1.4	158	20.4
180	6/14/2013		15.8	1009	65.6	0.1	200	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
181	6/15/2013	Cologne, summer	16.8	1006	60.6	1.1	172	0.0
182	6/16/2013		18.1	1007	61.0	0.3	159	0.0
183	6/17/2013		23.6	1005	64.7	0.2	186	0.6
184	6/18/2013		28.2	1005	57.4	0.2	181	0.0
185	6/19/2013		27.2	1003	64.4	1.1	190	0.0
186	6/20/2013		19.7	1003	79.5	0.4	187	32.4
187	6/21/2013		17.9	1006	73.8	0.7	155	2.7
188	6/22/2013		18.4	1004	67.4	1.0	172	2.4
189	6/23/2013		16.0	1006	69.7	1.6	176	1.5
190	6/24/2013		13.7	1014	76.2	1.8	163	0.3
191	6/25/2013		13.0	1019	68.8	0.9	232	0.0
192	6/26/2013		13.6	1018	71.0	0.7	197	11.2
193	6/27/2013		12.6	1014	77.9	0.4	191	8.9
194	6/28/2013		13.7	1010	89.5	0.2	173	22.5
195	6/29/2013		13.8	1014	74.0	1.1	222	0.0
196	6/30/2013		17.6	1012	67.3	0.5	163	0.0
197	7/1/2013		19.4	1008	68.3	0.4	189	0.0
198	7/2/2013		21.8	1003	59.2	0.2	179	0.9
199	7/3/2013		16.9	1005	87.7	0.1	179	12.7
200	7/4/2013		20.4	1015	68.6	0.6	187	0.0
201	7/5/2013		19.9	1021	73.4	0.3	186	0.0
202	7/6/2013		22.9	1020	61.9	0.2	147	0.0
203	7/7/2013		23.6	1021	54.0	0.7	174	0.0
204	7/8/2013		24.0	1019	55.0	0.8	156	0.0
205	7/9/2013		23.4	1014	55.6	0.8	207	0.0
206	7/10/2013		19.1	1012	61.2	2.0	191	0.0
207	7/11/2013		14.8	1014	73.1	0.4	174	0.0
208	7/12/2013		16.8	1014	68.2	0.7	184	0.0
209	7/13/2013		18.0	1015	66.5	0.5	196	0.0
210	7/14/2013		No weather data available					

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
211	7/30/2013	Rodenkirchen, summer	18.2	1006	80.0	2.4	201	7.3
212	7/31/2013		20.1	1006	75.8	3.4	233	0.0
213	8/1/2013		24.0	1004	62.5	2.9	117	0.0
214	8/2/2013		27.8	1000	48.6	3.4	128	2.7
215	8/3/2013		23.1	1006	64.3	3.3	230	0.0
216	8/4/2013		20.5	1009	64.3	1.6	122	0.0
217	8/5/2013		22.8	1004	62.3	2.6	128	0.1
218	8/6/2013		21.6	1003	62.9	2.7	213	0.0
219	8/7/2013		19.5	999	80.7	2.9	175	1.2
220	8/8/2013		16.8	1006	82.9	2.4	233	0.7
221	8/9/2013		17.9	1008	73.5	1.8	174	0.0
222	8/10/2013		17.3	1008	71.8	3.0	241	0.0
223	8/11/2013		17.0	1007	62.9	2.5	199	0.0
224	8/12/2013		16.9	1004	75.3	2.3	202	0.4
225	8/13/2013		15.5	1007	73.7	2.9	217	0.0
226	8/14/2013		14.5	1011	75.3	1.8	161	0.0
227	8/15/2013		17.2	1010	73.1	2.0	151	0.0
228	8/16/2013		20.9	1005	59.1	2.4	167	0.0
229	8/17/2013		21.4	1003	65.8	2.1	226	0.0
230	8/18/2013		19.6	1001	81.0	3.2	174	7.8
231	8/19/2013		16.9	1005	83.0	3.2	263	0.5
232	8/20/2013		14.3	1016	78.9	1.6	154	0.0
234	8/21/2013		15.5	1013	70.6	1.7	141	0.0
234	8/22/2013		18.2	1008	65.3	1.8	154	0.0
235	8/23/2013		20.3	1005	62.3	2.4	128	0.0
236	8/24/2013		17.8	1000	80.0	2.7	135	5.9
237	8/25/2013		16.2	1000	96.4	1.6	224	2.5
238	8/26/2013		16.1	1003	81.8	1.7	141	0.0
239	8/27/2013		17.1	1003	69.7	1.7	142	0.0
240	8/28/2013		15.7	1007	78.3	1.6	166	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
241	8/29/2013	Rodenkirchen, summer	17.0	1010	72.2	1.8	146	0.0
242	8/30/2013		17.1	1008	72.8	1.8	189	0.0
243	8/31/2013		16.4	1009	81.1	2.7	244	2.0
244	9/1/2013		13.9	1015	70.5	2.9	256	0.0
245	9/2/2013		17.1	1013	70.7	3.5	269	0.0
246	9/3/2013		17.2	1015	82.2	1.6	145	0.0
247	9/4/2013		20.5	1010	70.6	2.0	112	0.0
248	9/5/2013		23.6	1002	61.5	3.6	126	0.0
249	9/6/2013		23.7	998	60.2	3.6	166	0.0
250	9/7/2013		17.9	1005	88.0	2.2	225	21.3
251	9/8/2013		14.0	1007	94.6	2.5	244	2.1
252	9/9/2013		14.0	1005	80.5	2.8	186	2.7
253	9/10/2013		12.8	1001	81.3	5.0	255	9.2
254	9/11/2013		12.8	1001	91.5	3.2	270	5.8
255	9/12/2013		13.5	1004	92.0	2.5	277	7.2
256	9/13/2013		15.2	1008	84.4	2.0	194	1.0
257	9/14/2013		15.3	1001	91.0	3.1	214	3.8
258	9/15/2013		13.7	999	79.4	2.3	280	8.1
259	9/16/2013		12.8	990	72.3	4.3	238	0.0
260	9/17/2013		9.9	991	81.7	3.8	184	5.8
261	9/18/2013		11.7	988	92.8	2.7	270	1.2
262	9/19/2013		12.3	1000	79.4	2.7	225	1.8
263	9/20/2013		13.8	1004	83.7	2.9	248	0.0
264	9/21/2013		12.9	1014	83.8	1.2	165	0.0
265	1/13/2014	Cologne, winter 2014	6.8	1002	82.5	0.0	210	0.0
266	1/14/2014	validation campaign	6.3	1001	77.9	0.3	203	0.0
267	1/15/2014		5.3	998	86.2	0.3	205	3.9
268	1/16/2014		7.8	993	80.2	0.2	220	0.0
269	1/17/2014		8.2	994	72.4	0.3	209	0.3
270	1/18/2014		6.5	992	75.3	0.7	202	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
271	1/19/2014	Cologne, winter 2014 validation campaign	5.7	994	80.7	0.2	202	0.0
272	1/20/2014		3.8	1000	83.9	0.3	135	0.0
273	1/21/2014		4.0	1005	87.1	0.0	186	0.0
274	1/22/2014		2.7	1006	84.8	0.1	203	0.0
275	1/23/2014		3.8	1004	87.2	0.2	193	8.0
276	1/24/2014		4.1	1010	86.2	0.0	188	0.3
277	1/25/2014		5.0	1004	79.5	1.1	208	6.5
278	1/26/2014		5.1	991	79.6	0.8	207	18.9
279	1/27/2014		4.9	990	75.6	0.8	214	0.3
280	1/28/2014		3.8	992	73.6	0.6	204	0.0
281	1/29/2014		2.6	996	71.0	1.1	198	0.0
282	1/30/2014		2.5	1000	72.6	0.2	194	0.0
283	1/31/2014		5.7	996	70.7	0.6	204	0.3
284	2/1/2014		5.5	997	81.6	0.5	214	3.6
285	2/2/2014		4.2	1008	76.5	0.5	207	0.0
286	2/3/2014		4.9	1001	77.9	0.7	203	0.0
287	2/4/2014		5.9	998	75.1	0.3	204	0.0
288	2/5/2014		7.4	992	73.8	1.2	209	0.0
289	2/6/2014		10.2	989	66.1	1.6	210	5.1
290	2/7/2014		7.6	991	72.7	2.4	216	7.7
291	2/8/2014		7.7	984	70.0	1.9	219	0.6
292	2/9/2014		5.9	989	67.2	1.7	221	0.0
293	2/10/2014		5.5	990	75.2	0.3	205	1.8
294	2/11/2014		6.7	997	70.1	1.1	217	2.4
295	2/12/2014		7.1	994	68.5	1.7	224	0.3
296	2/13/2014		5.2	992	80.2	0.5	201	8.0
297	2/14/2014		8.6	992	74.6	1.4	217	9.5
298	2/15/2014		10.0	995	65.2	3.0	210	1.5
299	2/16/2014		7.4	1004	71.7	0.8	220	0.6
300	2/17/2014		4.2	1008	82.8	0.0	212	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
301	2/18/2014	Cologne, winter 2014 validation campaign	7.4	1005	76.0	0.1	214	1.8
302	2/19/2014		8.3	1006	77.5	0.3	208	0.0
303	2/20/2014		9.7	999	78.3	0.9	209	5.4
304	2/21/2014		5.8	1002	77.2	0.6	207	0.9
305	2/22/2014		5.5	1010	76.2	0.7	211	1.8
306	2/23/2014		7.3	1011	70.4	0.5	206	0.0
307	2/24/2014		12.9	1005	53.2	0.5	203	0.0
308	2/25/2014		No weather data available					
309	2/26/2014							
310	2/27/2014							
311	2/28/2014		6.6	994	75.3	0.3	199	0.0
312	3/1/2014		5.8	995	78.1	0.1	223	0.6
313	3/2/2014		6.1	990	69.9	0.7	199	0.0
314	3/3/2014		6.2	988	71.5	0.6	187	0.0
315	3/4/2014		7.9	1002	70.6	0.1	199	0.0
316	3/5/2014		4.6	1018	81.8	0.2	146	0.0
317	3/6/2014		7.6	1020	67.2	0.2	191	0.0
318	3/7/2014		11.1	1021	63.3	0.1	178	0.0
319	3/8/2014		12.4	1022	56.2	0.5	202	0.0
320	3/9/2014		13.1	1020	46.8	0.3	164	0.0

Annex 2:

Methods used for filter weighing

A.1 Performance of weighing

Weighing takes place in an air-conditioned weighing chamber. Conditions are as follows: 20 °C ±1 °C and 50% ±5% rel. humidity and thus meet the requirements of EN 14907.

Filters for the field test are weighed manually. For further processing, filters incl. the control filters are placed sieves to avoid cross-loading.
Conditions for pre- and post-weighing had previously been defined and are in line with the standard.

Before sampling = pre-weighing	After sampling = post-weighing
Processing 48 hours + 2 hours	Processing 48 hours + 2 hours
Filter weighing	Filter weighing
Additional processing 24 hours + 2 hours	Additional processing 24 hours + 2 hours
Filter weighing and immediate packaging	Filter weighing

The balance is available and ready for operation at all times. The balance is calibrated before every weighing series. If everything is in order, the calibration weight of 200 mg is weighed as a reference weight and the peripheral parameters are recorded. Deviations from the previous weighing meet the standard's requirements and do not exceed 20 µg (see Figure 72). Then the six control filters are weighed. For control filters deviating by more than 40 µg a warning is displayed on the evaluation page. These filters are not used for post-weighing. The first three flawless control filters are used for post-weighing, remaining filters stay safely stored in their can to be used in the event the first three filters are damaged or experience excessive deviations. Figure 73 presents the exemplary trend over a period of four weeks.

Filters, for which there is a difference or more than 40 µg between the first and the second weighing, are not used for pre-weighing. For post-weighing, filters with differences exceeding 60 µg are removed from the evaluation as required by the standard.

Weighed filters are kept separately in polystyrene boxes for transport to and from the measurement site and for storage. The box is not opened until the filter is inserted in the filter cartridge. The non-loaded filters can be stored in the weighing room for up to 28 days before sampling. Should this period be exceeded, initial weighing will be repeated.

Sampled filters can be stored for a maximum of 15 days at temperatures up to 23°C. Filters are stored in a fridge at 7°C.

A2 Evaluation of the filters

Filters are evaluated using a correction term. The purpose of this corrective calculation is to minimise changes in the mass as a result of conditions in the weighing chamber.

Equation:

$$Dust = MF_{post} – (M_{Tara} \times (MKon_{post} / MKon_{pre})) \qquad (F1)$$

$MKon_{pre}$ = mean mass of the 3 control filters after 48h and 72h pre-weighing

$MKon_{post}$ = mean mass of the 3 control filters after 48h and 72h post-weighing

M_{Tara} = mean mass of the filter after 48h and 72h pre-weighing

MF_{post} =mean mass of the loaded filter after 48h and 72h post-weighing

Dust = corrected dust mass on the filter

The corrective calculation proved to render the method independent of the conditions in the weighing chamber. This way, the influence of water contents on the filter mass comparing virgin and deposited filters can be controlled and does not influence the dust concentrations deposited on the used filters. This is sufficient to meet the requirements of EN 14907, chapter 9.3.2.5.

The exemplary trend for the calibration weight for Nov 2008 to Feb 2009 shows that the permissible difference of 20 µg compared to the previous measurement is not exceeded.

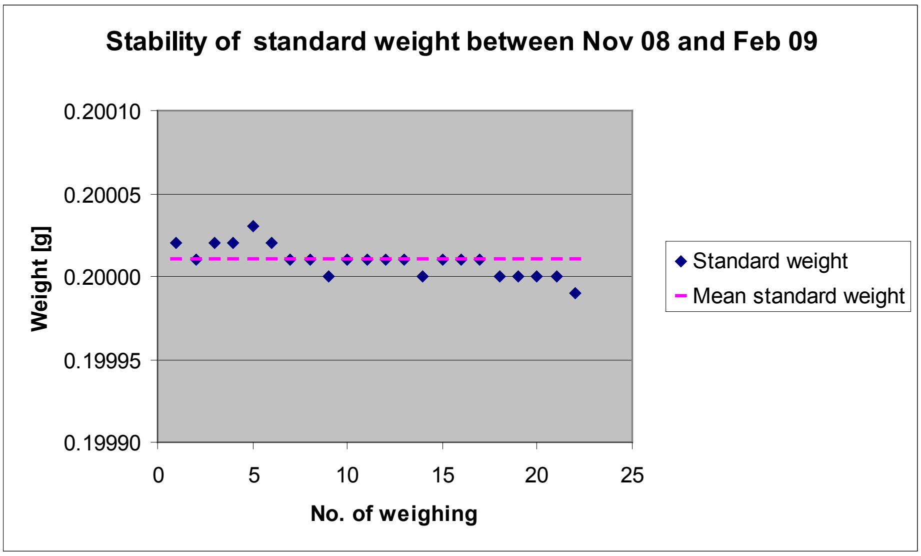

Figure 72: Stability calibration weight

Table 40: Stability calibration weight

Date	Weighing no.	Standard weight	Difference compared to previous weighing
		g	µg
12.11.2008	1	0.20002	
13.11.2008	2	0.20001	-10
10.12.2008	3	0.20002	10
11.12.2008	4	0.20002	0
17.12.2008	5	0.20003	10
18.12.2008	6	0.20002	-10
07.01.2009	7	0.20001	-10
08.01.2009	8	0.20001	0
14.01.2009	9	0.20000	-10
15.01.2009	10	0.20001	10
21.01.2009	11	0.20001	0
22.01.2009	12	0.20001	0
29.01.2009	13	0.20001	0
30.01.2009	14	0.20000	-10
04.02.2008	15	0.20001	10
05.02.2009	16	0.20001	0
11.02.2009	17	0.20001	0
12.02.2009	18	0.20000	-10
18.02.2009	19	0.20000	0
19.02.2009	20	0.20000	0
26.02.2009	21	0.20000	0
27.02.2009	22	0.19999	-10

Marked yellow = mean
Marked green = lowest value
Marked blue = highest value

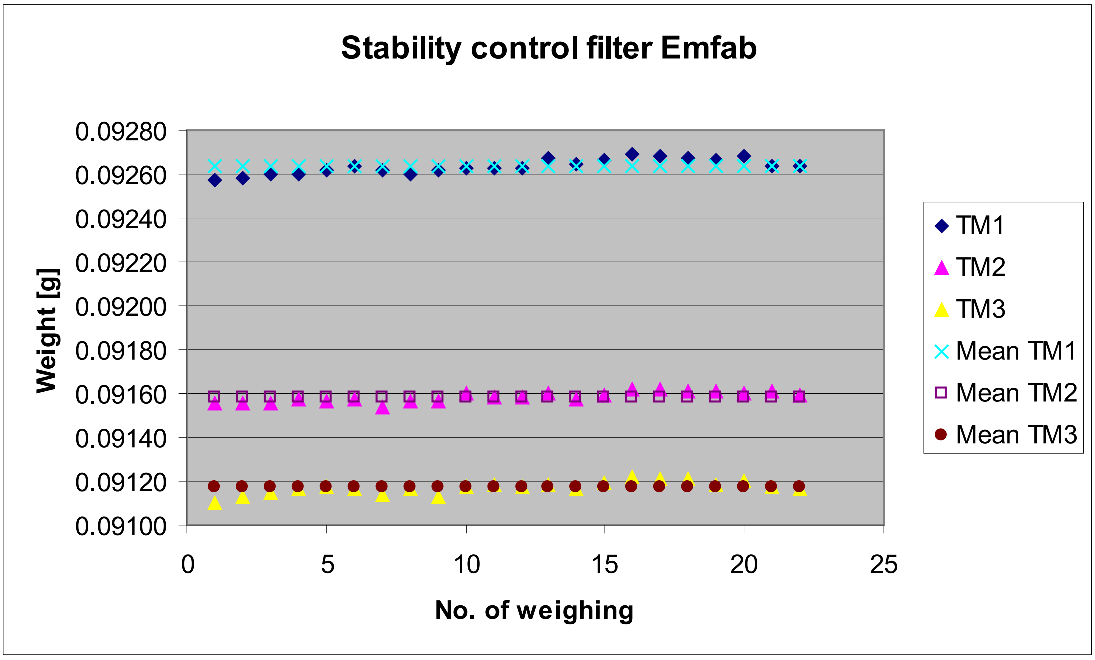

Figure 73: Stability of the control filters

Table 41: Stability of the control filters

	Control filter no.		
Weighing no.	TM1	TM2	TM3
1	0.09257	0.09155	0.09110
2	0.09258	0.09155	0.09113
3	0.09260	0.09155	0.09115
4	0.09260	0.09157	0.09116
5	0.09262	0.09156	0.09117
6	0.09264	0.09157	0.09116
7	0.09262	0.09154	0.09114
8	0.09260	0.09156	0.09116
9	0.09262	0.09156	0.09113
10	0.09263	0.09160	0.09117
11	0.09263	0.09158	0.09118
12	0.09263	0.09158	0.09117
13	0.09267	0.09160	0.09118
14	0.09265	0.09157	0.09116
15	0.09266	0.09159	0.09119
16	0.09269	0.09162	0.09122
17	0.09268	0.09162	0.09121
18	0.09267	0.09161	0.09121
19	0.09266	0.09161	0.09118
20	0.09268	0.09160	0.09120
21	0.09264	0.09161	0.09117
22	0.09264	0.09159	0.09116
Average	0.09264	0.09158	0.09117
Standard dev.	3,2911E-05	2,4937E-05	2,8558E-05
rel. Standard dev.	0.036	0.027	0.031
Median	0.09264	0.09158	0.09117
lowest value	0.09257	0.09154	0.09110
highest value	0.09269	0.09162	0.09122

Marked yellow = mean
Marked green = lowest value
Marked blue = highest value