TÜV RHEINLAND
ENERGIE UND UMWELT GMBH

Report on the suitability test of the ambient air quality measuring system TEOM 1405-F Ambient Particulate Monitor with $PM_{2.5}$ pre-separator of the company Thermo Fisher Scientific for the component $PM_{2.5}$

TÜV-Report: 936/21209885/C
Cologne, March 11, 2012

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is accredited for the following work areas:

- Determination of emissions and ambient airs of air pollution and odor substances;
- Inspection of correct installation, function and calibration of continuously running emission measuring devices including systems for data evaluation and remote monitoring of emissions;
- Suitability testing of measuring systems for continuous monitoring of emissions and ambient air, and of electronic systems for data evaluation and remote monitoring of emissions

according to EN ISO/IEC 17025.
The accreditation is valid up to 31-01-2013. DAkkS-register number:: D-PL-11120-02-00.

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Deutsche Akkreditierungsstelle D-PL-11120-02-00

Report on the suitability test of the ambient air quality measuring system TEOM 1405-F Ambient Particulate Monitor with PM2.5 pre-separator of the company Thermo Fisher Scientific for the component PM2.5

Device tested: TEOM 1405-F Ambient Particulate Monitor with PM2.5 pre-separator

Manufacturer: Thermo Fisher Scientific
27 Forge Parkway
Franklin, Ma 02038
USA

Test period: December 2009 to February 2012

Date of report: March 11, 2012

Report number: 936/21209885/C

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1. Summary and proposal for declaration of suitability

1.1 Summary

According to Directive 2008/50/EC of 21 May 2008 on “Air quality and cleaner air for Europe” (replaces Council Directive of 27 September 1996 on ambient air quality assessment and management including its daughter directives 1999/30/EC, 2000/69/EC, 2002/3/EC and the Council Decision 97/101/EC), the methods described in Standard EN12341 „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“ and Standard EN14907 „Ambient air quality - Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter“ serve as reference methods for suspended particle measurement of the respective mass fraction. However, EC member states are free to use any other method in the case of particulate matter for 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 Guidance “Demonstration of Equivalence of Ambient Air Monitoring Methods” [5] (which was developed by an ad hoc EC task group (Source:

http://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf, Version January 2010) describes an equivalence check method for non-standard measurement methods.

The specifications of the Guide for the equivalence testing were included in the last revision of the VDI Standards VDI 4202, Part 1 as well as VDI 4203, Part 3.

The following limits were applied during suitability testing:

	$PM_{2.5}$
Daily limit value (24 h)	not defined
Annual limit value (1 a)	25 µg/m³*

as well as for the calculations according to the Guide [4]

	$PM_{2.5}$
Limit value	30 µg/m³

Standard VDI 4202, Part 1 of June 2002 describes all „Minimum requirements for suitability tests of automatic ambient air measuring systems". General parameters for the related tests are given in Standard VDI 4203, Part 1 „Testing of automatic measuring systems - General concepts" of October 2001 and furthermore specified in VDI 4203, Part 3 „Testing of automatic measuring systems - Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants" of August 2004. The fulfilment of the requirements from VDI standards is mandatory in Germany.

Standard VDI 4202, Part 1 and VDI 4203, Part 3 were republished after an extensive revision with latest update September 2010. Unfortunately, after this revision uncertainties and contradictions remain regarding the concrete minimum requirements on the one hand and the general relevance of the test points on the other hand while testing particulate ambient air measuring devices. The following test points 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 for particulate devices
6.1 5.3.4 Linearity (Lack of fit)
not relevant for particulate devices
6.1 5.3.7 Sensitivity coefficient of the surrounding temperature
no minimum requirement defined
6.1 5.3.8 Sensitivity coefficient of the electric voltage
no minimum requirement defined
6.1 5.3.11 Standard deviation from paired measurement
no minimum requirement defined
6.1 5.3.12 Long-term drift
no minimum requirement defined
6.1 5.3.13 Short-time drift
not relevant for particulate devices
6.1 5.3.18 Overall uncertainty
not relevant for particulate devices

For this reason an official request to the competent German body was made, to define a co-ordinated procedure for dealing with inconsistencies in the Standard.

The following procedure was suggested:

The test points 5.3.2, 5.3.7, 5.3.8, 5.3.11 and 5.3.12 are evaluated as before based on the minimum requirements stated in VDI 4202 Part 1 from 2002 (i.e. using the reference values B_0, B_1 and B_2).

The testing of the test points 5.3.3, 5.3.4, 5.3.13 and 5.3.18 is waived, as they are not relevant for particulate measuring devices.

The competent German body agreed with the proposed procedure by decision of 27 June 2011 respectively 07 October 2011.

According to the applied standards the following reference values have been agreed upon: Since according to the applied standards the reference values to be used are explicitly adjusted to the mass component PM_{10}, for the mass component $PM_{2.5}$ the following reference values have been agreed upon:

	$PM_{2.5}$	PM_{10} (to compare)
B_0	2 µg/m³	2 µg/m³
B_1	25 µg/m³	40 µg/m³
B_2	200 µg/m³	200 µg/m³

Merely, an adaptation of B_1 on the level of the limit value for the annual average is performed.

Thermo Fisher Scientific has commissioned TÜV Rheinland Energie und Umwelt GmbH with the performance of a suitability testing of TEOM 1405-F Ambient Particulate Monitor for the component $PM_{2.5}$. The suitability testing of the measuring system was carried out applying the following standards and requirements:

- Standard VDI 4202 Part 1, „Minimum requirements for suitability tests of automatic ambient air measuring systems – Point-related measurement methods of gaseous and particulate pollutants“, September 2010 or June 2002
- Standard VDI 4203 Part 3, „Testing of automatic measuring systems - Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants“, September 2010 or August 2004
- 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
- Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of January 2010

The measuring system TEOM 1405-F Ambient Particulate Monitor determines the particulate concentration by an oscillating microbalance measuring principle (TEOM = Tapered Element Oscillating Microbalance). With the aid of a pump, ambient air is sucked at 16.7 l/min via a $PM_{2.5}$ pre-separator (consisting of a PM_{10} sampling inlet and a $PM_{2,5}$ Sharp Cut Cyclone). The dust-laden sampling air is collected and quantified on a TEOM-filter. By securing a constant flow rate of 3 l/min and by a continuous determination of the collected mass on the TEOM-filter, the $PM_{2.5}$-concentration can nearly be determined in real time. The measuring system TEOM 1405-F Ambient Particulate Monitor is equipped with a so called FDMS-system (= Filter Dynamics Measurement System). By using a FDMS-system non-volatile as well as the volatile particulate matter is taken into account while determining the concentration of the particulate matter.

The tests took place in the laboratory and for several months in the field.

The following test sites were chosen for the field test according to Table 1.

Table 1: Description of the test sites

	Teddington (UK)	Cologne, parking lot, winter	Bornheim, motorway parking lot, summer	Bornheim, motorway parking lot, winter
Time period	12/2009 – 07/2010	01/2011 – 05/2011	07/2011 – 11/2011	11/2011 – 02/2012
No. of paired values: Candidates	145	88	95	83
Characteristics	Urban background	Urban background	Rural structure + motorway	Rural structure + motorway
Rank of pollution	Average	Average to high	Low to average	Average

The complete test was performed within the scope of the test program „Combined MCERTS and TÜV PM Equivalence Testing Programme“. In the context of European harmonization, the test program was developed by British and German test institutes (Bureau Veritas UK Limited, National Physical Laboratory (NPL) and TÜV Rheinland) and comprises the testing of the latest series of suspended particle measuring systems by different manufacturers in the laboratory and at field test sites in the UK and in Germany.

The minimum requirements were fulfilled during suitability testing.

TÜV Rheinland Energie und Umwelt GmbH therefore suggests publication as a suitability-tested measuring system for continuous monitoring of suspended particulate matter $PM_{2.5}$ in ambient air.

1.2 Proposal of declaration of suitability

On the basis of the positive results that have been achieved, the following recommendation is made for the notification as a suitability-tested measuring system:

Measuring system:

TEOM 1405-F Ambient Particulate Monitor with PM2.5 pre-separator for PM2.5

Manufacturer:

Thermo Fisher Scientific, Franklin, USA

Suitability:

For continuous monitoring of suspended particulate matter of the $PM_{2.5}$-fraction in ambient air (stationary operation).

Measuring ranges during suitability test:

Component	Certification range	Unit
$PM_{2.5}$	0 – 1000	µg/m³

Software version:

1.56

Restrictions:

The allowed range of ambient temperature at the installation site is 8 °C to 25 °C.

Notes:

1. The requirements according to guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" are fulfilled for the measured components $PM_{2.5}$.
2. The measuring system is to be calibrated on test site in regular intervals by application of the gravimetric $PM_{2.5}$- reference method according to EN 14907.
3. The test report on the suitability test is visible in the internet under www.qal1.de.

Test report:

TÜV Rheinland Energie und Umwelt GmbH, Cologne, Germany

Report-No.: 936/21209885/C of March 11, 2012

1.3 Summary of test results

Minimum requirement	Specification	Test result	Fulfilled	Page
4 Requirements on the instrument design				
4.1 General requirements				
4.1.1 Measured value display	Shall be available.	The measuring device comprises a measured value display.	yes	59
4.1.2 Easy maintenance	Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.	Maintenance works can be carried out with commonly available tools taking reasonable time and effort.	yes	61
4.1.3 Functional test	If the operation or the functional check of the measuring system require 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 system functions listed in the manual are available, activatable and functioning. The current system status in continuously monitored and displayed by a set of different status messages (operation, warning and error messages.	yes	64
4.1.4 Set-up times and warm-up times	Shall be specified in the instruction manual.	The setup- and warm-up times were determined..	yes	66
4.1.5 Instrument design	Shall be specified in the instruction manual.	The instrument design specifications listed in the operating manual are complete and correct..	yes	67
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 AMS is protected against unauthorized and unintended adjustment. In addition, the AMS shall be locked in a measuring cabinet.	yes	68
4.1.7 Data output	The output signals shall be provided digitally and/or as analogue signals	Measured signals are offered analogue (0-1 or. 5 V) and digital (via Ethernet, RS 232, USB).	yes	69

Minimum requirement	Specification	Test result	Ful-filled	Page
5. Performance requirements				
5.1 General	The manufacturer's specifications in the instruction manual shall be by no means better than the results of the performance test.	Differences between the instrument design and the descriptions given in the manual could not be detected.	yes	71
5.2 General requirements on measuring systems				
5.2.1 Certification ranges	Have to comply with the requirements of Table 1 of the Standard VDI 4202 Part 1.	The assessment of the measuring device in the range of the relevant limit values is possible.	yes	72
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.	A measuring range of 0 – 1.000 µg/m³ is set by default. Other measuring ranges up to a maximum of 0 – 1.000.000 µg/m³ are possible. The measuring range value of the measuring device is higher than the respective upper limit of the certification range.	yes	73
5.2.3 Negative output signals	Negative output signals or measured values may not be suppressed (life zero).	Negative measuring signals are displayed directly and are output correctly via the respective measured value outputs by the measuring system.	yes	74
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 instrument parameters are protected against loss through buffering. After the power supply has returned, the measuring device goes back into a failure-free operational condition and continues independently the measuring operation after achieving the instrument status "fully operational".	yes	75
5.2.5 Operating states	The measuring system shall allow the control of important operating states by telemetrically transmitted status signals.	The measuring devices can be extensively monitored and controlled by an external PC via modem or router.	yes	76
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.	Generally all necessary operations for functional check can be monitored directly at the device or via telemetric remote control.	yes	77
5.2.7 Maintenance interval	If possible 3 months, minimum 2 weeks.	The maintenance interval is defined by necessary maintenance procedures and is 1 month.	yes	78

Minimum requirement	Specification	Test result	Ful-filled	Page
5.2.8 Availability	Minimum 95 %.	The availability was 98.7 % for SN 20012 and 96.5% for SN 20121 without outages due to test conditions, or 93.6 % for SN 20012 and 91.4 % for SN 20121 including outages due to test conditions.	yes	79
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 on the display. The test institute is informed on changes in the instrument software.	yes	81
5.3 Requirements on measuring systems for gaseous air pollutants				
5.3.1 General	Minimum requirement according VDI 4202 Part 1.	The test was done based on the minimum requirements stated in Standard VDI 4202 Part 1 (September 2010). The test points 5.3.2, 5.3.7, 5.3.8, 5.3.11 and 5.3.12 are evaluated as before based on the minimum requirements stated in Standard VDI 4202 Part 1 from 2002 (i.e. using the reference values B0, B1 and B2). The testing of the test points 5.3.3, 5.3.4, 5.3.13 and 5.3.18 is waived, as they are not relevant for particulate measuring devices.	yes	83
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 Standard VDI 4202 Part 1 (September 2010). For PM: Maximal B_0.	The detection limit was determined from investigations on 0.66 µg/m³ for device 1 (SN 20012) and 0.68 µg/m³ for device 2 (SN 20121).	yes	85
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 Standard VDI 4202 Part 1 (September 2010).	Not applicable.	-	87
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.	For particulate measuring devices for PM2.5 this test shall be performed according to minimum requirement 5.4.10 “Calculation of the expanded uncertainty of the instruments”.	-	88

Minimum requirement	Specification	Test result	Ful-filled	Page
5.3.5 Sensitivity coefficient of the sample gas pressure	The Sensitivity coefficient of the sample gas pressure at reference point shall not exceed the specifications of Table 2 of Standard VDI 4202 Part 1 (September 2010).	Not applicable.	-	89
5.3.6 Sensitivity coefficient of the sample gas temperature	The Sensitivity coefficient of the sample gas temperature at reference point shall not exceed the specifications of Table 2 of Standard VDI 4202 Part 1 (September 2010).	Not applicable.	-	90
5.3.7 Sensitivity coefficient of the surrounding temperature	The sensitivity coefficient of the surrounding temperature at zero and reference point shall not exceed the specifications of Table 2 of Standard VDI 4202 Part 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 permitted surrounding temperature at the test site of the measuring device pursuant to the manufacturer is 8 °C to 25 °C. When observing the values output by the device, a maximum influence of the surrounding temperature on the zero-point of -1.2 µg/m³ in the range 8 °C to 25 °C could be detected. At reference point no deviation > 0.4 % to the default value at 20 °C could be observed.	yes	91
5.3.8 Sensitivity coefficient of the electric voltage	The sensitivity coefficient of the electric voltage at reference point shall not exceed the specifications made in Table 2 of Standard VDI 4202 Part 1 (September 2010). For PM: Change in measured value at B_1 maximum B_0 within the voltage interval (230 +15/-20) V.	Due to voltage changes no deviation > -0.7 % could be detected for PM2.5, referring to the start value of 230 V.	yes	94
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 Standard VDI 4202 Part 1 (September 2010) at zero and reference point.	Not applicable.	-	96

Minimum requirement	Specification	Test result	Ful-filled	Page
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 Standard VDI 4202 Part 1 (September 2010).	Not applicable.	-	97
5.3.11 Standard deviation from paired measurement	The standard deviation from parallel determinations shall be done with two identical measuring devices during field test. It shall not exceed the specifications stated in Table 2 of Standard VDI 4202 Part 1 (September 2010). For PM: RD ≥ 10 referring to B_1.	The reproducibility RD for PM2.5 was 24 during field test for the complete data set.	yes	98
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. A value ct at 70% to 80% of the upper limit of the certification range shall be used as reference point. 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.	The maximum deviation found at zero-point was -2.1 µg/m³ with reference to the previous value and -2.1 µg/m³ with reference to the start value and are thus within the allowed range of B0 = 2 µg/m³. The values for the drift of the sensitivity, referring to the respective previous values, determined within the scope of the test, have been at maximum 2,1 % for PM2.5.	yes	100
5.3.13 Short-time drift	The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 of Standard VDI 4202 Part 1 (September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test.	Not applicable.	-	106

Minimum requirement	Specification	Test result	Ful-filled	Page
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 response time (fall) of the measuring system shall not exceed 10% of response time (rise) or 10 s, whatever value is larger.	Not applicable.	-	107
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 Standard VDI 4202 Part 1 (September 2010).	Not applicable..	-	108
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.	-	109
5.3.17 Increase of NO2 concentration due to residence in the measuring system	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 Standard VDI 4202 Part 1 (September 2010).	Not applicable.	-	110
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 Standard VDI 4202 Part 1 (September 2010).	According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.	-	111

Minimum requirement	Specification	Test result	Ful-filled	Page
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 Standard VDI 4202, Part 1. Furthermore, the particle mass concentration shall be related to a defined volume.	The test took place according to the minimum requirement stated in Table 5 of Standard VDI 4202, Part 1 (September 2010). The measuring unit TEOM 1405-F Ambient Particle Monitor is a gravimetric measuring device, which determines the mass deposited on a filter via oscillating micro weighing. The determined mass is related to a defined and actively regulated sampling volume and thereby the particulate concentration is determined.	yes	112
5.4.2 Equivalency of the sampling system	The equivalency to the reference method according to EN 12341 shall be demonstrated.	Not applicable for PM2.5-sampling systems. Reference is made to module 5.4.10 of this report.	-	113
5.4.3 Equivalency of the sampling systems	This shall be demonstrated in the field test.	Not applicable for PM2.5-sampling systems. Reference is made to module 5.4.10 of this report.	-	114
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 14907. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall the determined as a steady function.	A statistically secured relation between the reference measuring procedure and the instrument display could be demonstrated.	yes	115
5.4.5 Cross-sensitivity	Shall not exceed 10 % of the limit value	No interference caused by moisture in the sample > 1.6 µg/m³ deviation from nominal value for PM2.5 could be observed. During the field test, no negative influence on the measured values could be noted at changing relative humidities. The comparability of the candidates with the reference method according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods" [4] also is given for the days with a relative humidity > 70 %.	yes	117
5.4.6 Averaging effect	The measuring system shall allow for formation of 24 h averages. The time of the sum of all filter changes within 24 h may not exceed 1 % of this averaging time.	The formation of valid daily averages is possible.	yes	120

Minimum requirement	Specification	Test result	Ful-filled	Page
5.4.7 Constancy of sample volumetric flow	± 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.	All determined daily averages deviate less than ± 3 %, all instantaneous values less than ± 5 % from the nominal value.	yes	121
5.4.8 Tightness of the measuring system	Leakage shall not exceed 1 % of the sample volume sucked.	The criteria for passing the tightness check implemented by the manufacturer – a deviation of the flow values at a blocked inlet of no more than 0.15 l/min from zero flow at the PM2.5-path and no more 0.60 l/min from zero flow at the bypass-path – were approved as appropriate parameters for the monitoring of the device tightness. The tightness check may only be performed using the tightness check assistant to avoid damages of the instrument.	yes	127
5.4.9 Determination of uncertainty between systems under test ubs	Shall be determined according to chapter 9.5.2.1 of the guidance document „Demonstration of Equivalence of Ambient Air Monitoring Methods“ in the field test for at least two identical systems.	The in-between-uncertainty between the candidates ubs is with a maximum of 1.33 µg/m³ for PM2.5 below the required value of 2.5 µg/m³.	yes	130

Minimum requirement	Specification	Test result	Ful-filled	Page
5.4.10 Calculation of the expanded uncertainty of the instruments	Determination of the expanded uncertaintiy of the candidates according to chapter 9.5.2.2ff of the guidance document „Demonstration of Equivalence of Ambient Air Monitoring Methods".	The determined uncertainties WCM without application of correction factors lay for all observed data sets below the defined expanded relative uncertainty Wdqo of 25 % for particulate.	yes	136
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 A of Standard VDI 4202 Part 1 for the test of $PM_{2.5}$ measuring systems, the application of correction factors and terms is allowed. Values corrected shall meet the requirements of chapter 9.5.2.2 ff. of the guidance document „Demonstration of Equivalence of Ambient Air Monitoring Methods".	The candidate systems fulfil the requirements on the data quality of ambient air quality measurements during the test already without application of correction factors A correction of the intercept leads nevertheless to a significant improvement of the expanded measuring uncertainty of the "All data" comparison.	yes	149
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.	Not applicable.	-	154

2. Task definition

2.1 Type of test

Thermo Fisher Scientific has commissioned TÜV Rheinland Energie und Umwelt GmbH with the performance of a suitability test of TEOM 1405-F Ambient Particulate Monitor with PM2.5 pre-separator. The test was conducted as a complete suitability testing.

2.2 Objective

The AMS shall determine the content of $PM_{2.5}$ suspended particulate matter in ambient air within the concentration range of 0 to 1000 µg/m^3.

The suitability test was carried out based on the current standards for suitability tests while taking into account the latest developments.

The test was performed in consideration of the following standards:

- Standard VDI 4202 Part 1, „Minimum requirements for suitability tests of automatic ambient air measuring systems – Point-related measurement methods of gaseous and particulate pollutants“, September 2010 or June 2002 [1]
- Standard VDI 4203 Part 3, „Testing of automatic measuring systems - Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants“, September 2010 or August 2004 [2]
- 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
- Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of January 2010 [4]

3. Description of the tested measuring system

3.1 Measuring principle

The ambient air measuring system TEOM 1405-F Ambient Particulate Monitor is based on the measuring principle of oscillating micro weighing.

For the weighing principle, which is used in the TEOM mass transducer in the measuring system TEOM 1405-F Ambient Particulate Monitor, the change in mass determined with the sensor, results from the measurement of the change in frequency of the tapered element.

The tapered element at the heart of the mass detection system is a hollow tube, clamped on one end and free to oscillate at the other. An exchangeable TEOM filter cartridge is placed over the tip of the free end. The sample stream is drawn through this filter and then down the tapered element.

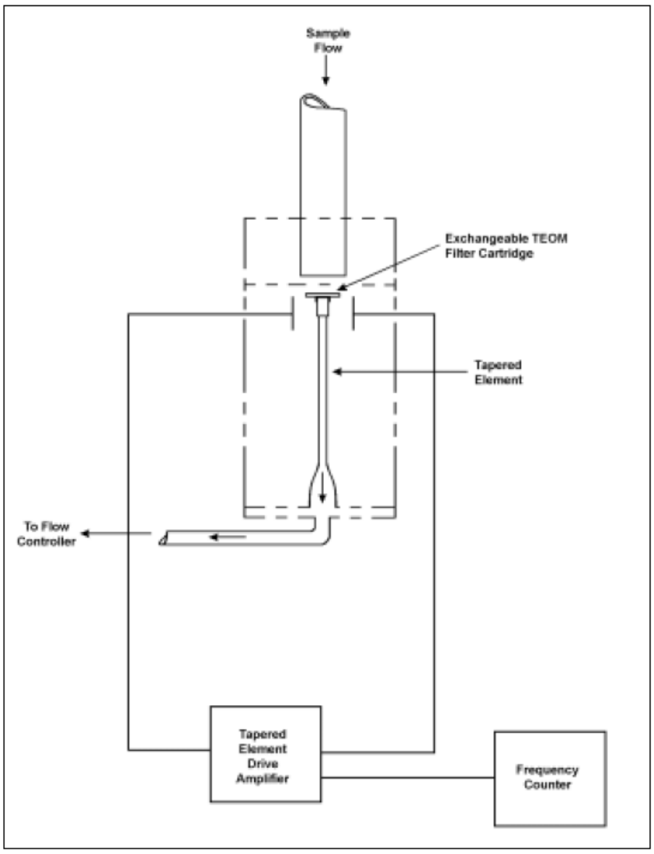

Figure 1: ***Schematic set-up of the mass transducer***

The tapered element oscillates precisely at its natural frequency, much like the tine of a tuning fork. An electronic control circuit senses this oscillation and, through positive feedback, adds sufficient energy to the system to overcome losses. An automatic gain control circuit maintains the oscillation at a constant amplitude. A precision electronic counter measures the oscillation frequency with a 10-second sampling period.

The tapered element is, in essence, a hollow cantilever beam with an associated spring rate and mass. As in any spring-mass system, if additional mass is added, the frequency of the oscillation decreases. This can be seen by observing the frequency on the display of the device, and operating the monitor both with and without a filter in place

In a spring-mass-system the frequency is obedient to the following equation:

$$F = \sqrt{\frac{K}{M}}$$

With F = Frequency

K = Spring rate

M = Mass

K and M are consistent units. The relation between mass and frequency change can me expressed as follows:

$$dm = K_0 \left(\frac{1}{f_1^2} - \frac{1}{f_0^2} \right)$$

with dm = Mass change

K_0 = Spring constant (incl. of the mass conversion)

f_0 = Initial frequency [Hz]

f_1 = End frequency [Hz]

After transposing the equation, it can be solved for the spring constant K_0.

$$K_0 = \frac{dm}{\frac{1}{f_1^2} - \frac{1}{f_0^2}}$$

Therefore, K_0 (= calibration constant of the device) can be determined easily by measuring the frequencies with and without known mass (e.g. with a pre-weighed TEOM-Filter from the K_0-calibration kit).

3.2 Functionality of the measuring system

The particle sample passes the $PM_{2.5}$ pre-separator, consisting of a PM_{10} sampling inlet and a $PM_{2.5}$ Sharp Cut Cyclone, with a flow rate of 16.67 l/min (=1 m³/h). Subsequently, the flow is directed over a flow-splitter and divided into two sub-flows – the $PM_{2.5}$-flow of 3 l/min and the bypass-flow of 13.67 l/min. The $PM_{2.5}$-flow is directed to the actual measuring system TEOM 1405-F via the FDMS-unit. There it is secreted to the respective TEOM-filter (constantly heated at 30 °C) and the secreted mass of particles is quantified.

To take into account non-volatile as well as volatile particulate during the measuring, the FDMS technology is used. The FDMS-unit is placed between the flow-splitter and the measuring device TEOM 1405-F in the so called FDMS-tower. The FDMS-unit compensated automatically the part of the semi-volatile particulate using a switching valve and two operation modi – the base mode and the reference mode.

Every six minutes the switching valve changes the sampling flow rate from base to reference mode. In the base mode the sampling is done on a straight way via a dryer directly to the mass measuring. In the reference mode the air flow is directed through a cooled filter after the dryer, to remove and restrain the non-volatile and volatile part of the particulate from the sample. During normal operation the temperature of the cooler is maintained at constantly 4°C.

Based on the mass concentration measuring during the base- and reference-modi, the FDMS-system updates every six minutes the 1h-average of the following results:

Base-MC	=	Particle concentration of the particle-loaded sampling flow.
Ref-MC	=	Particle concentration of the particle-free sampling flow after passing through the cooled filter.
MC	=	Base-MC adjusted for Ref-MC Base-mass-concentration (normally positive) minus reference-mass-concentration (negative, in case mass of the filter evaporates).

After the mass determination, the sampling flows are directed over a mass flow rate regulator. To guarantee a constant sampling volume flow at the inlet, taking into account the ambient temperature and pressure, the volume flow control shall be operated in the mode „active/ actual“.

3.3 AMS scope and layout

The particulate ambient air measuring device TEOM 1405-F Ambient Particulate Monitor is based on the measuring principle of oscillating micro weighing.

The tested measuring unit consists of PM_{10}-sampling inlet, $PM_{2.5}$ Sharp Cut Cyclone, flow splitter, the respective sampling tubes, a tripod to support the sample tubes, the measuring device TEOM 1405-F incl. FDMS-tower, the vacuum pump with its respective power supply cord and cables as well as adapters, the roof lead-through incl. a flange and a manual in German/English.

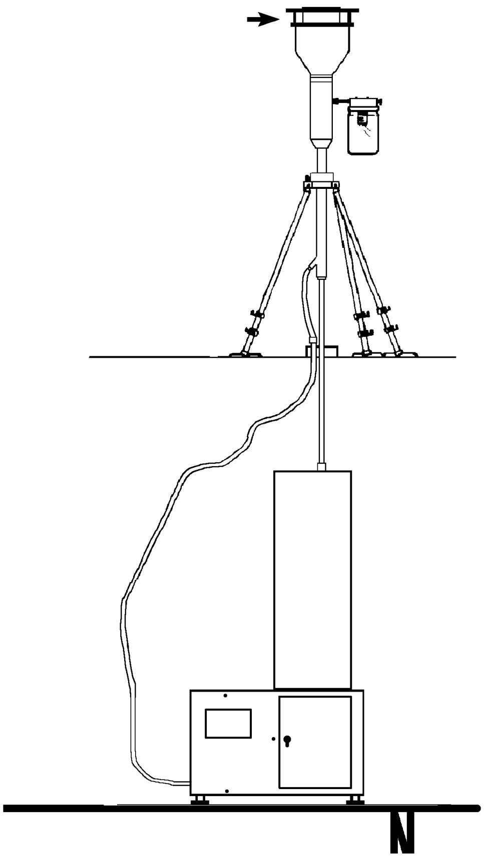

Figure 2: Overview of complete system TEOM 1405-F Ambient Particulate Monitor

Figure 3: ***American PM_{10}-sampling inlet (Original style, p/n 57-000596-0001) for TEOM 1405-F Ambient Particulate Monitor***

Figure 4: ***$PM_{2.5}$ Sharp Cut Cyclone for TEOM 1405-F Ambient Particulate Monitor***

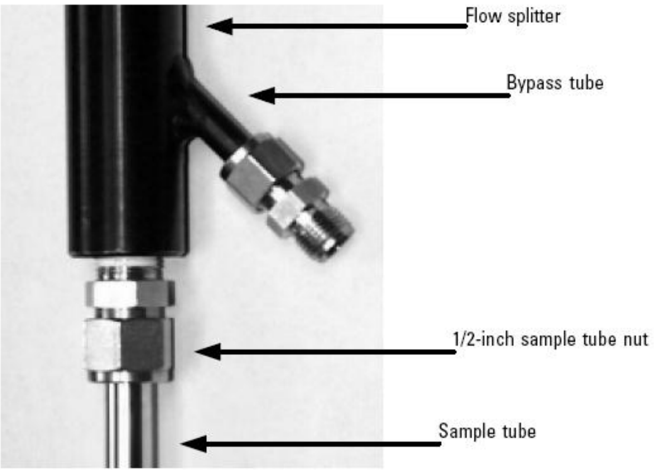

Figure 5: Flow-splitter

Figure 6: Measuring device TEOM 1405-F Ambient Particulate Monitor

Figure 7: ***Measuring device TEOM 1405-F Ambient Particulate Monitor (1st system from left) in measuring station***

Figure 8: ***Vacuum pump (p/n 10-011413)***

The measuring device is operated via touch screen at the front of the device. The user can retrieve data and instrument information, change parameters as well as perform tests and controls of the functionality of the measuring device.

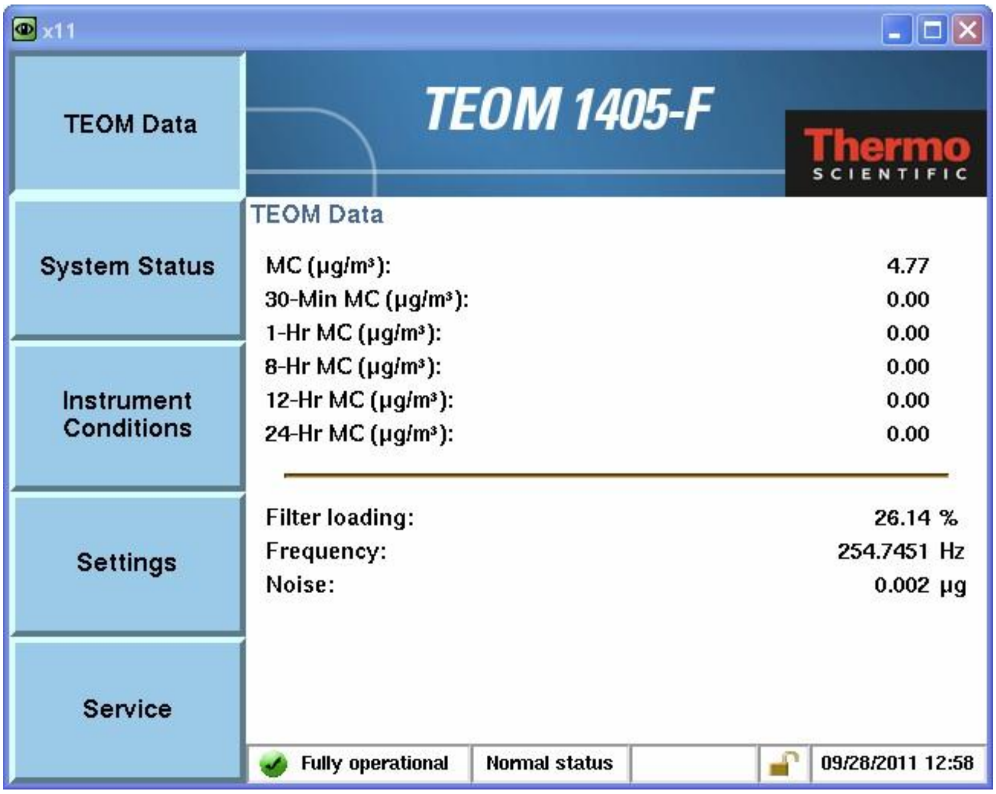

Figure 9: Main window of the user display

On the first level the main window of the user display is located – here the current time, the current date, the instrument status (normal/ warning), the current operational condition (e.g. fully operational, stabilizing…), the mass concentration values (MC (= moving hourly mean, every 6 minutes updated), 30 min. (presently not implemented) 1h-, 8h-, 12h- and 24h-averages), the vibration frequency, the noise of the mass measuring and the loading of the TEOM-filter are displayed.

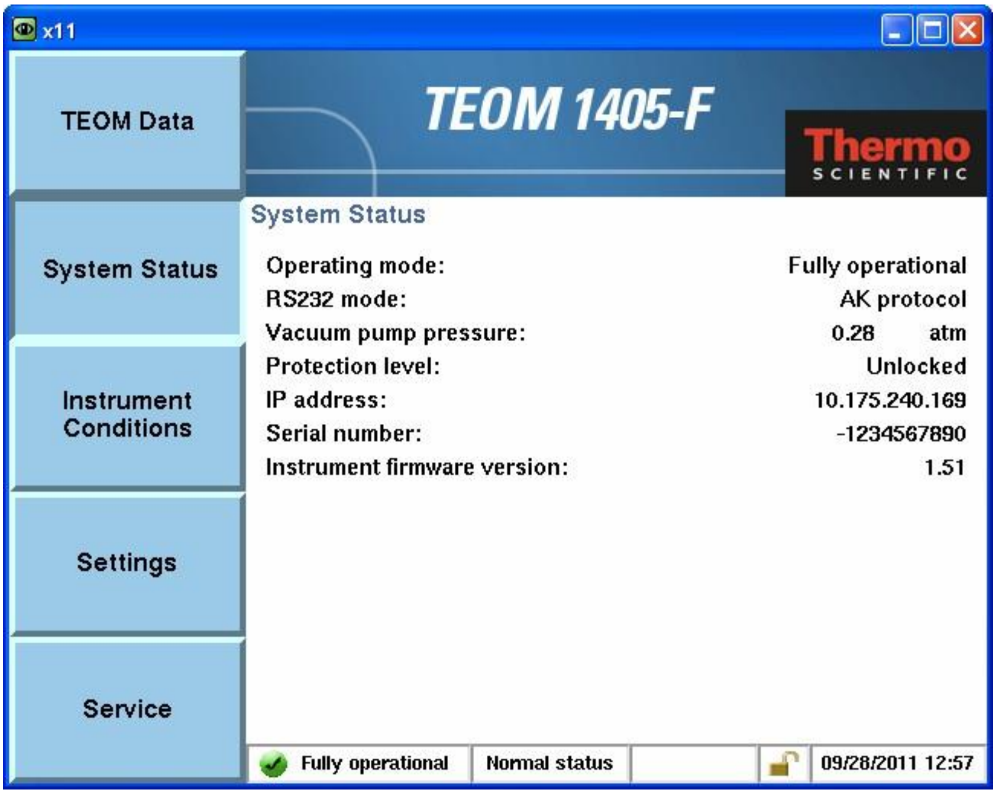

Figure 10: ***Menu: System status (here software version 1.51)***

In the menu „System Status“, status information of the instrument can be looked at. At this place, also the current software version can be looked at.

Note:

The testing was performed with software version 1.51 (2009).

During the testing the software was constantly developed and optimized up to the version 1.55. During the development, problems with the touch screen display were resolved, e.g. there have been problems with the button „reboot“ during a possible system crash.

Finally the manufacturer Thermo Fisher Scientific carried out a further update of the software to the now current version 1.56.

The carried out modifciations from 1.55 to 1.56 comprise the following points:

- As default the measuring devices record each 6 minutes the updated moving hourly average values. In the past the measuring system started immediately after reaching the status „ready for measurement“ with the determination and recording of the measured values in the 6-min interval without taking care of a correct syn-chronisation to the full hour. Because of this, sometimes no exact synchronisation of the measured values tot he full hour was possible. This is now changed by the software update, so that after the start of the measuring system, the system always first waits for the next full hour for determination and recording of the measured values and then stores the data in the following intervals hh:00 – hh:06 – hh:12 – hh:18 – hh:24…hh:54.. This update of the software increases easy operation of the measuring system and has no influence on the performance of the measuring system, because only the first hour after starting up the system might be affected by possible delays due to the applied change.

- Furthermore a couple of small bugs in the software have been corrected, which exclusively increase the safe operation of the systems and have no influence on the performance of the systems themselves.

No influence on the instrument performance is to be expected due to the realised changes up to the version 1.56.

In the case of warning messages an additional button appears in the centre of the display: „View Warnings“. After its confirmation, the pending warning messages can be looked at. In addition, an overview of the warning messages can be received at any time by clicking at the triangular warning symbols located at the right of the „TEOM Data“-button.

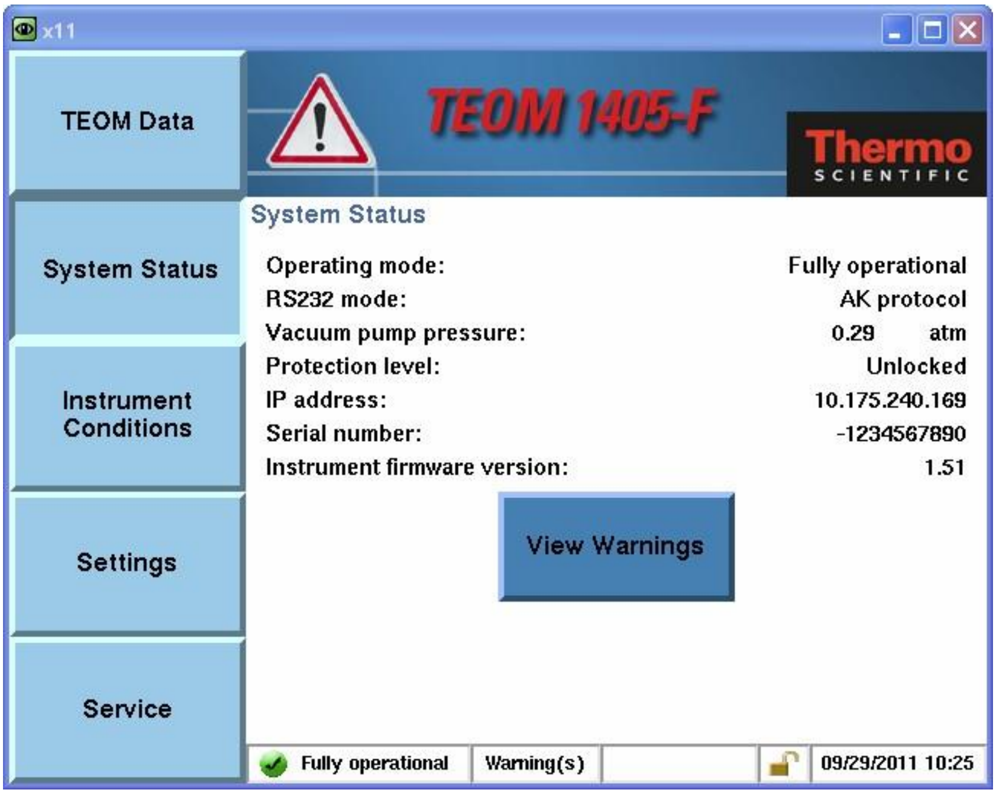

Figure 11: ***Warning messages display (triangular warning symbol + button „View Warnings")***

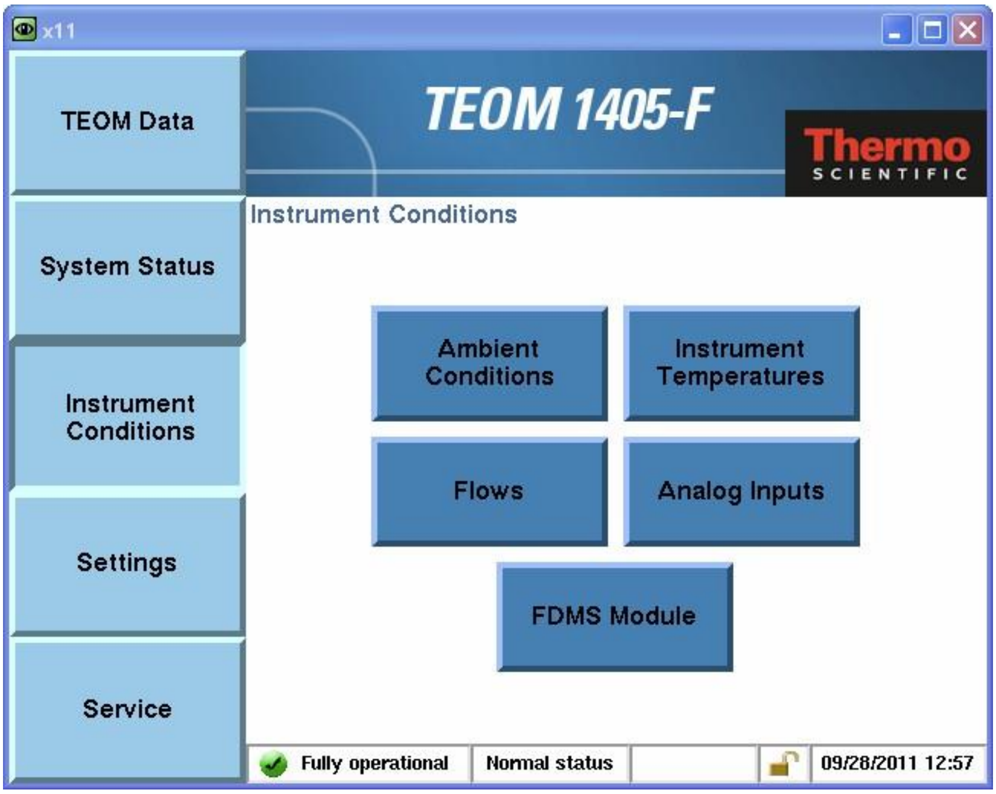

Figure 12: Menu: Instrument conditions

In the menu „Instrument conditions“, the user may control and modify different settings of the instrument regarding temperature and flow rates as well as inform him about ambient conditions of the instrument.

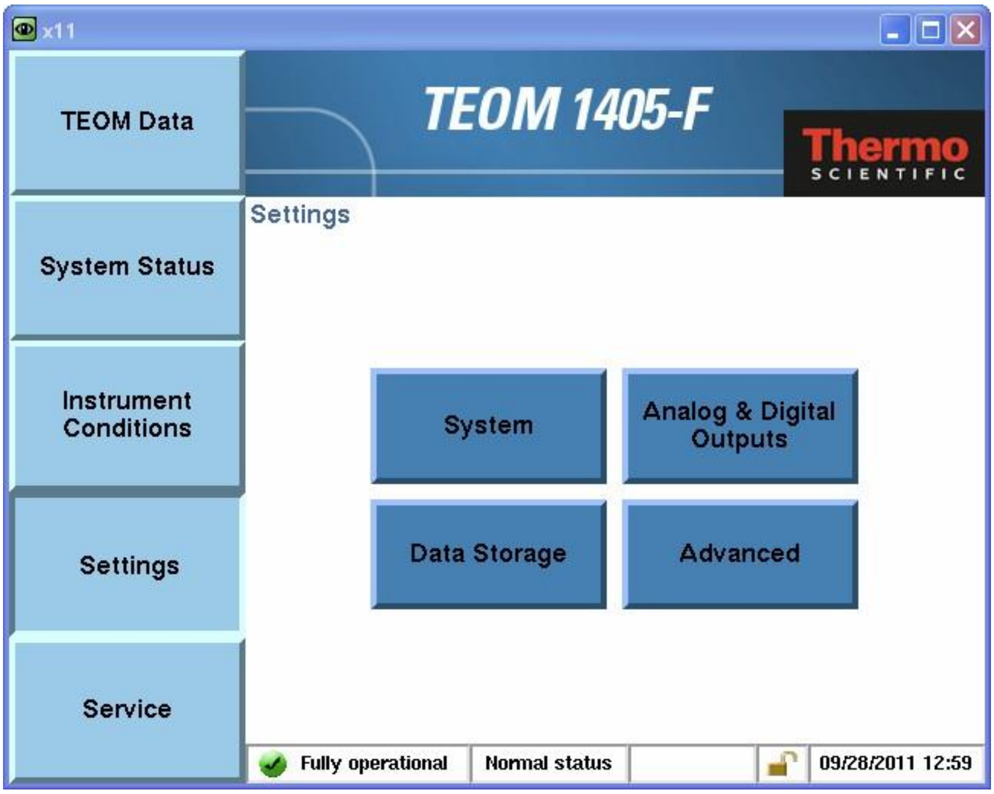

Figure 13: ***Menu: Settings***

In the menu „Settings“, the user has access to system-, data- and advanced settings. At this point e.g. date/ time can be set, the password protection can be activated, analogue and digital output can be parameterized or the calibration constant K_0 can be displayed.

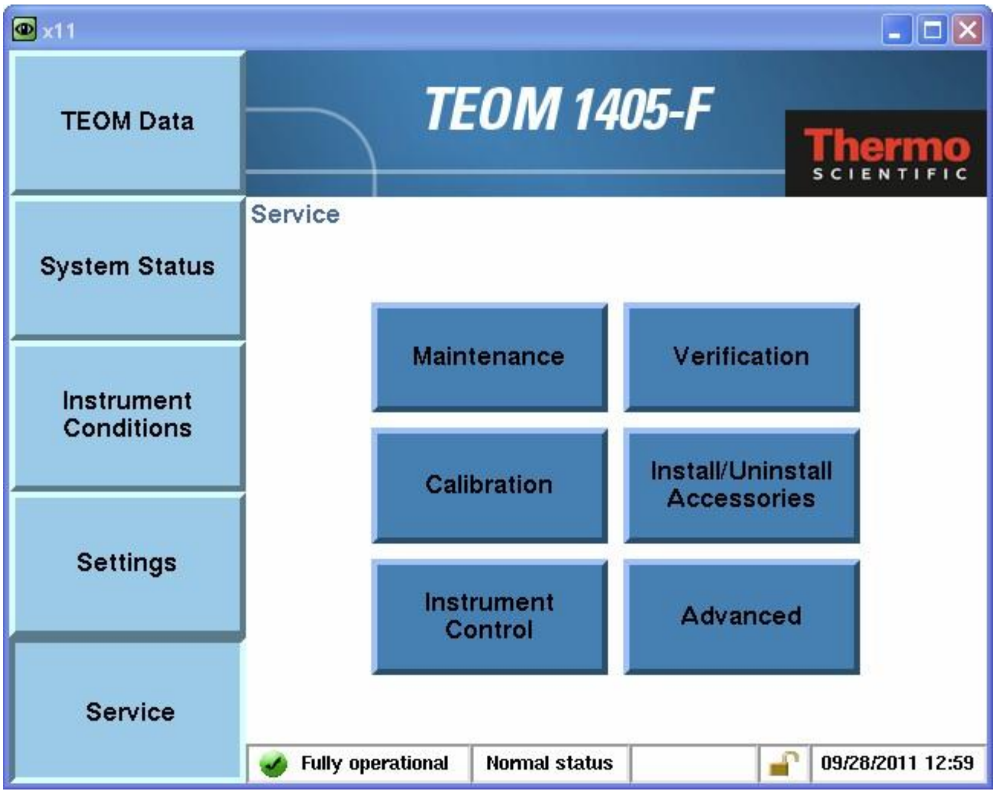

Figure 14: Menu: Service

In the menu „Service“, all implemented procedures for the instrument maintenance (e.g. change of TEOM-filter, cleaning of the cooler etc.), instrument checking (flow rate, leak test, check of the calibration constant K_0…), instrument calibration (flow rate, temperature- and pressure sensors) and other functionalities can be obtained.

By using the maintenance assistant of the software, the user is lead step by step through maintenance- and audit-work via different screens. Therefore no manual is needed at the test site for the performance of this work.

Besides the direct communication via operating keys/ display, extensive possibilities exist to communicate via different analogue outputs, RS232-interfaces, USB-interfaces as well as Ethernet-interfaces.

The following possibilities are available:

- 1 x 25-pin USER I/O interface for analogue in- and output and digital output.
- 1 x RS232-interface for the communication via RP Comm or HyperTerminal software
- 1 x Ethernet-interface for the connection to a PC for the data transfer and remote control via ePort software.
- 2 x USB-interfaces for direct data download and firmware update.

For the external zero point check of the measuring system and for the check of the calibration constant K_0, a zero-filter is installed at the instrument inlet. The use of this filter enables the provision of particulate-free air.

Figure 15: Zero-filter during field test

By means of the available shut-off valve, a leak test of the measuring system according to chapter 3 of the manual can also be performed with the zero-filter.

To check the calibration constant K_0 a special filter kit with pre-weighed TEOM-filters is used.

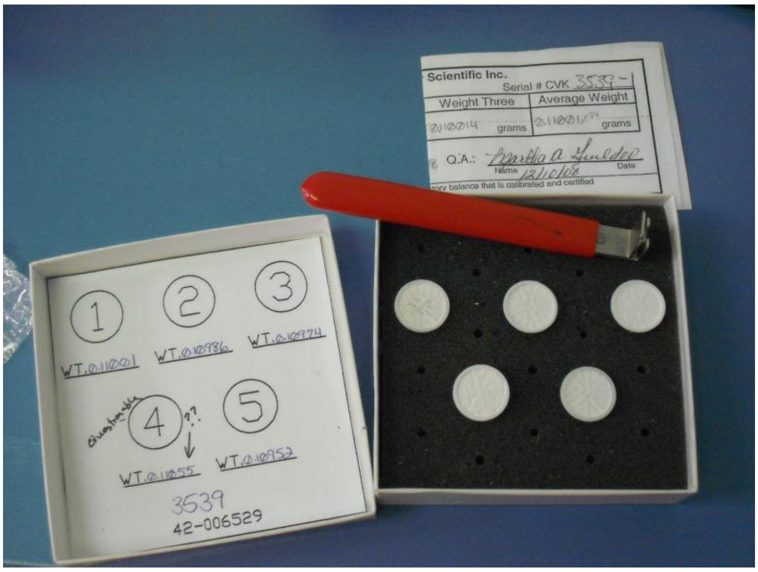

Figure 16: Set of filters for the check of the calibration constant K_0

Within the scope of the testing, after the test site "Teddington" a modification of the measuring system from configuration C to D was made. In doing so the following components were changed:

Table 2: Instrument modifications after field test site „Teddington"

No.	Component	Configuration C	Configuration D	Reason	Assessment
1	Mass Transducer Hinge	Belville washer spring with machined hinge blocks	Coil compression spring	Simplification of the manufacturing	No influence on the instrument performance
2	Mass Transducer Latch	High force screw latch	Consistent force hook latch	Simplification of the operability	No influence on the instrument performance
3	Mass Transducer Shipping Bracket	Not available	Removable plate couples mass transducer to enclosure	For the protection of the device during transport.	No influence on the instrument performance
4	Air Tube, Tower top interface	Rubber isolators between bulkhead fitting and cover	Direct connection using bulkhead fitting	Simplification of the manufacturing	No influence on the instrument performance
5	Diverter valve shipping bracket	Not available	Bracket coupling valve to tower	For the protection of the device during transport.	No influence on the instrument performance
6	Air tube / Valve coupler	Direct connection between weldment air tube and valve fitting	Sorbothane isolator between weldment air tube and valve fitting	Higher flexibility, compensation of thermal stress in the material.	Improvement of the instrument performance due to increased operating reliability.

The change was made after the performance of the field test site in England. In the following lab test and the three field test campaigns in Germany, no negative influence on the instrument performance could be observed.

Table 3 contains a list of the most important device-related characteristics of the particulate ambient air measuring device TEOM 1405-F Ambient Particulate Monitor.

Table 3: Device-related characteristics TEOM 1405-F Ambient Particulate Monitor (manufacturer information)

Dimensions / Weight	**TEOM 1405-F Ambient Particulate Monitor**
Measuring device	432 x 483 x 1400 mm / 33 kg (without pump)
Sampling tube	approx. 0,3 m between Inlet / SCC and Flow-Splitter + 1 m between Flow-Splitter and inlet of central unit
Sampling inlet	US, Original Style
Energy supply	100/115/230 V, 50/60 Hz
Power input	Approx. 100-130 W (normal operation), central unit Approx. 550-600 W (normal operation), pump
Ambient conditions	
Temperature	+8 to +25 °C
Humidity	Non condensing
Sampling flow rate (Inlet)	16,67 l/min = 1 m³/h
Flow-rate PM_{10}-Path Flow-rate Bypass	3 l/min 13,67 l/min
Filter material (TEOM)	Pallflex TX40
Mass measured values	MC moving 1h-average, updated every 6 minutes 1-Hr-MC moving 1h-average, updated every 60 minutes on the full hour 8-Hr-MC moving 8h-average, updated every 60 minutes on the full hour 12-Hr-MC moving 12h-average, updated every 60 minutes on the full hour 24-Hr-MC moving 24h-average, updated every 60 minutes on the full hour
Detector	Mass transducer
Checks	Cont.: Noise < 0,1 µg Frequency in the range 150-400 Hz Discont.: Check of the calibration constant K_O

Parameter instrument temperatures	
Nominal value for the following instrument temperatures:	
Mass transducer cap	30 °C
Mass transducer case	30 °C
$PM_{2.5}$ air tube	30 °C
Parameter FDMS	
Dryer type	NAFION-Dryer, Type C
Temperature dryer (normal conditions):	4 °C
Dew point of the air flows (normal conditions):	at >2 °C Warning message
Pump vacuum:	> 510 mm Hg
Storage capacity data (internal)	500.000 Data set (>2000d when storage in a 6-minute interval)
Device in- and outputs	1 x 25-pin USER I/O interface for analogue in- and output and digital output 1 x RS232 interface for the communication via RP Comm Software or AK Protocol 1 x Ethernet-interface for the connection with a PC for data transfer and remote control via ePort Software 2 x USB-interfaces for the direct data download and for Firmware-update
Status signals / error messages	Available, overview see annex A of the instruction manual

4. Test program

4.1 General

The suitability test has been performed with two identical devices with the serial numbers SN 20012 and SN 20121.

The test was performed with firmware version 1.51.

During the testing the software was constantly developed and optimized up to the version 1.56. During the development problems with the touch screen display were resolved, e.g. there have been problems with the button „reboot" during a possible system crash. Furthermore it is now implemented, that after a start of the measuring system, the system always waits for the next full hour for determination and recording of the measured values.

No influences on the system performance are expected from the changes which were made on the firmware up to version 1.56.

The laboratory tests for the determination of system characteristics were followed by a field test of several months at different test sites.

All concentrations, determined under operational conditions, are presented in µg/m³ (operational conditions).

The following report comprises a description of each minimum requirement according to standards [1, 2, 3, 4] in number and wording.

4.2 Laboratory test

The laboratory test was carried out with two identical devices of TEOM 1405-F Ambient Particulate Monitor measuring system with the serial numbers SN 20012 and SN 20121. According to the Standards [1, 2], the following test program was specified for the laboratory test:

- Description of system functions
- Determination of detection limits
- Determination of the dependence of zero point / sensitivity on ambient temperature
- Determination of the dependence of zero point / sensitivity on the mains voltage
- Sampling flow stability check

The following devices were used to determine the system characteristics during laboratory test:

- Climate chamber (temperature range from –20 °C to +50 °C, accuracy better than 1 °C)
- Adjustable isolating transformer
- Zero-filter for external zero point check.
- K_0-check kit

The measured values were recorded in the devices. The stored measured values were read out *via* Data download via USB.

Section 6 describes the laboratory tests and the results.

4.3 Field test

The field test was carried out with two identical systems with the serial numbers:

Device 1: SN 20012

Device 2: SN 20121

The following test program was specified for the field test:

- Determination of the comparability of the candidates according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"
- Determination of the comparability of the candidates and the reference methods according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"
- Sampling flow stability check
- Determination of the calibration ability and set-up of analysis function
- Determination of field reproducibility
- Determination of drift behaviour of zero point and sensitivity
- Investigation on the tightness of the sampling system
- Investigation of the dependency of the measured values on humidity
- Determination of the maintenance interval
- Determination of availability
- Determination of the total uncertainty of the candidates.

The following devices were used for the field test:

- Measurement cabinet of TÜV Rheinland, air-conditioned to approx. 20 °C
- Weather station (WS 500 of the company ELV Elektronik AG) for the determination of meteorological characteristics such as air temperature, air pressure, air humidity, wind velocity, wind direction and rainfall
- Two reference samplers LVS3 for$PM_{2.5}$ according to point 5
- Gas meter, dry
- 1 mass flow rate measuring device Type 4043 (Manufacturer: TSI)
- Measuring device Metratester 5 (Manufacturer: company Gossen Metrawatt) for the determination of power consumption
- Zero-filter for external zero point check
- K_0-check kit.

Two TEOM 1405-F Ambient Particulate Monitor-systems and two reference devices for $PM_{2.5}$ were simultaneously operated for 24 h each during the field test. The reference equipment operates discontinuously, i.e. the filters must be changed manually after each sample.

The impaction plates of the $PM_{2.5}$ sampling inlets of the reference devices were cleaned approx. every 2 weeks and lubricated with silicone-grease, in order to guarantee a safe separation and secretion of the particulate. The PM_{10} sampling inlets and the $PM_{2.5}$ Sharp Cut Cyclones of the candidates were cleaned approx. every 4 weeks. In general the sampling inlet shall be cleaned according to the manufacturer's instructions while taking into account the local suspended particulate matter concentrations.

The flow rate was tested on each candidate and each reference device prior to and after each change of location with a dry gas meter respectively a mass flow meter, which could be connected to the air inlet of the systems *via* a hose assembly.

Measurement test sites and test site of the measuring devices

The measuring devices have been installed in the field test in such a way, that only the sampling inlets, Sharp Cut Cyclones and the flow splitter are located above the roof of the measurement cabinet. The central units of both candidate systems as well as the central units of the reference systems LVS3 were installed inside the climate-controlled measurement cabinet.

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

Table 4: Field test sites

No.	Measuring test site	Period	Characterization
1	Teddington (UK)	12/2009 – 07/2010	Urban background
2	Cologne, parking lot, winter	01/2011 – 05/2011	Urban background
3	Bornheim, motorway parking lot, summer	07/2011 – 11/2011	Rural structure + traffic influence
4	Bornheim, motorway parking lot, winter	11/2011 – 02/2012	Rural structure + traffic influence

Figure 17 to Figure 19 show the course of time of the $PM_{2.5}$-concentrations at the field test sites, which were recorded with the reference measuring device.

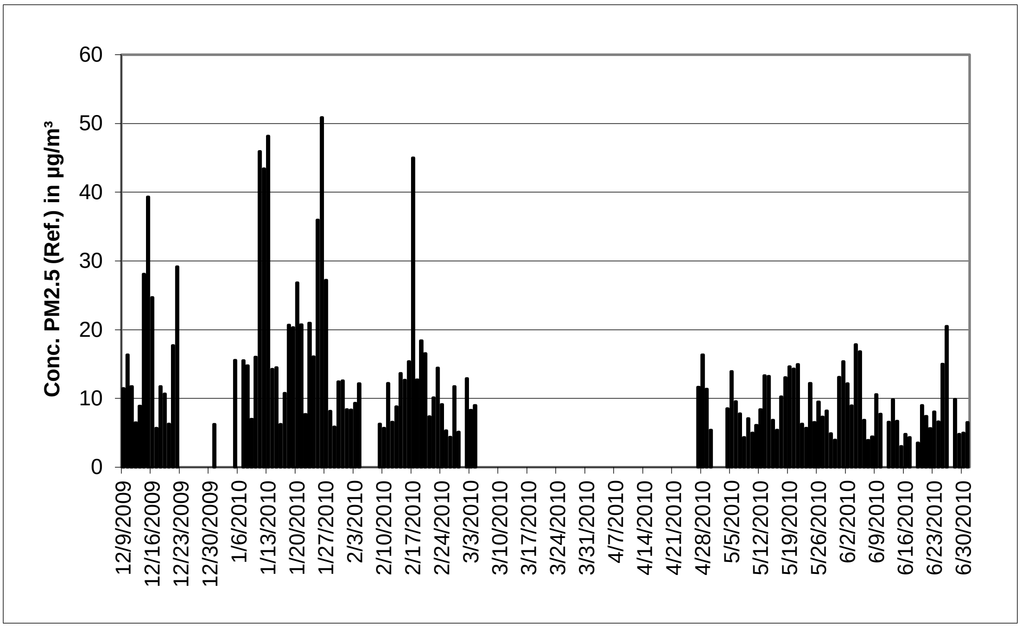

Figure 17: ***Course of time of the $PM_{2.5}$-concentrations (Reference) at the test site „Teddington“***

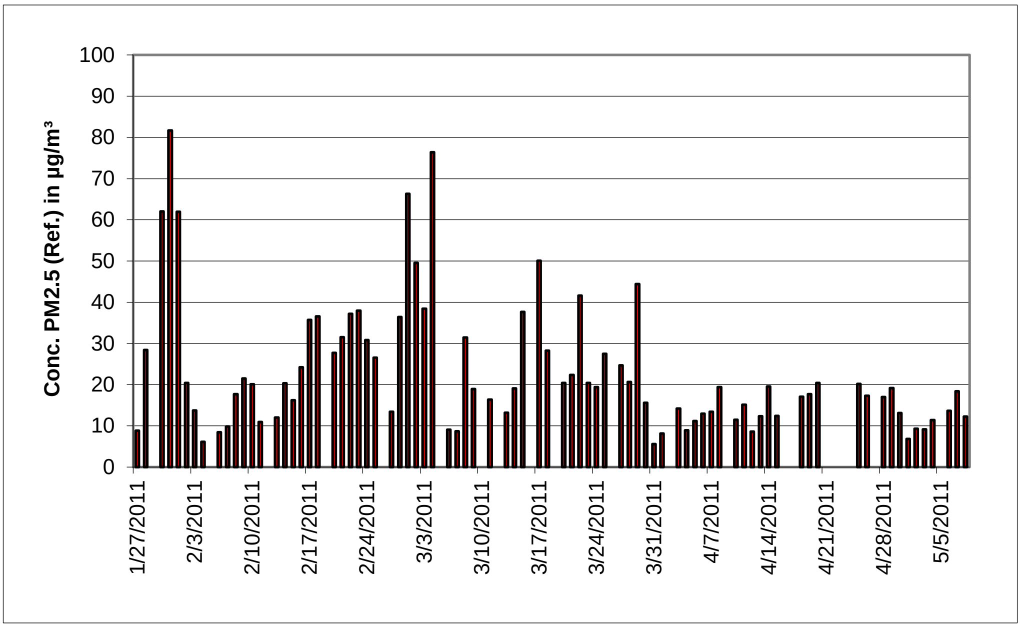

Figure 18: ***Course of time of the $PM_{2.5}$-concentrations (Reference) at the test site „Cologne, parking lot, winter***

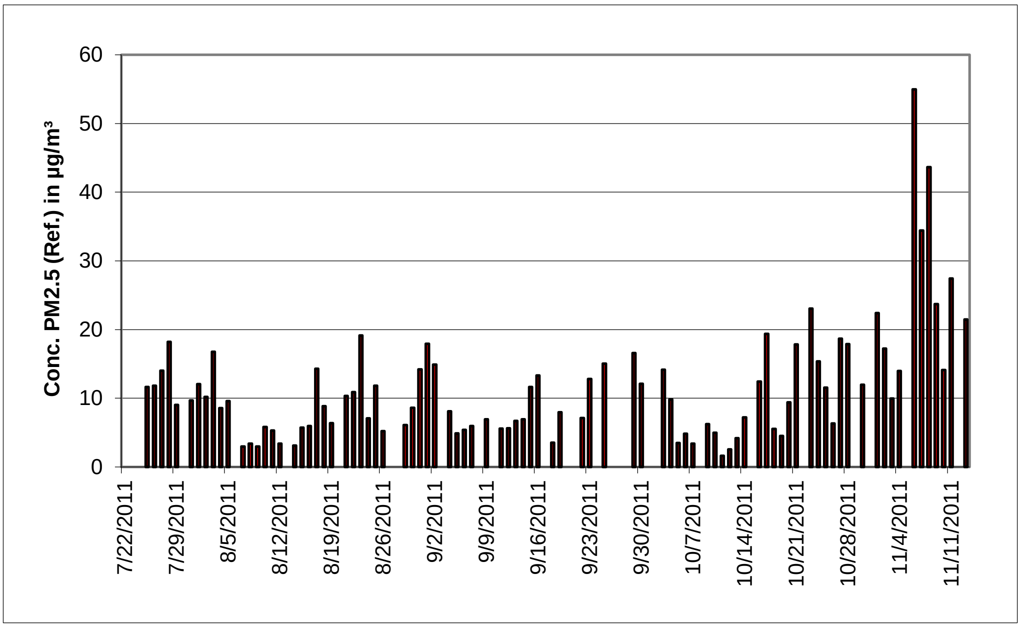

Figure 19: ***Course of time of the PM$_{2.5}$-concentrations (Reference) at the test site „Bornheim, motorway parking lot, summer“***

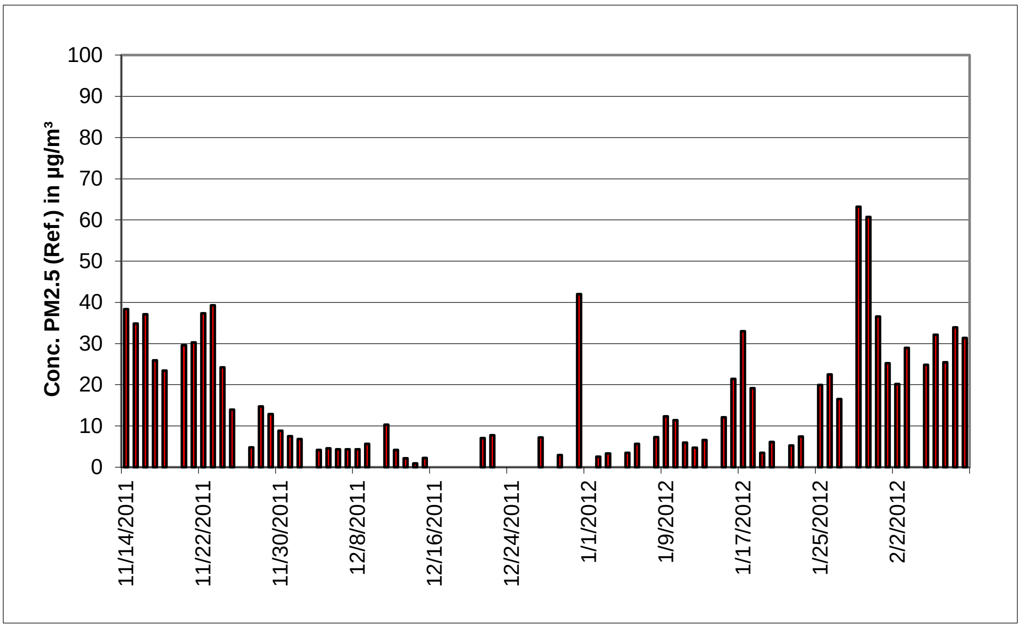

Figure 20: ***Course of time of the PM$_{2.5}$-concentrations (Reference) at the test site „Bornheim, motorway parking lot, winter“***

The following figures show the measuring cabinet at the field test sites Teddington, Cologne (parking lot) and Bornheim (motorway parking lot)

Figure 21: Field test site Teddington

Figure 22: Field test site Cologne, parking lot

Figure 23: Field test site Bornheim, motorway parking lot

Besides the measuring device for the determination of particulate ambient air, a device for the determination of meteorological characteristics was installed at the cabinet/ measuring test site. A continuous determination of ambient temperature, ambient pressure, relative humidity, wind velocity, wind direction and the amount of precipitation was made. The 30 min. averages were recorded.

The installation of the cabinet itself and the arrangement of the sampling probes were characterized by the following dimension.

- Height cabinet roof: 2.50 m
- Height of the sampling for the Candidate-/ 1.10 m / 0.51 m above the cabinet roof
- Reference device 3.61 / 3.01 m above ground
- Height of the wind vane: 4.5 m above ground

The following Table 5 contains therefore not only an overview on the most important meteorological data of the four test sites but also an overview on the PM conditions during the test. Refer to section 5 and 6 for detailed results.

Table 5: Ambient conditions at the field test sites, expressed as daily averages

	Teddington (UK)	Cologne. parking lot, winter	Bornheim, motorway parking lot, summer	Bornheim, motorway parking lot, winter
No. of paired values reference	128	81	87	65
Ratio $PM_{2.5}$ / PM_{10} [%]				
Range	30.2 – 92.3	38.8 – 93.5	27.1 – 88.1	31.1 – 90.9
Average	63.9	67.7	57.3	65.7
Ambient temperature [°C]				
Range	-3.7 – 23.2	-3.8 – 22.1	5.2 – 24.5	-8.9 – 12.2
Average	8.5	8.8	15.5	3.9
Ambient pressure [kPa]				
Range	979 – 1037	992 – 1031	995 – 1024	976 – 1031
Average	1009	1013	1008	1012
Rel. humidity [%]				
Range	43.9 – 98.3	34.2 – 94.2	53.8 – 91.1	50.2 – 94.4
Average	77.2	67	75.1	79.0
Wind velocity [m/s]				
Range	0.0 – 2.5	0.3 – 7.1	0.3 – 4.1	0.4 – 7.8
Average	0.7	2.3	1.4	2.4
Precipitation [mm]				
Range	0.0 – 23.1	0.0 – 33.0	0.0 – 51.7	0.0 – 16.4
Average	1.6	1.4	2.7	2.1

Sampling period

EN 14907 defines a sampling period of 24 h ± 1 h.

The sampling period was constantly set to 24 h during the field tests (10 am – 10 am (Teddington and Cologne) and 7 am – 7 am (Bornheim)).

Data handling

All paired reference values, determined during the field tests, were subject to statistical testing according to Grubbs (99 %) to prevent influences of obviously implausible data on the measuring results. Paired values, which are identified as significant outliers can be discarded until the critical value of the test statistic is exceeded. The January 2010 version of the Guidance [4] stipulates that not more than 2.5 % of the paired values in total for each field test site may be identified and removed as outliers.

Within the scope of the „Combined MCERTS and TÜV PM Equivalence Testing“ program we agreed with our British partners not to discard any measured value for the candidates, unless the implausibility is caused due to technical reasons. During the entire testing period, no measured value of the candidates was discarded.

Table 6 shows an overview on the amount of paired values (reference) which were recognized and removed as significant outliers at each test site.

Table 6: ***Results Grubbs-outlier test – Reference $PM_{2.5}$***

Graph Number	Site	Sampler	Number of data-pairs	Maximum Number that can be deleted	Number Identified	Number Deleted	Number of data-pairs remaining
A	Bornheim Winter	$PM_{2.5}$ Reference	65	2	0	0	65
B	Cologne Winter	$PM_{2.5}$ Reference	83	2	2	2	81
C	Bornheim Summer	$PM_{2.5}$ Reference	87	2	0	0	87
D	Teddington	$PM_{2.5}$ Reference	129	3	1	1	128

The following data pairs were removed:

Table 7: Removed data pairs reference $PM_{2.5}$ according to Grubbs

Test site	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Teddington	06.01.2010	13.5	16.0
Cologne (Winter)	16.03.2011	55.0	57.8
Cologne (Winter)	05.05.2011	11.2	14.8

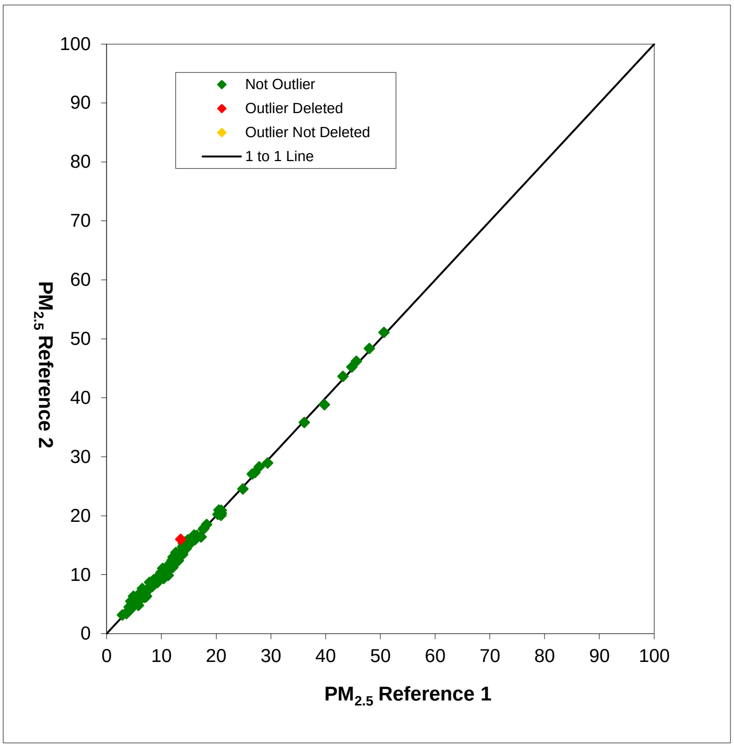

Figure 24: Grubbs test results for the $PM_{2.5}$ reference method, Teddington

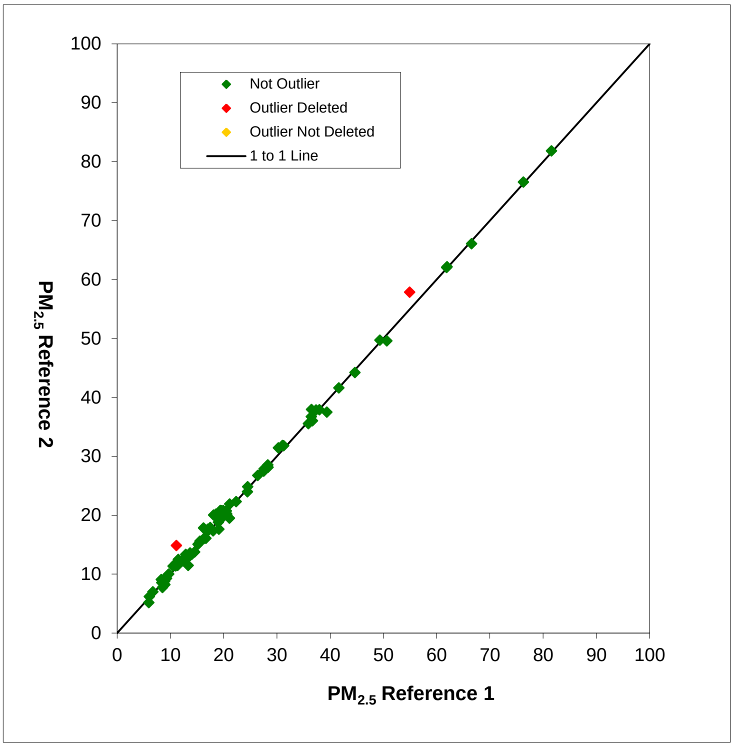

Figure 25: Grubbs test results for the $PM_{2.5}$ reference method, Cologne (winter)

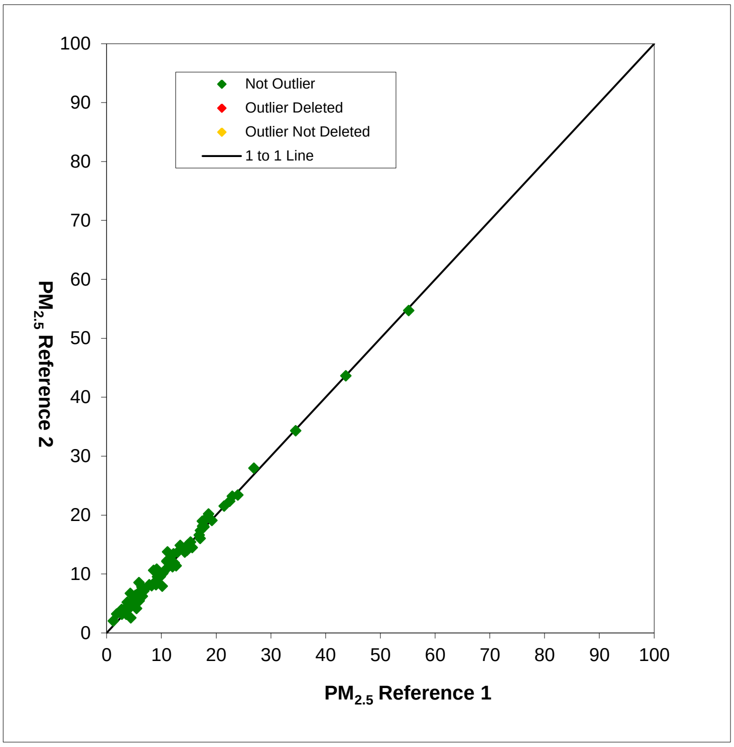

Figure 26: Grubbs test results for the $PM_{2.5}$ reference method, Bornheim (summeri)

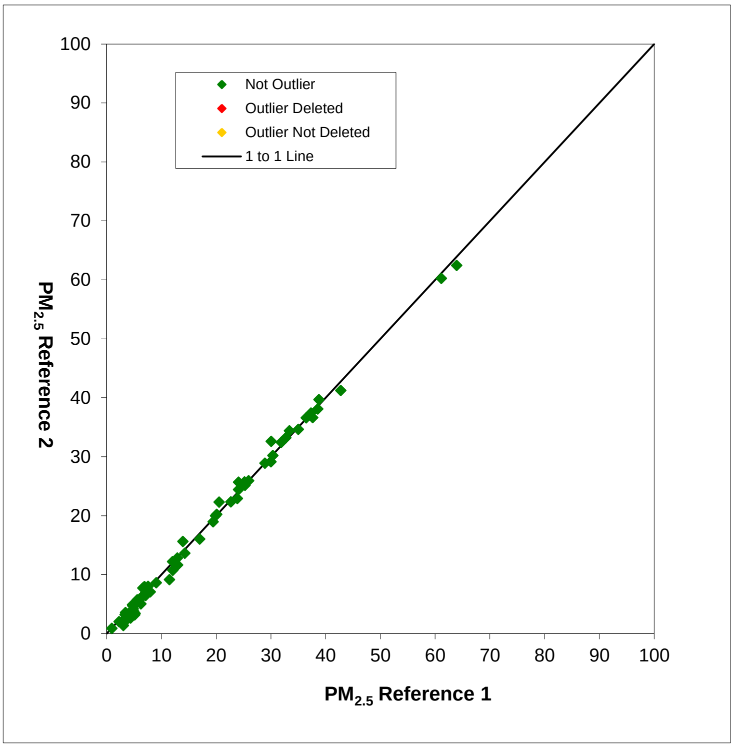

Figure 27: ***Grubbs test results for the $PM_{2.5}$ reference method, Bornheim (winter)***

Filter handling – Mass determination

The following filters were used for the suitability testing:

Table 8: Used filter materials

Measuring device	Filter material, type	Manufacturer
Reference value LVS3	Emfab™, ∅ 47 mm	Pall

The filter material EMFAB™ (Teflon-coated glass fibre filters) was used in the scope of the „Combined MCERTS and TÜV PM Equivalence Testing“ program by special request of our British partners, because according to [8], they consider it most appropriate for the test purpose.

The filter handling is according to the requirements of EN 14907.

The procedures of filter handling and weighing are described in detail in Appendix 2 of this report.

5. Referenzmessverfahren

The following devices were used during the field test in accordance with EN 14907:

1. Reference equipment for $PM_{2.5}$:

Small filter device ”Low Volume Sampler LVS3”
Manufacturer: Ingenieurbüro Sven Leckel, Leberstraße 63, Berlin, Germany
Date of manufacture: 2007
$PM_{2.5}$- Sampling inlet

Two reference devices each for $PM_{2.5}$ were simultaneously operated during the testing with a controlled volume flow of 2.3 m^3/h. The accuracy of the volume flow control is below <1 % of the nominal volume flow under standard conditions.

The sampling air is sucked in *via* the rotary vane vacuum pump through the sampling inlet for the small filter device LVS3. The sampling air volume flow is measured with a measuring orifice which is installed between filter and vacuum pump. In order to collect any dust created by the abrasion of the vanes, the incoming air passes a separator before flowing to the air outlet.

The electronic measuring equipment of the LVS3 small filter device displays the incoming sampling air volume in standard or operating m^3 as soon as the sampling is complete.

To determine the $PM_{2.5}$ concentration, the laboratory performed a gravimetric determination of the amount of suspended particulate matter on the respective filters. The obtained result was then divided by the respective volume of sampling air in operating m^3.

6. Test results

6.1 4.1.1 Measured value display

The measuring system shall be fitted with a measured value display.

6.2 Equipment

No additional devices are needed.

6.3 Performance of test

It was checked whether the measuring device has a display for measured values.

6.4 Evaluation

The measuring device has a display for measured values. The following values are displayed:

MC	Mass concentration, moving 1h-average, updated every 6 minutes.
30-Min-MC	not working at the moment
1-Hr-MC	moving 1h-average, updated every 60 minutes every full hour.
8-Hr-MC	moving 8h-average, updated every 60 minutes every full hour.
12-Hr-MC	moving 12h-average, updated every 60 minutes every full hour.
24-Hr-MC	moving 24h-average, updated every 60 minutes every full hour.

6.5 Assessment

The measuring device comprises a measured value display.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Figure 28 shows the user's display with the current measured concentration values.

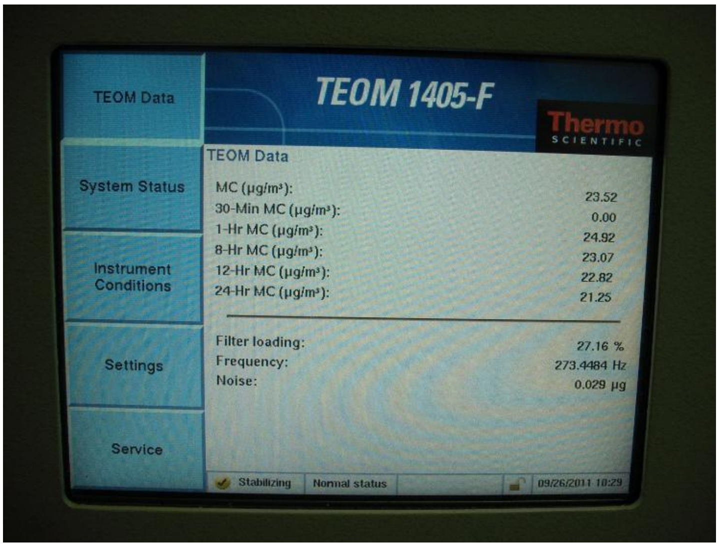

Figure 28: Display of the measured concentration value

6.1 4.1.2 Easy maintenance

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

6.2 Equipment

No additional equipment required.

6.3 Performance of test

Necessary regular maintenance works were carried out according to the instructions of the operating manual.

6.4 Evaluation

The following maintenance works should be carried out:

1. Check of device status:
   The device status can be monitored and controlled by controlling the system itself or controlling it online.
2. In general the sampling inlet and the Sharp Cut Cyclone shall be cleaned according to the manufacturer's instructions taking into account the local suspended particulate matter concentrations (during suitability test every 4 weeks).
3. A monthly change of the TEOM-Filter (as well when a filter loading >90% is reached) is necessary.
4. Simultaneously with the change of the TEOM-filter, the cooled 47 mm-filter of the FDMS-unit has to be changed.
5. According to the manufacturer's instructions, a monthly check of the sensors for ambient air and ambient pressure shall be done.
6. According to the manufacturer's instructions, a monthly leak-check shall be done.
7. According to the manufacturer's instructions, a monthly check of the flow rate shall be done.
8. Every 6 months (or if necessary) the inline-filter for $PM_{2.5}$- and the Bypass-path shall be changed in order to avoid a contamination of the flow rate regulator.
9. Once a year (or if necessary) the cooler, the switching valve and the air inlet system shall be cleaned.
10. Once a year the calibration of the mass transducer has to be checked using the K_0-check kit.
11. Once a year (or if necessary) the dryer of the FDMS-unit shall be changed or refurbished. For the monitoring/ securing of a proper dryer performance, the manufacturer recommends to monitor a pump vacuum (nominal: > 510 mm Hg) and a dew point of the air flow (nominal: <2 °C at 4 °C cooler temperature) as well as to carry out periodical (at least once a year) zero point checks (running of the measuring device with zero-filter at the inlet).
12. Every 18 months (or if necessary) the sampler pump shall be maintained or renewed.

To carry out the maintenance works the instruction of the manual (chapter 5) are to be taken into account. All works can usually be carried out with commonly available tools.

6.5 Assessment

Maintenance works can be carried out with commonly available tools taking reasonable time and effort. For the maintenance works as per points 3, 4, 6 and 10, the device is switched to setup-mode. The restart of the normal measuring process occurs after one hour after having finished the check and after having left the setup-mode. The maintenance works as per points 8, 9, 11 and 12 can only be done when shutting off the measuring device. These works come up every 6 or 12 months. In the remaining time, maintenance works are limited to the check of contaminations, plausibility checks and eventual status/ error messages.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

The maintenance works were carried out during the test in accordance with the instructions given in the manual. No problems were noticed while following the described procedures. All maintenance works could be done with customary tools without taking much time and effort.

6.1 4.1.3 Functional test

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 Equipment

Manual, zero-filter, K_0-check kit

6.3 Performance of test

The device status is constantly monitored and problems are indicated by a series of different warning messages. Important parameters for a proper performance (e.g. noise of the mass measurement, flow rates, pump vacuum, dew point of the air sample) moreover can be looked up at the device itself or while recording the data.

Furthermore there is also the possibility to check the zero point of the measuring device externally. For this a zero-filter is installed at the device inlet. The use of this filter allows the provision of particle-free air.

Within the scope of the test work, a determination of the zero point by using the zero-filter was also performed approx. every 4 weeks.

Moreover, there is the possibility to check the calibration constant of the mass measurement externally. For this the calibration constant is determined using the K_0-check kit and afterwards compared with the nominal value stored within the device.

Within the scope of the check the calibration constant was determined at the beginning and the end of each test site.

6.4 Evaluation

All instrument functions, which are listed in the manual, are available and can be activated. The current status of the system is monitored continuously and problems are indicated by a series of different warning messages.

An external check of the zero point by using the zero-filter is possible at any time. An external check of the mass measured value transducer using the K_0-check kit also is possible at any time.

6.5 Assessment

All system functions listed in the manual are available, activatable and functioning. The current system status in continuously monitored and displayed by a set of different status messages (operation, warning and error messages.

The results of the external checks of the zero point with a zero-filter during the field test period as well as periodically performed checks of the calibration constant K_0 are described in chapter 6.1 5.3.12 Long-term drift of this report.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Refer to chapter 6.1 5.3.12 Long-term drift

6.1 4.1.4 Set-up times and warm-up times

The set-up times and warm-up times shall be specified in the instruction manual.

6.2 Equipment

A clock was required for this test.

6.3 Performance of test

The AMS were started up according to the description given by the manufacturer. Necessary setup- and warm-up times were recorded separately.

Necessary constructional works prior to the measurement, such as the installation of an inlet through the cabinet roof, were not included in this test.

6.4 Evaluation

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

The measuring system must be protected from weather inconsistencies e.g. in an acclimated measuring cabinet. Extensive construction work is required in order to lead the sample tube through the roof of a measuring cabinet. A non-stationary application is therefore only assumed together with the belonging peripheral devices.

The following steps are generally necessary for the installation of the measuring device:

- Unpacking and installation of the measuring system (in a rack or on a table)
- Connection of the sampling tube, flow splitter, tripod, Sharp Cut Cyclone and PM_{10}-sampling inlet
- Connection of the pump
- Mounting of ambient air sensor (nearby the sampling inlet)
- Connection of all connecting and control lines
- Connection of power supply
- Switch-on of the measuring system
- Performance of the leak test
- Installation of the TEOM-filter as well as the two 47 mm-filter
- Check of the instrument setting regarding die regulation of the flow rate (here: Active/Actual), date and time and the parameterization of the proper calibration constant K_0
- Check of the sensors for ambient temperature and pressure and the flow rate.
- Optional connection of peripheral recording and control systems (data logger, PC with ePort, RPComm and HyperTerminal) to the respective interfaces

The performance of these actions and therewith the set-up time takes approx. 2 hours.

The warm-up time contains the time need between the start of operation of the measuring system and the readiness for measurement.

After switching on the system, the system is in the stabilizing phase ("stabilizing") until reaching the stabilized condition regarding the instrument temperature. The duration of the stabilizing phase is dependent of the ambient temperature at the installation place and of the thermic instrument condition when switched on. In the scope of the suitability test, the stabilizing times where between 30 min and 90 min. After reaching a stabilized condition, the instrument starts collecting first data ("Collecting Data"). This data is not yet used to determine mass concentration. The collecting of first data is followed by first data computation ("Computing Data"). Afterwards the instrument is fully operational („Fully operational"). The intermediate steps „Collecting Data" and „Computing Data" take one hour. After that, the instrument delivers the moving 1h-average values of the mass concentration, which are updated every 6 minutes.

If required, possible changes of the basic parameterization of the measuring system can likewise be performed within few minutes by personal, familiar with the devices. However, the measuring operation is for this purpose interrupted and the instrument switched in setup-mode.

6.5 Assessment

The setup- and warm-up times were determined..

The measuring system can be operated at different measurement test sites with manageable effort. The set-up time is approximately 2 hours and the warm-up time is, depending on the necessary stabilizing time, 1.5 to 2.5 hours.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this test.

6.1 4.1.5 Instrument design

The instruction manual shall include specifications of the manufacturer regarding the design of the measuring system. The main 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

A measuring device for power consumption measurement and a scale were used for this test.

6.3 Performance of test

The installation of the delivered instruments was compared with the description given in the manuals. The specified power consumption was continuously tested for 24 h under standard operation conditions during field test.

6.4 Evaluation

The measuring system has to be installed in horizontal mounting position (e.g. on a table or a rack), independent from atmospheric conditions. The temperature at the installation test site shall be within the range of 8 °C to 25 °C with a relatively low amount of temperature fluctuation (maximum 2 °C per hour/ no direct sun, no direct exposure to heater or air conditioner).

The dimensions and the weights of the measuring system are in compliance with the specifications in the manual.

The power consumption of the measuring system with the used pump is specified by the manufacturer with at maximum 100-130 W for the measuring device and approximately 550-600 W for the pump. During a 24 h-test, these specifications were checked. At no time the mentioned value was exceeded during these investigations.

6.5 Assessment

The instrument design specifications listed in the operating manual are complete and correct..

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

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 Equipment

No additional equipment required.

6.3 Performance of test

The operation of the measuring device is carried out *via* a touch screen-display at the front panel or *via* the RS232- or Ethernet interfaces from an external computer.

A change of the parameters or the adjustment of sensors is only possible via several key sequences.

The measuring device has the following level of password protection.

Low Lock Mode:

In this mode the user can see all instrument views and can change the operation mode in order to perform a filter change.

High Lock Mode:

In this mode the user can only see the „TEOM-Data".

Because an installation of the measuring device outdoors is not possible, an additional protection is granted by installing it at test sites where no unauthorised people can go to (e.g. locked measuring cabinet).

6.4 Evaluation

Unintended adjustment of instrument parameters is avoided by the password protection. The adjustment of sensors and a change of the parameters can only be done via several key sequences. Moreover there is an additional protection against unauthorized intervention by the installation in a locked measurement cabinet.

6.5 Assessment

The AMS is protected against unauthorized and unintended adjustment. In addition, the AMS shall be locked in a measuring cabinet.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

6.1 4.1.7 Data output

The output signals shall be provided digitally (e.g. RS 232) and/or as analogue signals (e.g. 4 mA to 20 mA).

6.2 Equipment

PC with software „ePort“

6.3 Performance of test

The test was carried out using a PC with the software „ePort“(via Ethernet).

The AMS was connected to a PC via Ethernet and the data were downloaded. As usual, the data was in parallel downloaded to an USB-stick via USB interface. The test was performed by comparing both data.

The AMS has the possibility to offer analogue signals (maximum 8 analogue exits) as well as to offer measuring signals/ communication via serial interface RS 232 (AK protocol, software e.g. RPComm or HyperTerminal).

6.4 Evaluation

The measured signals are offered at the rear side of the instrument in the following way:

Analogue:	0-1 resp. 5 V	concentration range selectable
Digital:	Ethernet with Software „ePort“	
	RS 232-interface, AK protocol	
	USB	

The transmitted measured values via Ethernet comply with the data downloaded via USB-interface.

6.5 Assessment

Measured signals are offered analogue (0-1 or. 5 V) and digital (via Ethernet, RS 232, USB).

The connection of additional measuring and peripheral devices to the respective ports of the devices is possible (e.g. analogue entrances).

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Figure 29 shows a view of the rear side of the instrument with the respective measured value outputs.

Figure 29: View on rear of the device TEOM 1405-F Ambient Particulate Monitor

6.1 5.1 General

The manufacturer's specifications in the instruction manual shall be by no means better than the results of the performance test. Deviating specifications shall be corrected in the instruction manual by the manufacturer before declaration of suitability.

6.2 Equipment

Not necessary for this minimum requirement.

6.3 Performance of test

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

6.4 Evaluation

Found deviations between the first draft of the manual and the actual design were resolved.

6.5 Assessment

Differences between the instrument design and the descriptions given in the manual could not be detected.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Refer to point 6.4 of this module.

6.1 5.2.1 Certification ranges

The certification range for the testing must be determined.

6.2 Equipment

No additional equipment required.

6.3 Performance of test

The certification range for the testing must be determined.

6.4 Evaluation

Standard VDI 4202, Part 1 contains the following minimum requirements for the certification ranges for particulate ambient air measuring devices:

Table 9: Certification ranges (CR)

Measured component	Lower limit of CR	Upper limit of CR	Limit value	Evaluation period
	in µg/m³	in µg/m³	in µg/m³	
$PM_{2.5}$	0	50	25	Calendar year

The certification range is oriented at the limit value of the smallest assessment period of the measuring device in the range of the limit value. This assessment of the measuring device in the range of the limit value is made within the scope of the determination of the advanced uncertainty of the candidates according to the Guide [4]. For this purpose, according to the Guide the following values are used as reference values:

$PM_{2.5}$: 30 µg/m³

Reference is made to test point 6.1 5.4.10 Calculation of the expanded uncertainty of the instruments in this report.

6.5 Assessment

The assessment of the measuring device in the range of the relevant limit values is possible.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

See test point 6.1 5.4.10 Calculation of the expanded uncertainty of the instruments in this report.

6.1 5.2.2 Measuring range

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

6.2 Equipment

No additional equipment required.

6.3 Performance of test

It was tested, whether the upper limit of measuring range of the measuring system is greater or equal to the upper limit of the certification range.

6.4 Evaluation

At the measuring devices, measuring ranges up to a maximum of 0 – 1.000.000 µg/m³ can be set theoretically.

As appropriate default setting of the analogue output for European conditions a measuring range of 0 – 1.000 µg/m³ is recommended.

Measuring range: 0 – 1.000 µg/m³ (Standard)

Upper limit of the certification range: $PM_{2,5}$: 50 µg/m³

6.5 Assessment

A measuring range of 0 – 1.000 µg/m³ is set by default. Other measuring ranges up to a maximum of 0 – 1.000.000 µg/m³ are possible.

The measuring range value of the measuring device is higher than the respective upper limit of the certification range.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

6.1 5.2.3 Negative output signals

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

6.2 Equipment

No additional equipment required.

6.3 Performance of test

The AMS was tested on its ability to display negative output signals in the laboratory and in the field.

6.4 Evaluation

The AMS was tested on its ability to display negative output signals in the laboratory and in the field.

6.5 Assessment

Negative measuring signals are displayed directly and are output correctly via the respective measured value outputs by the measuring system.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

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 for this minimum requirement.

6.3 Performance of test

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

6.4 Evaluation

Since the measuring devices need neither operational nor calibration gases for operating, an uncontrolled escape of gases is not possible.

In the case of a failure in the mains voltage the measuring device remains in a stabilizing phase (“Stabilizing”) after the return of the power supply until reaching a stabilized condition regarding the instrument temperatures. The duration of the stabilizing phase depends on the ambient conditions at the sampling test site and on the thermic instrument condition when switching on.

In the scope of the suitability test the stabilizing times were between 30 min and 90 min. After reaching of the stable condition, the device starts to collect first data (“Collecting Data”). This data are not used yet for the determination of the mass concentrations. The collecting of the first data is followed by first computing of data (“Computing Data”). Afterwards the device is ready to operate (“Fully operational”). The intermediate steps „Collecting Data“ and „Computing Data“ take one hour. Afterwards the device delivers moving 1h-average values of the mass concentrations, which are updated every 6 minutes (refer to point 6.1 4.1.4 Set-up times and warm-up times).

6.5 Assessment

All instrument parameters are protected against loss through buffering. After the power supply has returned, the measuring device goes back into a failure-free operational condition and continues independently the measuring operation after achieving the instrument status “fully operational”.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

6.1 5.2.5 Operating states

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

6.2 Equipment

PC for data acquisition.

6.3 Performance of test

A PC was connected locally via Ethernet to the AMS and data transfer incl. instrument status tested.

Furthermore, it is possible to control the instrument via serial interface (AK Protocol).

With a respective router or modem, the remote control is possible.

6.4 Evaluation

The measuring device enables a complete telemetric control of the AMS through a choice of different possibilities (Ethernet, RS232).

6.5 Assessment

The measuring devices can be extensively monitored and controlled by an external PC via modem or router.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not necessary for this minimum requirement.

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 for this minimum requirement.

6.3 Performance of test

The AMS can be monitored and partly controlled by a user directly at the instrument or via telemetric remote control. Some functions, as for example the performance of the K_0-test , can only be done directly at the instrument.

6.4 Evaluation

All operating procedures that do not require practical work on test site, can be monitored by a user directly at the instrument as well as by telemetric remote control.

6.5 Assessment

Generally all necessary operations for functional check can be monitored directly at the device or via telemetric remote control.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

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 for this minimum requirement.

6.3 Performance of test

This test was done in order to determine, which maintenance procedures are required at which period to maintain correct functionality of the measuring system. Moreover, the results of the drift test for zero and span point according to point 6.1 5.3.12 Long-term drift were included into the determination of the maintenance interval.

6.4 Evaluation

No unacceptable drifts were detected for the measuring systems during the entire field test period.

Therefore, the maintenance interval is determined by scheduled maintenance procedures (refer to module 4.1.2).

During operation, the maintenance works can be limited to checks on contamination, plausibility and status / error message.

6.5 Assessment

The maintenance interval is defined by necessary maintenance procedures and is 1 month.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Necessary maintenance works can be found in module 4.1.2 of this report and in chapter 5 of the operating 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 for this minimum requirement.

6.3 Performance of test

Start time and end time of the availability tests were defined by the start and end of the field tests at each test site. All measurement interruptions, *e.g.* due to system outage or maintenance works, were considered for this test.

6.4 Evaluation

Table 10 and Table 11 show a compilation of the operation, maintenance and malfunction times. The measuring systems have been operated over a time period of 454 measuring days. This time period includes 17 days of zero-filter operation and 6 days, which had to be rejected due to the change to zero-filter (see annex 5).

Data loss caused by external influences, which cannot be attributed to the devices themselves, have been recorded on 19.01.2010, 10.03.2011 and 14.03.2011 (power outage). Therefore, the total operating time is reduced to 451 (SN 20012) and 451 (SN 20121) measuring days.

The following malfunctions of the devices have been observed:

SN 20012:

On 29.07.2011 it was detected, that the AMS was in stabilizing-mode. The problem could be solved by switching the device off and on again.

On 28.09.2011 2011 the device had to be stopped in order to fix a leak.

SN 20121:

On 27.07.2011 and on 28.07.2011 a communication error signal was emitted. The problem could be solved by switching the device off and on again.

Starting on 09.08.2011 the device emitted various error signals. Finally on 17.08.2011 the main board had to be changed. All measuring signals between 09.08.2011 and 17.08.2011 were rejected.

On 28.09.2011 the device had to be stopped in order to fix a leak.

No further malfunctions of the devices have been observed.

The regular cleaning of the sampling inlets in the maintenance interval, the change of the TEOM-filter, the 47 mm-filter (approx. every 4 weeks) and the regular check of the flow rates respectively of the tightness can lead to outages of more than 2 h per device, especially when all is done on one day. The affected daily averages in this case have been rejected.

6.5 Assessment

The availability was 98.7 % for SN 20012 and 96.5% for SN 20121 without outages due to test conditions, or 93.6 % for SN 20012 and 91.4 % for SN 20121 including outages due to test conditions.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 10: Determination of availability (without test-related outages)

		Device 1 (SN 20012)	Device 2 (SN 20121)
Operating time	d	451	451
Outage time	d	2	12
Maintenance	d	4	4
Actual operating time	d	445	435
Availability	%	98.7	96.5

Table 11: Determination of availability (including test-related outages)

		Device 1 (SN 20012)	Device 2 (SN 20121)
Operating time	d	451	451
Outage time	d	2	12
Maintenance incl. zero-filter operation	d	27	27
Actual operating time	d	422	412
Availability	%	93.6	91.4

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 for this minimum requirement.

6.3 Performance of test

It was tested, if the instrument software can be displayed at the instrument. The manufacturer of the instrument was told that any change to the instrument software shall be reported to the test body.

6.4 Evaluation

The present software is shown in the display when turning on the device. At any time it can be looked at in the menu “system status”.

The suitability test was performed with the software version 1.51 (2009).

During the testing the software was constantly developed and optimized up to the version 1.56. During the development problems with the touch screen display were resolved, e.g. there have been problems with the button „reboot“ during a possible system crash. Furthermore it is now implemented, that after a start of the measuring system, the system always waits for the next full hour for determination and recording of the measured values.

No influences on the system performance are expected from the changes which were made on the firmware up to version 1.56.

6.5 Assessment

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

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

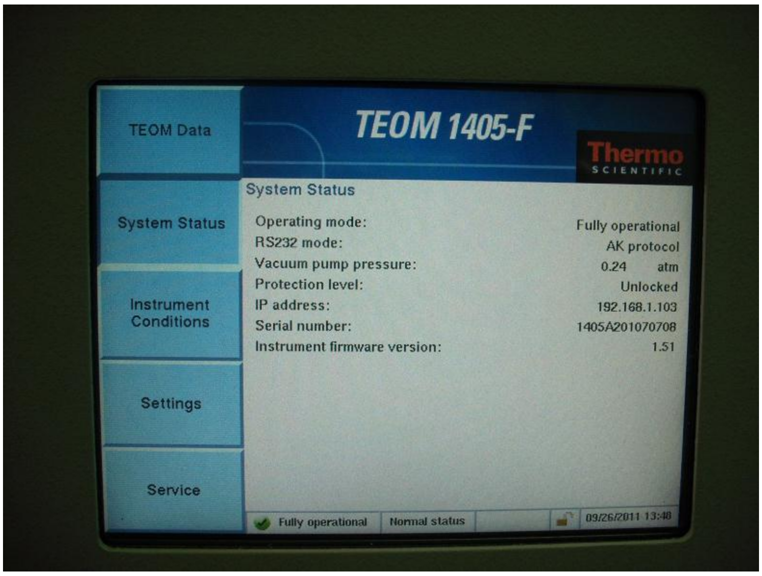

Figure 30: Display of the software version (here 1.51) in the menu „System Status“

6.1 5.3.1 General

The testing is done based on the minimum requirement according to Standard VDI 4202 Part 1 (September 2010).

6.2 Equipment

Not required for this minimum requirement.

6.3 Performance of test

The test is made on the basis of the minimum requirements of Standard VDI 4202, Part 1 (September 2010).

6.4 Evaluation

Standard VDI 4202, Part 1 and VDI 4203, Part 3 have been republished after a detailed revision in September 2010. Unfortunately, after this revision uncertainties and contradictions remain regarding the concrete minimum requirements on the one hand and the general relevance of the test points on the other hand while testing particulate ambient air measuring devices. The following test points 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 for particulate devices

6.1 5.3.4 Linearity (Lack of fit)

not relevant for particulate devices

6.1 5.3.7 Sensitivity coefficient of the surrounding temperature

no minimum requirement defined

6.1 5.3.8 Sensitivity coefficient of the electric voltage

no minimum requirement defined

6.1 5.3.11 Standard deviation from paired measurement

no minimum requirement defined

6.1 5.3.12 Long-term drift

no minimum requirement defined

6.1 5.3.13 Short-time drift

not relevant for particulate devices

6.1 5.3.18 Overall uncertainty

not relevant for particulate devices

For this reason an official request to the competent German body was made, to define a co-ordinated procedure for dealing with inconsistencies in the Standard.

The following procedure was suggested:

The test points 5.3.2, 5.3.7, 5.3.8, 5.3.11 and 5.3.12 are evaluated as before based on the minimum requirements stated in Standard VDI 4202 Part 1 from 2002 (i.e. using the reference values B_0, B_1 and B_2).

The testing of the test points 5.3.3, 5.3.4, 5.3.13 and 5.3.18 is waived, as they are not relevant for particulate measuring devices.

The competent German body agreed with the proposed procedure by decision of 27 June 2011 respectively 07 October 2011.

6.5 Assessment

The test was done based on the minimum requirements stated in Standard VDI 4202 Part 1 (September 2010). The test points 5.3.2, 5.3.7, 5.3.8, 5.3.11 and 5.3.12 are evaluated as before based on the minimum requirements stated in Standard VDI 4202 Part 1 from 2002 (i.e. using the reference values B_0, B_1 and B_2). The testing of the test points 5.3.3, 5.3.4, 5.3.13 and 5.3.18 is waived, as they are not relevant for particulate measuring devices.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required for this minimum requirement.

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 the certification range according to Table 1 of Standard VDI 4202 Part 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:

This test point is not evaluable for particulate measuring devices on the basis of the currently valid version of Standard VDI 4202 Part 1 (September 2010) and VDI 4203 Part 3 (September 2010) due no non-defined minimum requirements. According to the decision of the competent German body (see module 5.3.1), reference is made alternatively to the following previous version of Standard VDI 4202 Part 1 (June 2002).

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

6.2 Equipment

Zero-filter for zero point check.

6.3 Performance of test

The determination of the detection limit is done for the candidates SN 20012 and SN 20121 by operating the devices with the respective zero-filters which are installed at both measuring device inlets.

The offering of particulate-free sampling air is done for a time period of 15 days for 24 h each.

The determination of the detection limit is done in the laboratory, because under field conditions a provision of particulate-free air for such a long time period was not possible.

6.4 Evaluation

The detection limit X is determined from the standard deviation s_{x0} of the measured values at the intake of particulate-free sampling air by both candidates.

It corresponds with the standard deviation of the average x_0 of the measured values x_{0i} multiplied with the student factor for the respective candidate.

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

Reference value: $B_0 = 2$ µg/m³

6.5 Assessment

The detection limit was determined from investigations on 0.66 µg/m³ for device 1 (SN 20012) and 0.68 µg/m³ for device 2 (SN 20121).

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 12: Detection limit $PM_{2.5}$

		Device SN 20012	Device SN 20121
Amount of values n		15	15
Average of the zero values $\overline{x_0}$	µg/m³	1.22	0.84
Standard deviation of the values s_{x0}	µg/m³	0.31	0.32
Student-Factor $t_{n-1;0.95}$		2.14	2.14
Detection limit X	µg/m³	**0.66**	**0.68**

Single values from the determination of the detection limit can be looked up in annex 1 in the appendix.

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 the certification range according to Table 1 of Standard VDI 4202 Part 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 ct at 70% to 80% of the upper limit of this certification range shall be used as reference point.

Note:

According to the decision of the competent German body (see module 5.3.1) this test point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the 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.

The linearity is considered as secured when the deviation of the group averages of the measured values of the calibration function in the certification range meet the specifications stated in Table 2 of Standard VDI 4202 Part 1 (September 2010).

For other certification ranges the deviation of the group average of the measured values of the calibration function shall not exceed 5 % of the upper limit of the respective certification range.

Note:

According to the decision of the competent German body (see module 5.3.1) this test point is not relevant for particulate measuring devices.

For particulate measuring devices for $PM_{2.5}$ this test shall be performed according to minimum requirement 5.4.10 “Calculation of the expanded uncertainty of the instruments”

6.2 Equipment

See module 5.4.10 ($PM_{2.5}$)

6.3 Performance of test

For particulate measuring devices for $PM_{2.5}$ this test shall be performed according to minimum requirement 5.4.10 “Calculation of the expanded uncertainty of the instruments”

6.4 Evaluation

See module 5.4.10 ($PM_{2.5}$)

6.5 Assessment

For particulate measuring devices for $PM_{2.5}$ this test shall be performed according to minimum requirement 5.4.10 “Calculation of the expanded uncertainty of the instruments”.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

See module 5.4.10 ($PM_{2.5}$)

6.1 5.3.5 Sensitivity coefficient of the sample gas pressure

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

Note:

This point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable.

6.1 5.3.6 Sensitivity coefficient of the sample gas temperature

The sensitivity coefficient of sample gas temperature at reference point shall not exceed the requirements of Table 2. A value ct at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable.

6.1 5.3.7 Sensitivity coefficient of the surrounding temperature

The sensitivity coefficient of surrounding temperature at zero and reference point shall not exceed the requirements of Table 2. A value ct at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test point is not evaluable for particulate measuring devices on the basis of the currently valid version of Standard VDI 4202 Part 1 (September 2010) and VDI 4203 Part 3 (September 2010) due no non-defined minimum requirements. According to the decision of the competent German body (see module 5.3.1), reference is made alternatively to the following previous version of Standard VDI 4202 Part 1 (June 2002).

The temperature dependence of the zero-point measured value shall not exceed the reference value B_0 when changing the surrounding temperature by 15 K in the range between +5 °C and +20 °C or respectively by 20 K in the range between +20 °C and +40 °C.

The temperature dependence of the measured value in the range of the reference value B_1 shall not exceed ± 5 % of the measured value when changing the surrounding temperature by 15 K in the range between +5 °C and +20 °C or respectively by 20 K in the range between +20 °C and +40 °C.

6.2 Equipment

Climate chamber for the temperature range +8 to +25 °C, zero-filter for zero-point check, K_0-test kit for reference point check.

6.3 Performance of test

The permitted surrounding temperature at the test site of the measuring device pursuant to the manufacturer is 8 °C to 25 °C. For this reason the test was limited to this surrounding temperature.

For the investigation of the dependence of the zero-point and the measured values on the surrounding temperature, the complete measuring devices were run in the climatic chamber.

For the zero-point check the two candidates SN 20012 and SN 20121 by installation of zero-filters were fed at both device inlets each with particulate-free sampling air.

For the reference point check at the two candidates SN 20012 and SN 20121 the calibration constant K_0 was tested to check the stability of the sensitivity.

The surrounding temperatures in the climatic chamber were varied in this order: 20 °C – 8 °C – 20 °C – 25 °C – 20 °C. After an equilibration time of approx. 24 h per temperature step, the recording of the measured values at zero-point (per temperature step 3 times 24 h each) as well as the measured values at reference point (per temperature step 3 times each) started

6.4 Evaluation

Zero-point:

The measured values for the concentration of the respective 24 h-single measurements were read out and evaluated. The absolute deviation in µg/m³ per temperature step is observed in relation to the default point of 20 °C.

Reference value: B_0 = 2 µg/m³

Reference point:

The deviation as a percentage of the determined measured values for the calibration constant K_0 was observed for each temperature step in relation to the default point at 20 °C.

As note it should be mentioned that by using the check of the calibration constant K_0 no concentration values could be simulated, an assessment in the range B_1 was not possible for this reason.

6.5 Assessment

The permitted surrounding temperature at the test site of the measuring device pursuant to the manufacturer is 8 °C to 25 °C. When observing the values output by the device, a maximum influence of the surrounding temperature on the zero-point of -1.2 µg/m³ in the range 8 °C to 25 °C could be detected.

At reference point no deviation > 0.4 % to the default value at 20 °C could be observed.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 13: Dependence of the zero-point on the surrounding temperature, deviation in µg/m³, average for 3 measurements

Temperature		Deviation	
Start temperature	End temperature	SN 20012	SN 20121
°C	°C	µg/m³	µg/m³
20	8	-1.2	-0.4
8	20	0.5	0.0
20	25	1.1	0.4
25	20	-0.1	-0.6

Table 14: Dependence of sensitivity (calibration constant K_0) on the surrounding temperature, deviation in %, average for 3 measurements

Temperature		Deviation	
		SN 20012	SN 20121
Start temperature	Endtemperature	K_0	K_0
°C	°C	%	%
20	8	0.3	0.3
8	20	0.2	0.3
20	25	0.4	0.3
25	20	0.3	0.2

The respective results of the 3 single measurements can be taken from annex 2 and 3 in the appendix.

6.1 5.3.8 Sensitivity coefficient of the electric voltage

The sensitivity coefficient of supply voltage shall not exceed the requirements of Table 2. A value ct at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test point is not evaluable for particulate measuring devices on the basis of the currently valid version of Standard VDI 4202 Part 1 (September 2010) and VDI 4203 Part 3 (September 2010) due no non-defined minimum requirements. According to the decision of the competent German body (see module 5.3.1), reference is made alternatively to following previous version of Standard VDI 4202 Part 1 (June 2002).

The changes of the measured value for the reference value B_1 caused by the voltage changes typical for an electrical grid within the interval (230 +15/-20) V, shall not exceed B_0.

6.2 Equipment

Adjustable isolating transformer, K_0-test kit for reference point check.

6.3 Performance of test

To check the dependence of the measuring signals on the mains voltage, the voltage was reduced from 230 V to 210 V and afterward increased with an intermediate step of 230 V to 245 V.

For the reference point check at both candidates SN 20012 and SN 20121 the calibration constant K_0 was tested to check the stability of the sensitivity.

Since the mobile use of the AMS is not planned, an additional check of the dependence of the measuring signal on the mains frequency was waived.

6.4 Evaluation

At reference point the change as a percentage of the determined measured value for the calibration constant K_0 is observed for each test step in relation to the default point at 230 V.

As note it should be mentioned that by using the check of the calibration constant K_0 no concentration values could be simulated, an assessment in the range B_1 was not possible for this reason.

6.5 Assessment

Due to voltage changes no deviation > -0.7 % could be detected for $PM_{2.5}$, referring to the start value of 230 V.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

shows the summarized representation of the test results

Table 15 shows the summarized representation of the test results

Table 15: Dependence of the measured value of the mains voltage, deviation in %

Mains voltage		Deviation	
		SN 20012	SN 20121
Start voltage	End voltage	K_0	K_0
V	V	%	%
230	210	-0.7	-0.1
210	230	-0.3	0.2
230	245	-0.3	0.2
245	230	-0.3	0.4

The single values can be taken from annex 4 of the appendix.

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 of Standard VDI 4202 Part 1 (September 2010) at zero and reference point.

Note:

This point is not relevant for particulate measuring devices. The minimum requirement 5.4.5 is valid. Therefore, the results of this test can be found in module 5.4.5.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the 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 of Standard VDI 4202 Part 1 (September 2010).

Note:

This point is not relevant for particulate measurements.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable.

6.1 5.3.11 Standard deviation from paired measurement

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 of Standard VDI 4202 Part 1 (September 2010).

Note:

This test point is not evaluable for particulate measuring devices on the basis of currently valid Standard versions of the Standard VDI 4202 Part 1 (September 2010) and VDI 4203 Part 3 (September 2010) due to a lack of defined minimum requirements. According to the decision of the competent authorities in Germany (see Module 5.3.1), alternatively the following specifications of the previous version of Standard VDI 4202 Part 1 (June 2002) are referred to.

The reproducibility R_D of the measuring device shall be determined with repeat determinations of two identical measuring devices and shall not fall below the value 10. The reference value B_1 shall be used.

6.2 Equipment

Additional measuring devices as stated in Chapter 5 were used when determining the reproducibility.

6.3 Performance of test

Reproducibility R_D is defined as the maximum deviation of two randomly chosen single values which were obtained under equal conditions in relation to each other. This test has been carried out with two identical devices which were simultaneously operated during the field test. The measured data from all four field tests was used for this test.

6.4 Evaluation

The reproducibility R_D is calculated as follows:

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

- R = Reproducibility R_D at B_1
- U = Uncertainty
- B_1 = 25 µg/m³ for $PM_{2.5}$
- s_D = Standard deviation from repeat determinations
- n = No. of parallel measurements
- $t_{(n;0,95)}$ = Student factor for 95% certainty
- x_{1i} = Measuring signal of device 1 (e.g. SN 20012) at i^{th} concentration.
- x_{2i} = Measuring signal of device 2 (e.g. SN 20121) at i^{th} concentration.

6.5 Assessment

The reproducibility R_D for $PM_{2.5}$ was 24 during field test for the complete data set.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

The test results are summarized in Table 16. The graphical representation for $PM_{2.5}$ is shown in Figure 41 to Figure 45.

Note: The determined uncertainties are applied to the reference value B_1 for each test site.

Table 16: Concentration averages, standard deviation, uncertainty range and reproducibility in the field, measured component $PM_{2.5}$

Test site	Amount	$\bar{c}$ (SN 20012)	$\bar{c}$ (SN 20121)	$\bar{c}_{ges}$	s_D	t	U	R
		µg/m³	µg/m³	µg/m³	µg/m³		µg/m³	
Teddington	145	14.2	14.0	14.1	0.43	1.976	0.85	30
Cologne (winter)	88	23.5	23.3	23.4	0.57	1.987	1.14	22
Bornheim (summer)	95	14.1	13.5	13.8	0.52	1.985	1.04	24
Bornheim (winter)	83	15.8	16.7	16.3	1.33	1.989	2.65	9
Alle test sites	411	16.5	16.5	16.5	0.52	1.966	1.03	24

- $\bar{c}$ (SN 20012): Concentration averages, device SN 20012
- $\bar{c}$ (SN 20121): Concentration averages, device SN 20121
- $\bar{c}_{ges}$: Concentration averages of the devices SN 20012 & SN 20121

Single values can be taken from the 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 in the field test. A value ct at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test point is not evaluable for particulate measuring devices on the basis of currently valid Standard versions of the Standard VDI 4202 Part 1 (September 2010) and VDI 4203 Part 3 (September 2010) due to a lack of defined minimum requirements. According to the decision of the competent authorities in Germany (see Module 5.3.1), alternatively the following specifications of the previous version of Standard VDI 4202 Part 1 (June 2002) are referred to.

The temporal change of the zero point measured value shall not exceed the reference value B_0 within 24 h and the maintenance interval.
The temporal change of the measured values in the range of the reference value B_1 shall not exceed ± 5 % of B_1 within 24 h and the maintenance interval.

6.2 Equipment

Zero-filter for zero-point check, K_0-test kit for reference-point check.

6.3 Performance of test

The test was performed within the scope of the field test with a total time period of 25 months.

Within the scope of a regular check approx. once a month (incl. at the beginning and the end of every test site), the measuring device was run for a time period of at least 24 h each with zero-filters at the device-inlets; the measured zero-valued were evaluated. The zero-measurements were performed as planned with a monthly change of the TEOM-filter and the 47 mm-filter.

Furthermore, the stability of the calibration constant was tested and evaluated for the reference point check at the beginning and end auf each test site.

6.4 Evaluation

An evaluation of the drift at zero-point and the measured value within 24 h is not possible.

The evaluation at zero-point is done on the basis of the measuring results of the regular external zero-point measurements by comparing the respective values with the „measured values“ of the previous test and the „measured values“ of the first test.

The evaluation at reference-point is done on the basis of the measuring results for the calibration constant K_0 by comparing the respective values with the „measured values“ of the previous test and the „measured values“ of the first test.

It should be noted that using the test of the calibration constant K_0 no concentration values can be simulated. Therefore, an assessment in the range of B_1 was not possible.

6.5 Assessment

The maximum deviation found at zero-point was -2.1 µg/m³ with reference to the previous value and -2.1 µg/m³ with reference to the start value and are thus within the allowed range of B_0 = 2 µg/m³.

The values for the drift of the sensitivity, referring to the respective previous values, determined within the scope of the test, have been at maximum 2,1 % for $PM_{2.5}$.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 17 contains the determined values for the zero-point and the calculated deviation referring to the previous value and the start value in µg/m³. Figure 31 to Figure 32 show the graphical representation of the zero-point drift over the test period.

In Table 18 the deviations of the measured values are shown in % of the respective previous value. Figure 33 and Figure 34 show the graphical representation of the drift of the measured values (referring to the previous value).

Table 17: Zero-point drift SN 20012 & SN 20121, with zero-filter

	SN 20012			SN 20121		
Date	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
06.12.2009	1.2	-	-	1.6	-	-
07.12.2009	1.0	-0.2	-0.2	1.6	0.0	0.0
04.01.2010	1.9	0.9	0.7	1.9	0.3	0.3
06.02.2010	1.6	-0.3	0.4	2.7	0.8	1.1
07.02.2010	1.9	0.3	0.7	2.2	-0.5	0.6
07.03.2010	2.1	0.2	0.9	1.8	-0.4	0.2
26.04.2010	1.6	-0.5	0.4	2.3	0.5	0.7
26.05.2010	2.0	0.4	0.8	1.6	-0.7	0.0
02.07.2010	1.9	-0.1	0.7	2.0	0.4	0.4
29.01.2011	1.7	-0.2	0.4	1.2	-0.8	-0.4
30.01.2011	1.3	-0.4	0.0	1.6	0.4	0.0
31.01.2011	0.9	-0.3	-0.3	1.4	-0.2	-0.2
05.03.2011	1.6	0.6	0.4	2.6	1.2	1.0
06.03.2011	1.4	-0.2	0.2	1.0	-1.6	-0.6
07.03.2011	2.1	0.7	0.9	1.4	0.4	-0.2
09.04.2011	1.8	-0.3	0.6	2.2	0.8	0.6
10.04.2011	2.8	1.0	1.6	1.6	-0.7	0.0
22.07.2011	1.2	-1.6	0.0	-0.5	-2.1	-2.1
23.07.2011	0.9	-0.3	-0.3	0.5	1.0	-1.1
24.07.2011	1.1	0.2	-0.2	0.1	-0.4	-1.5
17.09.2011	0.9	-0.1	-0.3	0.7	0.7	-0.9
18.09.2011	1.2	0.2	-0.1	1.1	0.4	-0.5
17.12.2011	1.9	0.8	0.7	1.7	0.6	0.1
18.12.2011	1.8	-0.2	0.5	1.7	-0.1	0.0
15.02.2012	0.8	-0.9	-0.4	0.3	-1.3	-1.3
16.02.2012	1.4	0.6	0.2	0.9	0.6	-0.7

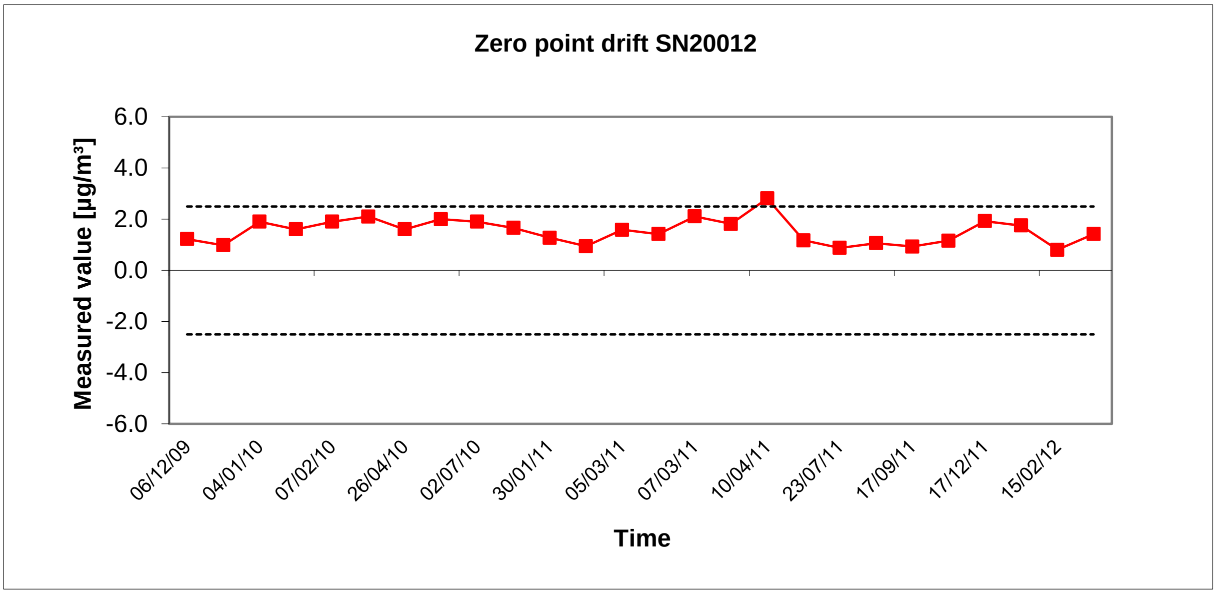

Figure 31: ***Zero-point drift SN 20012, measured component $PM_{2.5}$***

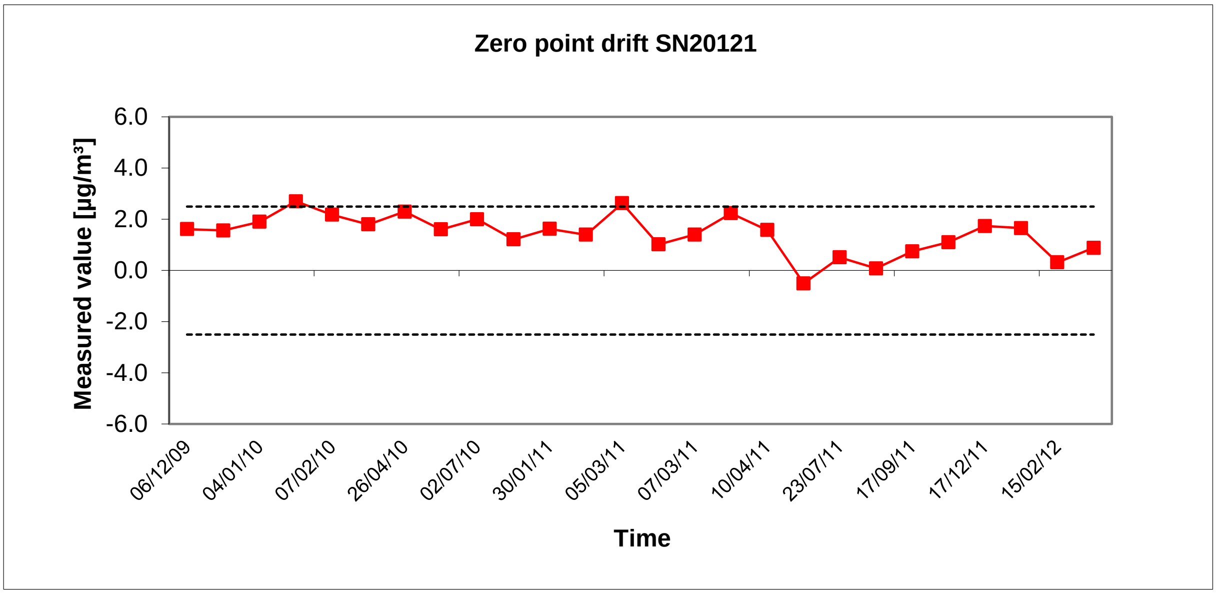

Figure 32: ***Zero-point drift SN 20121, measured component $PM_{2.5}$***

Table 18: Sensitivity drift SN 20012 & SN 20121

Date	SN 20012			SN 20121		
	Measured value K_0	Deviation from previous value %	Deviation from start value %	Measured value K_0	Deviation from previous value %	Deviation from start value %
06.12.2009	13751.0	-	-	16257.0	-	-
05.03.2010	13589.6	-1.2	-1.2	16123.2	-0.8	-0.8
19.04.2010	13635.6	0.3	-0.8	16095.0	-0.2	-1.0
07.07.2010	13673.0	0.3	-0.6	16157.0	0.4	-0.6
27.01.2011	13519.0	-1.1	-1.7	16085.0	-0.4	-1.1
12.05.2011	13649.4	1.0	-0.7	15966.9	-0.7	-1.8
19.07.2011	13740.5	0.7	-0.1	16306.2	2.1	0.3
26.09.2011	13724.3	-0.1	-0.2	16221.8	-0.5	-0.2
22.02.2012	13688.6	-0.3	-0.5	16158.5	-0.4	-0.6

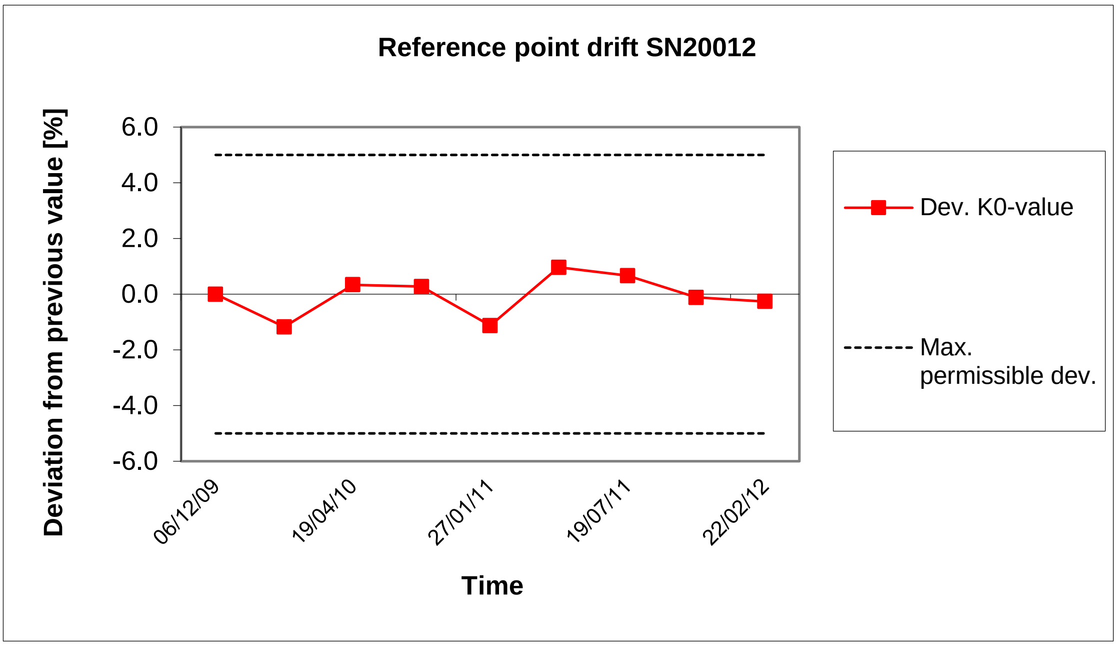

Figure 33: Drift of the measured value SN 20012, measured component $PM_{2.5}$

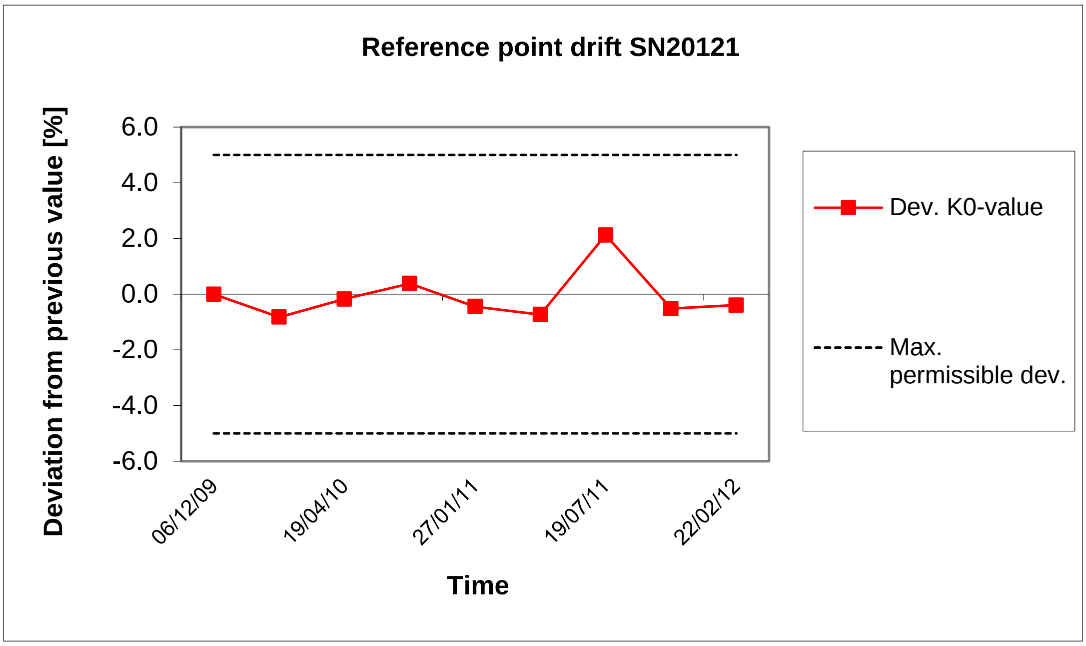

Figure 34: Drift of the measured value SN 20121, measured component $PM_{2.5}$

6.1 5.3.13 Short-time drift

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

Note:

According to the decision of the competent German body (see module 5.3.1) this test point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the 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 response time (fall) of the measuring system shall not exceed 10% of response time (rise) or 10 s, whatever value is larger.

Note:

This point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the 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 Standard VDI 4202 Part 1 (September 2010). A value ct at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable..

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable.

6.1 5.3.16 Converter efficiency

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

Note:

This point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable.

6.1 5.3.17 Increase of NO_2 concentration due to residence in the measuring system

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

Note:

This point is not relevant for particulate measuring devices.

6.2 Equipment

Not applicable.

6.3 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the 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 A1 of Standard VDI 4202 Part 1 (September 2010).

Note:

According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.

6.2 Equipment

According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.

6.3 Performance of test

According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.

6.4 Evaluation

According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.

6.5 Assessment

According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

According to the decision of the competent German body (see module 5.3.1 this test point is not relevant for particulate measuring devices. Reference is made to module 5.4.10.

6.1 5.4.1 General

Test for particulate measuring units according to the minimum requirement stated in Table 5 of Standard VDI 4202, Part 1.
Furthermore, the particle mass concentration shall be related to a defined volume. The relation to volume with respect to pressure and temperature shall be comprehensively described.

6.2 Equipment

Not necessary for this minimum requirement.

6.3 Performance of test

The test took place according to the minimum requirement stated in Table 5 of Standard VDI 4202, Part 1.

It was tested, if the measured particulate mass concentrations are referred to a defined volume.

6.4 Evaluation

The test took place according to the minimum requirement stated in Table 5 of Standard VDI 4202, Part 1 (September 2010).

The measuring unit TEOM 1405-F Ambient Particle Monitor is a gravimetric measuring device, which determines the mass deposited on a filter via oscillating micro weighing. The determined mass is related to a defined and actively regulated sampling volume and thereby the particulate concentration is determined.

6.5 Assessment

The test took place according to the minimum requirement stated in Table 5 of Standard VDI 4202, Part 1 (September 2010).

The measuring unit TEOM 1405-F Ambient Particle Monitor is a gravimetric measuring device, which determines the mass deposited on a filter via oscillating micro weighing. The determined mass is related to a defined and actively regulated sampling volume and thereby the particulate concentration is determined.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not necessary for this minimum requirement.

6.1 5.4.2 Equivalency of the sampling system

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

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.2 Equipment

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.3 Performance of test

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.4 Evaluation

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.5 Assessment

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.1 5.4.3 Equivalency of the sampling systems

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

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.2 Equipment

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.3 Performance of test

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.4 Evaluation

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

6.5 Assessment

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable for $PM_{2.5}$-sampling systems. Reference is made to module 5.4.10 of this report.

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 EN 14907. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall the determined as a steady function.

6.2 Equipment

See module 5.4.10.

6.3 Performance of test

For $PM_{2.5}$:

The comparability of the measuring systems was demonstrated within the scope of the testing according to module 5.4.10.

For the determination of the calibration and the analysis function, the complete data set is used (344 (SN 20012) and 335 (SN 20121) valid measured value pairs).

The parameters of the calibration function

$$y = m * x + b$$

were determined by linear regression. The analysis function is the reversal of the calibration function. It reads

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

The slope m of the regression line characterized the sensitivity of the measuring device; the ordinate intercept b characterized the zero-point.

6.4 Evaluation

The values for $PM_{2.5}$ result as shown in Table 19.

Table 19: Results of the calibration and analysis function, measured component $PM_{2.5}$

Device-No.	Calibration function		Analysis 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
Device 1 (SN 20012)	1.023	1.446	0.978	1.413
Device 2 (SN 20121)	1.010	1.491	0.990	1.476

6.5 Assessment

A statistically secured relation between the reference measuring procedure and the instrument display could be demonstrated.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

See module 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 necessary for this minimum requirement.

6.3 Performance of test

The determination of the interference caused by moisture in the sample has been carried out under field conditions.

Instead, the differences between the determined reference value (= nominal value) and the measured value of the respective candidate system were calculated for days of more than 70 % relative humidity during field test, and the average difference was set as a conservative estimation of the interfering effect of humidity contained in the measured medium.

In addition, the reference-equivalence-functions were determined from the field investigations for days of more than 70 % relative humidity for both candidate systems.

6.4 Evaluation

The average difference between the determined reference value (= nominal value) and the measured value of the respective candidate system was calculated for days of more than 70 % relative humidity during field test, and the relative deviation of the average concentration was determined.

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

Further investigations were made to determine whether the comparability of the candidate systems with the reference method according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods" [4] is also given at days of more than 70 % relative humidity.

6.5 Assessment

No interference caused by moisture in the sample > 1.6 µg/m³ deviation from nominal value for $PM_{2.5}$ could be observed.

During the field test, no negative influence on the measured values could be noted at changing relative humidities. The comparability of the candidates with the reference method according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods" [4] also is given for the days with a relative humidity > 70 %.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 20 shows a summarizing presentation.

Table 20: ***Deviation between reference measurement and candidates at the days with a relative humidity > 70 %, measured component $PM_{2.5}$***

Field test, days with a relative humidity >70 %				
		Reference	SN 20012	SN 20121
Average	µg/m³	14.7	16.3	16.2
Deviation to average reference in µg/m³	µg/m³	-	1.6	1.5
Deviation in % of average reference	%	-	10.9	10.2
Deviation in % of ALV	%	-	6.4	6.0

Single values can be taken from annex 5 and 6 in the appendix.

The presentation and the assessment of the measuring uncertainties W_{CM} at the days with a relative humidity > 70 % is made in Table 21 and in Table 22. Single values can be taken from annex 5 and 6 in the appendix.

Table 21: Comparison candidate 20012 with 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	1405-F	SN	SN 20012	
Test site	All test sites, rH>70%	Limit value	30	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Results of regression analysis				
Slope b	**1.03**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**1.18**	**significant**		
Uncertainty of a	**0.18**			
Results of the equivalence test				
Deviation at limit value	**2.09**	**µg/m³**		
Uncertainty $u_{c\_s \text{ at limit value}}$	**2.60**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**8.65**	**%**		
Expanded measurement uncertainty W_{CM}	**17.31**	**%**		
Status equivalence test	**pass**			

Table 22: Comparison candidate 20121 with 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	1405-F	SN	SN 20121	
Test site	All test sites, rH>70%	Limit value	30	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Results of regression analysis				
Slope b	**1.02**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**1.23**	**significant**		
Uncertainty of a	**0.18**			
Results of the equivalence test				
Deviation at limit value	**1.85**	**µg/m³**		
Uncertainty $u_{c\_s \text{ at limit value}}$	**2.42**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**8.06**	**%**		
Expanded measurement uncertainty W_{CM}	**16.12**	**%**		
Status equivalence test	**pass**			

6.1 5.4.6 Averaging effect

The measuring system shall allow for formation of 24 h averages.
The time of the sum of all filter changes within 24 h may not exceed 1 % of this averaging time.

6.2 Equipment

For the test a clock was provided.

6.3 Performance of test

It was tested, if the AMS allows the formation of daily averages.

6.4 Evaluation

The FDMS-unit of the AMS switches alternately every 6 minutes between the operating modi "base mode" and "reference mode" to take into account the amount of semi-volatile particle matter (see as well point 3.2 Functionality of the measuring system).

On the basis of the determined mass concentration in the "base mode" and the respective following "reference mode" the expended mass concentration is determined.

Example:

The device collects for 6 minutes in the „base mode" and determines a base mass concentration of 5 µg/m³. Afterwards the device collects for 6 minutes in the "reference mode" and determines a reference mass concentration of -1 µg/m³. The expended mass concentration amounts therefore to 5 µg/m³ - (-1 µg/m³) = 6 µg/m³.

The actual available sampling time (= base mode) per measuring cycle therefore is exactly 50 % of the total cycle. The results of the field tests according to 6.1 5.4.10 Calculation of the expanded uncertainty of the instruments in this report show, that for this instrument configuration a comparability of the candidates could be demonstrated securely with the reference method and the formation of daily averages therefore is possible securely.

6.5 Assessment

The formation of valid daily averages is possible.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Not required.

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

For the test additionally a flow meter according to point 4 was provided.

6.3 Performance of test

The sample volumetric flow was calibrated before the first field sampling test site and tested for its correctness before each field sampling test site, using a dry gas meter or a mass flow meter, and readjusted if necessary.

For the measuring device TEOM 1405-F Ambient Particulate Monitor, a total flow rate of 16,67 l/min at the inlet is split in two sub flows, the $PM_{2.5}$-path with 3 l/min and the Bypass with 13,67 l/min.

To determine the constancy of the relevant sample volumetric flow, a flow rate for PM_{10} and a total flow rate for the test site Cologne (Winter), which partly was characterized by high concentrations and filter loads up to >50 %, were recorded in the candidates and the flow rates were evaluated on a 24 h-basis.

6.4 Evaluation

From the determined average for the flow rate, average, standard deviation and maximum- and minimum value were defined.

6.5 Assessment

The results from the performed flow rate checks before each field test site are represented in Table 23.

Table 23: Results control flow rate

Flow rate check before		SN 20012		SN 20121	
Test site		[l/min]	Deviation from nominal value [%]	[l/min]	Deviation from nominal value [%]
Teddington, Dec. 2009	$PM_{2.5}$	2.95	-1.67	3.02	0.67
	Total	16.20	-2.82	16.59	-0.48
Teddington, Apr. 2010	$PM_{2.5}$	3.14	4.67	3.12	4.00
	Total	17.37	4.20	17.19	3.12
Cologne, winter	$PM_{2.5}$	3.01	0.33	3.00	0.00
	Total	16.55	-0.72	16.52	-0.90
Bornheim, summer	$PM_{2.5}$	3.11	3.67	3.15	5.00
	Total	16.81	0.84	16.84	1.02

The graphical representation of the flow rates for $PM_{2.5}$ (Nominal: 3 l/min) and the total flow rate (Nominal: 16.67 l/min) show that all values determined during sampling deviate less than ±5 % from the respective nominal value. The deviation of the 24h-average for the total flow rate of 16.67 l/min are as well significantly smaller than the demanded ±3 % of the nominal value.

All determined daily averages deviate less than ± 3 %, all instantaneous values less than ± 5 % from the nominal value.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

In Table 24 and Table 25 determined parameter for the flow are shown. Figure 35 to Figure 40 show the graphical representation of the flow measurements at both candidates SN 20012 and SN 20121.

Table 24: Parameter for the total flow measurement (24h-average, Cologne (Winter), SN 20012

No. of 24h values	Average [l/min]	ev. from nominal value [%	Std. Dev. [l/min]	Max [l/min]	Min [l/min]
106	16.67	0.000	0.02	16.75	16.59

Table 25: Parameter for the total flow measurement (24h-average, Cologne (Winter)), SN 20121

No. of 24h values	Average [l/min]	ev. from nominal value [%	Std. Dev. [l/min]	Max [l/min]	Min [l/min]
104	16.67	-0.015	0.02	16.80	16.56

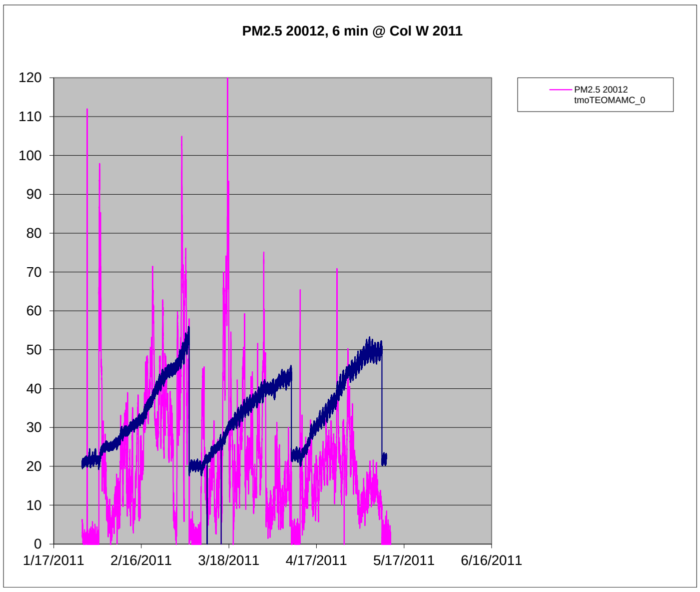

Figure 35: ***Course of time of the PM-concentration [µg/m³] and the filter load [%], Candidate SN 20012, Cologne, winter***

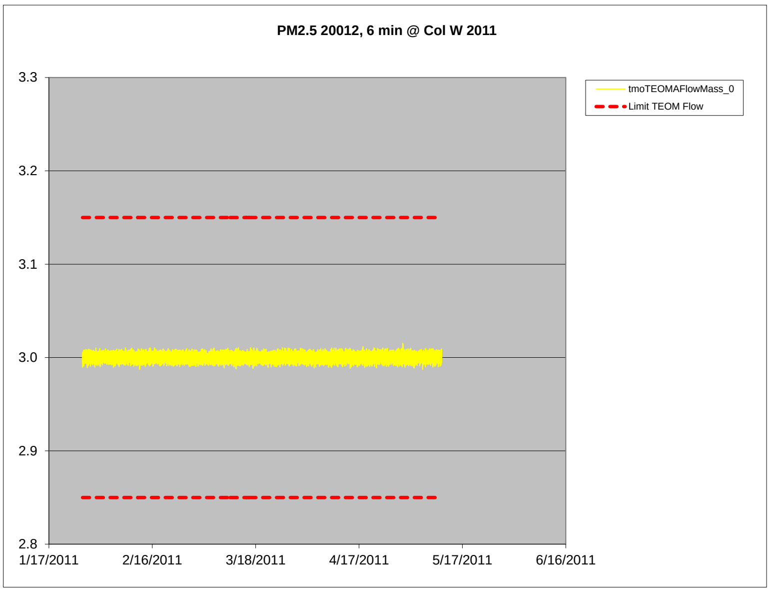

Figure 36: ***$PM_{2.5}$- flow rate at candidate SN 20012, Cologne, winter***

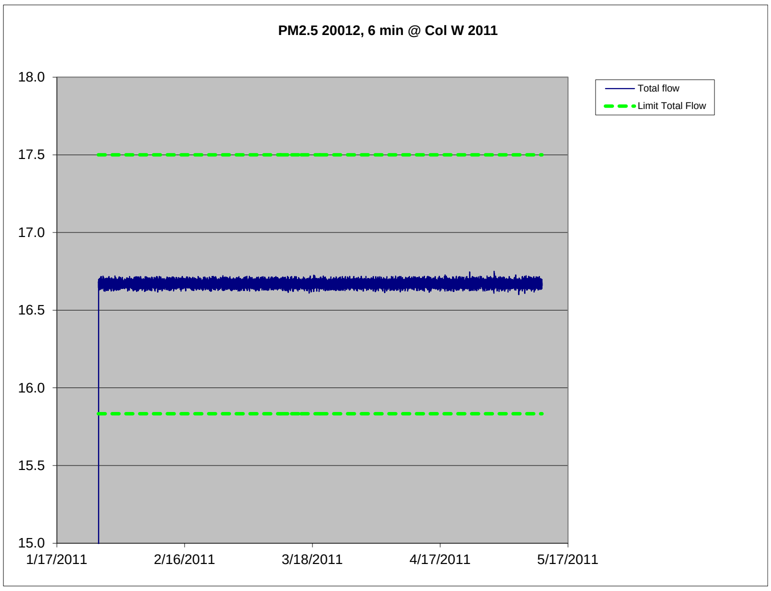

Figure 37: Total flow rate at candidate SN 20012, Cologne, winter

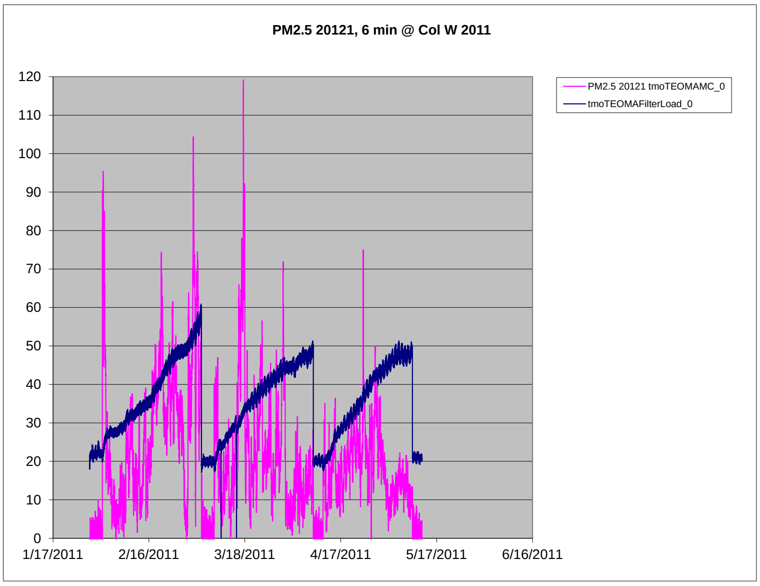

Figure 38: Course of time of the PM-concentration [µg/m³] and the filter load [%], Candidate SN 20121, Cologne, winter

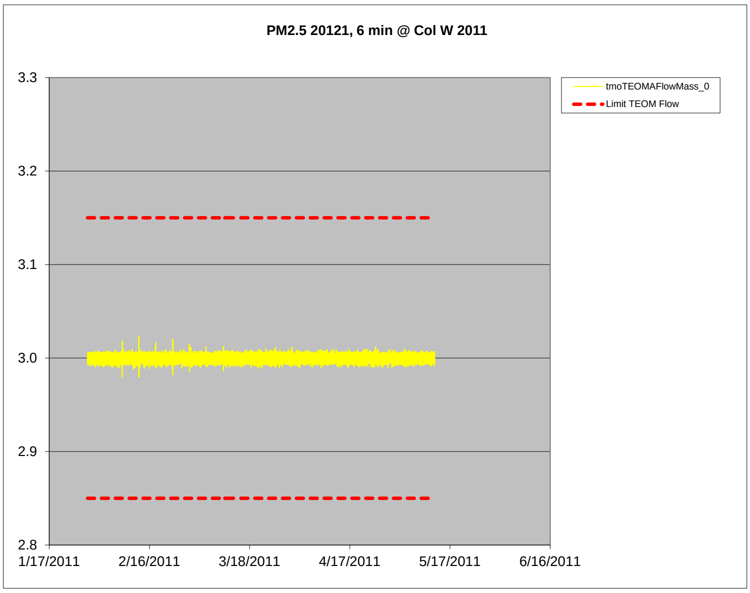

Figure 39: ***$PM_{2.5}$- flow rate at candidate SN 20121, Cologne, winter***

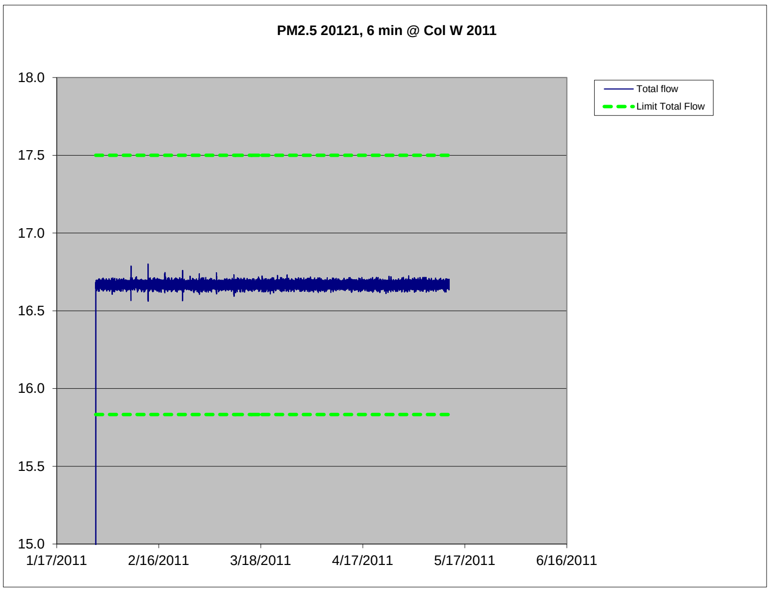

Figure 40: ***Total flow rate at candidate SN 20121, Cologne, winter***

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

Adapter for flow rate check/ tightness check

6.3 Performance of test

The AMS TEOM 1405-F Ambient Particulate Monitor can perform a tightness check using a device internal implemented tightness check assistant.

The tightness check assistant compares the different measured values between zero flow (with turned off vacuum) and flow through the device when the inlet is blocked (ideally again a zero flow should be measured).

The tightness check is considered as passed, when the flow values during blocked inlet deviate no more than 0.15 l/min from zero flow at the $PM_{2.5}$-path and no more 0.60 l/min from zero flow at the bypass-path.

The tightness check includes the base path as well as the reference path.

The tightness check may only be performed using the tightness check assistant in order to avoid damages of the instrument.

This procedure has been carried out at the beginning of each field test site.

It is recommended to check the tightness of the AMS once a month using the described procedure.

6.4 Evaluation

The tightness check via the tightness check assistant was done at the beginning of each field test site.

The criteria for approving the tightness check implemented by the manufacturer – a deviation of the flow values at a blocked inlet of no more than 0.15 l/min from zero flow at the $PM_{2.5}$-path and no more 0.60 l/min from zero flow at the bypass-path – were approved as appropriate parameters for the monitoring of the device tightness.

The tightness check may only be performed using the tightness check assistant to avoid damages of the instrument.

6.5 Assessment

The criteria for passing the tightness check implemented by the manufacturer – a deviation of the flow values at a blocked inlet of no more than 0.15 l/min from zero flow at the $PM_{2.5}$-path and no more 0.60 l/min from zero flow at the bypass-path – were approved as appropriate parameters for the monitoring of the device tightness.

The tightness check may only be performed using the tightness check assistant to avoid damages of the instrument.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 26 contains the determined values from the tightness check.

Table 26: Results of the tightness check during field test

		SN 20012			SN 20121		
		Limit [l/min]	Basis [l/min]	Reference [l/min]	Limit [l/min]	Basis [l/min]	Reference [l/min]
Teddington, Dec. 2009	$PM_{2.5}$	0.15	-0.02	-0.02	0.15	0.0	0.0
	Bypass	0.60	0.0	0.0	0.60	0.0	0.0
Teddington, Apr. 2010	$PM_{2.5}$	0.15	-0.03	-0.02	0.15	0.0	0.0
	Bypass	0.60	-0.01	0.0	0.60	0.0	0.0
Cologne, winter	$PM_{2.5}$	0.15	-0.01	0.0	0.15	-0.01	-0.01
	Bypass	0.60	0.0	0.0	0.60	-0.01	0.0
Bornheim, summer	$PM_{2.5}$	0.15	0.13	-0.02	0.15	-0.01	0.07
	Bypass	0.60	0.0	0.0	0.60	0.0	0.48

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

According to the version of the Guide from January 2010 [4] the following 5 criteria must be fulfilled to proof the equivalence.

1. Of the full dataset at least 20 % of the results obtained using the standard method shall be greater than the upper assessment threshold specified in 2008/50/EC for annual limit values *i.e.*: 28 µg/m³ for PM_{10} and currently 17 µg/m³ for $PM_{2.5}$.

2. The intra instrument uncertainty of the candidate 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 intra instrument uncertainty of the reference method 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 individual candidate instrument against the average results of the reference method. For each of the following permutations, the expanded uncertainty must be less than 25 %:

   - Full dataset;
   - Datasets representing PM concentrations greater than or equal to 30 µg/m³ for PM_{10}, or concentrations greater than or equal to 18 µg/m³ for $PM_{2.5}$, provided that the subset contains 40 or more valid data pairs;
   - Datasets for each individual test 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 of all paired instruments together.

The fulfilment of the 5 criteria is checked in the following chapters:

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 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 case, that criterion 5 cannot be fulfilled without the 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 guidance document „Demonstration of Equivalence of Ambient Air Monitoring Methods“ in the field test at least at four sampling test sites representative of the future application.

6.2 Equipment

Not required for this minimum requirement.

6.3 Performance of test

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

Of the complete data set, at least 20 % of the concentration values determined with the reference method, shall be greater than the upper assessment threshold according to 2008/50/EC [7]. For $PM_{2.5}$ the upper assessment threshold is at 17 µg/m³.

At each comparison campaign at least 40 valid data pairs were determined. Of the complete data set (4 test sites, 344 valid data pairs for SN 20012, 335 valid data pairs for SN 20121) in total 30.5 % of the measured values are above the upper assessment threshold of 17 µg/m³ for $PM_{2.5}$. The measured concentrations were referred to ambient conditions.

6.4 Evaluation

According to **point 9.5.3.1** of the Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“ applies:

The uncertainty between the candidates u_{bs} must be ≤ 2.5 µg/m³. An uncertainty of more than 2,5 µg/m³ between the two candidates is an indication that the performance of one or both systems is not sufficient and the equivalence cannot be declared.

The uncertainty is determined for:

- All test sites respectively comparisons together (complete data set)
- 1 data set with measured values ≥ 18 µg/m³ for PM_{10} (Basis: averages reference measurement)

Furthermore the evaluation of the following data sets is done:

- Each test site respectively comparison individually
- 1 Data set with measured values < 30 µg/m³ for PM_{10} (Basis: averages of reference measurement)

The in-between-instrument uncertainty u_{bs} is calculated from the differences of all 24-hour results of the simultaneously operated candidate systems according to 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 24h-values I
n = No. of 24h-values

6.5 Assessment

The in-between-uncertainty between the candidates u_{bs} is with a maximum of 1.33 µg/m³ for $PM_{2.5}$ below the required value of 2.5 µg/m³.

Minimum requirement fulfilled? yes

6.6 Detailed representation of the test results

Table 27 shows the calculated values for the uncertainty between systems under test u_{bs}. The graphical representation is done in Figure 41 to Figure 47.

Table 27: Uncertainty between systems under test u_{bs} for the candidates SN 20012 and SN 20121, measured component $PM_{2.5}$

Candidate	Test site	No. of values	Uncertainty u_{bs}
SN			µg/m³
20012 / 20121	**All test site**	**411**	**0.81**
Single test sites			
20012 / 20121	Teddington	145	0.57
20012 / 20121	Köln, winter	88	0.62
20012 / 20121	Bornheim, summer	95	0.66
20012 / 20121	Bornheim, winter	83	1.33
Classification via reference value			
20012 / 20121	**Values ≥ 18 µg/m³**	**91**	**0.76**
20012 / 20121	Values < 18 µg/m³	243	0.67

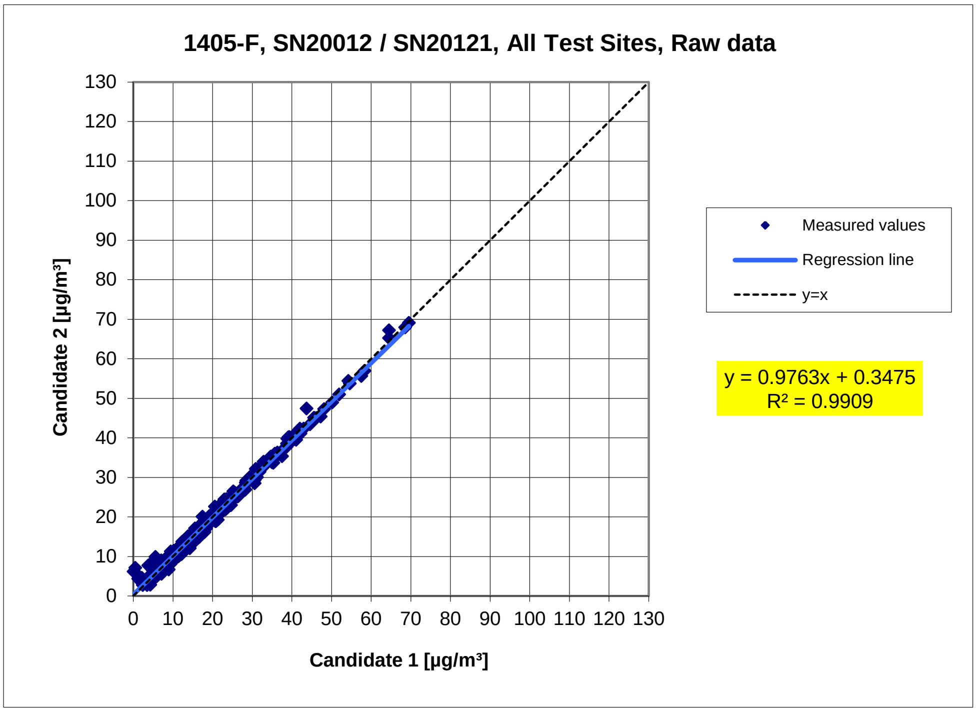

Figure 41: ***Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, all test sites***

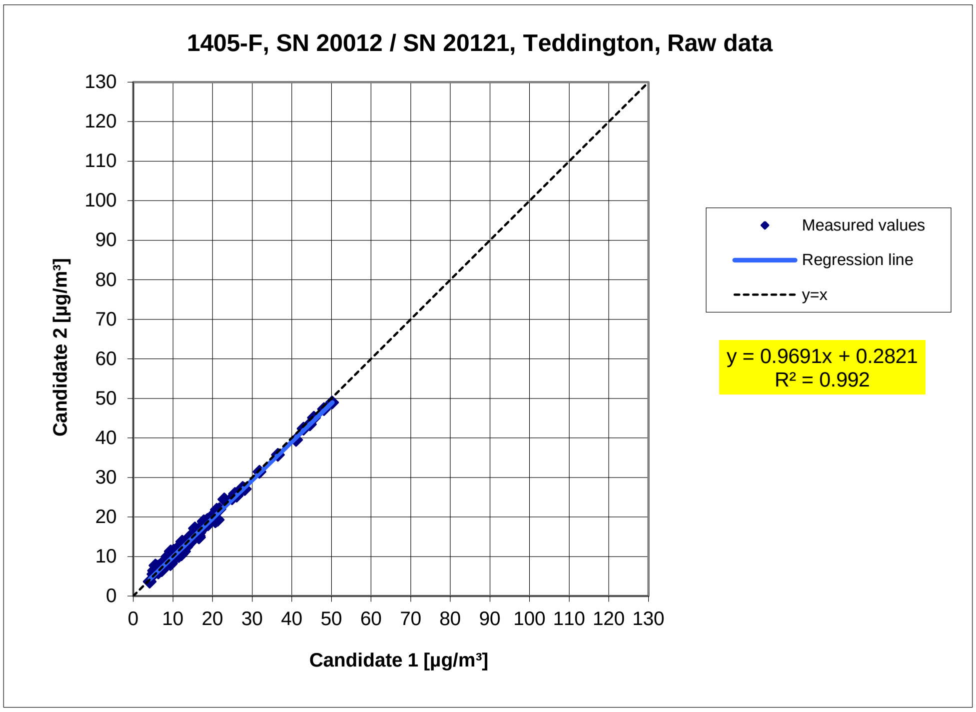

Figure 42: ***Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, test site Teddington***

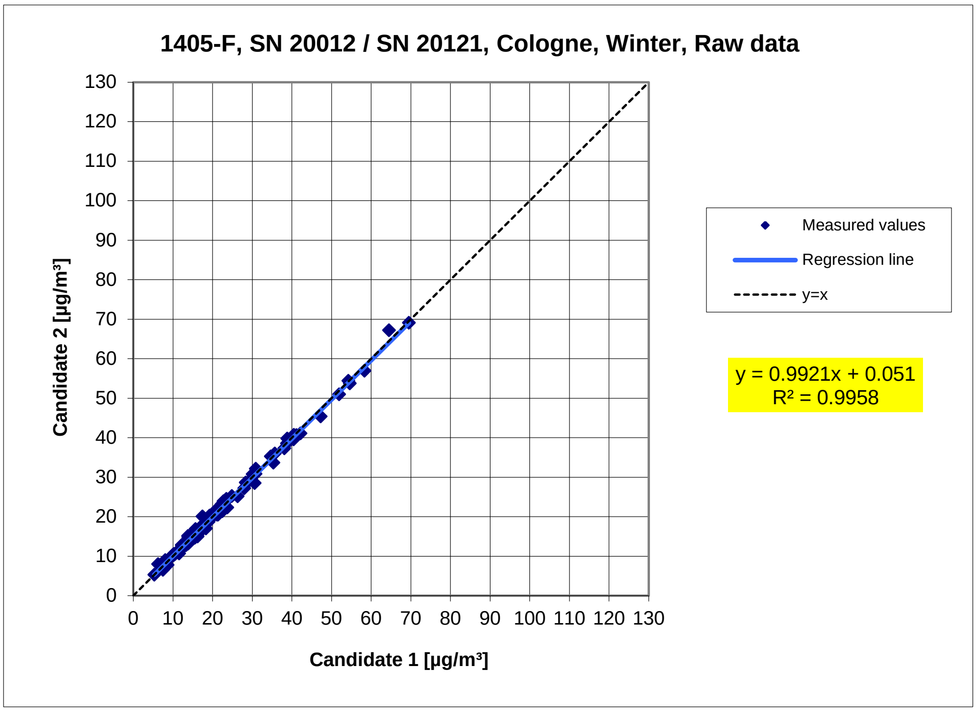

Figure 43: Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, test site Cologne, winter

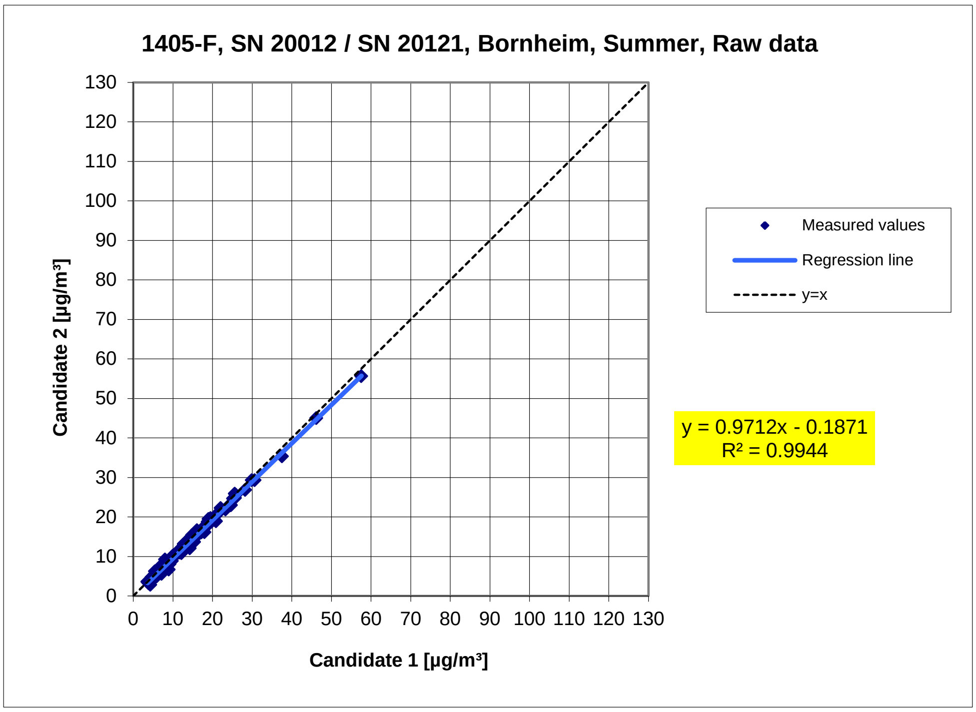

Figure 44: Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, test site Bornheim, summer

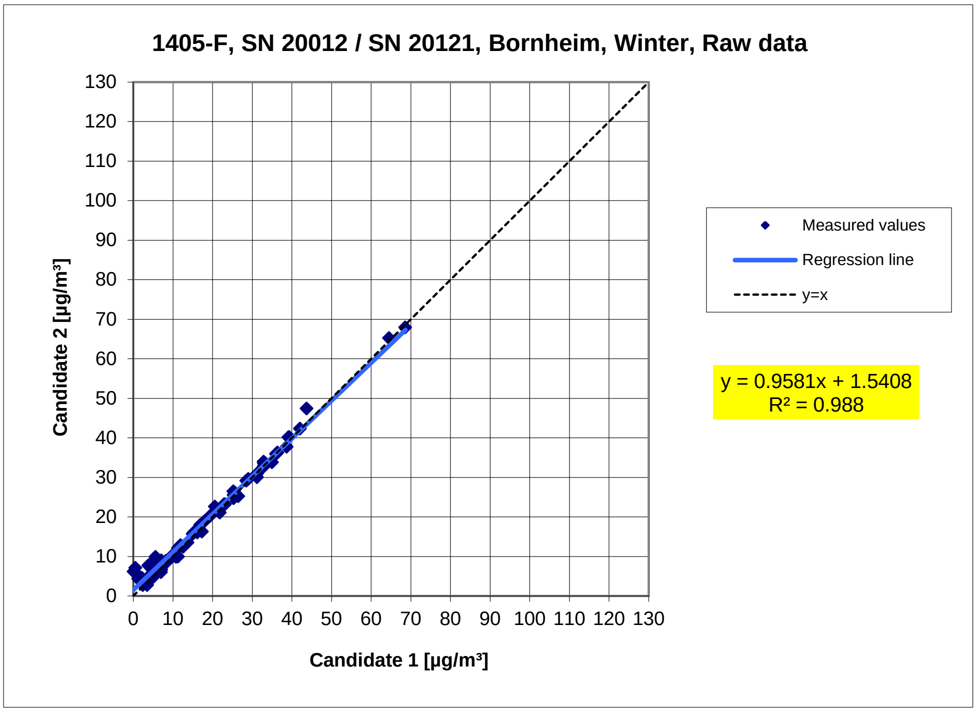

Figure 45: ***Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, test site Bornheim, winter***

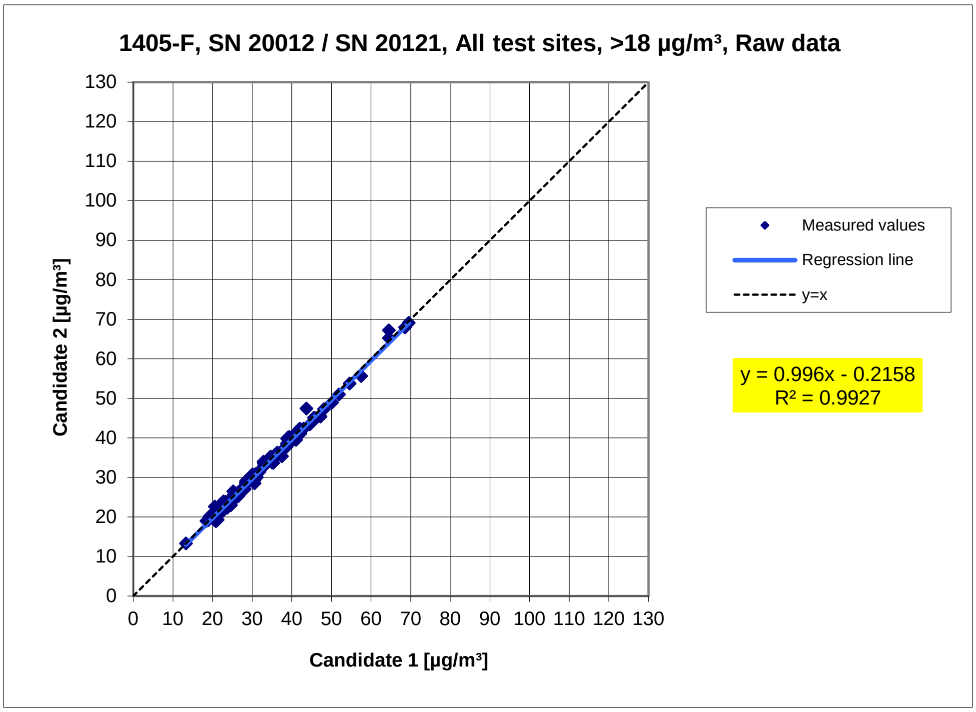

Figure 46: ***Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, all test sites, values ≥ 18 µg/m³***

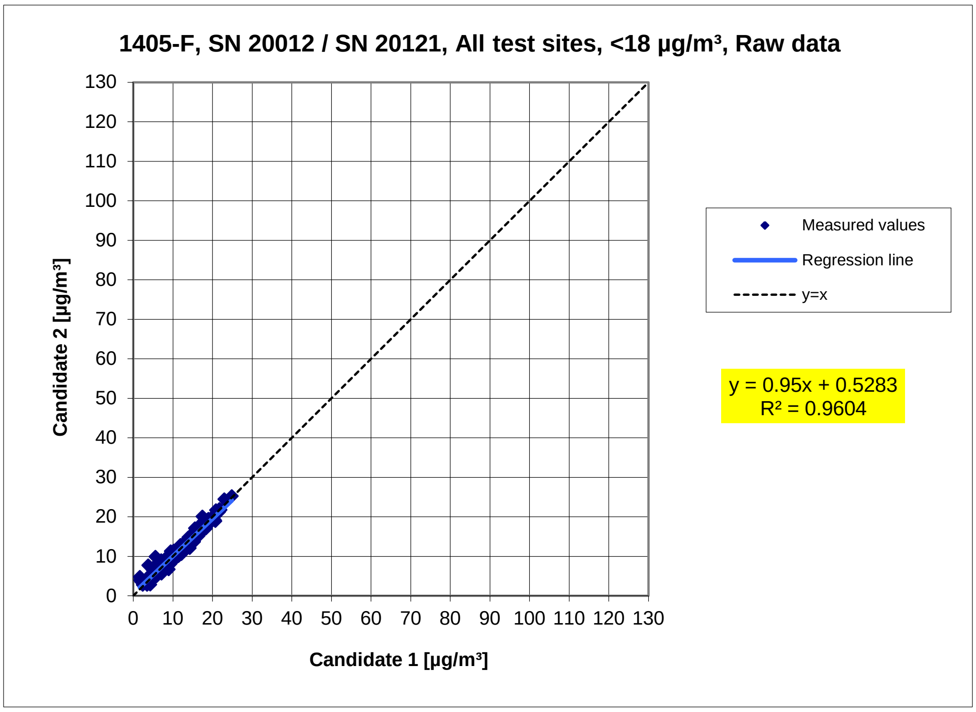

Figure 47: ***Results of the parallel measurements with the candidates SN 20012 / SN 20121, measured component $PM_{2.5}$, all test sites, values < 18 µg/m³***

6.1 5.4.10 Calculation of the expanded uncertainty of the instruments

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

6.2 Equipment

For this test point additionally the devices according to chapter 5 of this report were used.

6.3 Performance of test

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

Of the complete data set, at least 20 % of the concentration values determined with the reference method, shall be greater than the upper assessment threshold according to 2008/50/EC [7]. For $PM_{2.5}$ the upper assessment threshold is at 17 µg/m³.

At each comparison campaign at least 40 valid data pairs were determined. Of the complete data set (4 test sites, 344 valid data pairs for SN 20012, 335 valid data pairs for SN 20121) in total 30.5 % of the measured values are above the upper assessment threshold of 17 µg/m³ for $PM_{2.5}$. The measured concentrations were referred to ambient conditions.

6.4 Evaluation

[Point 9.5.3.2] The calculation of the in-between-instrument uncertainty u_{ref} of the reference devices is carried out prior to the calculation of the expanded uncertainty of the candidates.

The in-between-instrument uncertainty u_{ref} of the reference devices shall be ≤ 2 µg/m³.

Section 7.6 of this test point shows the evaluated results.

A linear correlation $y_i = a + bx_i$ is assumed between the results of both methods in order to evaluate the comparability of the candidates y and the reference procedure x. The correlation between the average values of the reference devices and the candidates is established by orthogonal regression.

Regression is calculated for:

- All test sites respectively comparisons together
- Each test site respectively comparison separately
- 1 data set with measured values $PM_{2.5}$ ≥ 18 µg/m³ (Basis: average value of reference measurement)

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

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

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

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

Algorithm for the calculation of ordinate intercept a as well as slope b and its variances by orthogonal regression are described in detail in annex B of [4].

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

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

Uncertainty u_{c_s} is calculated for:

- All test sites respectively comparisons together
- Each test site respectively comparison individually
- 1 data set with measured values $PM_{2.5}$ ≥ 18 µg/m³ Basis: average values of the reference measurement)

Preconditions for acceptance of the full dataset are that:

- The slope b is significantly different from 1: $|b-1| \leq 2 \cdot u(b)$

and

- The intercept a is insignificantly different from 0: $|a| \leq 2 \cdot u(a)$

Where u(b) and u(a) are the standard uncertainties of the slope and intercept, respectively calculated as the square root of their variances. If these preconditions are not met, the candidate method may be calibrated according to point 9.7 of the Guide (refer to 6.1 5.4.11 Application of correction factors and terms. The calibration shall only be applied to the full dataset.

[Point 9.5.4] The combined uncertainty of the candidates $w_{c,CM}$ is calculated for each data set by combining the contributions from 9.5.2.1 and 9.5.2.2 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 $PM_{2.5}$.

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

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

In practice: k=2 for large n

[Point 9.6] The highest resulting uncertainty W_{CM} is compared and assessed with the requirements on data quality of ambient air measurements according to EU Standard [7]. Two results are possible:

1. $W_{CM} \le W_{dqo}$ → 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 % [7].

6.5 Assessment

The determined uncertainties W_{CM} without application of correction factors lay for all observed data sets below the defined expanded relative uncertainty W_{dqo} of 25 % for particulate.

Minimum requirement fulfilled? yes

The following Table 28 shows an overview of the results of the equivalence check for the candidate TEOM 1405-F Ambient Particulate Monitor for $PM_{2.5}$. For the case, that a criterion is fulfilled or not, the text is represented in green or red colour. Furthermore the five criteria from chapter 6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11) are taken into account, the related cells are highlighted in colour.

Table 28: Overview equivalence test TEOM 1405-F Ambient Particulate Monitor for $PM_{2.5}$

PM2.5 1405F FDMS	30.5% > 17 µg m-3	Orthogonal Regression								Between Instrument Uncertainties	
	WCM / %	nc-s	r2	Slope (b) +/- ub			Intercept (a) +/- ua			Reference	Candidate
All Data	16.4	334	0.982	1.016	+/-	0.008	1.454	+/-	0.145	0.55	0.81
< 18 µg m-3	28.5	243	0.894	1.111	+/-	0.023	0.686	+/-	0.241	0.54	0.67
> 18 µg m-3	15.5	91	0.977	1.040	+/-	0.017	0.335	+/-	0.546	0.56	0.76

SN 20012	Dataset	Orthogonal Regression								Limit Value of 30 µg m-3	
		nc-s	r2	Slope (b) +/- ub			Intercept (a) +/- ua			WCM / %	% > 17 µg m-3
Individual Datasets	Bornheim Winter	64	0.991	1.060	+/-	0.013	0.273	+/-	0.282	16.19	40.6
	Cologne Winter	71	0.984	1.045	+/-	0.016	0.815	+/-	0.404	18.15	59.2
	Bornheim Summer	84	0.971	1.068	+/-	0.020	1.309	+/-	0.289	24.28	19.0
	Teddington	125	0.971	0.948	+/-	0.014	2.491	+/-	0.228	11.71	15.2
Combined Datasets	< 18 µg m-3	252	0.888	1.136	+/-	0.024	0.518	+/-	0.246	32.31	4.4
	> 18 µg m-3	92	0.978	1.039	+/-	0.016	0.567	+/-	0.535	16.30	100.0
	All Data	344	0.981	1.023	+/-	0.008	1.446	+/-	0.147	17.69	29.9

SN 20121	Dataset	Orthogonal Regression								Limit Value of 30 µg m-3	
		nc-s	r2	Slope (b) +/- ub			Intercept (a) +/- ua			WCM / %	% > 17 µg m-3
Individual Datasets	Bornheim Winter	64	0.991	1.041	+/-	0.012	1.157	+/-	0.270	17.85	40.6
	Cologne Winter	71	0.982	1.040	+/-	0.017	0.738	+/-	0.424	17.31	59.2
	Bornheim Summer	75	0.970	1.041	+/-	0.021	0.952	+/-	0.315	17.48	20.0
	Teddington	125	0.968	0.921	+/-	0.015	2.684	+/-	0.236	10.48	15.2
Combined Datasets	< 18 µg m-3	244	0.883	1.100	+/-	0.024	0.787	+/-	0.250	27.16	4.5
	> 18 µg m-3	91	0.973	1.041	+/-	0.018	0.135	+/-	0.594	15.63	100.0
	All Data	335	0.979	1.010	+/-	0.008	1.491	+/-	0.153	16.13	30.4

KEY	
(light cyan)	Criterion 1
(grey)	Criterion 2
(light orange)	Criterion 3
(light yellow)	Criterion 4
(light blue)	Criterion 5
(orange-yellow)	Other

The check of the five criteria from chapter 6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11) resulted as follows:

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

Criterion 2: The intra instrument uncertainty of the candidates is smaller than 2.5 µg/m³.

Criterion 3: The intra instrument uncertainty of the reference is smaller than 2.0 µg/m³.

Criterion 4: All of the expanded uncertainties are below 25 %.

Criterion 5: The slope and the intercept are not significant for the "All data" comparison for SN 20012 and for SN 20121 are significantly greater than allowed.

Other: The evaluation of the All data set for both candidates together shows that the AMS demonstrates a very good correlation with the reference method with a slope of 1.016 and an intercept of 1.454 at an expanded total uncertainty of 16.4 %

The January 2010 version of The Guidance is ambiguous with respect to which slope and intercept should be used to correct a candidate should it fail the test for equivalence. After communication with the convenor of the EC working group, which is responsible for setting up the Guide Mr. Theo Hafkenscheid), it was decided that the requirement of the November 2005 version of the Guidance are still valid, and that the slope and intercept from the orthogonal regression of all the paired data should be used. These are shaded gold and marked 'other' in the key on the above Table 28.

The 2006 UK Equivalence Report highlighted that this was a flaw in the mathematics required for equivalence as per the November 2005 version of The Guidance as it penalised instruments that were more accurate (Appendix E Section 4.2 therein). This same flaw is copied in the July 2009 version. It is the opinion of TŰV Rheinland and their UK partners that the TEOM 1405-F Ambient Particulate Monitor for PM_{10} is indeed being penalised by the mathematics for being accurate. It is proposed that the same pragmatic approach is taken here that was previously undertaken in earlier studies. Namely: as some of the individual data set slopes are greater than 1, and some are less, there should be no need to correct the data for this slope offset.

In this particular case the slope for the "All data" comparison was 1.016.

The intercept for the "All data" comparison lays at 1.454. Therefore, under point 6.1 5.4.11 Application of correction factors and terms an additional evaluation, using the respective calibration factor for the data sets, is done.

The reworked version of the Guide of January 2010 requires that when operating in networks, a candidate method needs to be tested annually at a number of sites and that the number of the instruments to be tested is dependent on the expanded measurement uncertainty of the device. The respective realisation is the responsibility of the network operator or of the responsible authority of the member state. However TÜV Rheinland and their UK partners recommend, that the expanded uncertainty for the full data set is referred to for this, namely 16.4 %, which again would require an annual test at 4 measurement sites (Guide [4], chapter 9.9.2, Table 6).

6.6 Detailed representation of the test results

Table 29 shows an overview on the uncertainties between the reference devices $u_{ref\ from}$ the field tests. In Table 30 a summarized representation of the results of the equivalence test incl. the determined expanded measuring uncertainties W_{CM} from the field test is shown.

Table 29: In-between-instrument uncertainty u_{ref} of the reference devices for $PM_{2.5}$

Reference device	Test site	Amount values	Uncertainty u_{bs}
Nr.			µg/m³
1 / 2	Teddington	128	0.37
1 / 2	Cologne, winter	81	0.51
1 / 2	Bornheim, summer	87	0.66
1 / 2	Bornheim, winter	65	0.70
1 / 2	All test sites	361	0.55

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

Table 30: Summary of the results of the equivalence test, SN 20012 & SN 20121, measured component $PM_{2.5}$, raw data

PM2.5 1405F FDMS	30.5% > 17 µg m-3	Orthogonal Regression								Between Instrument Uncertainties	
	W_{CM} / %	n_{c-s}	r^2	Slope (b) +/- u_b			Intercept (a) +/- u_a			Reference	Candidate
All Data	16.4	334	0.982	1.016	+/-	0.008	1.454	+/-	0.145	0.55	0.81
< 18 µg m-3	28.5	243	0.894	1.111	+/-	0.023	0.686	+/-	0.241	0.54	0.67
> 18 µg m-3	15.5	91	0.977	1.040	+/-	0.017	0.335	+/-	0.546	0.56	0.76

SN 20012	Dataset	Orthogonal Regression								Limit Value of 30 µg m-3	
		n_{c-s}	r^2	Slope (b) +/- u_b			Intercept (a) +/- u_a			W_{CM} / %	% > 17 µg m-3
Individual Datasets	Bornheim Winter	64	0.991	1.060	+/-	0.013	0.273	+/-	0.282	16.19	40.6
	Cologne Winter	71	0.984	1.045	+/-	0.016	0.815	+/-	0.404	18.15	59.2
	Bornheim Summer	84	0.971	1.068	+/-	0.020	1.309	+/-	0.289	24.28	19.0
	Teddington	125	0.971	0.948	+/-	0.014	2.491	+/-	0.228	11.71	15.2
Combined Datasets	< 18 µg m-3	252	0.888	1.136	+/-	0.024	0.518	+/-	0.246	32.31	4.4
	> 18 µg m-3	92	0.978	1.039	+/-	0.016	0.567	+/-	0.535	16.30	100.0
	All Data	344	0.981	1.023	+/-	0.008	1.446	+/-	0.147	17.69	29.9

SN 20121	Dataset	Orthogonal Regression								Limit Value of 30 µg m-3	
		n_{c-s}	r^2	Slope (b) +/- u_b			Intercept (a) +/- u_a			W_{CM} / %	% > 17 µg m-3
Individual Datasets	Bornheim Winter	64	0.991	1.041	+/-	0.012	1.157	+/-	0.270	17.85	40.6
	Cologne Winter	71	0.982	1.040	+/-	0.017	0.738	+/-	0.424	17.31	59.2
	Bornheim Summer	75	0.970	1.041	+/-	0.021	0.952	+/-	0.315	17.48	20.0
	Teddington	125	0.968	0.921	+/-	0.015	2.684	+/-	0.236	10.48	15.2
Combined Datasets	< 18 µg m-3	244	0.883	1.100	+/-	0.024	0.787	+/-	0.250	27.16	4.5
	> 18 µg m-3	91	0.973	1.041	+/-	0.018	0.135	+/-	0.594	15.63	100.0
	All Data	335	0.979	1.010	+/-	0.008	1.491	+/-	0.153	16.13	30.4

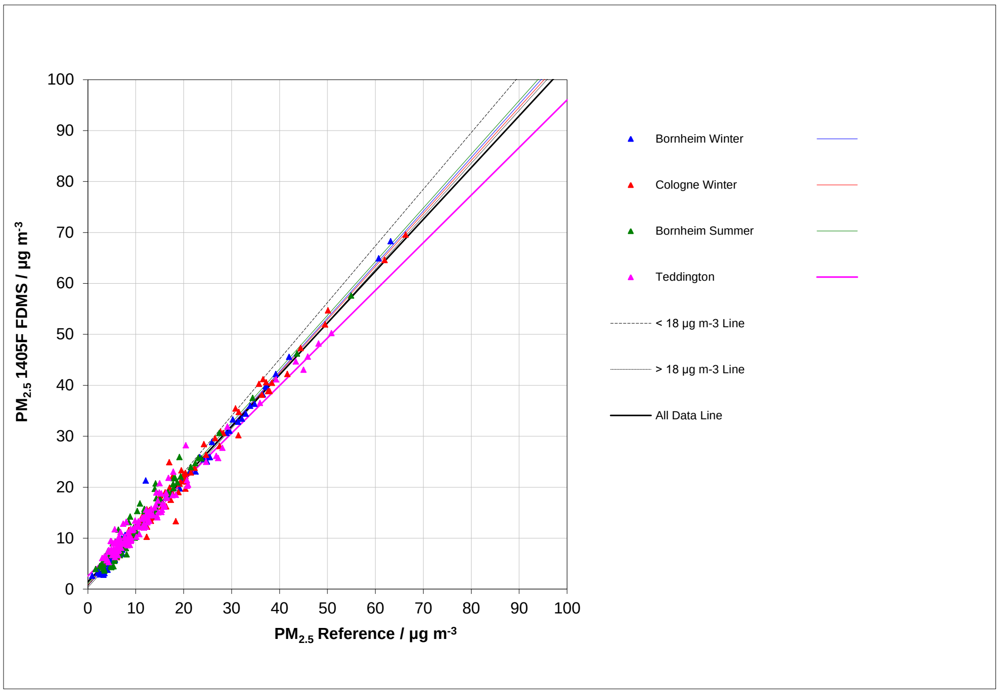

Figure 48: ***Reference vs. candidate, SN 20012 & SN 20121 measured component $PM_{2.5}$, all test sites***

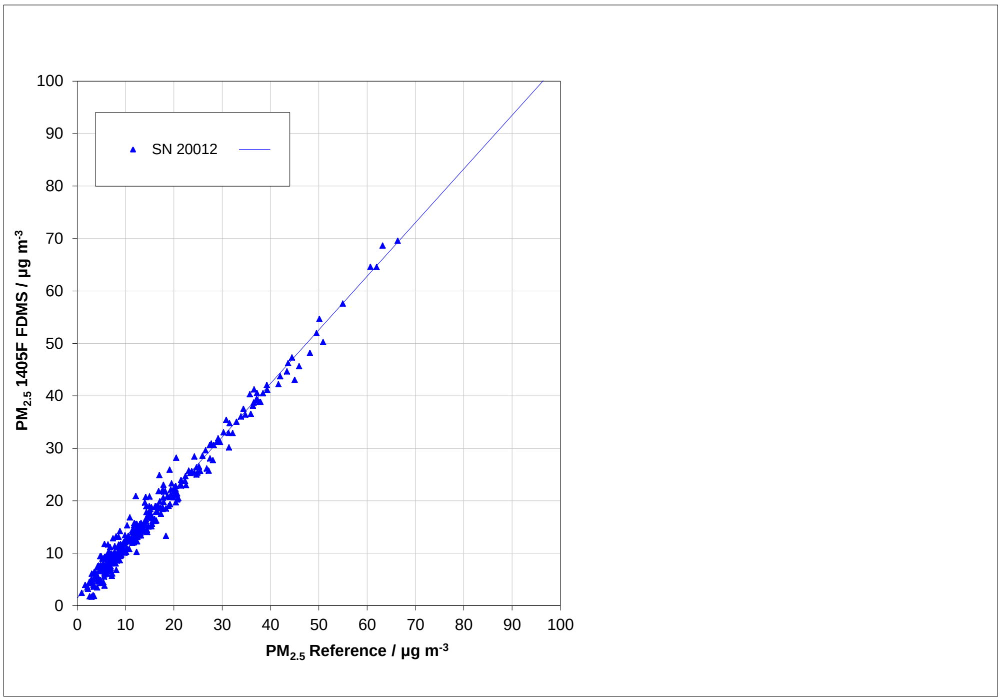

Figure 49: Reference vs. candidate, SN 20012 measured component $PM_{2.5}$ all test sites

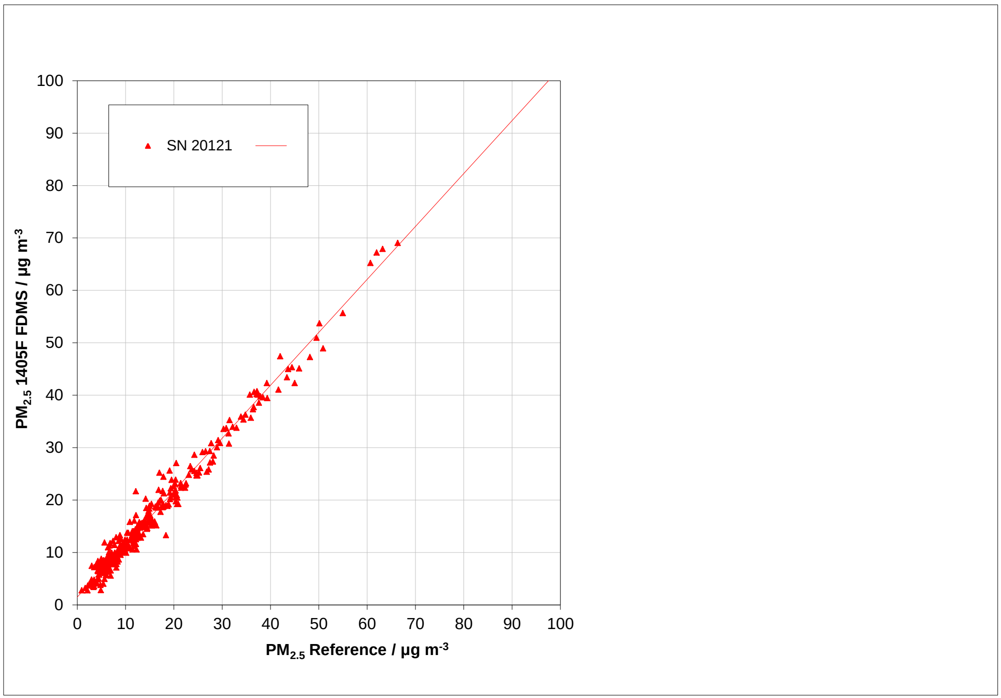

Figure 50: Reference vs. candidate, SN 20121 measured component $PM_{2.5}$ all test sites

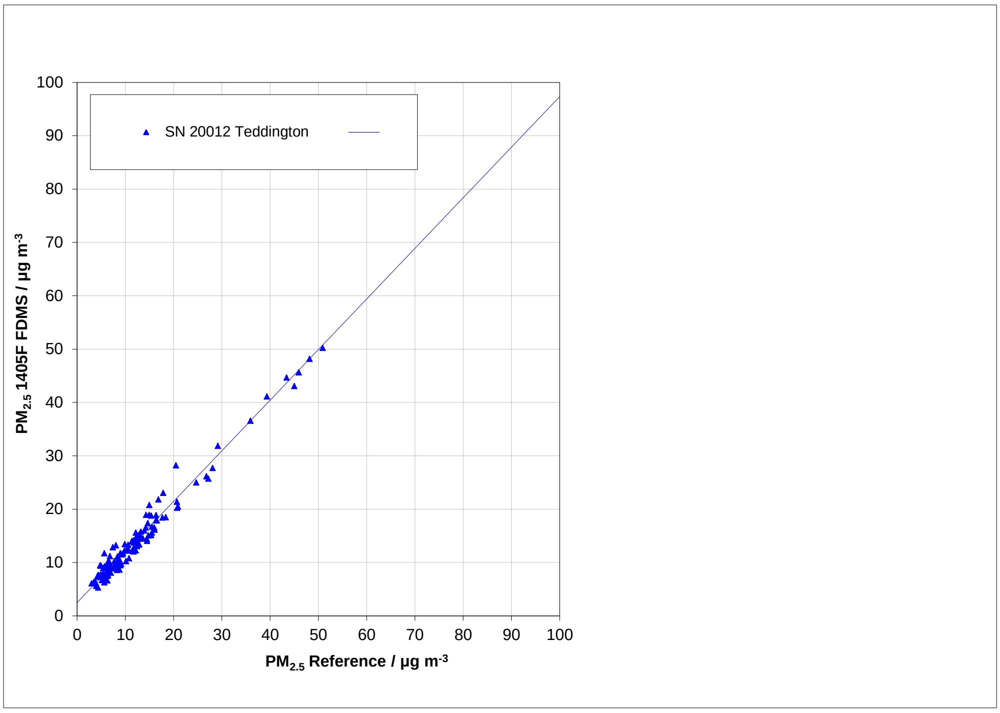

Figure 51: Reference vs. candidate, SN 20012 measured component $PM_{2.5}$, Teddington

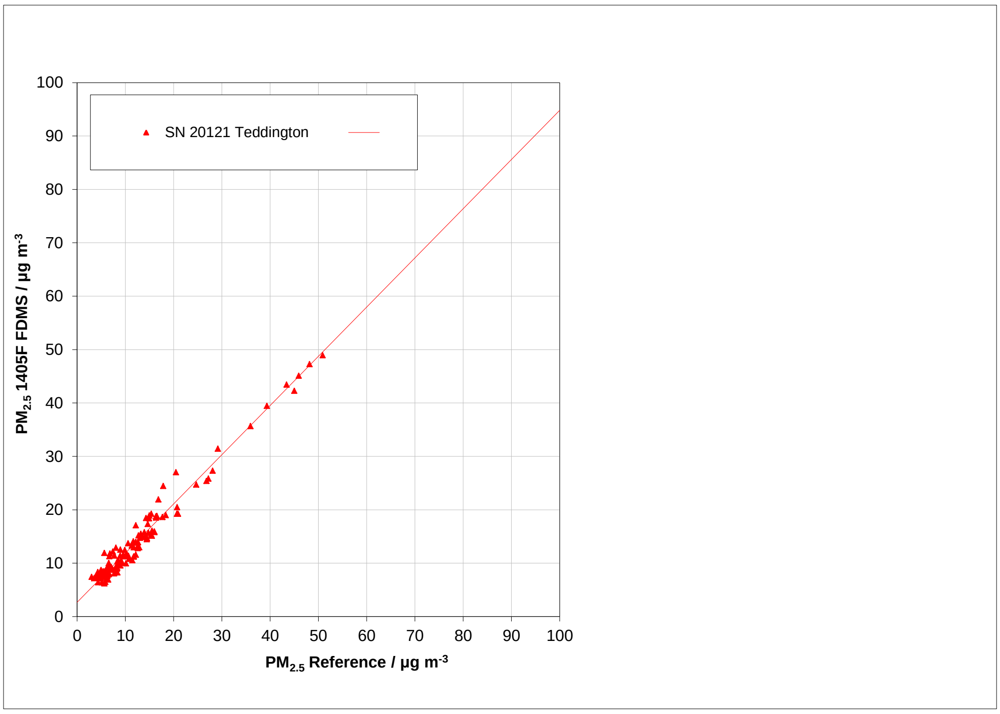

Figure 52: Reference vs. candidate, SN 20121 measured component $PM_{2.5}$, Teddington

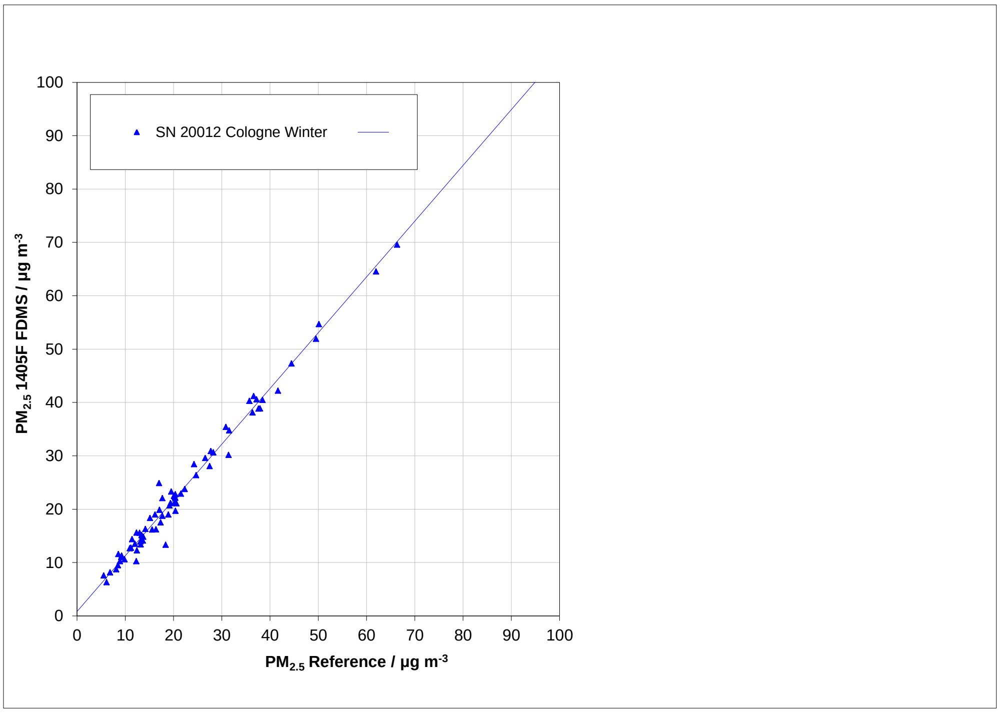

Figure 53: Reference vs. candidate, SN 20012 measured component $PM_{2.5}$, test site Cologne, winter

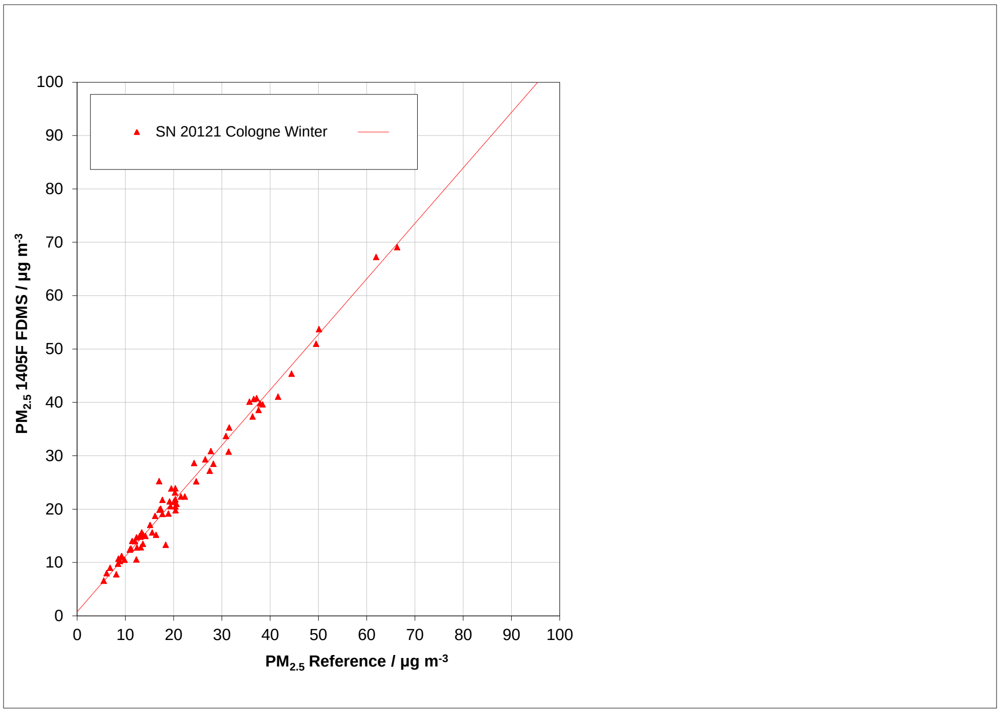

Figure 54: Reference vs. candidate, SN 20121 measured component $PM_{2.5}$, test site Cologne, winter

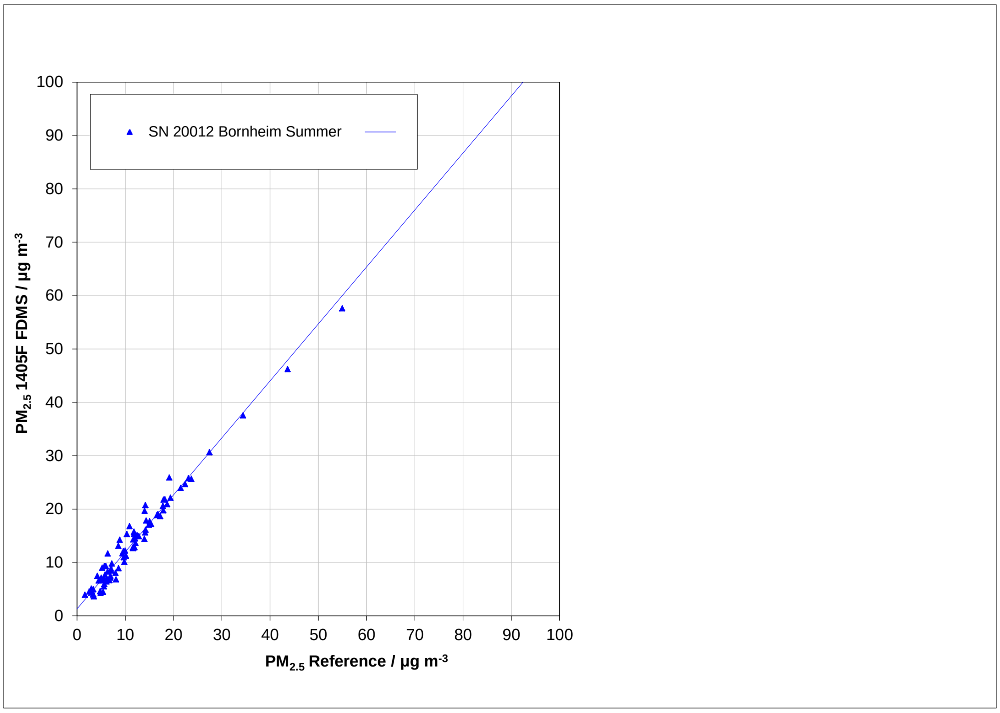

Figure 55: ***Reference vs. candidate, SN 20012 measured component $PM_{2.5,}$ test site Bornheim, summer***

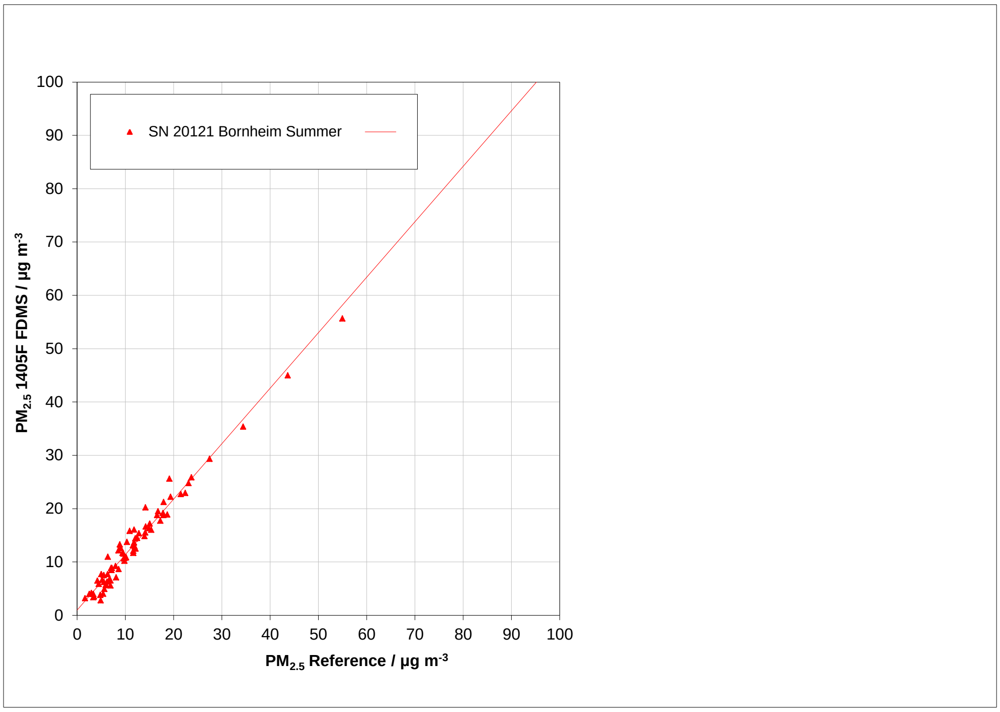

Figure 56: ***Reference vs. candidate, SN 20121 measured component $PM_{2.5,}$ test site Bornheim, summer***

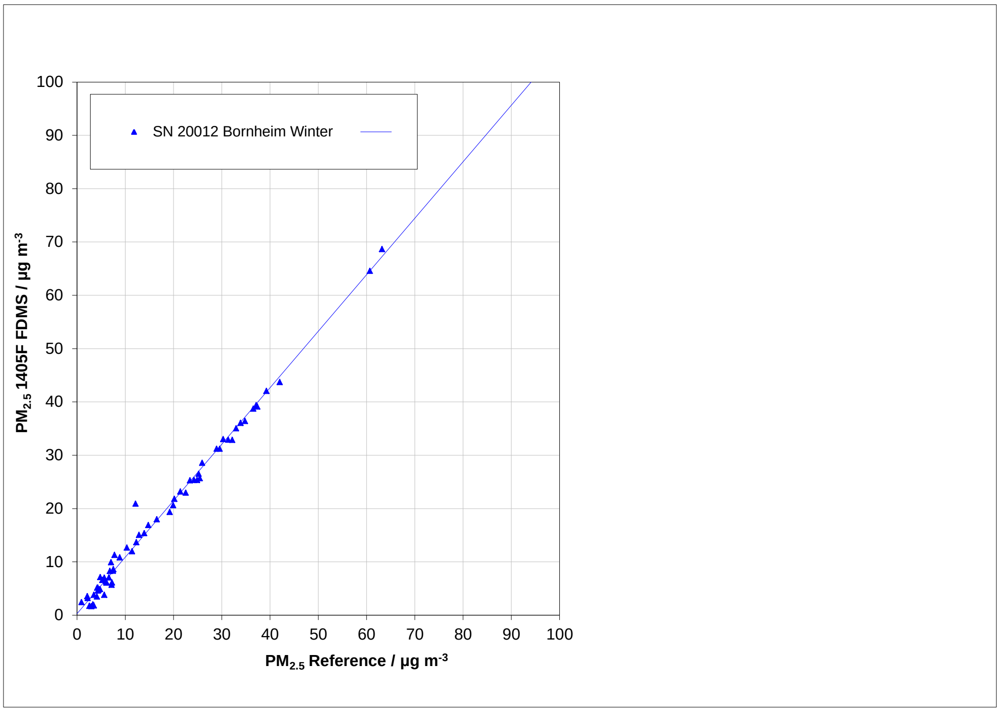

Figure 57: Reference vs. candidate, SN 20012 measured component $PM_{2.5}$, test site Bornheim, winter

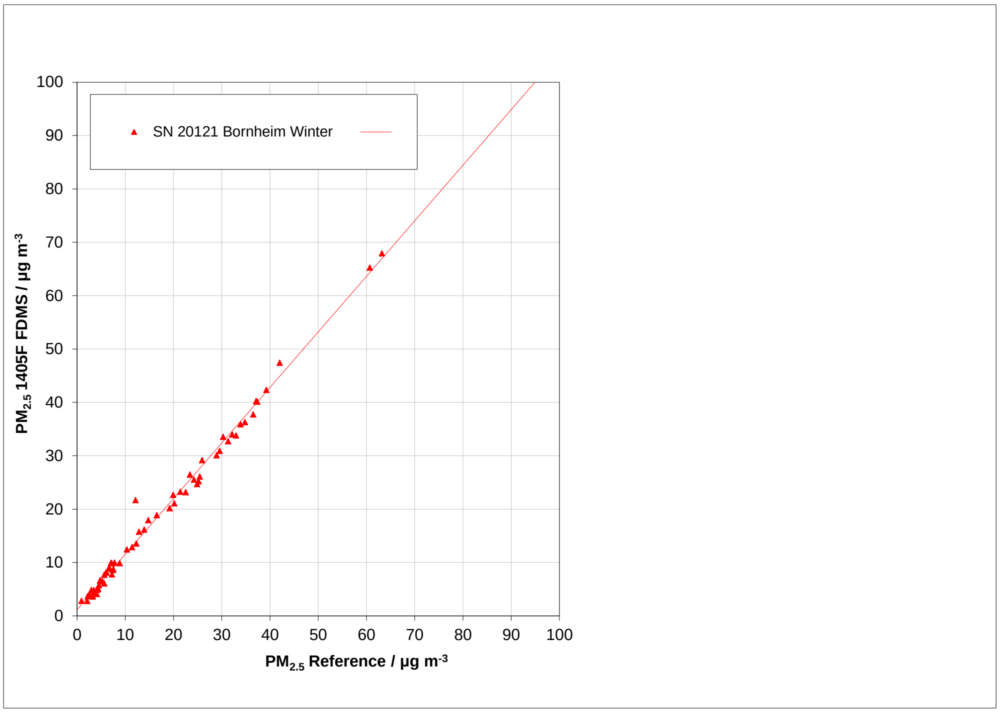

Figure 58: Reference vs. candidate, SN 20121 measured component $PM_{2.5}$, test site Bornheim, winter

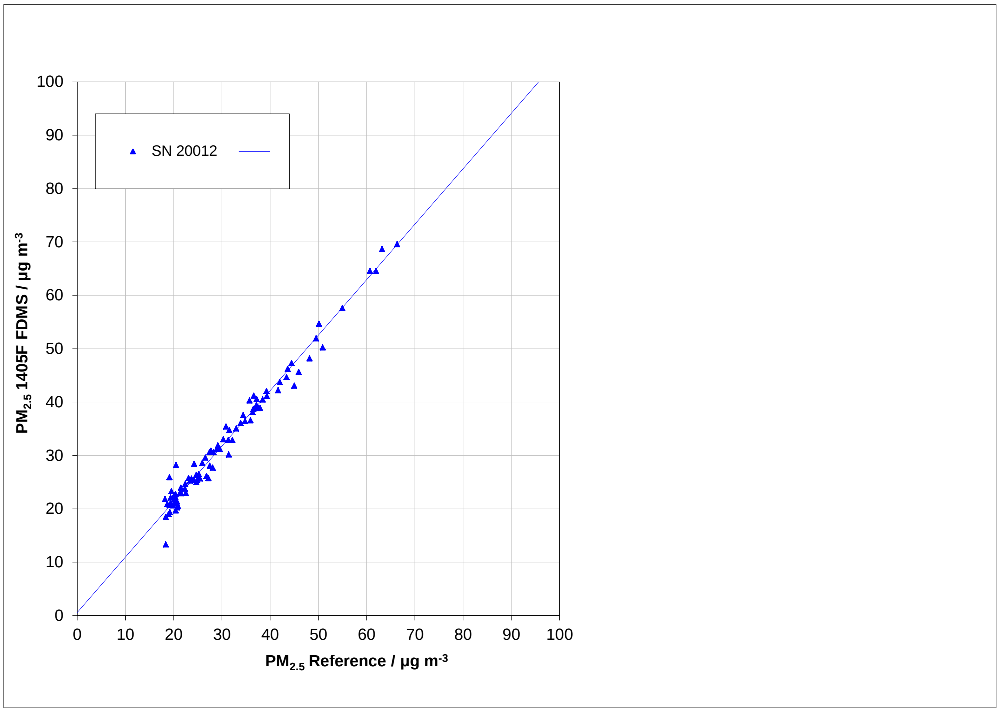

Figure 59: ***Reference vs. candidate, SN 20012 measured component $PM_{2.5,}$ values ≥ 18 µg/m³***

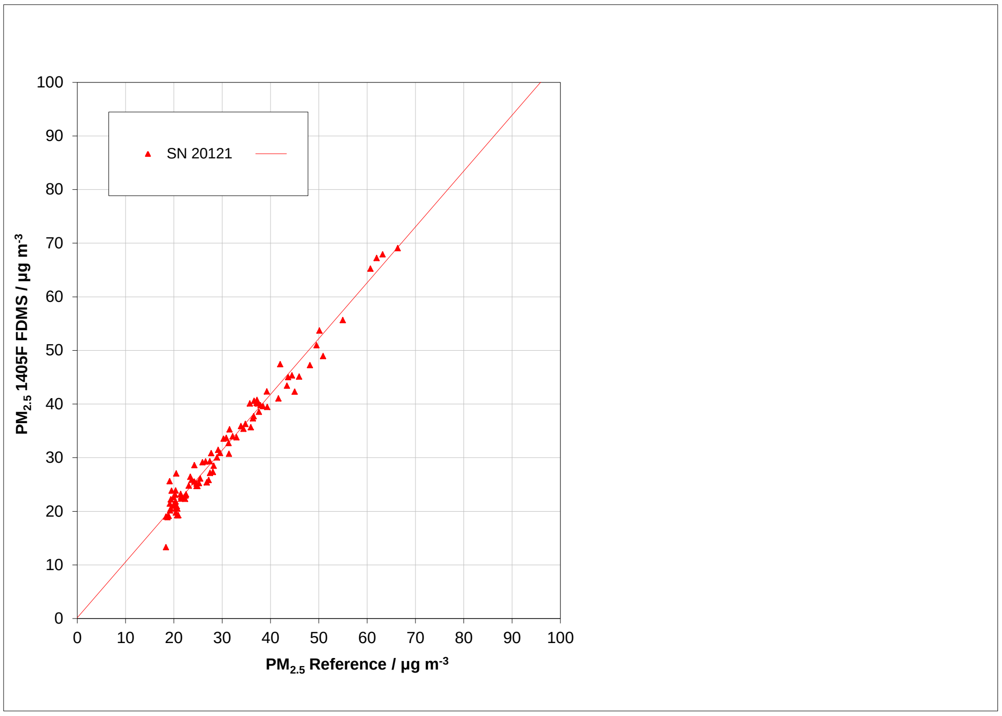

Figure 60: ***Reference vs. candidate, SN 20121 measured component $PM_{2.5,}$ values ≥ 18 µg/m³***

6.1 5.4.11 Application of correction factors and terms

If the highest resulting expanded uncertainty of the candidate method is larger than the expanded relative uncertainty, which is defined in the requirements on the data quality of ambient air measurements according to EU-Guideline [7], the application of correction factors or terms is permitted. The corrected values have to fulfil the requirements according to point 9.5.3.2 et seqq. of the Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“.

6.2 Equipment

Not required for this minimum requirement.

6.3 Performance of test

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 data set. The corrected values shall satisfy the requirements for all data sets 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

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

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 [6]. 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 factor 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

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

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 [4]. 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 data set, uncertainty is calculated at the daily limit value $w_{c,CM,corr}$ by taking as y_i 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} is compared and assessed with the requirements on data quality of ambient air measurements according to EU Standard [7]. 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 % [7]

6.5 Assessment

The candidate systems fulfil the requirements on the data quality of ambient air quality measurements during the test already without application of correction factors

A correction of the intercept leads nevertheless to a significant improvement of the expanded measuring uncertainty of the “All data” comparison.

Minimum requirement fulfilled? yes

The evaluation of the “All data” comparison for both candidate nevertheless delivers a significant intercept for Table 28).

Theslopet for the “All data” comparison is 1.016 with an uncertainty of the slope of merely 0.008.

The UK Equivalence Report of 2006 [7] described exactly this point as a weak spot within the statistic for the equivalence proof in the November 2005 version of the Guideline, since “precise” devices were put at a disadvantage (Annex E part 4.2). The same weak spot was taken over 1:1 into the January 2010 version of the Guideline. Both the TÜV Rheinland and its UK partners are of the opinion that the TEOM 1405-F Ambient Particulate Monitor for $PM_{2.5}$ is indeed put at a disadvantage by its precision. Therefore it recommended to use the same pragmatically approach as in the past studies. Since some of the slopes form single data sets are greater than 1 and others are smaller than 1, there has been no reason for a correction of the slope.

The intercept for the all data comparison lays at 1.454. For this reason an intercept correction of the entire data set was performed and again evaluated with the corrected values. All data sets fulfil after the correction the requirements on data quality. The measuring uncertainty was improved significantly, only at the test site “Teddington” a slight worsening could be observed for SN 20121 (see Table 31 in comparison to Table 28).

The version of the Guide of January 2010 requires that when operating in networks, a candidate method needs to be tested annually at a number of sites corresponding to the highest expanded uncertainty found during equivalence testing. These criteria are banded in 5 % steps (Guide [4], point 9.9.2, Table 6). We have to bear in mind that the highest determined expanded uncertainty lays after the correction of the intercept in the range 15 % to 20 %.

The respective realization of the above mentioned requirement on ongoing QA/QC in networks is the responsibility of the network operator or of the responsible authority of the member state. However TÜV Rheinland and their UK partners recommend, that the expanded uncertainty for the full data set is referred to for this, namely 16.4 % (uncorrected dataset) respectively 10.7 % (dataset after offset-correction), which again would require an annual test at 4 respectively 3 measurement sites.

6.6 Detailed representation of the test results

Table 31 shows the results of the evaluations of the equivalence check after the application of the correction factor for the intercept on the complete data set.

Table 31: Summary of the results of the equivalence check, SN 20012 & SN 20121, after intercept correction

PM2.5 1405F FDMS Intercept Corrected	30.5% > 17 µg m-3	Orthogonal Regression				Between Instrument Uncertainties	
	W_{CM} / %	n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	Reference	Candidate
All Data	10.7	334	0.982	1.016 +/- 0.008	0.000 +/- 0.145	0.55	0.81
< 18 µg m-3	19.7	243	0.894	1.111 +/- 0.023	-0.768 +/- 0.241	0.54	0.67
> 18 µg m-3	11.6	91	0.977	1.040 +/- 0.017	-1.119 +/- 0.546	0.56	0.76

SN 20012	Dataset	Orthogonal Regression				Limit Value of 30 µg m-3	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m-3
Individual Datasets	Bornheim Winter	64	0.991	1.060 +/- 0.013	-1.182 +/- 0.282	9.51	40.6
	Cologne Winter	71	0.984	1.045 +/- 0.016	-0.640 +/- 0.404	12.00	59.2
	Bornheim Summer	84	0.971	1.068 +/- 0.020	-0.145 +/- 0.289	15.87	19.0
	Teddington	125	0.971	0.948 +/- 0.014	1.036 +/- 0.228	10.50	15.2
Combined Datasets	< 18 µg m-3	252	0.888	1.136 +/- 0.024	-0.936 +/- 0.246	23.35	4.4
	> 18 µg m-3	92	0.978	1.039 +/- 0.016	-0.887 +/- 0.535	11.61	100.0
	All Data	344	0.981	1.023 +/- 0.008	-0.008 +/- 0.147	11.53	29.9

SN 20121	Dataset	Orthogonal Regression				Limit Value of 30 µg m-3	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m-3
Individual Datasets	Bornheim Winter	64	0.991	1.041 +/- 0.012	-0.297 +/- 0.270	10.24	40.6
	Cologne Winter	71	0.982	1.040 +/- 0.017	-0.717 +/- 0.424	12.05	59.2
	Bornheim Summer	75	0.970	1.041 +/- 0.021	-0.502 +/- 0.315	10.97	20.0
	Teddington	125	0.968	0.921 +/- 0.015	1.230 +/- 0.236	12.76	15.2
Combined Datasets	< 18 µg m-3	244	0.883	1.100 +/- 0.024	-0.668 +/- 0.250	18.54	4.5
	> 18 µg m-3	91	0.973	1.041 +/- 0.018	-1.319 +/- 0.594	12.70	100.0
	All Data	335	0.979	1.010 +/- 0.008	0.037 +/- 0.153	11.10	30.4

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 Performance of test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of the test results

Not applicable.

7. Recommendations for practical use

Works in the maintenance interval (4 weeks)

The following procedures are required to be undertaken at regular intervals:

- Regular visual inspection / telemetric monitoring
- Check, if device status is o.k.
- Check, if there are no error messages
- Check, if there are no contaminations
- Check of the instrument functions according to the instructions of the manufacturer
- Maintenance of the sampling inlet and of the Sharp Cut Cyclone according to the instructions of the manufacturer
- Monthly change of the TEOM-filters (or in case the filter load >90 % is reached)
- Simultaneously with the change of the TEOM-filters, the cooled 47 mm-filter of the FDMS-unit have to be changed.
- Every 4 weeks: plausibility check of temperature, pressure sensors, if necessary re-calibration
- Every 4 weeks: leak check
- Every 4 weeks: check of the flow rate, if necessary re-calibration

Apart from that follow the manufacturer's directions and recommendations.

Further maintenance works

The following works are necessary in addition to the regular works in the maintenance interval:

- Every 6 months (or when necessary) the Inline-filter for $PM_{2.5}$- and Bypass-path shall be changed to avoid a contamination of the flow rate regulator.
- Once a year (or when necessary) the cooler, the switching valve and the air inlet system are to be cleaned.
- Once a year the calibration of the mass measuring transducer is to be checked using the K_0-test kit.
- The dryer inside the FDMS-unit has to be change or refurbished once a year or when necessary. For the monitoring/ securing of a correct dryer performance the manufacturer recommends to observe the pump vacuum (nominal: > 510 mm Hg) and the dew point of the air flow (nominal: <2°C at 4°C cooler temperature) and periodically perform a zero point test (operation of the measuring device with zero-filter at the entrance).
- Every 18 months or when necessary the sampling pump must be maintained or renewed.

Further details are provided in the user manual.

Department of Environmental Protection

Karsten Pletscher	Dr. Peter Wilbring

Cologne, March 11, 2012
936/21209885/C

8. Literature

[1] Standard VDI 4202, Part 1, „Minimum requirements for suitability tests of automated ambient air quality measuring systems – Point-related measurement methods of gaseous and particulate pollutants “, June 2002 & September 2010

[2] Standard VDI 4203, Part 3, „Testing of automated measuring systems – Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants “, August 2004 & September 2010

[3] 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] Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of January 2010)

[5] Operating manual 42-0109785 Revision A.000, Sep 22 2009

[6] Operating manual LVS3, Status 2000

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

[8] Report „UK Equivalence Programme for Monitoring of Particulate Matter“, Report No.: BV/AQ/AD202209/DH/2396 of June 5^{th}, 2006

9. Appendix

Appendix 1	**Measured and calculated values**
Annex 1:	Detection limit
Annex 2:	Temperature dependency of zero-point
Annex 3:	Temperature dependency of the sensibility
Annex 4:	Dependency on supply voltage
Annex 5:	Measured values at the field test sites
Annex 6:	Surrounding conditions at the field test sites
Appendix 2	**Filter weighing procedure**
Appendix 3	**Manuals**

Annex 1 **Detection limit** **Page 1 of 1**

Manufacturer Thermo Fisher Scientific

Type 1405F

Serial-No. SN 20012 / SN 20121

Standards ZP Measured value with zero filter

No.	Date	Measured values [µg/m³]	
		SN 20012	SN 20121
1	10/25/2010	1.8	0.5
2	10/26/2010	1.3	1.0
3	10/27/2010	1.9	0.8
4	10/28/2010	0.9	1.0
5	10/29/2010	1.1	1.0
6	10/30/2010	1.3	0.9
7	10/31/2010	1.2	0.8
8	11/1/2010	1.1	0.1
9	11/2/2010	1.3	1.3
10	11/3/2010	1.3	1.2
11	11/4/2010	1.5	0.9
12	11/5/2010	0.8	0.5
13	11/6/2010	0.8	1.2
14	11/7/2010	1.1	0.7
15	11/8/2010	1.0	0.5
	No. of values	15	15
	Mean	1.2	0.8
	Standard deviation s_{x0}	0.3	0.3
	Detection limit x	**0.7**	**0.7**

$$s_{xo} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Annex 2 **Dependence of zero point on ambient temperature** **Page 1 of 1**

Manufacturer Thermo Fisher Scientific

Standards ZP Measured value with zero filter

Type 1405F

Serial-No. SN 20012 / SN 20121

			Cycle 1		Cycle 2		Cycle 3			
SN 20012	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
	1	20	2.7	-	2.3	-	1.5	-		
	2	8	0.9	-1.8	1.1	-1.2	1.0	-0.5		
RP	3	20	2.3	-0.4	2.7	0.4	2.9	1.4		
	4	25	3.3	0.6	3.4	1.1	3.2	1.7		
	5	20	2.0	-0.7	1.9	-0.4	2.4	0.9		
SN 20121	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
	1	20	1.4	-	1.3	-	1.6	-		
	2	8	0.9	-0.5	0.9	-0.4	1.2	-0.4		
RP	3	20	1.5	0.1	1.5	0.2	1.2	-0.4		
	4	25	2.6	1.2	1.0	-0.3	1.9	0.3		
	5	20	0.9	-0.5	1.1	-0.2	0.6	-1.0		

Annex 3 **Dependence of measured value on ambient temperature** **Page 1 of 1**

Manufacturer Thermo Fisher Scientific

Standards RP K_0-Test

Type 1405F

Serial-No. SN 20012 / SN 20121

			Cycle 1		Cycle 2		Cycle 3			
SN 20012	No.	Temperature [°C]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]		
	1	20	13585.1	-	13697.5	-	13719.8	-		
	2	8	13679.0	0.7	13729.8	0.2	13697.9	-0.2		
RP	3	20	13714.8	1.0	13695.1	0.0	13694.9	-0.2		
	4	25	13715.9	1.0	13717.7	0.1	13745.9	0.2		
	5	20	13709.7	0.9	13715.3	0.1	13698.3	-0.2		
SN 20121	No.	Temperature [°C]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]		
	1	20	16078.8	-	16200.2	-	16168.1	-		
	2	8	16157.1	0.5	16229.1	0.2	16208.9	0.3		
RP	3	20	16238.9	1.0	16208.5	0.1	16127.6	-0.3		
	4	25	16176.9	0.6	16237.4	0.2	16164.9	0.0		
	5	20	16186.8	0.7	16165.1	-0.2	16170.2	0.0		

Annex 4 **Dependence of measured value on mains voltage** **Page 1 of 1**

Manufacturer Thermo Fisher Scientific

Standards RP K_0-Test

Type 1405F

Serial-No. SN 20012 / SN 20121

			Cycle 1		Cycle 2		Cycle 3			
SN 20012	No.	Voltage [V]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]		
	1	230	13594.9	-	13631.0	-	13642.6	-		
	2	190	13619.6	0.2	13548.8	-0.6	13396.9	-1.8		
RP	3	230	13582.6	-0.1	13571.8	-0.4	13604.3	-0.3		
	4	245	13519.6	-0.6	13602.5	-0.2	13606.9	-0.3		
	5	230	13571.2	-0.2	13622.1	-0.1	13533.2	-0.8		
SN 20121	No.	Voltage [V]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]	Measured value K_0	Dev. [%]		
	1	230	15998.5	-	16104.9	-	16058.8	-		
	2	190	16103.9	0.7	15971.0	-0.8	16051.1	0.0		
RP	3	230	16007.3	0.1	16096.0	-0.1	16153.8	0.6		
	4	245	16033.3	0.2	16085.9	-0.1	16124.5	0.4		
	5	230	16117.6	0.7	16092.6	-0.1	16127.7	0.4		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 1 of 16**

Manufacturer: Thermo Fisher Scientific

Type of instrument: TEOM 1405-F

Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
1	12/9/2009	11.3	11.6	27.5	27.5	41.6	12.1	10.5		Teddington
2	12/10/2009	16.4	16.2	25.4	25.4	64.2	17.9	18.7		
3	12/11/2009	11.8	11.7	20.3	20.2	57.9	12.0	11.2		
4	12/12/2009	6.4	6.5	13.5	13.6	47.6	7.6	6.9		
5	12/13/2009	8.6	9.1	13.4	13.9	65.1	9.6	10.0		
6	12/14/2009	27.9	28.3	35.3	35.3	79.6	27.7	27.3		
7	12/15/2009	39.8	38.8	47.6	47.4	82.8	41.1	39.4		
8	12/16/2009	24.9	24.5	30.0	30.3	82.0	25.0	24.7		
9	12/17/2009	5.7	5.6	10.2	10.1	55.7	6.3	6.2		
10	12/18/2009	11.6	11.9	16.9	17.0	69.3	12.9	11.3		
11	12/19/2009	10.3	11.0	15.4	14.9	70.4	12.4	11.4		
12	12/20/2009	6.2	6.4	11.1	11.0	56.9	7.5	7.7		
13	12/21/2009	17.7	17.7	20.2	20.4	87.2	18.4	18.6		
14	12/22/2009	29.4	28.9				31.9	31.4	PM10 Grubbs outlier	
15	12/23/2009						16.6	16.0		
16	12/24/2009						17.5	17.0		
17	12/25/2009						9.7	9.4		
18	12/26/2009						4.2	3.6		
19	12/27/2009						5.1	5.5		
20	12/28/2009						19.0	18.2		
21	12/29/2009						10.6	9.8		
22	12/30/2009						9.9	9.2		
23	12/31/2009	6.0	6.5	15.2	13.9	42.9	7.7	7.2		
24	1/1/2010						14.1	13.9		
25	1/2/2010						12.8	12.1		
26	1/3/2010						17.6	17.8		
27	1/4/2010								Zero filter	
28	1/5/2010	15.6	15.5	20.1	18.7	80.1	16.7	16.1	PM10 Grubbs outlier	
29	1/6/2010			19.2	19.3		14.2	13.8	PM2,5 Grubbs outlier	
30	1/7/2010	15.3	15.7	19.4	20.1	78.4	15.6	15.1		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 2 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
31	1/8/2010	14.6	14.9	18.3	18.4	80.3	15.1	15.7		Teddington
32	1/9/2010	7.1	6.9	14.6	14.9	47.4	8.1	8.8		
34	1/10/2010	16.0	16.1	19.5	19.2	82.9	16.5	15.9		
34	1/11/2010	45.7	46.2	51.8	51.3	89.1	45.6	45.1		
35	1/12/2010	43.2	43.6	48.1	48.0	90.4	44.6	43.4		
36	1/13/2010	48.0	48.3	53.4	53.0	90.6	48.2	47.2		
37	1/14/2010	14.1	14.4	16.2	16.3	87.5	16.5	15.2		
38	1/15/2010	14.6	14.4	26.9	27.1	53.6	14.1	14.7		
39	1/16/2010	6.5	6.1	13.5	13.6	46.1	7.8	7.9		
40	1/17/2010	11.0	10.5	20.6	20.6	52.3	10.8	10.8		
41	1/18/2010	21.0	20.4	27.1	26.9	76.7	21.4	19.3		
42	1/19/2010	20.4	20.2	26.5	26.6	76.4			Power supply interrupted	
43	1/20/2010	26.6	27.0	32.0	31.9	83.8	26.1	25.4		
44	1/21/2010	20.5	20.9	27.5	27.9	75.0	20.2	20.5		
45	1/22/2010	7.8	7.6	9.7	9.8	78.5	9.4	8.1		
46	1/23/2010	21.0	20.9	25.8	25.1	82.3	20.5	19.2		
47	1/24/2010	16.2	15.9	20.7	20.3	78.4	16.1	15.8		
48	1/25/2010	36.1	35.8	42.0	42.4	85.1	36.5	35.7		
49	1/26/2010	50.7	51.1	60.4	60.4	84.2	50.2	48.9		
50	1/27/2010	27.1	27.3	38.9	39.1	69.7	25.7	25.8		
51	1/28/2010	8.3	8.0	13.9	14.1	58.3	8.8	8.5		
52	1/29/2010	5.7	6.0	9.4	9.6	61.5	7.3	6.5		
53	1/30/2010	12.4	12.5	17.6	17.6	70.7	13.1	12.9		
54	1/31/2010	12.2	13.0	17.3	16.9	73.5	13.4	12.8		
55	2/1/2010	8.4	8.3	14.7	14.4	57.5	9.6	8.2		
56	2/2/2010	8.3	8.3	12.0	11.7	70.0	9.4	9.2		
57	2/3/2010	9.4	9.3	19.2	19.2	48.6	11.5	10.1		
58	2/4/2010	12.0	12.4	19.7	19.8	61.7	14.1	14.0		
59	2/5/2010								Inlet -> Zero filter	
60	2/6/2010								Zero filter	

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 3 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
61	2/7/2010								Zero filter	Teddington
62	2/8/2010						16.6	14.8		
63	2/9/2010	6.3	6.3	11.6	11.8	53.8	6.6	7.6		
64	2/10/2010	5.8	5.6	12.0	12.4	46.6	6.9	7.7		
65	2/11/2010	12.4	12.0	20.2	20.1	60.5	12.3	11.6		
66	2/12/2010	6.7	6.5	12.6	12.4	52.7	8.4	7.9		
67	2/13/2010	8.8	8.8	15.1	15.4	57.6	8.7	10.0		
68	2/14/2010	13.9	13.4	16.0	16.3	84.8	14.5	14.9		
69	2/15/2010	12.5	12.8	16.0	15.9	79.2	13.4	13.9		
70	2/16/2010	14.9	15.9	18.2	18.5	83.9	15.1	15.4		
71	2/17/2010	44.8	45.2	52.2	52.1	86.3	43.1	42.3		
72	2/18/2010	13.1	12.3	14.8	14.8	85.9	15.1	15.2		
73	2/19/2010	18.3	18.5	21.7	21.7	84.6	18.5	19.0		
74	2/20/2010	16.5	16.6	19.3	19.5	85.2	17.9	18.9		
75	2/21/2010	7.4	7.3	10.2	10.2	71.7	8.9	8.9		
76	2/22/2010	9.9	10.3	16.6	16.5	61.1	10.3	9.9		
77	2/23/2010	14.5	14.4	22.2	22.3	64.9	14.4	14.5		
78	2/24/2010	9.2	9.1	17.8	17.7	51.6	9.7	10.5		
79	2/25/2010	5.9	4.8	9.2	9.4	57.2	6.7	7.4		
80	2/26/2010	4.4	4.3	11.2	11.4	38.8	5.3	6.4		
81	2/27/2010	11.8	11.7	18.9	19.2	61.6	13.8	13.0		
82	2/28/2010	5.0	5.2	9.6	9.6	53.5	6.7	6.4		
83	3/1/2010						21.1	21.8		
84	3/2/2010	12.7	13.1	21.7	21.0	60.4	13.4	13.0		
85	3/3/2010	7.9	8.7	20.9	21.3	39.3	8.6	9.0		
86	3/4/2010	9.3	8.7	16.5	16.6	54.2	9.5	9.5		
87	4/27/2010	12.1	11.2	20.2	20.9	56.7	14.1	14.1		
88	4/28/2010	16.0	16.7	25.8	25.0	64.3	18.9	18.5		
89	4/29/2010	11.3	11.4	19.2	19.3	58.9	14.0	13.3		
90	4/30/2010	5.4	5.4	11.5	11.9	45.9	7.9	8.3		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 4 of 16**

Manufacturer: Thermo Fisher Scientific

Type of instrument: TEOM 1405-F

Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
91	5/1/2010						9.2	8.8		Teddington
92	5/2/2010						6.4	6.0		
93	5/3/2010						6.7	7.0		
94	5/4/2010	8.5	8.6	15.0	15.1	56.7	10.5	10.4		
95	5/5/2010	14.0	13.9	18.8	19.7	72.5	16.0	15.8		
96	5/6/2010	9.8	9.2	16.2	16.6	58.0	11.7	11.5		
97	5/7/2010	7.8	7.7	12.9	13.1	59.8	9.5	8.8		
98	5/8/2010	4.5	4.2	8.9	8.9	48.5	7.3	7.6		
99	5/9/2010	6.5	7.6	14.1	14.0	50.4	9.1	9.3		
100	5/10/2010	4.9	5.1	10.2	9.8	49.7	7.3	7.1		
101	5/11/2010	6.2	6.0	10.6	9.8	60.1	8.5	8.5		
102	5/12/2010	8.4	8.3	12.3	12.5	67.5	11.1	10.4		
103	5/13/2010	13.4	13.2	17.2	17.1	77.7	14.6	15.1		
104	5/14/2010	12.7	13.7	19.1	18.7	69.9	15.8	15.5		
105	5/15/2010	7.0	6.7	12.7	12.7	54.0	9.7	9.3		
106	5/16/2010	5.6	5.2	9.5	9.6	56.4	9.0	8.5		
107	5/17/2010	10.2	10.3	16.2	16.6	62.5	12.2	11.7		
108	5/18/2010	12.7	13.4	21.5	21.5	60.8	15.0	14.7		
109	5/19/2010	14.0	15.2	20.0	19.4	74.2	17.4	17.3		
110	5/20/2010	13.9	14.7	18.7	19.0	75.9	18.9	18.5		
111	5/21/2010	14.3	15.5	17.9	18.6	81.7	18.9	18.4		
112	5/22/2010	6.4	6.2	9.0	8.9	70.3	9.8	9.3		
113	5/23/2010	5.6	5.7	9.3	9.6	60.0	9.3	8.4		
114	5/24/2010	12.0	12.4	17.5	17.6	69.7	14.7	13.8		
115	5/25/2010	6.1	6.9	15.6	15.2	42.4	9.5	8.3		
116	5/26/2010	9.7	9.2	19.1	19.0	49.8			Zero filter	
117	5/27/2010	7.3	7.3	8.0	7.9	92.3			Zero filter-> Inlet	
118	5/28/2010	8.2	8.2	14.4	13.9	57.7	8.9	9.6		
119	5/29/2010	5.0	4.9	10.5	10.7	46.1	7.7	7.6		
120	5/30/2010	4.0	3.9	8.2	7.9	48.9	5.6	7.7		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 5 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
121	5/31/2010	13.2	13.0	20.6	21.1	62.8	14.4	14.9		Teddington
122	6/1/2010	15.2	15.5	20.0	20.5	76.0	18.8	19.2		
123	6/2/2010	12.4	11.9	17.7	17.4	69.5	15.6	17.1		
124	6/3/2010	9.0	8.8	15.5	15.7	57.1	10.3	11.4		
125	6/4/2010	17.8	17.9	26.0	26.6	67.9	23.0	24.4		
126	6/5/2010	17.3	16.4	23.8	24.3	70.1	21.8	21.9		
127	6/6/2010	7.3	6.4	11.6	11.2	59.8	11.2	11.8		
128	6/7/2010	4.0	3.7	7.8	7.2	51.9	6.2	7.2		
129	6/8/2010	4.5	4.4	9.2	9.9	46.5	7.6	7.7		
130	6/9/2010	11.3	9.8	15.5	16.0	66.9	13.3	13.7		
131	6/10/2010	7.8	7.6	10.4	10.8	73.1	10.2	11.4		
132	6/11/2010			10.5	11.8		9.6	10.2	No ref. measurement PM2.5	
134	6/12/2010	6.6	6.6	13.4	13.5	48.8	9.1	10.0		
134	6/13/2010	9.7	9.9	17.4	17.7	55.8	12.2	11.3		
135	6/14/2010	7.2	6.2	13.4	12.7	51.4	9.5	11.3		
136	6/15/2010	2.9	3.1	10.2	9.8	30.2	6.1	7.4		
137	6/16/2010	5.0	4.6	10.8	10.3	45.4	7.5	7.4		
138	6/17/2010	4.1	4.5	7.1	7.9	57.6	7.6	8.3		
139	6/18/2010						7.5	8.4		
140	6/19/2010	3.7	3.4	9.1	9.3	38.1	6.4	7.2		
141	6/20/2010	9.1	8.9	15.5	15.3	58.4	11.8	12.5		
142	6/21/2010	7.5	7.3				12.8	12.2	PM10 Grubbs outlier	
143	6/22/2010	4.9	6.3	13.1	13.8	41.9	11.7	11.9		
144	6/23/2010	8.1	8.0	15.3	15.7	52.0	13.2	12.9		
145	6/24/2010	6.9	6.3	11.5	11.0	58.5	10.3	9.6		
146	6/25/2010	14.6	15.4	23.0	23.8	64.0	20.8	18.9		
147	6/26/2010	20.9	20.1	29.1	29.4	70.1	28.2	27.0		
148	6/27/2010						12.4	13.7		
149	6/28/2010	10.4	9.3				13.4	12.4	PM10 Grubbs outlier	
150	6/29/2010	4.9	4.7	8.9	9.0	53.3	9.4	8.3		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 6 of 16**

Manufacturer: Thermo Fisher Scientific

Type of instrument: TEOM 1405-F

Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
151	6/30/2010	4.4	5.5	9.6	9.5	51.7	9.4	8.7		Teddington
152	7/1/2010	6.9	6.1	11.0	11.6	57.7	10.3	9.4		
153	1/27/2011	8.9	8.8	12.8	13.3	67.8			Audits	Köln
154	1/28/2011	28.3	28.5	36.3	36.8	77.8			Audits	(Winter)
155	1/29/2011								Zero filter	
156	1/30/2011	62.0	62.1	82.7	83.7	74.6			Zero filter	
157	1/31/2011	81.6	81.8	95.5	94.0	86.2			Zero filter	
158	2/1/2011	61.9	62.0	75.3	73.6	83.2	64.6	67.2		
159	2/2/2011	20.6	20.1	25.2	24.7	81.8	22.1	21.8		
160	2/3/2011	14.1	13.4	20.1	20.4	67.7	14.8	15.1		
161	2/4/2011	6.1	6.2	11.0	11.4	54.6	6.3	8.0		
162	2/5/2011						5.3	5.3		
163	2/6/2011	8.4	8.5	14.8	15.0	57.0	9.5	9.7		
164	2/7/2011	9.7	10.0	17.5	18.8	54.2	10.6	10.5		
165	2/8/2011	18.0	17.3	30.6	31.3	57.2	18.7	19.1		
166	2/9/2011	21.2	21.9	29.6	30.6	71.5	22.9	22.3		
167	2/10/2011	19.4	20.8	24.9	26.7	77.9	22.5	21.4		
168	2/11/2011	10.5	11.3	13.2	14.1	80.0	12.6	12.4		
169	2/12/2011						15.7	16.9		
170	2/13/2011	11.5	12.5	17.0	18.5	67.5	13.5	14.0		
171	2/14/2011	21.1	19.5	23.8	24.2	84.6	22.3	23.1		
172	2/15/2011	16.4	16.0	19.0	19.7	83.7	19.0	18.7		
173	2/16/2011	24.5	24.0	34.0	34.2	71.1	28.4	28.6		
174	2/17/2011	36.0	35.5	42.2	42.1	84.8	40.3	40.1		
175	2/18/2011	36.5	36.7	43.4	43.5	84.3	41.2	40.6		
176	2/19/2011						54.3	54.4		
177	2/20/2011	27.6	27.8	29.5	29.8	93.5	30.9	30.8		
178	2/21/2011	31.3	31.8	36.6	36.2	86.6	34.8	35.2		
179	2/22/2011	36.5	37.9	43.3	43.8	85.4	40.6	40.7		
180	2/23/2011	38.0	37.9	45.7	45.7	83.0	38.9	39.8		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 7 of 16**

Manufacturer: Thermo Fisher Scientific

Type of instrument: TEOM 1405-F

Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
181	2/24/2011	30.3	31.4	36.0	35.8	85.9	35.4	33.7		Köln
182	2/25/2011	26.4	26.7	30.4	29.6	88.6	29.6	29.3		(Winter)
183	2/26/2011						16.8	17.2		
184	2/27/2011	13.5	13.3	15.4	14.8	88.5	15.2	15.5		
185	2/28/2011	36.7	36.0	44.7	43.7	82.3	38.1	37.3		
186	3/1/2011	66.6	66.0	75.6	74.7	88.2	69.6	69.0		
187	3/2/2011	49.4	49.7	60.6	58.5	83.1	51.9	51.0		
188	3/3/2011	39.4	37.5	50.8	48.9	77.1	40.5	39.6		
189	3/4/2011	76.3	76.5						PM10 Grubbs outlier; Inlet -> Zero filter	
190	3/5/2011								Zero filter	
191	3/6/2011	8.9	9.2	13.6	14.1	65.1			Zero filter	
192	3/7/2011	8.3	9.0	13.8	12.4	66.2			Zero filter	
193	3/8/2011	31.1	31.8	43.9	43.8	71.7	30.2	30.7		
194	3/9/2011	19.1	18.8	30.5	28.7	63.9	19.0	19.2		
195	3/10/2011								Power cut (complete)	
196	3/11/2011	16.7	16.1	33.5	33.1	49.2	16.2	15.2		
197	3/12/2011						16.6	15.9		
198	3/13/2011	13.3	13.1	16.2	15.6	83.0	13.4	12.8		
199	3/14/2011	18.2	20.0	27.7	25.6	71.5			Power cut (only Thermo)	
200	3/15/2011	37.4	37.8	44.1	43.1	86.3	38.8	38.5		
201	3/16/2011			67.3	65.8		58.4	56.9	PM2,5 Grubbs outlier	
202	3/17/2011	50.7	49.6	68.0	67.1	74.1	54.7	53.7		
203	3/18/2011	28.4	28.1	38.4	38.4	73.5	30.6	28.5		
204	3/19/2011						13.2	12.8		
205	3/20/2011	20.4	20.3	28.6	28.0	72.0	19.7	19.7		
206	3/21/2011	22.4	22.3	34.7	34.3	64.8	23.8	22.3		
207	3/22/2011	41.7	41.6	55.7	54.8	75.4	42.2	41.0		
208	3/23/2011	20.3	20.4	33.1	31.6	63.0	21.4	20.5		
209	3/24/2011	18.6	20.2	33.3	32.7	58.7	21.1	20.5		
210	3/25/2011	27.6	27.5	36.9	37.2	74.2	28.0	27.2		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 8 of 16**

Manufacturer: Thermo Fisher Scientific

Type of instrument: TEOM 1405-F

Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
211	3/26/2011						13.9	13.1		Köln
212	3/27/2011	24.6	24.8	35.6	35.4	69.5	26.4	25.2		(Winter)
213	3/28/2011	20.5	20.7	32.4	31.9	64.2	21.1	20.9		
214	3/29/2011	44.7	44.2	65.4	65.6	67.8	47.3	45.3		
215	3/30/2011	15.6	15.6	24.0	23.4	65.8	16.2	15.6		
216	3/31/2011	6.0	5.1	10.5	9.3	56.2	7.6	6.5		
217	4/1/2011	8.5	7.7	13.3	13.0	61.7	8.7	7.8		
218	4/2/2011						16.7	16.0		
219	4/3/2011	14.6	13.7	22.1	22.4	63.6	16.3	14.9		
220	4/4/2011	8.8	9.0	17.9	16.6	51.6	10.2	10.2		
221	4/5/2011	11.0	11.4	19.2	19.0	58.7	12.8	12.6		
222	4/6/2011	13.0	12.9	23.6	23.8	54.6	15.6	14.9		
223	4/7/2011	13.7	13.1	23.2	24.2	56.7	15.1	15.6		
224	4/8/2011	19.0	19.8	34.9	34.8	55.7			Inlet -> Zero filter	
225	4/9/2011								Zero filter	
226	4/10/2011	11.1	11.8	23.4	22.3	50.1			Zero filter	
227	4/11/2011	15.2	15.1	31.3	31.5	48.2	18.4	17.0		
228	4/12/2011	9.0	8.2	18.0	17.1	49.0	11.6	10.7		
229	4/13/2011	12.5	12.2	24.4	23.2	51.9	15.6	14.7		
230	4/14/2011	19.6	19.4	32.0	31.5	61.5	23.3	23.8		
231	4/15/2011	13.3	11.4	31.9	31.9	38.8	12.2	12.8		
232	4/16/2011						15.1	14.4		
234	4/17/2011						15.5	15.4		
234	4/18/2011	17.0	17.2	26.4	26.6	64.6	19.9	19.9		
235	4/19/2011	17.5	17.9	30.3	30.7	58.0	22.1	21.7		
236	4/20/2011	20.0	20.8	33.9	34.2	59.8	22.8	23.9		
237	4/21/2011						23.5	24.5		
238	4/22/2011						19.3	20.3		
239	4/23/2011						31.0	32.1		
240	4/24/2011						23.1	23.7		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 9 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
241	4/25/2011	19.6	20.7	27.4	27.4	73.6	21.2	21.4		Köln
242	4/26/2011	17.0	17.6	31.0	31.3	55.7	17.5	20.0		(Winter)
243	4/27/2011			44.3	45.1		35.7	36.0	No ref. measurement PM2.5	
244	4/28/2011	16.2	17.8	28.0	28.0	60.8	24.9	25.2		
245	4/29/2011	19.0	19.3	25.9	27.3	72.0	20.7	21.4		
246	4/30/2011	12.9	13.3	21.0	22.0	61.0	13.9	14.8		
247	5/1/2011	6.7	7.0	13.0	12.9	52.9	8.1	9.0		
248	5/2/2011	9.3	9.2	16.1	14.9	59.8	11.3	11.2		
249	5/3/2011	9.0	9.3	15.9	15.1	59.2	11.0	11.0		
250	5/4/2011	11.4	11.5	20.5	20.2	56.1	14.4	14.0		
251	5/5/2011			20.1	19.5		13.9	15.1	PM2,5 Grubbs outlier	
252	5/6/2011	13.7	13.6	30.7	31.1	44.2	14.1	13.5		
253	5/7/2011	19.1	17.6	46.1	47.5	39.2	13.3	13.3		
254	5/8/2011	12.3	12.2	23.4	23.0	53.0	10.2	10.5		
255	7/25/2011	12.1	11.2	17.8	17.8	65.4	14.3	12.1		Bornheim
256	7/26/2011	11.8	11.8	19.6	19.1	61.2	15.7	16.0		(Sommer)
257	7/27/2011	14.3	13.7	21.5	20.9	65.9	19.6		SN20121 Comm.Error	
258	7/28/2011	17.5	19.0	26.5	25.2	70.6	21.8		SN20121 Comm.Error	
259	7/29/2011	10.2	7.9	16.8	16.6	54.2		12.6	SN20012 problem with stabilization	
260	7/30/2011						6.9	6.3		
261	7/31/2011	9.8	9.5	13.3	14.2	70.4	11.0	10.7		
262	8/1/2011	12.7	11.4	18.0	19.2	64.8	14.5	14.4		
263	8/2/2011	10.3	10.1	19.0	20.1	52.1	11.2	10.9		
264	8/3/2011	17.0	16.6	24.4	26.1	66.5	19.0	19.5		
265	8/4/2011	8.7	8.4	13.8	14.7	60.2	13.1	12.2		
266	8/5/2011	8.6	10.6	17.1	18.0	54.7	12.1	11.5		
267	8/6/2011						7.7	6.6		
268	8/7/2011	2.8	3.1	5.6	6.4	49.5	4.3	4.2		
269	8/8/2011	2.8	4.0	7.9	7.5	44.1	3.9	3.4		
270	8/9/2011	2.7	3.2	10.8	11.2	27.1	5.1		SN20121 various errors	

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 10 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
271	8/10/2011	5.3	6.4	12.1	12.7	47.0	7.7		SN20121 various errors	Bornheim
272	8/11/2011	5.5	5.2	11.4	11.1	47.3	6.6		SN20121 various errors	(Sommer)
273	8/12/2011	3.0	3.8	6.4	7.0	50.2	4.9		SN20121 various errors	
274	8/13/2011						6.6		SN20121 various errors	
275	8/14/2011	2.6	3.6	7.0	6.7	45.5	4.6		SN20121 various errors	
276	8/15/2011	6.0	5.4	13.5	13.9	41.7	9.3		SN20121 various errors	
277	8/16/2011	6.0	6.0	13.7	12.9	45.1	9.3		SN20121 various errors	
278	8/17/2011	14.7	14.0	25.8	25.0	56.3	17.8		Replacing main board	
279	8/18/2011	9.0	8.7	16.8	15.9	54.1	14.2	13.3		
280	8/19/2011	6.6	6.2	13.3	12.8	48.8	11.6	11.0		
281	8/20/2011						11.5	11.0		
282	8/21/2011	10.4	10.3	17.1	17.2	60.4	15.3	13.7		
283	8/22/2011	10.9	10.8	19.7	19.3	55.8	16.8	15.8		
284	8/23/2011	19.2	19.1	29.9	30.1	63.7	25.9	25.6		
285	8/24/2011	6.7	7.4	16.9	16.7	41.9	8.8	8.9		
286	8/25/2011	11.5	12.1	18.8	18.6	63.4	15.3	13.6		
287	8/26/2011	4.9	5.5	10.7	10.7	48.8	9.0	6.7		
288	8/27/2011						3.6	3.6		
289	8/28/2011			7.7	7.6		4.6	4.7		
290	8/29/2011	5.9	6.2	11.4	11.5	53.0	6.4	5.6		
291	8/30/2011	9.1	8.1	17.1	16.6	51.1	8.9	8.6		
292	8/31/2011	14.5	13.9	26.0	23.6	57.2	16.1	16.6		
293	9/1/2011	17.7	18.2	27.5	26.1	66.9	21.7	21.2		
294	9/2/2011	14.9	15.0	25.1	24.1	60.6	17.0	16.3		
295	9/3/2011						18.0	16.1		
296	9/4/2011	8.2	8.0	12.7	12.1	65.3	6.8	7.1		
297	9/5/2011	4.8	5.0	9.2	9.1	53.8	4.3	2.8		
298	9/6/2011	5.2	5.6	11.1	10.6	49.8	4.5	4.0		
299	9/7/2011	6.1	5.8	12.5	13.2	46.1	6.5	5.7		
300	9/8/2011						4.9	4.4		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 11 of 16**

Manufacturer: Thermo Fisher Scientific
Type of instrument: TEOM 1405-F
Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
301	9/9/2011	6.8	7.1	12.1	11.8	57.9	7.5	6.5		Bornheim
302	9/10/2011						9.2	8.1		(Sommer)
303	9/11/2011	5.7	5.5	9.4	9.3	59.5	5.5	6.2		
304	9/12/2011	5.2	6.1	11.6	11.6	48.5	5.9	4.9		
305	9/13/2011	6.3	7.2	16.3	16.8	40.6	6.7	6.8		
306	9/14/2011	6.7	7.2	15.3	15.6	44.9	7.1	5.6		
307	9/15/2011	11.1	12.2	24.3	24.9	47.4	12.7	11.7		
308	9/16/2011	13.0	13.7	23.0	25.1	55.4			Inlet -> Zero filter	
309	9/17/2011								Zero filter	
310	9/18/2011	3.2	3.9	7.0	7.1	50.4			Zero filter	
311	9/19/2011	7.8	8.2	12.5	11.6	66.2	8.0	9.2		
312	9/20/2011						7.0	6.7		
313	9/21/2011			12.4	12.3		6.7	6.8		
314	9/22/2011	6.4	7.8	19.2	18.9	37.3	8.4	8.5		
315	9/23/2011	12.2	13.4	26.1	26.2	49.1	14.9	15.4		
316	9/24/2011						15.8	15.5		
317	9/25/2011	15.7	14.5	21.3	21.7	70.0	17.7	17.2		
318	9/26/2011			18.8	20.6				Audits	
319	9/27/2011			38.3	39.8		25.2	24.7		
320	9/28/2011								Leak repairs	
321	9/29/2011	17.1	16.0				18.8	18.8		
322	9/30/2011	12.4	11.8	23.4	24.5	50.6	13.6	12.5		
323	10/1/2011						13.3	13.0		
324	10/2/2011						29.9	29.3		
325	10/3/2011	13.5	14.8				20.7	20.2		
326	10/4/2011	9.8	9.8	15.9	16.3	60.9	10.1	10.2		
327	10/5/2011	4.5	2.5	7.0	6.5	51.8	3.6	3.6		
328	10/6/2011	5.5	4.1	10.8	10.4	45.6	4.6	3.8		
329	10/7/2011	3.6	3.1	8.1	7.6	42.9	4.0	4.0		
330	10/8/2011						5.3	5.4		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 12 of 16**

Manufacturer: Thermo Fisher Scientific

Type of instrument: TEOM 1405-F

Serial-No.: SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
331	10/9/2011	6.0	6.4	10.1	10.4	60.7	6.8	6.3		Bornheim
332	10/10/2011	4.7	5.2	11.9	12.5	40.9	7.1	7.7		(Sommer)
333	10/11/2011	1.3	2.0	5.5	5.0	31.2	3.9	3.2		
334	10/12/2011	1.9	3.2	5.3	5.0	49.3	4.5	4.0		
335	10/13/2011	4.2	4.2	11.5	11.7	36.3	7.4	6.5		
336	10/14/2011	5.9	8.5	14.8	14.0	50.2	9.8	8.9		
337	10/15/2011						11.6	11.0		
338	10/16/2011	11.1	13.7	17.0	16.7	73.7	15.1	14.5		
339	10/17/2011	18.6	20.1	28.0	27.3	70.0	22.1	22.2		
340	10/18/2011	4.3	6.7	11.6	11.5	47.7	7.1	7.5		
341	10/19/2011	3.8	5.2				6.6	5.9		
342	10/20/2011	9.3	9.5	11.9	15.8	67.9	11.7	11.7		
343	10/21/2011	17.6	18.1	28.0	26.4	65.5	20.6	19.2		
344	10/22/2011						21.1	20.5		
345	10/23/2011	23.0	23.2				25.7	24.8		
346	10/24/2011	15.4	15.4				17.2	16.0		
347	10/25/2011	11.0	12.1				12.8	13.1		
348	10/26/2011	6.0	6.7				8.2	7.7		
349	10/27/2011	18.1	19.3				20.9	18.9		
350	10/28/2011	17.8	18.0	27.2	27.3	65.6	19.8	18.8		
351	10/29/2011						19.5	19.7		
352	10/30/2011	11.7	12.2	16.8	16.3	72.0	12.9	12.9		
353	10/31/2011						24.5	23.0		
354	11/1/2011	22.5	22.3	30.8	28.4	75.7	24.7	22.9		
355	11/2/2011	17.2	17.3				18.6	17.7		
356	11/3/2011	9.2	10.8	17.8	17.5	56.4	12.2	10.8		
357	11/4/2011	13.7	14.3	21.0	21.1	66.5	14.4	14.8		
358	11/5/2011						23.3	21.9		
359	11/6/2011	55.2	54.7	62.1	63.5	87.5	57.6	55.6		
360	11/7/2011	34.6	34.3	39.5	40.6	85.9	37.5	35.4		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 13 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
361	11/8/2011	43.7	43.6	53.1	54.2	81.4	46.2	45.0		Bornheim (Sommer)
362	11/9/2011	24.0	23.4	28.6	29.9	81.1	25.6	25.9		
363	11/10/2011	14.3	13.9	17.3	17.3	81.4	15.6	15.5		
364	11/11/2011	26.9	27.9	35.1	35.3	78.0	30.6	29.3		
365	11/12/2011						28.3	26.8		
366	11/13/2011	21.5	21.5	24.1	24.7	88.1	24.0	22.7		
367	11/14/2011	38.6	38.1	43.8	45.1	86.3			Changing of TEOM / 47mm Filter	Bornheim (Winter)
368	11/15/2011	35.0	34.6	44.3	45.1	77.8	36.4	36.3		
369	11/16/2011	37.7	36.6	44.1	44.2	84.2	39.4	40.2		
370	11/17/2011	26.0	25.9	32.3	32.0	80.7	28.6	29.1		
371	11/18/2011	23.9	22.9	31.2	32.6	73.4	25.3	26.4		
372	11/19/2011						29.1	29.6		
373	11/20/2011	30.0	29.1	35.1	35.3	84.1	31.2	30.9		
374	11/21/2011	30.4	30.2	38.5	39.5	77.6	33.0	33.5		
375	11/22/2011	37.4	37.4	47.7	48.3	77.8	39.1	40.1		
376	11/23/2011	38.8	39.7	54.2	55.4	71.6	42.1	42.3		
377	11/24/2011	24.1	24.4	30.6	31.6	77.9	25.4	25.5		
378	11/25/2011	14.3	13.6	21.5	22.7	63.1	15.4	16.1		
379	11/26/2011						6.6	6.6		
380	11/27/2011	4.8	4.9	11.0	9.4	47.1	7.1	6.7		
381	11/28/2011	14.0	15.6	28.5	27.8	52.5	16.9	17.9		
382	11/29/2011	13.0	12.8	18.2	18.0	71.1	15.0	15.7		
383	11/30/2011	9.1	8.6	20.9	21.1	42.1	10.8	9.8		
384	12/1/2011	8.0	7.1	8.6	10.1	80.6	8.6	8.7		
385	12/2/2011	7.2	6.4	11.7	11.6	58.4	8.3	8.8		
386	12/3/2011						4.4	4.1		
387	12/4/2011	5.1	3.1	6.3	6.3	65.3	3.5	4.1		
388	12/5/2011	4.9	4.2	6.6	6.7	68.0	4.8	5.7		
389	12/6/2011	5.0	3.8	7.2	8.1	57.3	4.6	5.0		
390	12/7/2011	5.2	3.4	8.8	9.2	48.0	5.2	5.0		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 14 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
391	12/8/2011	5.0	3.7	8.2	8.1	53.6	4.7	5.1		Bornheim
392	12/9/2011	5.6	5.7	12.6	13.2	43.9	7.0	6.1		(Winter)
393	12/10/2011						8.1	8.5		
394	12/11/2011	11.5	9.1	14.4	13.8	73.1	12.7	12.4		
395	12/12/2011	4.7	3.7	7.2	6.7	60.2	5.1	4.9		
396	12/13/2011	2.3	2.0	4.3	4.0	51.7	3.6	2.8		
397	12/14/2011	1.0	0.9	3.5	2.5	31.1	2.4	2.8		
398	12/15/2011	3.1	1.3	4.9	4.3	47.5	3.2	3.7		
399	12/16/2011								Inlet->Zero filter	
400	12/17/2011								Zero filter	
401	12/18/2011								Zero filter	
402	12/19/2011								Zero filter -> Inlet	
403	12/20/2011			15.5	15.3		9.9	10.3		
404	12/21/2011	7.2	7.0	11.4	11.0	63.0	9.9	9.9		
405	12/22/2011	7.6	8.0				11.3	9.9		
406	12/23/2011						3.9	3.9		
407	12/24/2011						0.5	7.1		
408	12/25/2011						1.2	4.3		
409	12/26/2011						0.1	6.2		
410	12/27/2011	6.6	7.7	11.2	11.1	64.3	5.7	9.8		
411	12/28/2011						-0.9	5.6		
412	12/29/2011	3.4	2.5	8.5	7.6	36.6	1.7	4.8		
413	12/30/2011						4.3	8.1		
414	12/31/2011	42.8	41.2	50.2	50.1	83.7	43.7	47.4		
415	1/1/2012						-2.0	2.4		
416	1/2/2012	3.2	1.9	6.2	5.2	44.7	1.8	3.9		
417	1/3/2012	3.4	3.2	6.8	6.8	48.5	2.0	3.6		
418	1/4/2012						2.2	4.6		
419	1/5/2012	4.4	2.6	7.9	8.3	43.2	1.8	4.4		
420	1/6/2012	6.3	5.0	14.2	14.2	39.8	3.8	7.7		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 15 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
421	1/7/2012						5.0	6.9		Bornheim
422	1/8/2012	7.5	7.0	13.6	13.2	54.1	6.1	7.7		(Winter)
423	1/9/2012	13.0	11.6	16.9	17.4	71.7	13.7	13.5		
424	1/10/2012	12.1	10.7	17.8	15.5	68.5	12.0	12.9		
425	1/11/2012	6.1	5.9	8.5	9.6	66.3	6.3	8.1		
426	1/12/2012	4.8	4.7	10.7	11.4	43.0	4.9	6.5		
427	1/13/2012	6.8	6.4	17.5	17.7	37.5	7.1	9.0		
428	1/14/2012						11.3	12.1		
429	1/15/2012	12.1	12.2	19.3	19.9	61.8	20.9	21.6		
430	1/16/2012	20.6	22.3	28.9	28.1	75.1	23.2	23.2		
431	1/17/2012	32.7	33.2	44.3	45.6	73.4	35.1	33.8		
432	1/18/2012	19.5	18.9	28.9	26.4	69.4	19.3	20.2		
433	1/19/2012	3.5	3.5	4.1	5.3	74.2	3.8	4.8		
434	1/20/2012	6.2	5.9	8.6	9.5	67.3	6.1	8.1		
435	1/21/2012						4.1	4.7		
436	1/22/2012	5.4	5.1	11.4	12.9	43.1	6.6	6.4		
437	1/23/2012	7.0	7.9	11.7	13.5	59.0	8.3	8.6		
438	1/24/2012			20.9	21.5		16.2	16.0		
439	1/25/2012	19.9	20.0	28.3	25.5	74.1	20.6	22.6		
440	1/26/2012	22.7	22.3	29.3	27.6	79.0	23.0	23.2		
441	1/27/2012	17.0	16.0	24.1	24.3	68.2	18.0	18.9		
442	1/28/2012						17.3	16.3		
443	1/29/2012	64.0	62.4	69.2	69.8	90.9	68.7	67.9		
444	1/30/2012	61.2	60.2	71.2	71.6	85.0	64.6	65.2		
445	1/31/2012	36.5	36.6	44.2	42.8	84.0	38.7	37.7		
446	2/1/2012	25.3	25.1	31.6	31.4	80.0	26.5	25.2		
447	2/2/2012	20.1	20.2	25.6	25.3	79.2	21.8	21.0		
448	2/3/2012	29.0	28.9	37.6	36.7	77.9	31.2	30.0		
449	2/4/2012						33.3	33.6		
450	2/5/2012	24.1	25.6	31.3	30.1	81.1	25.4	24.7		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 16 of 16**

Manufacturer Thermo Fisher Scientific

Type of instrument TEOM 1405-F

Serial-No. SN 20012 & SN 20121

Suspended particulate matter PM2,5
Measured values in µg/m³ (ACT)

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 20012 PM2,5 [µg/m³]	SN 20121 PM2,5 [µg/m³]	Remark	Test site
451	2/6/2012	31.9	32.4	41.3	40.4	78.7	32.9	34.0		Bornheim
452	2/7/2012	25.2	25.7	37.6	35.5	69.7	25.7	26.1		(Winter)
453	2/8/2012	33.4	34.4	43.6	42.7	78.6	36.1	35.9		
454	2/9/2012	30.1	32.6	38.7	37.7	82.0	32.9	32.7		

Annex 6 **Ambient conditions at the field test sites** **Page 1 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
1	12/9/2009	Teddington	9.8	12.6	1017	94.1	0.1	221	0.3
2	12/10/2009		3.9	11.3	1028	90.9	0.2	244	0.3
3	12/11/2009		5.7	7.8	1029	93.8	0.4	231	0.0
4	12/12/2009		5.8	9.4	1026	83.9	0.8	200	0.0
5	12/13/2009		4.2	7.2	1022	87.7	0.5	234	0.3
6	12/14/2009		3.4	5.6	1017	88.8	0.2	201	0.0
7	12/15/2009		-0.6	3.3	1015	87.5	0.2	196	0.3
8	12/16/2009		1.5	3.9	1006	96.9	0.2	245	2.8
9	12/17/2009		1.3	4.6	1008	85.2	2.4	225	1.3
10	12/18/2009		-0.8	2.3	1013	86.6	0.9	281	0.0
11	12/19/2009		-0.1	1.7	1002	85.9	0.2	240	1.8
12	12/20/2009		-0.9	2.7	995	87.3	0.1	206	0.0
13	12/21/2009		1.1	3.3	984	97.3	0.3	187	8.6
14	12/22/2009		-2.1	2.7	988	98.3	0.0	218	0.3
15	12/23/2009		2.8	5.4	987	95.9	0.4	173	7.1
16	12/24/2009		4.1	6.6	986	94.1	0.3	217	0.5
17	12/25/2009		4.1	7.3	998	94.5	0.2	210	2.5
18	12/26/2009		5.9	9.4	995	90.2	0.3	200	0.8
19	12/27/2009		2.4	7.8	1000	86.2	0.3	240	0.0
20	12/28/2009		3.7	6.1	998	88.6	1.2	80	1.8
21	12/29/2009		4.8	5.6	988	95.9	1.7	94	11.7
22	12/30/2009		4.3	5.6	992	93.1	1.9	101	5.6
23	12/31/2009		2.3	4.5	998	81.8	1.1	207	0.0
24	1/1/2010		-0.1	3.9	1008	88.3	0.2	243	0.0
25	1/2/2010		1.6	5.0	1016	87.2	0.1	245	0.0
26	1/3/2010		-1.6	3.5	1021	88.3	0.3	205	0.0
27	1/4/2010		-3.7	0.6	1012	97.2	0.0	232	0.0
28	1/5/2010		0.8	2.2	998	89.9	0.7	129	4.8
29	1/6/2010		-2.3	1.1	1005	94.3	0.7	215	1.8
30	1/7/2010		-1.2	0.0	1013	91.1	0.5	240	0.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
31	1/8/2010	Teddington	-1.6	1.6	1022	91.1	0.8	225	0.3
32	1/9/2010		0.9	2.2	1018	79.3	1.8	161	0.0
34	1/10/2010		1.4	2.8	1015	90.5	0.7	92	1.3
34	1/11/2010		1.5	2.4	1015	86.0	0.3	137	0.3
35	1/12/2010		1.4	2.8	1000	85.9	1.5	103	0.0
36	1/13/2010		1.5	3.0	998	94.8	0.1	151	8.6
37	1/14/2010		2.5	4.4	1008	97.0	0.1	229	0.3
38	1/15/2010		5.6	6.7	1011	90.0	1.8	151	1.8
39	1/16/2010		5.7	7.8	1003	96.3	0.4	202	9.1
40	1/17/2010		4.1	9.4	1019	93.9	0.1	219	0.0
41	1/18/2010		6.2	7.8	1021	97.8	0.1	199	0.0
42	1/19/2010		6.4	8.7	1012	83.7	1.4	111	1.0
43	1/20/2010		3.0	3.9	1012	92.1	0.2	227	3.8
44	1/21/2010		6.1	8.3	1015	85.2	1.1	154	0.3
45	1/22/2010		7.6	8.6	1014	95.0	0.5	209	7.4
46	1/23/2010		4.8	6.7	1018	87.0	0.2	262	0.0
47	1/24/2010		4.4	6.7	1022	91.1	0.1	241	1.3
48	1/25/2010		3.2	5.0	1033	80.0	0.9	161	0.5
49	1/26/2010		0.0	3.3	1037	83.2	0.5	167	0.0
50	1/27/2010		4.4	7.2	1018	85.5	0.3	247	1.0
51	1/28/2010		5.5	7.6	1000	86.4	0.5	247	8.1
52	1/29/2010		1.3	6.2	992	76.9	0.9	279	0.3
53	1/30/2010		-0.9	4.5	1001	84.4	0.2	240	0.0
54	1/31/2010		0.0	4.0	1005	91.2	0.1	241	0.0
55	2/1/2010		3.1	7.1	1010	83.9	0.4	222	0.3
56	2/2/2010		5.9	8.4	1002	89.6	0.3	229	1.0
57	2/3/2010		6.7	8.9	1004	91.0	0.2	180	2.0
58	2/4/2010		7.6	8.9	997	86.1	1.3	153	2.3
59	2/5/2010		7.2	12.8	1000	84.9	0.6	143	0.3
60	2/6/2010		5.1	7.8	1017	89.7	0.6	227	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 3 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
61	2/7/2010	Teddington	3.8	5.6	1015	85.1	0.8	201	0.0
62	2/8/2010		1.4	3.3	1008	82.1	2.0	137	0.5
63	2/9/2010		3.2	5.8	1010	77.7	1.3	233	0.0
64	2/10/2010		1.1	3.9	1016	70.1	1.8	215	0.0
65	2/11/2010		2.3	3.9	1019	74.1	1.1	233	1.0
66	2/12/2010		3.0	5.0	1020	76.5	1.1	167	0.5
67	2/13/2010		2.4	4.0	1017	82.4	0.5	254	0.0
68	2/14/2010		2.2	5.0	1010	91.8	0.1	241	0.3
69	2/15/2010		3.3	5.0	997	89.7	0.1	203	7.9
70	2/16/2010		3.7	5.6	988	94.6	0.1	186	23.1
71	2/17/2010		3.4	9.4	988	78.8	0.3	139	1.0
72	2/18/2010		3.7	6.6	986	92.6	0.7	216	4.6
73	2/19/2010		0.8	6.7	993	87.5	0.2	238	0.3
74	2/20/2010		1.7	7.2	994	87.9	0.2	216	3.3
75	2/21/2010		5.3	7.5	986	92.2	0.5	150	14.7
76	2/22/2010		3.1	4.0	985	88.2	1.4	140	2.8
77	2/23/2010		4.8	7.9	988	92.2	0.8	127	3.6
78	2/24/2010		8.4	11.1	985	91.6	0.5	188	2.8
79	2/25/2010		7.7	10.0	979	88.1	1.0	174	8.6
80	2/26/2010		6.4	9.4	991	77.0	0.7	208	1.3
81	2/27/2010		7.8	11.2	983	88.4	0.7	181	17.5
82	2/28/2010		3.4	6.7	997	88.5	0.5	258	4.3
83	3/1/2010		4.1	11.7	1013	78.0	0.2	236	0.0
84	3/2/2010		6.4	12.0	1020	62.9	0.9	101	0.0
85	3/3/2010		4.7	7.2	1016	71.6	2.5	85	0.0
86	3/4/2010		2.1	8.3	1026	72.0	1.0	196	0.0
87	4/27/2010		14.8	22.7	1020	64.1	0.3	187	0.0
88	4/28/2010		15.6	21.7	1011	61.9	0.5	192	0.0
89	4/29/2010		14.2	20.0	1003	76.8	0.2	238	2.5
90	4/30/2010		12.6	16.1	1004	76.4	0.4	227	2.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
91	5/1/2010	Teddington	12.4	18.2	1004	75.3	0.5	184	9.4
92	5/2/2010		7.4	9.5	1012	76.5	1.8	233	4.8
93	5/3/2010		7.7	12.2	1021	60.1	1.7	240	0.5
94	5/4/2010		7.9	13.4	1021	66.2	0.8	226	0.0
95	5/5/2010		12.1	16.7	1012	64.2	0.8	209	0.0
96	5/6/2010		10.9	17.3	1007	59.1	1.2	175	0.0
97	5/7/2010		9.9	14.2	1007	64.5	1.4	181	0.8
98	5/8/2010		8.6	10.5	1009	78.3	1.1	213	0.0
99	5/9/2010		9.2	12.2	1008	69.6	1.0	153	0.0
100	5/10/2010		9.5	14.3	1008	56.5	1.4	173	0.0
101	5/11/2010		6.7	11.1	1009	66.1	0.6	196	0.0
102	5/12/2010		8.1	13.4	1011	61.1	0.6	220	0.0
103	5/13/2010		9.7	15.0	1009	59.8	0.3	212	0.0
104	5/14/2010		12.0	16.3	1008	58.0	0.4	213	0.0
105	5/15/2010		12.5	19.2	1011	60.3	0.4	260	0.0
106	5/16/2010		11.3	17.2	1014	82.3	0.2	219	4.8
107	5/17/2010		12.8	19.8	1021	63.0	0.4	266	0.0
108	5/18/2010		14.1	20.5	1024	62.0	0.4	189	0.0
109	5/19/2010		16.0	23.3	1025	68.8	0.1	235	0.0
110	5/20/2010		18.1	24.4	1026	72.3	0.1	247	0.0
111	5/21/2010		18.9	25.5	1024	62.4	1.2	111	0.0
112	5/22/2010		18.2	24.6	1022	60.0	1.2	131	0.0
113	5/23/2010		21.7	31.1	1014	51.3	0.3	213	0.0
114	5/24/2010		20.5	30.8	1007	54.6	1.4	158	0.0
115	5/25/2010		15.0	20.2	1006	54.5	2.3	91	0.0
116	5/26/2010		13.2	18.2	1005	66.0	1.0	140	1.5
117	5/27/2010		13.3	19.4	1006	58.9	0.4	241	0.3
118	5/28/2010		15.2	21.8	1010	59.6	0.6	209	0.0
119	5/29/2010		14.1	16.7	1003	82.5	1.0	209	1.0
120	5/30/2010		14.6	21.0	1010	52.9	1.6	263	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 5 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
121	5/31/2010	Teddington	14.3	16.7	1014	72.1	0.6	203	0.0
122	6/1/2010		13.0	16.7	1013	86.7	0.4	176	2.8
123	6/2/2010		17.4	24.5	1017	55.2	0.7	152	0.0
124	6/3/2010		17.5	22.7	1016	51.8	1.6	91	0.0
125	6/4/2010		20.3	29.6	1014	55.5	0.5	179	0.0
126	6/5/2010		22.1	28.4	1008	60.2	0.4	185	0.0
127	6/6/2010		18.2	24.7	1006	68.1	0.6	262	0.0
128	6/7/2010		15.8	22.7	1002	73.9	0.5	154	7.9
129	6/8/2010		15.7	20.9	997	81.3	0.5	193	2.3
130	6/9/2010		17.8	22.2	1000	72.1	1.1	154	0.0
131	6/10/2010		15.2	19.4	1002	83.2	1.8	211	0.3
132	6/11/2010		15.5	21.7	1006	68.2	0.5	243	0.0
134	6/12/2010		15.6	21.5	1012	63.0	0.7	201	0.0
134	6/13/2010		16.9	21.7	1007	65.8	0.7	192	0.3
135	6/14/2010		14.6	20.6	1017	70.4	1.5	163	1.8
136	6/15/2010		14.4	19.3	1022	56.1	1.8	171	0.0
137	6/16/2010		15.2	21.0	1018	57.8	1.9	164	0.0
138	6/17/2010		17.6	24.3	1015	58.5	1.6	142	0.0
139	6/18/2010		14.5	21.1	1014	69.7	1.1	216	0.8
140	6/19/2010		12.5	16.2	1014	55.8	1.5	253	0.0
141	6/20/2010		15.6	22.1	1017	55.8	0.7	240	0.0
142	6/21/2010		19.8	27.5	1017	55.1	0.4	194	0.0
143	6/22/2010		21.5	29.5	1017	50.1	0.3	238	0.0
144	6/23/2010		21.8	30.0	1014	52.4	0.3	226	0.0
145	6/24/2010		21.3	27.7	1012	54.7	0.4	261	0.0
146	6/25/2010		21.9	28.3	1011	56.1	1.0	130	0.0
147	6/26/2010		21.1	27.1	1011	63.2	0.9	146	0.0
148	6/27/2010		22.8	30.8	1013	50.3	0.3	203	0.0
149	6/28/2010		23.2	31.0	1013	43.9	0.3	218	2.8
150	6/29/2010		21.5	30.0	1013	70.2	0.2	210	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 6 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
151	6/30/2010	Teddington	20.1	28.7	1011	63.2	0.3	197	0.0
152	7/1/2010		21.9	26.4	1005	58.8	0.6	173	0.0
153	1/27/2011	Cologne	-0.2	3.2	1015	72.1	1.6	49	0.0
154	1/28/2011	(Winter)	-1.8	3.4	1015	77.0	1.3	98	0.0
155	1/29/2011		-2.1	4.7	1013	77.0	0.9	157	0.0
156	1/30/2011		-3.4	1.8	1015	83.9	0.7	168	0.0
157	1/31/2011		-3.8	-2.2	1020	86.9	1.3	127	0.0
158	2/1/2011		-2.3	-0.4	1022	88.2	2.1	172	0.0
159	2/2/2011		0.8	2.5	1021	88.6	3.1	144	8.7
160	2/3/2011		4.3	7.6	1018	83.0	2.9	193	0.3
161	2/4/2011		9.9	10.7	1014	72.4	6.9	239	0.3
162	2/5/2011		11.0	12.0	1017	71.2	7.1	241	0.0
163	2/6/2011		8.2	10.6	1018	69.5	3.9	224	0.0
164	2/7/2011		9.8	15.5	1011	60.9	3.6	212	0.6
165	2/8/2011		3.2	10.3	1017	77.0	1.1	166	0.0
166	2/9/2011		6.1	10.9	1014	67.6	3.2	120	0.0
167	2/10/2011		8.7	11.0	1007	84.2	3.2	185	14.0
168	2/11/2011		8.9	11.2	1007	93.5	2.0	193	33.0
169	2/12/2011		6.0	7.8	1007	89.8	2.7	130	3.0
170	2/13/2011		6.3	9.1	1002	81.1	4.2	106	0.0
171	2/14/2011		6.0	8.7	998	87.5	2.5	143	5.1
172	2/15/2011		5.4	8.2	992	86.9	3.5	110	1.8
173	2/16/2011		4.0	9.8	994	86.7	1.4	125	0.0
174	2/17/2011		4.1	10.2	1002	76.8	1.7	124	0.0
175	2/18/2011		2.7	3.6	1009	78.4	1.5	104	0.0
176	2/19/2011		2.7	5.3	1010	73.6	4.5	95	0.0
177	2/20/2011		-0.5	2.9	1011	67.1	4.1	77	0.0
178	2/21/2011		-2.7	0.9	1011	65.5	3.1	94	0.0
179	2/22/2011		-1.6	4.2	1015	56.2	3.0	124	0.0
180	2/23/2011		1.2	3.6	1016	59.6	5.0	132	0.0

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No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
181	2/24/2011	Cologne	2.2	3.8	1019	94.2	2.6	102	5.7
182	2/25/2011	(Winter)	5.3	7.2	1018	87.1	3.4	111	0.0
183	2/26/2011		6.3	8.5	1005	86.0	4.3	196	10.5
184	2/27/2011		4.2	6.4	1010	86.0	3.9	251	1.5
185	2/28/2011		3.8	6.6	1022	83.3	0.9	202	0.0
186	3/1/2011		5.2	10.3	1026	69.9	2.1	139	0.3
187	3/2/2011		4.8	13.6	1024	54.7	2.2	137	0.0
188	3/3/2011		3.7	10.6	1024	50.4	1.4	90	0.0
189	3/4/2011		3.4	10.8	1021	67.8	1.2	222	0.0
190	3/5/2011		2.7	7.0	1021	73.4	2.2	206	0.0
191	3/6/2011		3.0	8.2	1024	52.4	1.9	84	0.0
192	3/7/2011		4.0	9.3	1023	34.2	5.1	101	0.0
193	3/8/2011		7.9	14.4	1013	54.0	2.3	147	0.0
194	3/9/2011		7.1	10.6	1010	75.8	3.5	232	0.9
195	3/10/2011		9.2	10.1	1008	68.9	5.3	231	0.0
196	3/11/2011		8.1	11.4	1008	69.5	3.8	197	0.3
197	3/12/2011		12.1	16.4	998	61.6	3.3	147	0.3
198	3/13/2011		11.2	14.1	1001	77.3	2.0	156	1.5
199	3/14/2011		9.8	13.8	1010	81.2	0.3	114	0.0
200	3/15/2011		12.3	19.6	1006	66.2	2.2	96	0.0
201	3/16/2011		9.5	16.9	1000	71.9	2.5	126	0.0
202	3/17/2011		5.7	7.2	1009	86.9	4.7	267	0.0
203	3/18/2011		6.0	7.6	1018	89.1	1.1	135	11.1
204	3/19/2011		5.0	12.1	1027	59.5	1.2	123	0.0
205	3/20/2011		5.3	13.2	1027	57.7	0.9	150	0.0
206	3/21/2011		6.9	16.1	1029	56.5	1.0	166	0.0
207	3/22/2011		9.4	17.2	1031	62.7	1.1	184	0.0
208	3/23/2011		10.7	18.6	1030	66.8	1.2	161	0.0
209	3/24/2011		10.9	18.6	1021	67.2	1.0	174	0.0
210	3/25/2011		11.8	18.0	1010	59.4	1.6	183	0.0

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No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
211	3/26/2011	Cologne	7.7	11.6	1010	64.8	1.5	105	0.0
212	3/27/2011	(Winter)	9.3	16.3	1006	60.9	1.1	196	0.0
213	3/28/2011		7.2	13.7	1009	60.2	1.9	172	0.0
214	3/29/2011		9.6	18.5	1007	62.1	1.1	168	0.0
215	3/30/2011		12.6	15.9	1008	66.7	2.4	170	0.0
216	3/31/2011		13.8	15.6	1011	78.2	3.7	230	6.5
217	4/1/2011		13.9	18.8	1014	78.1	2.3	175	0.0
218	4/2/2011		17.6	24.3	1006	62.2	2.6	159	0.0
219	4/13/2011		10.9	15.8	1009	85.3	2.0	251	8.7
220	4/14/2011		10.0	15.0	1017	65.3	2.7	214	0.0
221	4/15/2011		11.8	15.1	1020	71.9	2.1	173	0.9
222	4/16/2011		16.2	23.0	1019	73.9	1.8	196	0.0
223	4/17/2011		13.8	21.6	1019	67.2	3.0	245	0.0
224	4/18/2011		12.9	18.2	1018	64.7	2.9	255	0.0
225	4/19/2011		11.3	18.9	1018	59.8	1.3	183	0.0
226	4/20/2011		14.0	23.1	1016	60.2	1.1	191	0.0
227	4/21/2011		16.0	25.0	1012	58.8	3.9	244	2.7
228	4/22/2011		7.7	12.4	1018	66.7	4.1	257	0.9
229	4/13/2011		10.1	14.3	1013	57.1	2.0	203	0.0
230	4/14/2011		8.0	14.2	1013	65.4	0.6	159	0.0
231	4/15/2011		10.4	17.0	1014	53.6	1.2	169	0.0
232	4/16/2011		11.9	16.9	1017	51.7	0.9	166	0.0
234	4/17/2011		11.4	19.2	1017	53.7	1.2	139	0.0
234	4/18/2011		14.3	21.2	1011	48.6	1.9	149	0.0
235	4/19/2011		15.5	25.5	1009	52.4	1.2	146	0.0
236	4/20/2011		16.6	25.7	1008	51.3	1.1	154	0.0
237	4/21/2011		17.8	26.3	1006	54.1	0.7	180	0.0
238	4/22/2011		20.0	27.8	1003	51.8	1.3	146	8.3
239	4/23/2011		18.0	28.9	1005	58.0	0.7	152	0.0
240	4/24/2011		18.1	28.0	1011	51.7	1.0	172	0.0

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No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
241	4/25/2011	Cologne	16.8	26.0	1013	50.3	1.2	153	0.0
242	4/26/2011	(Winter)	16.7	23.4	1011	51.5	1.8	166	2.1
243	4/27/2011		10.8	12.5	1010	90.4	0.7	213	8.9
244	4/28/2011		14.2	20.5	1005	77.6	0.7	176	0.3
245	4/29/2011		17.2	24.9	1002	56.8	1.7	112	3.0
246	4/30/2011		16.9	24.2	1002	47.4	1.7	141	0.0
247	5/1/2011		14.8	22.4	1002	44.5	1.6	111	0.0
248	5/2/2011		11.0	17.8	1004	53.3	2.0	116	0.0
249	5/3/2011		10.0	17.2	1011	49.4	1.0	164	0.0
250	5/4/2011		9.7	16.2	1016	61.5	1.3	168	0.0
251	5/5/2011		14.1	19.8	1015	46.9	2.2	119	0.0
252	5/6/2011		18.6	24.8	1012	41.1	2.5	110	0.0
253	5/7/2011		21.9	28.3	1011	37.0	3.4	109	0.0
254	5/8/2011		22.1	28.6	1013	34.7	4.1	97	0.0
255	7/25/2011	Bornheim	17.2	22.8	1001	73.8	0.8	193	1.2
256	7/26/2011	(Sommer)	17.0	20.6	1006	78.4	1.1	259	0.0
257	7/27/2011		17.3	24.3	1010	84.8	0.7	229	51.7
258	7/28/2011		17.7	24.5	1011	85.6	0.6	228	5.9
259	7/29/2011		16.9	20.2	1011	76.2	2.9	299	0.0
260	7/30/2011		14.5	16.1	1010	80.4	2.3	288	0.0
261	7/31/2011		13.4	16.6	1009	76.2	0.9	244	0.0
262	8/1/2011		19.1	26.1	1008	68.1	0.9	177	0.0
263	8/2/2011		23.2	30.0	1007	60.8	1.5	143	0.0
264	8/3/2011		19.7	24.1	1006	82.9	1.1	195	5.4
265	8/4/2011		22.3	29.2	1005	71.6	0.8	204	3.6
266	8/5/2011		20.6	25.0	1004	75.8	1.1	221	0.6
267	8/6/2011		19.3	25.4	996	85.0	1.4	171	7.7
268	8/7/2011		17.8	22.4	998	64.0	1.5	209	1.8
269	8/8/2011		15.5	18.4	1000	74.7	2.5	219	6.2
270	8/9/2011		13.8	17.8	1012	76.8	2.7	265	14.8

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
271	8/10/2011	Bornheim	18.0	22.4	1013	57.5	1.3	224	0.0
272	8/11/2011	(Sommer)	20.9	25.5	1004	53.8	1.2	220	0.3
273	8/12/2011		18.5	21.7	1003	78.9	1.1	228	2.1
274	8/13/2011		20.1	23.7	1001	77.0	0.7	185	0.0
275	8/14/2011		17.4	19.9	1000	86.2	1.1	219	17.4
276	8/15/2011		17.9	22.4	1009	71.8	1.2	230	0.0
277	8/16/2011		19.1	23.9	1010	69.0	0.7	190	0.6
278	8/17/2011		21.1	27.8	1007	73.8	0.7	206	4.7
279	8/18/2011		22.5	31.3	1004	76.6	1.2	174	20.9
280	8/19/2011		16.8	21.2	1011	80.0	1.5	235	3.3
281	8/20/2011		20.7	28.1	1011	66.6	0.8	157	0.0
282	8/21/2011		23.2	31.4	1007	74.8	1.0	184	0.3
283	8/22/2011		20.4	24.4	1009	76.5	1.2	253	0.0
284	8/23/2011		22.6	27.8	1005	78.4	0.9	206	0.0
285	8/24/2011		20.1	27.2	1007	76.6	0.7	192	0.6
286	8/25/2011		20.8	27.6	1003	83.4	1.0	176	2.1
287	8/26/2011		19.4	30.2	999	83.7	1.5	195	29.1
288	8/27/2011		15.3	20.0	1007	77.0	1.1	207	0.3
289	8/28/2011		15.6	19.7	1009	69.2	1.3	212	0.0
290	8/29/2011		14.5	18.4	1008	66.7	2.0	243	0.0
291	8/30/2011		13.6	18.4	1008	73.6	0.8	236	0.0
292	8/31/2011		14.8	21.4	1007	72.0	0.7	225	0.0
293	9/1/2011		16.4	23.4	1006	71.6	0.6	182	0.0
294	9/2/2011		21.2	29.4	1004	72.2	0.8	160	0.0
295	9/3/2011		24.5	30.9	1002	67.0	1.3	132	3.6
296	9/4/2011		20.2	27.4	1002	79.5	1.1	223	0.6
297	9/5/2011		16.6	21.4	1009	62.9	1.9	217	0.0
298	9/6/2011		17.4	20.6	1005	66.8	2.6	219	4.8
299	9/7/2011		14.9	18.1	1004	73.1	2.2	246	5.7
300	9/8/2011		14.7	16.2	1003	84.7	1.1	209	3.3

Annex 6 **Ambient conditions at the field test sites** **Page 11 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
301	9/9/2011	Bornheim	19.0	21.6	1004	86.9	0.4	167	0.0
302	9/10/2011	(Sommer)	23.8	29.7	1001	73.0	1.5	155	0.0
303	9/11/2011		16.2	22.1	1003	86.0	0.7	165	16.2
304	9/12/2011		19.4	24.6	1004	71.1	1.7	204	0.0
305	9/13/2011		16.7	20.8	1006	67.3	1.6	219	0.0
306	9/14/2011		15.2	19.6	1011	65.1	1.5	224	0.0
307	9/15/2011		14.1	20.4	1013	75.3	0.6	207	0.0
308	9/16/2011		17.1	21.9	1006	72.6	1.4	145	0.0
309	9/17/2011		16.8	21.4	1001	70.6	1.0	207	3.6
310	9/18/2011		13.3	16.5	998	76.4	1.0	200	4.5
311	9/19/2011		13.6	18.1	1008	75.8	1.4	231	0.9
312	9/20/2011		15.6	18.5	1014	78.0	0.5	196	0.0
313	9/21/2011		16.9	20.5	1011	69.5	0.8	204	0.0
314	9/22/2011		15.2	18.7	1011	72.2	1.2	231	0.0
315	9/23/2011								
316	9/24/2011								
317	9/25/2011								
318	9/26/2011		Outage of weather station						
319	9/27/2011								
320	9/28/2011								
321	9/29/2011								
322	9/30/2011		18.4	26.8	1017	68.3	1.2	155	0.0
323	10/1/2011		18.1	28.0	1018	70.6	0.5	176	0.0
324	10/2/2011		17.8	26.8	1016	75.4	0.3	213	0.0
325	10/3/2011		18.8	26.5	1013	65.9	0.8	168	0.0
326	10/4/2011		17.8	20.5	1013	72.4	1.6	214	0.0
327	10/5/2011		17.5	20.0	1011	70.8	1.2	199	0.0
328	10/6/2011		13.2	19.3	1001	71.2	2.3	213	0.3
329	10/7/2011		9.9	13.4	1005	81.6	3.6	272	5.7
330	10/8/2011		8.7	11.4	1009	85.5	2.1	258	6.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
331	10/9/2011	Bornheim	12.2	16.3	1011	84.5	1.4	190	5.4
332	10/10/2011	(Sommer)	17.7	21.3	1009	74.4	3.2	261	0.3
333	10/11/2011		16.3	18.0	1010	77.4	3.6	251	0.0
334	10/12/2011		12.5	15.8	1012	91.1	0.9	226	17.9
335	10/13/2011		9.9	15.8	1022	76.3	0.6	209	0.0
336	10/14/2011		8.7	15.9	1024	69.6	1.0	151	0.0
337	10/15/2011		7.8	14.8	1020	68.8	1.2	162	0.0
338	10/16/2011		8.5	14.8	1016	73.8	1.5	157	0.0
339	10/17/2011		10.5	16.6	1011	78.5	0.8	163	0.0
340	10/18/2011		9.2	15.0	1003	82.0	1.2	197	3.0
341	10/19/2011		8.1	14.0	1010	74.4	1.5	225	0.0
342	10/20/2011		5.6	10.6	1018	79.8	1.0	223	0.0
343	10/21/2011		5.2	11.4	1019	79.3	1.1	154	0.0
344	10/22/2011		6.8	11.9	1013	69.3	3.9	128	0.0
345	10/23/2011		7.4	13.6	1007	71.6	2.3	138	0.0
346	10/24/2011		9.8	12.4	999	67.2	3.8	132	0.0
347	10/25/2011		10.9	13.0	997	68.8	1.9	132	0.0
348	10/26/2011		9.4	15.7	1006	74.9	0.9	171	0.0
349	10/27/2011		10.1	13.4	1008	80.4	2.7	126	0.0
350	10/28/2011		14.0	20.1	1016	75.8	0.7	149	0.0
351	10/29/2011		13.5	17.2	1015	79.8	1.0	132	0.9
352	10/30/2011		13.5	18.2	1014	86.7	0.4	170	0.0
353	10/31/2011		11.9	17.2	1009	87.0	1.0	152	0.3
354	11/1/2011		12.2	15.6	1007	83.2	2.0	134	1.8
355	11/2/2011		12.5	14.7	1002	80.8	2.9	124	0.3
356	11/3/2011		13.7	17.3	995	69.7	3.8	140	0.0
357	11/4/2011		Outage of weather station						
358	11/5/2011								
359	11/6/2011								
360	11/7/2011								

Annex 6 **Ambient conditions at the field test sites** **Page 13 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
361	11/8/2011	Bornheim (Sommer)	Outage of weather station						
362	11/9/2011								
363	11/10/2011								
364	11/11/2011								
365	11/12/2011		7.2	9.4	1024	81.6	4.1	135	0.0
366	11/13/2011		5.4	10.1	1023	83.7	2.4	131	0.0
367	11/14/2011	Bornheim (Winter)	3.7	9.8	1017	79.3	2.2	117	0.6
368	11/15/2011		2.7	8.7	1013	82.1	1.3	123	0.0
369	11/16/2011		2.6	7.4	1013	77.9	2.9	129	0.3
370	11/17/2011		5.8	7.7	1015	81.8	1.7	103	0.0
371	11/18/2011		8.3	10.0	1014	85.3	1.0	122	0.0
372	11/19/2011		7.8	12.3	1013	79.2	1.1	145	0.0
373	11/20/2011		7.4	13.2	1011	80.4	0.5	126	0.0
374	11/21/2011		5.9	12.0	1009	80.7	1.2	135	0.0
375	11/22/2011		5.6	10.4	1013	84.9	0.5	149	0.0
376	11/23/2011		7.8	10.1	1020	84.2	0.4	156	0.0
377	11/24/2011		5.7	10.0	1022	82.3	1.5	122	0.0
378	11/25/2011		6.0	9.1	1019	80.9	1.6	169	0.0
379	11/26/2011		7.9	11.7	1019	76.1	2.4	180	0.0
380	11/27/2011		7.2	11.8	1016	80.1	2.3	212	0.3
381	11/28/2011		3.5	9.3	1017	84.5	1.0	130	0.0
382	11/29/2011		6.9	11.1	1010	80.3	2.6	147	0.3
383	11/30/2011		6.2	11.4	1017	77.7	1.3	144	0.0
384	12/1/2011		11.2	13.4	1003	76.0	4.2	167	0.3
385	12/2/2011		6.4	12.5	1005	79.8	2.9	205	1.2
386	12/3/2011		8.3	10.0	997	78.5	3.1	188	3.6
387	12/4/2011		7.5	9.5	991	83.0	2.4	218	10.7
388	12/5/2011		4.5	6.9	998	74.1	3.0	215	0.0
389	12/6/2011		4.8	7.1	999	74.5	2.6	211	1.5
390	12/7/2011		Outage of weather station						

Annex 6 **Ambient conditions at the field test sites** **Page 14 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
391	12/8/2011	Bornheim	Outage of weather station						
392	12/9/2011	(Winter)	4.8	7.5	1003	70.8	2.1	228	0.0
393	12/10/2011		2.3	6.3	1009	75.0	1.5	199	0.0
394	12/11/2011		3.5	6.3	1004	78.5	2.3	127	0.0
395	12/12/2011		6.0	8.4	999	78.7	3.3	188	3.9
396	12/13/2011		7.1	11.4	992	76.1	4.6	184	2.4
397	12/14/2011		5.9	9.5	993	76.8	3.7	196	5.3
398	12/15/2011		5.4	7.7	993	76.8	3.8	177	1.5
399	12/16/2011		4.3	12.0	976	85.3	5.7	243	11.3
400	12/17/2011		3.2	6.1	998	82.4	2.6	244	0.6
401	12/18/2011		1.1	4.3	1005	85.4	2.0	229	4.8
402	12/19/2011		1.5	4.0	1007	82.6	1.4	175	0.3
403	12/20/2011		3.7	5.4	1004	87.2	2.8	243	16.4
404	12/21/2011		4.7	5.7	1011	84.9	0.8	195	1.5
405	12/22/2011		8.5	9.6	1015	93.5	2.1	230	8.1
406	12/23/2011		8.3	10.6	1009	82.2	3.3	204	2.4
407	12/24/2011		5.1	6.5	1021	80.6	3.5	230	3.3
408	12/25/2011		8.6	10.0	1025	79.2	2.0	200	0.0
409	12/26/2011		9.7	11.0	1028	84.6	0.9	210	0.0
410	12/27/2011		7.7	9.2	1026	81.0	1.2	220	0.0
411	12/28/2011		6.4	8.6	1015	77.9	3.1	194	0.0
412	12/29/2011		5.4	7.5	1007	77.0	4.7	238	7.1
413	12/30/2011		3.5	5.2	1007	82.9	3.2	215	2.1
414	12/31/2011		7.3	10.8	1003	93.6	1.0	148	9.9
415	1/1/2012		12.2	15.0	1001	83.1	2.9	176	7.2
416	1/2/2012		6.3	8.9	1006	81.5	1.8	204	2.7
417	1/3/2012		8.4	12.3	1001	72.2	5.6	227	0.9
418	1/4/2012		6.9	9.3	1002	72.9	5.0	239	3.0
419	1/5/2012		6.0	10.9	991	77.1	7.8	285	12.7
420	1/6/2012		5.5	7.6	1011	79.8	4.3	255	2.1

Annex 6 **Ambient conditions at the field test sites** **Page 15 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
421	1/7/2012	Bornheim	6.8	9.5	1009	81.2	4.8	275	6.0
422	1/8/2012	(Winter)	5.9	7.6	1016	84.8	3.5	279	5.9
423	1/9/2012		7.7	8.9	1020	88.4	1.9	248	1.5
424	1/10/2012		7.9	9.2	1025	80.2	1.1	231	0.3
425	1/11/2012		8.6	10.4	1023	79.4	1.3	210	0.0
426	1/12/2012		7.1	10.6	1016	78.8	4.3	260	1.2
427	1/13/2012		4.5	6.0	1020	74.8	4.8	299	0.0
428	1/14/2012		2.3	5.3	1020	82.8	1.4	245	0.0
429	1/15/2012		-1.5	0.5	1019	94.4	0.6	156	0.0
430	1/16/2012		-0.9	3.9	1020	81.8	0.6	138	0.3
431	1/17/2012		-0.6	4.7	1022	81.5	0.5	123	0.3
432	1/18/2012		3.1	7.1	1018	84.3	1.5	126	6.6
433	1/19/2012		7.2	11.9	1006	84.8	4.1	253	12.8
434	1/20/2012		3.1	5.4	1008	85.5	3.1	239	5.1
435	1/21/2012		7.3	10.3	1000	81.9	5.3	261	6.9
436	1/22/2012		6.4	9.3	1003	77.0	4.7	271	1.8
437	1/23/2012		4.2	7.1	1008	83.7	3.0	268	3.6
438	1/24/2012		2.3	5.5	1014	87.4	0.9	188	0.0
439	1/25/2012		2.5	4.2	1012	81.0	3.9	126	0.0
440	1/26/2012		2.6	4.0	1010	78.6	4.1	127	0.6
441	1/27/2012		2.3	7.4	1016	85.6	1.1	124	0.0
442	1/28/2012		1.6	4.4	1021	81.0	0.9	166	0.3
443	1/29/2012		-0.4	0.3	1020	81.2	1.4	238	0.0
444	1/30/2012		-0.1	0.9	1017	75.8	1.5	110	0.0
445	1/31/2012		-2.7	0.9	1018	62.8	2.0	116	0.0
446	2/1/2012		-5.2	0.7	1023	53.6	2.2	144	0.0
447	2/2/2012		-7.0	-0.8	1026	50.2	1.5	186	0.0
448	2/3/2012		-8.5	-4.0	1031	69.0	1.0	252	0.0
449	2/4/2012		-8.5	-3.7	1031	69.8	1.0	182	0.0
450	2/5/2012		-7.9	-3.6	1027	57.9	1.7	142	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 16 of 16**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. temperature (max) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
451	2/6/2012	Bornheim	-8.9	-3.6	1029	57.8	1.1	152	0.0
452	2/7/2012	(Winter)	-7.6	-4.3	1031	61.6	1.8	148	0.0
453	2/8/2012		-5.7	0.0	1030	68.4	0.8	187	0.0
454	2/9/2012		-5.4	-2.2	1030	81.1	1.6	259	0.0

Appendix 2

Filter weighing procedure

A) German test sites (Cologne and Bornheim)

A.1 Carrying out the weighing

All weightings 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. The filters (including control filters) are placed on sieves for the purpose of conditioning 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 kept 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 if nothing out of ordinary results from the calibration process. Deviations to prior measurements conform to the Standard and do not exceed 20 µg (refer to Figure 61). 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 62 shows an exemplary process over a period of more than 4 months.

All filters which deviate more than 40 µg between the first and second weighing are excluded during the pre-weighing process. Filters which deviate 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 placed in the filter holder. 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 not more than 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:

$$Dust = MF_{post} - (M_{Tara} \times (MKon_{post} / MKon_{pre})) \qquad (F1)$$

$MKon_{pre}$ = average mass of the 3 control filters after 48 h and 72 h pre-weighing

$MKon_{post}$ = average mass of the 3 control filters after 48 h and 72 h post-weighing

M_{Tara} = average mass of the filter after 48 h and 72 h pre-weighing

MF_{post} = average 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 EN 14907 9.3.2.5 is fulfilled.

The below example of the standard weight between November 2008 and February 2009 shows that the allowed deviation of not more than 20 µg on the previous measurement is not exceeded.

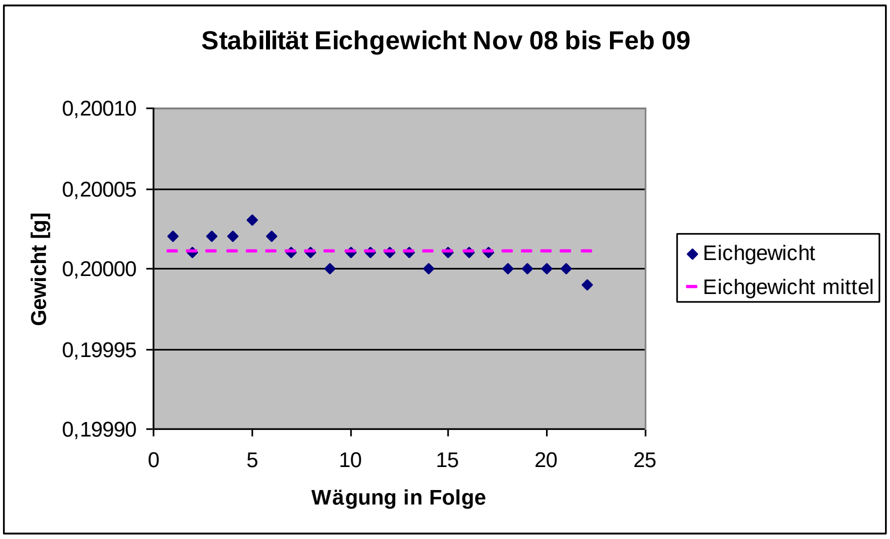


Figure 61: Stability of standard weight

Table 32: 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

Highlighted yellow = average value

Highlighted green = lowest value

Highlighted blue = highest value

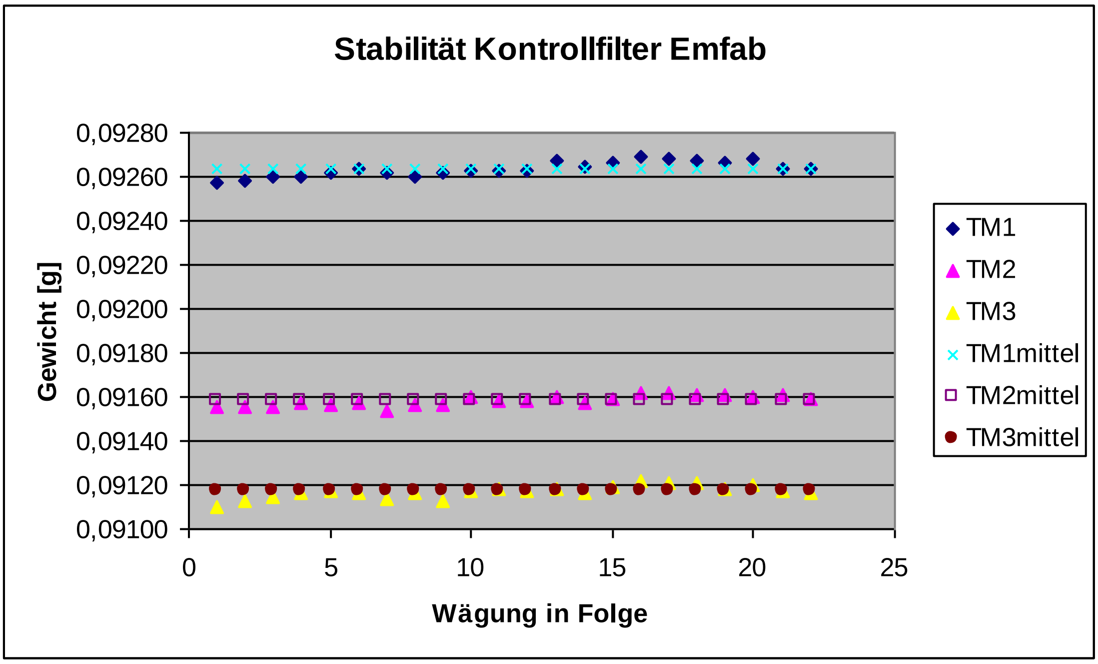


Figure 62: Stability of the control filters

Table 33: 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 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

Highlighted yellow = average value

Highlighted green = lowest value

Highlighted blue = highest value

B) UK test site (Teddington)

B.1 Implementation of Weighing Protocols

NPL (National Physical Laboratory) were subcontracted to weigh filters manually for the field study. In line with EN14907 filters were kept in the weighing room for less than 28 days; the glove box used for weighing was maintained at (20 ± 1) °C and (50 ± 5) %; and filters were weighed twice before and after sampling. summarizes the conditioning and weighing time-scales utilised:

Table 34 summarizes the conditioning and weighing timescales utilised:

Table 34: conditioning and weighing timescales

Pre Sampling	Post Sampling
Condition minimum of 48 hours Weigh Filters Condition 24 hours Weigh Filters	Condition 48 hours Weigh Filters Condition 24 hours Weigh Filters

At the start of each weighing session the balance was exercised to remove mechanical stiff-ness, and then calibrated. At the start and end of each batch of filters, a 50 and 200 mg check weight were weighed. In line with the recommendations of the UK PM Equivalence Report, filters were weighed relative to a 100 mg check weight, and not a tare filter, as the latter was shown to lose mass over time. Four filters were weighed between check weights, as the balance drift over time had been shown to be small.

The **Check weight Mass (CM)** of the filter was calculated for each weighing session using **E A.1** below:

$$CM = \frac{\left(m_{check,Beg} + m_{check,End}\right)}{2}$$ **E A.1**

Where:

$M_{check,bef}$ = Mass of check weight weighed immediately prior to sample filter.

$M_{check,aft}$ = Mass of check weight weighed immediately after sample filter.

The **Relative Mass (RM)** of the filter was calculated for each weighing session using **E A.2** below:

$$RM = m_{filter} - CM$$ **E A.2**

Where:

m_{filter} = Mass of sample filter

Particulate Mass (PM) is calculated using the following equation in accordance with EN14907.

$$PM = \left(\frac{RM_{End1} + RM_{End2}}{2}\right) - \left(\frac{RM_{Beg1} + RM_{Beg2}}{2}\right)$$ **E A.3**

Where:

Pre1 denotes weighing session 1 prior to sampling

Pre2 denotes weighing session 2 prior to sampling

Post1 denotes weighing session 1 after sampling

Post2 denotes weighing session 2 after sampling

Pre Spread (S_{Pre}), Post Spread (S_{Post}) and Blank Spread (S_{Blank}) were calculated using the following equations:

$$S_{Pre} = RM_{Anf1} - RM_{Anf2}$$ **E A.4**

$$S_{Post} = RM_{End1} - RM_{End2}$$ **E A.5**

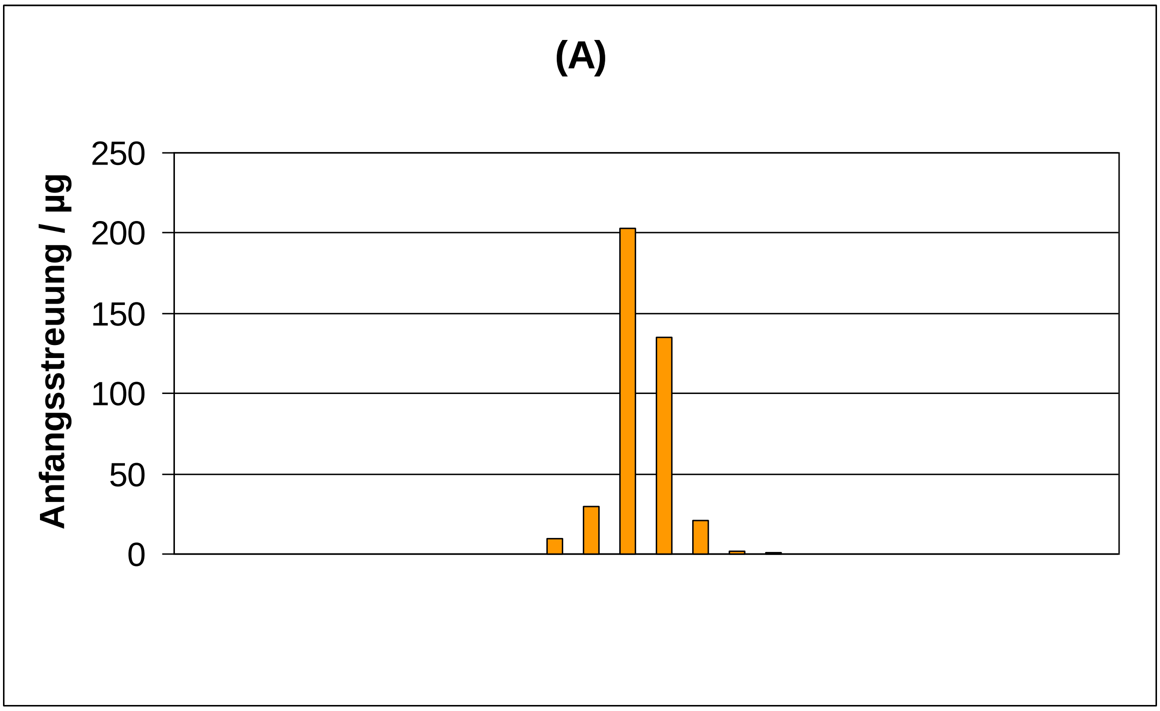
$$S_{Blank} = \left(\frac{CM_{End2} + CM_{End1}}{2}\right) - \left(\frac{CM_{Anf2} + CM_{Anf1}}{2}\right)$$ **E A.6**

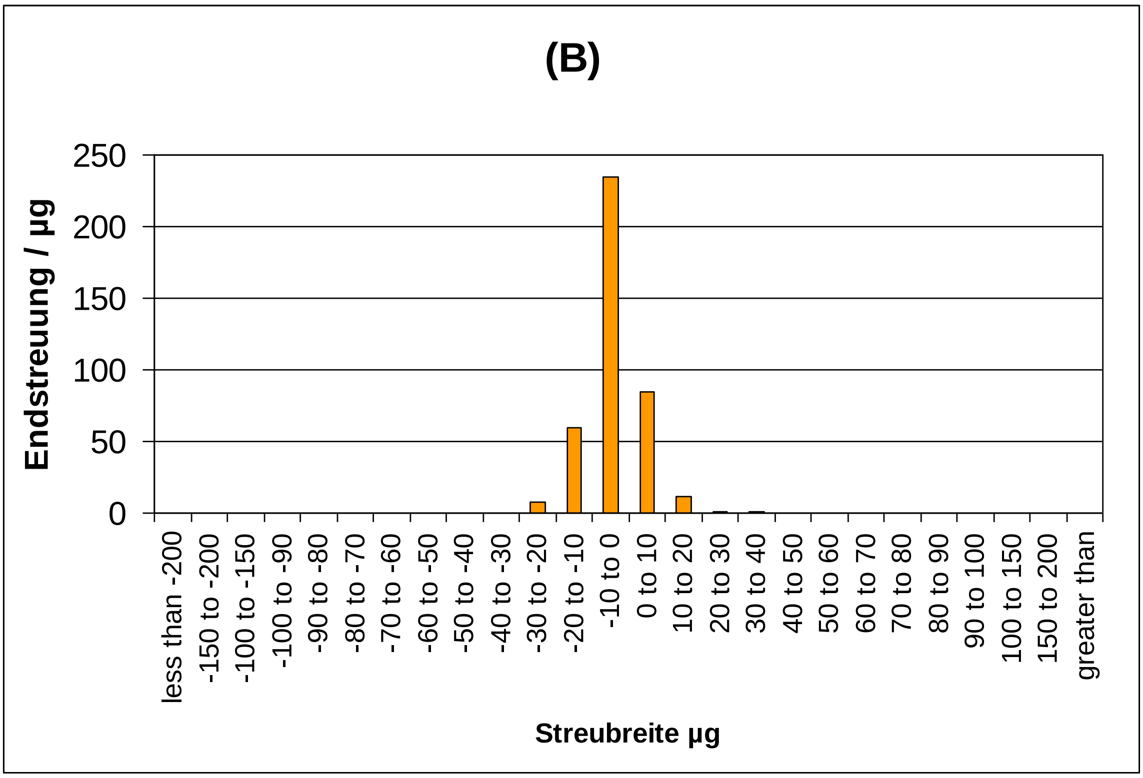
As with the UK PM Equivalence Report [11], it was not possible to weigh all filters within the 15 day timeframe suggested in EN14907. However, as filters were removed immediately from the reference samplers and placed in the refrigerator, it was not necessary to determine if $T_{Ambient}$ exceeded 23 ºC. It is felt that as 15 days was impractical for a relatively small scale field study, it is less likely to be attainable if this methodology were adopted by a National or Regional network, and as such, the methodology employed herein is representative of how the reference samplers would be operated in practice.

A.2 Analysis of Protocols Employed

The distributions of pre and post weight for all Emfab filters weighed relative to the tare filter and check weight are shown in Figure 63. If filters lose relative mass between weightings, then the distribution will be shifted to the right, whereas if there is a gain in the relative mass the distribution will shift to the left. EN14907 states that unsampled filters should be rejected if the difference between the masses of the two pre weightings is greater than 40 µg. Similarly, EN14907 states that sampled filters should be rejected if the difference between the masses of the two post weightings is greater than 60 µg. Filters were not rejected based on these criteria. The observed distributions of repeat mass measurements are considered unlikely to have had a significant effect on the results.

Figure 63: Distribution for Emfab filters of (**A**) Pre spread weighed relative to the check weight and (**B**) Post spread weighed relative to the check weight.





Appendix 3

Manuals