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VERIFICATION OF PM-ANALYZERS FOR PM_{10} AND $PM_{2.5}$ WITH THE PM REFERENCE METHOD

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Verification of PM-analyzers for PM_{10} and $PM_{2.5}$ with the PM reference method

Abstract

The Air Quality Directive, AQD, (2008/50/EC), set up the rules concerning the reference methods (RM) for the measurements of e.g. mass concentration of particulate matter in air. A member state (MS) can use any other method, which it can demonstrate to display a consistent relationship with the reference method. Demonstration of equivalence (DoE) for automated continuous monitoring systems (AMS) for determination of the $PM_{2.5}$ and PM_{10} mass concentration of suspended particulate matter was conducted in Finland at the city of Kuopio during 2014-15 (Walden et al., 2017). The tested AMS were used in Finland at the local air quality networks for controlling the limit values for $PM_{2.5}$ and PM_{10} mass concentration measurements. The purpose of the verification exercise was to demonstrate whether the AMS tested and approved during the DoE study in Kuopio are applicable elsewhere in Finland.

The comparison of the AMS of the local network (site) with the RM was performed in various parts of Finland (south and north, east and west) to see if the AMS, which was approved as equivalence method still fulfills the suitability criteria elsewhere in Finland. Verification campaigns took place at eight measurement sites of different local air quality networks in Finland either for $PM_{2.5}$ or PM_{10} measurements. AMS whose DoE was approved were: FH62-IR, Grimm model 180, MP101 CPM, Osiris, SHARP model 5030 and TEOM 1405. Additionally TEOM 1405D and APM-2 were tested for verification, though they did not participate in the DoE tests in Kuopio, but are used at some of the networks.

The test strategy was modified from the relevant EN-standard for using the AMS for measurements of $PM_{2.5}$ and PM_{10} concentrations in ambient air. This strategy enabled to include more sites and tested instruments into the study but with lack of less seasonality than would have been needed by following the guide accurately. As a result of the verification study the calibration factors achieved at DoE in Kuopio are applicable for the same model of AMS tested in Kuopio in different locations in Finland with few limitations. The FH62-IR made better performance by using the calibration factor obtained in this study in Helsinki than based on the DoE in Kuopio. Osiris passed the test for PM_{10} but not for $PM_{2.5}$ measurements just like in Kuopio. APM-2 has been tested by Rheinland Energie und Umwelt GmbH, TÜV that is accredited testing laboratory and found to be equivalent with the reference method both for $PM_{2.5}$ and for PM_{10} measurements. Based on the test results by TÜV and the verification results achieved in this study, the APM-2 can be used for $PM_{2.5}$ and for PM_{10} measurements in Finland, but applying the calibration factors obtained in this study. TEOM 1405D has not been tested for DoE and cannot be claimed equivalent to reference method. Therefore calibration factors obtained in this study cannot be used for TEOM 1405D.

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Nimike

Jatkuvatoimisten hiukkasmittalaitteiden soveltuvuus $PM_{2.5}$- ja PM_{10}-mittauksiin Suomessa.

Tiivistelmä

Euroopan Yhteisön CAFÉ-direktiivi (2008/50/EY) määrittää vertailumenetelmät esimerkiksi hiukkasten massapitoisuuden mittaamiseksi ilmassa. EU:n jäsenmaa voi käyttää mitä tahansa muuta menetelmää, jonka tulokset ovat yhteneviä vertailumenetelmän antamien tulosten kanssa. Jatkuvatoimisten hiukkasmittalaitteiden (AMS) vastaavuutta vertailumenetelmää vastaan on testattu Kuopiossa PM_{10} ja $PM_{2.5}$ vertailumittauksissa vuosina 2014-15 (Walden ym. 2017). Testauksessa mukana olleet laitteet ovat yleisesti käytössä raja-arvoja valvovissa ilmanlaadun mittausverkoissa eri puolella Suomea. Tämän tutkimuksen tavoitteena oli osoittaa, miten hyvin Kuopion vertailumittauksissa hyväksytyt mittalaitteet toimivat eri puolella Suomea.

Tässä tutkimuksessa testattiin jatkuvatoimisten hiukkasmittalaitteiden vastaavuutta vertailumenetelmää vastaan, jotta voitaisiin todentaa, että Kuopion testeissä hyväksyttyä laitetta voidaan käyttää eri osissa Suomea (etelässä ja pohjoisessa, idässä ja lännessä). Vertailumittaukset toteutettiin kahdeksalla mittausasemalla joko PM_{10}- tai $PM_{2.5}$-mittauksissa. Vertailu tehtiin seuraaville hiukkasmittalaitteille FH62-IR, Grimm 180, MP101 CPM, Osiris, SHARP 5030 and TEOM 1405, jotka läpäisivät Kuopion testit. Näiden laitteiden lisäksi tässä vertailussa olivat myös TEOM 1405D ja APM-2 laitteet, jotka eivät olleet Kuopion testeissä, mutta olivat mittausasemalla käytössä.

Testiohjelmaa oli muunneltu standardin mukaisesta vertailusta jotta voitiin sisällyttää useampi mittausasema ja hiukkasmittalaite, mutta tämän takia jouduttiin tinkimään vuodenaikaisvaihtelun aiheuttamasta vaikutuksesta, mikä vaaditaan ohjeen mukaisessa vertailussa. Lopputuloksena voitiin osoittaa, että Kuopion vertailumittauksissa saadut korjauskertoimet eri laitteille soveltuivat käytettäväksi eri puolella Suomea muutamin poikkeuksin. FH62-IR osoittautui toimivan Helsingissä paremmin tämän tutkimuksen perusteella saadulla kalibrointikertoimella kuin Kuopion mittauksissa saadulla kertoimella. Osiris soveltuu PM_{10}-mittauksiin, mutta ei $PM_{2.5}$-mittauksiin kuten Kuopionkin vertailumittauksessa ilmeni. APM-2 –laite on todettu ekvivalentiksi referenssimenetelmää vastaan sekä PM_{10}- että $PM_{2.5}$-mittauksissa Rheinland Energie und Umwelt GmbH, TÜV toimesta, mikä on akkreditoitu testauslaboratorio. TÜV:n tutkimusraportin sekä tämän vertailun tulosten perusteella APM-2 –laitetta voidaan käyttää $PM_{2.5}$-mittauksissa sekä PM_{10}-mittauksissa Suomessa, mutta ainoastaan tässä tutkimuksessa saaduilla kalibrointikertoimilla. TEOM 1405D ei ole testattu ekvivalenttisuuden osalta ja näin ollen TEOM 1405D;lle määritettyjä kalibrointikertoimia ei voida käyttää.

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Contents

1 Introduction

According to European air quality directive, AQD (2008/50/EC) the methods for assessment of air quality within the EU regions are air quality measurements, use of model results and by objective estimation. The measurements are divided into two categories, fixed measurements and indicative measurements. For fixed measurements the data quality objectives (DQO) i.e. measurement uncertainty, minimum data capture and minimum data coverage for the measurements, are the most stringent compared to other assessment methods. The directive also defines the reference methods to be used for fixed measurements. For this purpose, the European Committee for Standardization (CEN) prepared the EN-standards for the reference methods. The directive allows, however, to use any other method e.g. for the measurements of mass concentration of particulate matter if the Member State (MS) can demonstrate that it

'*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*'.

In case of non-reference method, the demonstration of equivalence (DoE) should be conducted following the guidance document 'Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods, GDE' (http://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf). The document was prepared by an EC Working group. Tests for demonstration of equivalence for continuous particle analyzers (candidate method, CM) were conducted in Helsinki in 2007-08 (Waldén et al. 2010) and in Kuopio in 2014-15, referred in the text as DoE in Kuopio (Waldén et al. 2017). PM-analyzers that were tested in both of the comparison studies were in use at the local air quality networks in Finland. Equivalence is claimed for the CMs to be in line with the reference method (RM) either directly or by a calibration factor which corrects the result of the CM to be equivalent to RM. To ensure that the calibration factor can be used at the field sites, other than those where the equivalence has been claimed, periodic side-by-side comparisons of equivalence analyzers and the reference method are required by the GDE. Requirements that are more detailed, frequency and number of sites for these comparisons are defined in the EN-standard for automated measuring systems for the measurement of the concentration of particulate matter (EN 16450:2017). Member states have conducted trials for Demonstration of Equivalence of Candidate Methods (Beijk et al. 2008, Harrison 2010, D'Hondt, 2011, Areskoug, 2014). In addition, testing laboratory of Rheinland Energie und Umwelt GmbH, TÜV has completed equivalence tests for a number of AMS and provides the full test reports with the certificates (www.qal1.de).

The purpose of the study was to test whether the calibration factors obtained from the equivalent study in Kuopio are applicable in different locations in Finland for the tested equivalent methods. The EN 14650:2017, requires side by side comparison of the PM-reference method (EN 12341:2014) with the automated continuous measurement system (AMS). The number of sites for a tested AMS depends on the uncertainty of the results obtained at the equivalence tests, being in the range of 2 to 5 sites for a period of full year.

The conducted test procedure did not, however, follow the ongoing verification of suitability requirements by the EN 16450 (see in Ch 8.6). Instead, the tests were mostly conducted by intensive campaign of daily sampling during a period of eight weeks with the exception of one campaign lasting 169 days and one lasting six months where sampling took place every third day. Normally one model of site analyzer was tested against the single reference sampler for size class while at some sites there were more than one model of AMS under tests. The eight-week campaigns are similar to the campaigns that the European Reference Laboratory for Air Pollution at the Joint Research Centre in Ispra (JRC/ERLAP) conducts for PM_{10} and $PM_{2.5}$ for the national reference laboratories (Lagler et al., 2016).

2. Experimental

2.1 Measurement sites

The verification tests were conducted with reference samplers as defined by the EN-standard (EN 12341:2014) against the site AMS at selected sites across Finland (Figure 2.1). Also where applicable at the site additional AMS from the FMI were installed in the cabin in order to have more information of the performance of the same AMS at different location. The verification tests period was normally eight weeks, except in Tornio, and in Helsinki. At Tornio the filter sampling was every third day during a half year period. At Helsinki two sites were selected for this study, Mäkelänkatu and Kallio. At Mäkelänkatu the PM_{10} verification test lasted 169 days, while at Kallio it took eight weeks. The schedule for the verification test with the site and the AMS is presented in Table 2.1. Air quality network is run by the municipality or by associated areal operator e.g. Helsinki Region Environmental Services Authority, HSY including the area of Helsinki, Espoo, Kauniainen and Vantaa. The other areal operator in this study was Etelä-Karjala, which include the area of Lappeenranta and Imatra. Tornio is not a permanent network but used for special survey for detecting the influence of dispersion of pollutants from the nearby industrial area. The Finnish Meteorological Institute (FMI) is responsible for the background air quality network of which Virolahti/Ääpälä takes part in the European Monitoring and Evaluation Programme, EMEP.

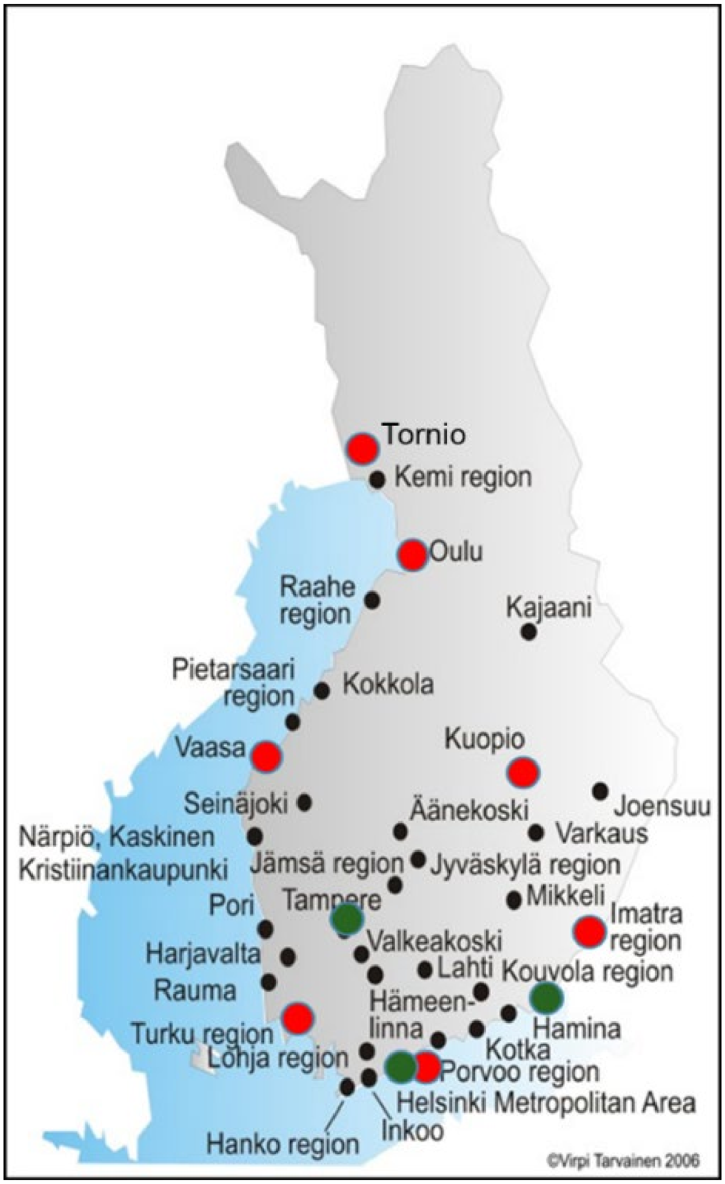

Figure 2.1. The verification tests for the reference method and the AMS were conducted at the local air quality network for PM_{10} measurements (red dots) and for $PM_{2.5}$ measurements (green dots). The DoE campaigns were conducted at the city of Kuopio.

Table 2.1. List of sites, dates, RM-instruments and AMS during the verification tests .

Network	Site	Dates	Reference sampler: PM10/PM2.5	AMS
Etelä-Karjala	Mansikkala	23.3. - 15.5.2017	Leckel 47/50 SEQ PM10	TEOM 1405: PM10
				Grimm 164: PM10
Turku	Naantali	21.3. - 23.5.2017	Leckel 47/50 SEQ PM10	MP 101: PM10
				Grimm 180(FMI): TSP
				SHARP 5030 (FMI): PM10
HSY-Helsinki	Mäkelänkatu	21.3. - 4.9.2017	Derenda sampler: PM10	TEOM 1405: PM10
				TEOM 1405D: PM10 + PM2.5/coarse
				FH-62 IR: PM10
				Grimm 180:TSP
				Osiris: TSP
				APM-2: TSP
Oulu	Keskusta	20.4 - 19.6.2017	Leckel 47/50 SEQ PM10	TEOM 1405: PM10
Tampere	Epila	7.6 - 8.8.2017	Leckel 47/50 SEQ: PM2.5	Grimm 180: TSP
				Grimm 180(FMI): TSP
				SHARP 5030 (FMI): PM2.5
Virolahti	Ääpälä	2.7 - 30.8.2017	Derenda sampler: PM2.5	TEOM 1405: PM2.5
				SHARP 5030: PM2.5
HSY-Helsinki	Kallio	8.9. - 10.11.2017	Leckel 47/50 SEQ: PM2.5	TEOM 1400: PM2.5
				TEOM 1405: PM2.5
HSY-Helsinki	Mäkelänkatu	8.9- 31.10.2017	Leckel 47/50 SEQ: PM2.5	TEOM 1405: PM2.5
				TEOM 1405D: PM10 + PM2.5/coarse
				Thermo FH62-IR: 2.5
				Grimm 180: TSP
				Osiris: TSP
				APM-2: TSP
Tornio	Puuluoto	30.6 - 31.12.2017	Leckel 47/50 SEQ PM10	SHARP 5030: PM10
Vaasa	Keskusta	6.11 - 28.12.2018	Leckel 47/50 SEQ PM10	MP 101: PM10

Etelä-Karjala/Mansikkala site is located in a residential area next to a kindergarden, nearby to several shopping centers and apartment houses. The site is affected by traffic emissions from a nearby highway and long-range air pollution as well as by emissions from a nearby power plant.

Turku/Naantali site is located on the corner of the Naantali market square in the centre of Naantali. There are detached buildings and some trees surrounding the market square and the site.

HSY Helsinki Mäkelänkatu is a traffic site next to a busy road located in a street canyon. Mäkelänkatu is one of the main entrance streets in Helsinki.

HSY Helsinki Kallio is an urban background site. It is located at the edge of a football field in the Kallio residential area [near to the center of Helsinki].

Oulu Keskusta is a traffic site, located in the city center of Oulu, near a busy street, one of the main streets of Oulu. There are detached buildings on both sides of the street.

Tampere/Epilä, is a traffic site, and is located in a suburban one-family house area. There is a small road crossing, compact buildings and some large trees next to the site and in the surroundings.

Vaasa Keskusta is a traffic site, and is located in the city center of Vaasa.

Virolahti Koivuniemi Ääpälä site is a rural background air quality measurement site.

Tornio Puuluoto is an urban background site located in a small residence type area with one-family houses, in the vicinity of a steel factory. There are small roads, compact buildings and some forest in the surroundings of the site. At Puuluoto there was one-year air quality measuring campaign, this is not a permanent site.

2.2 Reference samplers

The reference sampler used in this study for both PM_{10} and $PM_{2.5}$ was a sequential type sampler SEQ47/50 by Sven Leckel, Ingenieurbüro GmbH, Germany. One reference sampler was used for both PM_{10} and $PM_{2.5}$ tests. The layout of the reference sampler is shown in Figure 2.2. Additionally also another sequential type reference sampler PNS 16T by Comre Derenda was used at two campaigns, at Virolahti and at HSY/Mäkelänkatu. The size classification inlet for both of the reference samplers followed the designing criteria of EN 12341. By switching the jets inside, the inlet can be used for PM_{10} or $PM_{2.5}$ measurements. Both type of samplers are equipped with a heater and cooling capabilities to keep the temperature above the dew point to prevent sample filters from freezing in winter conditions. In addition, cooled sample tube by sheath flow and enclosed sample filters within the filter cartridge prevent the volatilization of semi-volatile compounds such as sulphate, ammonia and nitrate. Sampling data was collected to each sampler's flash memory card, which was then read regularly using StatusView 2.44 program.

The filter types used in the tests were polytetrafluoroethylene (PTFE) filters, Millipore Fluoropore FSLW047 # 3 µm, by Millipore.

Figure 2.2: The layout of the reference samplers Leckel SEQ 47/50 (left), and Derenda PNS (right) used for the PM_{10} and the $PM_{2.5}$ verificaion tests.

2.3 Site PM-analyzers

The AMS were selected for tests based on the results at the DoE in Kuopio. The most common types of AMS in the local air quality networks are TEOM 1400/1405, FH 62-IR, MP 101, Grimm 180 and SHARP 5030. Besides these tested AMS also some additional AMS that were not tested according to DoE, but were installed in selected measurement sites, were tested in the verification study, see Table 2.2. The location of the test sites were then selected to reach regional coverage across the Finland, see Table 2.1.

Table 2.2. The AMS, the manufacturer, and the acronym of the instrument (in parenthesis) tested in the verification study.

1. FH 62 I-R by Thermo Fisher Scientific, USA (FH 62 I-R);
2. Grimm Environmental Dust Monitor, model 180, by GRIMM Aerosol Technik GmbH & Co. Member of Durag Group, Germany (Grimm 180);
3. MP101 CPM, by Environnement SA, France (MP101_CPM)
4. Osiris, by Turnkey Instruments Ltd, England (Osiris);
5. Synchronized Hybrid Ambient Real-time Particulate Monitor, model 5030 by Thermo Fisher Scientific, USA (SHARP);
6. Tapered element oscillating microbalance, TEOM 1405 by Thermo Fisher Scientific, USA (TEOM 1405);
7. Tapered element oscillating microbalance, TEOM 1405D by Thermo Fisher Scientific, USA (TEOM 1405D)
8. APM-2 nephelometer by Comre Derenda, Germany.

More details of the operation of the AMS shown in Table 2.2 can be found elsewhere (Waldén et al. 2017). The APM-2 was not tested at DoE in Kuopio, but it has been tested by TÜV Rheinland Energie und Umwelt GmbH (TÜV 2014) for PM_{10} and $PM_{2.5}$ for DoE. Test results demonstrate that the instrument passed the tests for DoE both for $PM_{2.5}$ and PM_{10} measurements. The instrument is based on optical method following the same principle as Grimm 180 and Osiris. The TEOM 1405D was also not tested at DoE in Kuopio. It is a modified version of TEOM 1405 with the capability of simultaneous measurements of PM_{10}, the difference between PM_{10} and $PM_{2.5}$ (=coarse particles), and $PM_{2.5}$.

2.3 Quality control procedures (QA/QC)

During the verification tests of AMS the quality control procedures (QA/QC) were conducted according to clause 8.6 in EN 16450. In case of the reference samplers QA/QC included:

- Flow measurement: once during the individual campaign (2 month period)
- Cleaning and greasing the sampling head: every month where size selective inlet is used according to instruction by EN 12341: 1998 and 2014 or EN 14907:2005.

In case of the AMS, the QA/QC procedures were conducted according to the standard operating procedures by the network, including:

- Flow measurement
- Cleaning and greasing of the sampling head
- Check of sensor operation (temperature, pressure)

The flow rates of the reference samplers were measured with a mass flow meter by TSI Inc, model 4043. The mass flow meter was calibrated at the calibration laboratory of Finnish Meteorological Institute, which maintains the traceability of the calibration facility through regular calibration against the primary flow calibration method at the national metrology institute, VTT-MIKES (www.mikes.fi). The uncertainty of the flow calibration facility at the sampling flow rate of the size selective inlets is 0.7 % (https://www.finas.fi/sites/en/operators/Pages/default.aspx, calibration laboratory K043). The uncertainty of the mass flow meter of TSI model 4043 was estimated based on the calibration certificate as 1.5 % as expanded uncertainty.

The cleaning of the size selective inlets was conducted according to the recommendation by the manufacturer of the inlet and according to EN-standard (EN 12341). The time interval for cleaning of the inlets was once a month. The impactor plates were wiped with silicon vacuum grease after the cleaning of inlets in order to prevent the larger particles than the cut-off size to bounce off the impactor plate. The use of grease is instructed for the size selective inlets manufactured according to the EN-standard. In case of US-EPA type of inlet no grease is used, based on the instructions by the manufacturer.

2.4 Filter weighing

The EN 12341 standard describes the environmental conditions for filter conditioning during the filter weighing process: temperature 20 ± 1 ºC, relative humidity 45 to 50 %. The weighing facility of the filters was made in house, consisting of the weighing chamber and the conditioning and control system.

The weighing process of the filters is accredited according to ISO EN 17025:2005 quality standard. A detailed description of the weighing system and procedure is given elsewhere (Waldén et al. 2017).

2.5 Data collection and analysis

The data from the verification study included the meteorological data (ambient temperature, pressure, humidity, wind speed and direction), sampling data from the reference samplers (flow rate, sampling volume, sampling temperature and pressure) and hourly average values for AMS at every site. FMI collected the data from the reference samplers and the data from AMS were delivered to FMI by the networks. The sampling filters were conditioned and weighed according to EN 12341. Two filter cartridges with weighed filters were loaded and delivered to the measurement sites at the beginning and at the middle of the campaign. FMI personnel provided training to the staff of the local network to operate the reference sampler and to install and remove the filter cartridges in the sampler unit. After the first filter sampling was completed (after 14 days) the staff personnel of the local network removed the sampled filter cartridge and replaced the new unsampled filter cartridge in place in the sampling side of the sampler. The sampled filter cartridge was stored in a cool place until the next change of filter cartridge took place. At this time, FMI personnel brought two sets of weighed filters to be loaded in the filter cartridge for the next two sampling periods (2 x 14 days). The two sets of sampled filters were delivered directly to FMI for weighing. The complete data analysis of the filters and the results of the AMS was conducted following the GDE procedures (Walden et al. 2017).

2.6 Analysis of the results

Analysis of the verification data was conducted according to the GDE similarly to the DoE in Kuopio (Waldén et al. 2017). The data during the verification test was requested directly from the network in order to be clear with the correct identification of the used AMS with the operation and sampling details (sample inlet and sampling tube condition) and data correction i.e. data calibration function, as presented in Table 2.3.

Table 2.3. Details of the used sampling system and calibration functions for each of the AMS.

Network/Site	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU
AMS	Teom	Teom	Teom	Teom	Thermo	Thermo
Model	1405	1405	1405D	1405D	FH 62 I-R	FH62 I-R
Serial no:						
Factory setting for signal	1.03 + 3.0	1.03 + 3.0	1.0 + 0	1.0 + 0	1	1
Calibration factor	0.868y - 2.068	1.009y - 1.681	No correction	No correction	1.300y - 0.904	0.850y + 1.709
Temperature of sample tube	50	50	50	50	40	40
Type of inlet	PM10	PM10+PM2.5	PM10+PM2.5/PMcoarse	PM10+PM2.5/PM-coarse impactor	PM10	PM2.5
Inlet manufacturer	Teom (US-EPA)	Teom (US-EPA)	Teom (US-EPA)	Teom (US-EPA)	Digitel	Digitel

Network/Site	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU	HSY/MÄKELÄNKATU
AMS	Grimm PM10	Grimm PM2.5	Osiris PM10	Osiris PM2.5	Derenda PM10	Derenda PM2.5
Model	Model 180	Model 180			APM-2	APM-2
Serial no:					20050	20050
Factory setting for signal	1	1	1	1		
Calibration factor	0.855y + 2.139	0.747y + 0.532	No correction	No correction	No correction	No correction
Temperature of sample tube						
Type of inlet	TSP	TSP	TSP	TSP	TSP	TSP
Inlet manufacturer					Derenda	Derenda

Network/Site	HSY/KALLIO	HSY/KALLIO	HSY/KALLIO
AMS	Teom	Teom	Teom
Model	1400	1400	1405
Serial no:			
Factory setting for signal	1.03 + 3.0	1.0 + 0	1.03 + 3.0
Calibration factor	No correction	1.25y + 1.56	1.009y - 1.681
Temperature of sample tube	50	50	50
Type of inlet	PM10	PM10+PM2.5	PM10+PM2.5
Inlet manufacturer	Teom (US-EPA)	Teom	Teom

Network	Turku	Imatra	Oulu	Vaasa	Tornio	Tampere	Tampere Ref lab	Tampere Ref lab
Site	Naantali	Mansikkala	Keskusta	Keskusta	Puuluoto	Epilä	Ongoing	Ongoing
AMS	Environnement	TEOM	TEOM	Environnement	SHARP	Grimm	Grimm	SHARP
Model	MP101	1405	1405	MP101	5030	180	180	5030
Serial no:			1405A228891407.					
Factory setting for signal	1	1.03 + 3.0	1.03 + 3.0	1	1	1	1	1
Calibration factor	0,91	1	1	0,938	1,319	1	0,78	0,998 (C-dust) 0,971 (beta)
Temperature of sample tube	Tambient + 5 C	No heating	50 C	Tambient + 5 C	30 C	No heating	No heating	30 C
Type of inlet	PM10	PM10	PM10	PM10	PM10	TSP/PM2.5	TSP/PM2.5	PM2.5
Inlet manufacturer	Environnement S.A.	Teom (US-EPA)	Teom (US-EPA)	Environnement S.A.	Digitel	Grimm	Grimm	Digitel

2.7 Calibration equations for the AMS

The calibration equations from the DoE study in Kuopio are presented for the tested PM_{10} analyzers in Table 2.4 and for tested $PM_{2.5}$ analyzers in Table 2.5. The results in black color in Table 2.4 and Table 2.5 signify acceptable results, whereas results in red color are unacceptable results.

*Table 2.4. The calibration range and the equations (X_{REF} = b*x + a; b=slope, a=intercept and y = is the AMS) against the reference method X_{REF} for PM_{10} together with the relative combined standard uncertainty from DoE in Kuopio (*Waldén *et al., 2017).*

PM10	Measurement range < 325 µg/m3		Measurement range < 325 µg/m3	
Candidate method	Calibration equation PM_{10}	Relative expanded uncertainty U(%)	Calibration equation through origin PM10	Relative expanded uncertainty U(%)
BAM 1020	0,942y + 0,437	12,6%	0,947y	12,6%
GRIMM 180	0,855y + 2,139	17,0 %	0,908y	18,0 %
SHARP 5030 C-dust	1,404y -2,750	17,2%	1,362y	17,3%
SHARP 5030 (beta)	1,415y -2,233	12,8%	1,380y	13,0%
FH 62 IR	1,300y -0,904	16,5%	1,288y	16,4%
TEOM 1405	0,868y -2,068	14,4%	0,848y	14,4%
MP101M	0,811y + 2,311	11,0%	0,830y	12,1%
OSIRIS	1,401y -0,153	15,7%	1,398y	15,7%
Dusttrak	7,478y -76,819	402,3%	-	-
PM10	Measurement range < 100 µg/m3		Measurement range < 100 µg/m3	
Candidate method	Calibration equation PM10	Relative expanded uncertainty U(%)	Calibration equation through origin PM10	Relative expanded uncertainty U(%)
BAM 1020	0,858y + 1,919	10,3%	0,913y	11,7%
GRIMM 180	0,871y + 1,927	17,0 %	0,922y	17,9 %
SHARP 5030 C-dust	1,486y -3,904	16,5%	1,319y	16,3%
SHARP 5030 (beta)	1,489y -3,301	12,5%	1,351y	12,5%
FH 62 IR	1,372y -1,850	17,1%	1,297y	12,6%
TEOM 1405	0,804y -0,623	13,6%	0,788y	13,0%
MP101M	0,887y + 0,826	9,4%	0,910y	9,6%
OSIRIS	1,338y + 0,57	15,3%	1,363y	15,7%
Dusttrak	5,761y -55,073	1132,0%	2,07y	94,0%
PM10	Measurement range < 50 µg/m3		Measurement range < 50 µg/m3	
Candidate method	Calibration equation PM10	Relative expanded uncertainty U(%)	Calibration equation through origin PM10	Relative expanded uncertainty U(%)
BAM 1020	0,844y + 2,072	9,5%	0,921y	13,3%
GRIMM 180	0,92y + 1,251	11,2 %	0,975y	13,0 %
SHARP 5030 C-dust	1,375y -2,564	14,2%	1,242y	15,2%
SHARP 5030 (beta)	1,421y -2,530	9,3%	1,278y	11,8%
FH 62 IR	1,311y -1,193	16,2%	1,247y	15,2%
TEOM 1405	0,771y -0,149	10,6%	0,766y	9,9%
MP101M	0,938y + 0,001	8,8%	0,938y	8,4%
OSIRIS	1,290y + 0,886	13,6%	1,343y	15,4%
Dusttrak				

*Table 2.5. The calibration range and the equations (X_{REF} = b*y + a; b=slope, a=intercept and y = is the AMS) against the reference method X_{REF} for $PM_{2.5}$ together with the relative combined standard uncertainty from DoE in Kuopio (*Waldén *et al., 2017).*

PM2.5 Candidate method	Measurement range < 25 µg/m3 Calibration equation $PM_{2.5}$	Relative expanded uncertainty U(%)	Measurement range < 25 µg/m3 Calibration equation through origin PM2.5	Relative expanded uncertainty U(%)
BAM 1020	1,100y + 0,733	7,4%	1,215y	19,9%
GRIMM 180 (*	0,747y + 0,532	12,6 %	0,780y	12,3 %
SHARP 5030 C-dust	0,854y + 1,187	7,3%	0,998y	24,9%
SHARP 5030 (beta)	0,971y -0,003	0,2%	0,971y	0,2%
FH 62 IR	0,850y + 1,709	17,3%	1,097y	51,8%
TEOM 1405	1,009y -1,681	8,8%	0,821y	31,4%
MP101M	0,812y -0,306	8,9%	0,780y	31,4%
OSIRIS (*	3,324y -1,073	124,2%	2,020y	76,1%
Dusttrak (*	0,602y -1,002	37,9%	0,550y	143,9%
(*Measurement range < 75 µg/m3				

BAM 1020 and Dusttrak were the two AMS that were not tested during the verification study. According to the list of instruments that are used in Finland those two AMS are not in the list. Instead, TEOM 1405D and APM-2 which were not tested in the DoE in Kuopio, are in use at the air quality networks in Finland. As mentioned earlier, APM-2 has been tested by TÜV while TEOM 1405D has not been tested for DoE. The calibration equations for APM-2 are as follows (TÜV Certificate 40336):

X_{REF} = 1.001y – 0.02, for PM_{10} all results (four campaign)

X_{REF} = 1.001y + 0.3 for $PM_{2.5}$ all results (four campaign)

The slope in single campaigns for PM_{10} varied between 0.87 to 1.1 and for $PM_{2.5}$ variation of slope was 0.93 to 1.17.

3. Results

3.1. Time series of individual PM_{10} verification test

The duration of the verification test was eight weeks for all sites except at HSY/Mäkelänkatu for PM_{10} campaign where it lasted 169 days and in Tornio where sampling was every third day lasting six months. In Helsinki the longer period for verification was used because the site is equipped with several AMS for PM_{10} and $PM_{2.5}$, providing a good opportunity to have four campaigns of at least 40 days for verification. In Tornio the verification test was conducted within another survey where heavy metals were collected every third day from PM10 samples of which the mass concentration was used in this study. The time series of PM_{10}-verificaions are presented as daily averages in Figures 3.1 – 3.6.

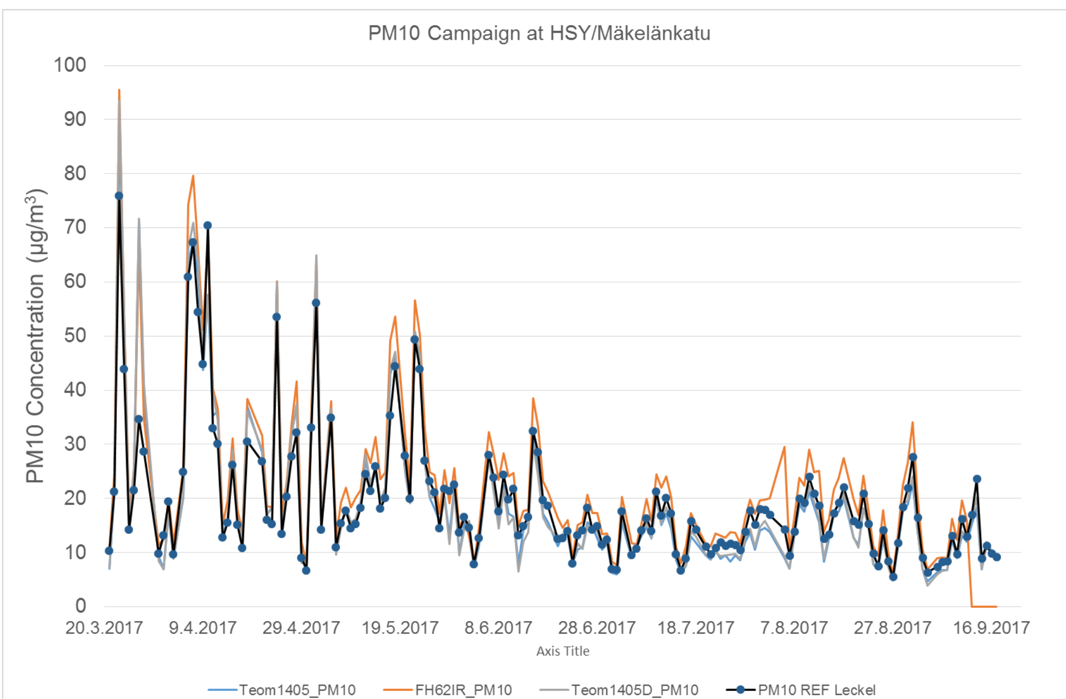

Figure 3.1a. Time series of daily average PM10 mass concentration at HSY/Mäkelänkatu.

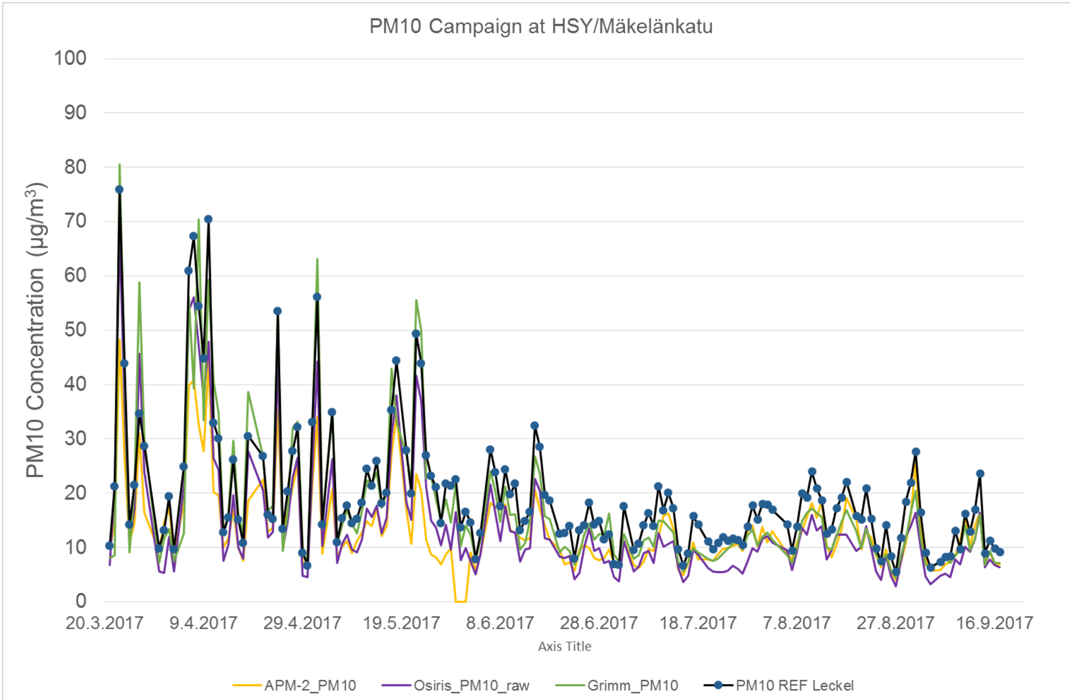

Figure 3.1b. Time series of daily average PM10 mass concentration at HSY/Mäkelänkatu.

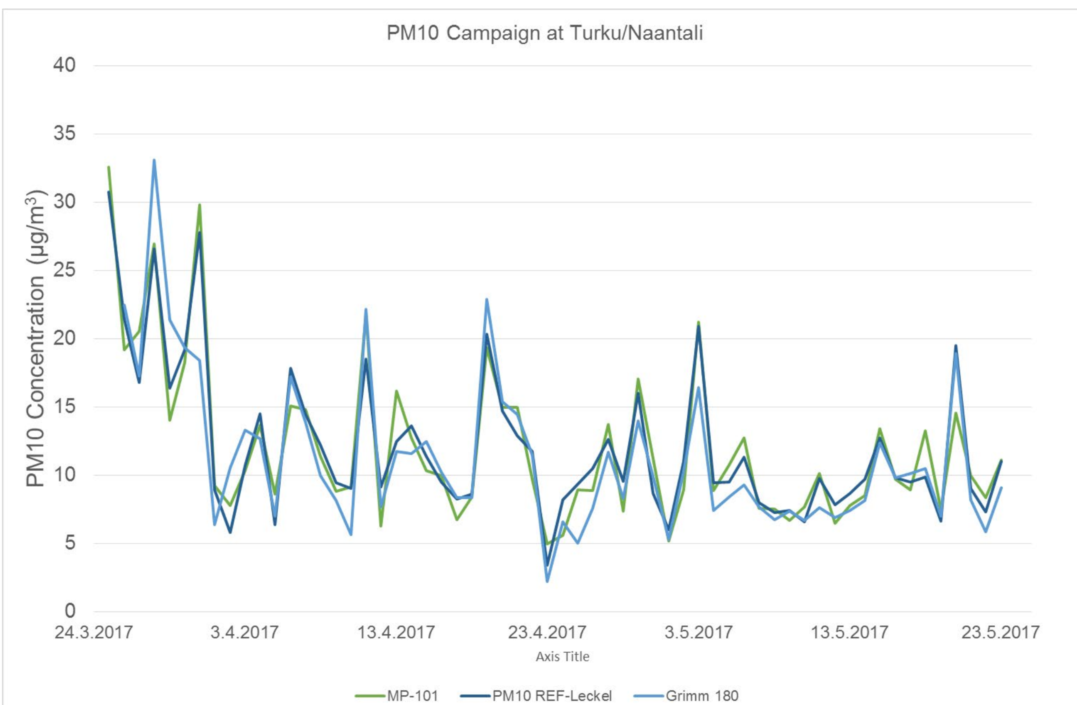

Figure 3.2. Time series of daily average PM10 mass concentration at Naantali.

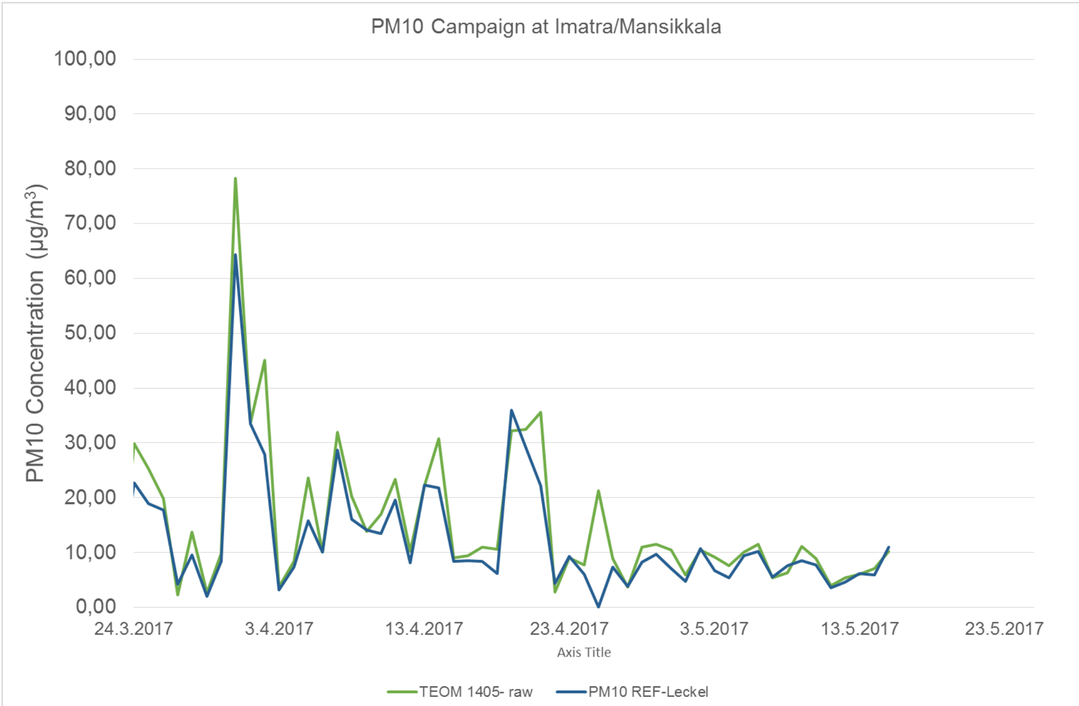

Figure 3.3. Time series of daily average PM10 mass concentration at Etelä-Karjala/Mansikkala.

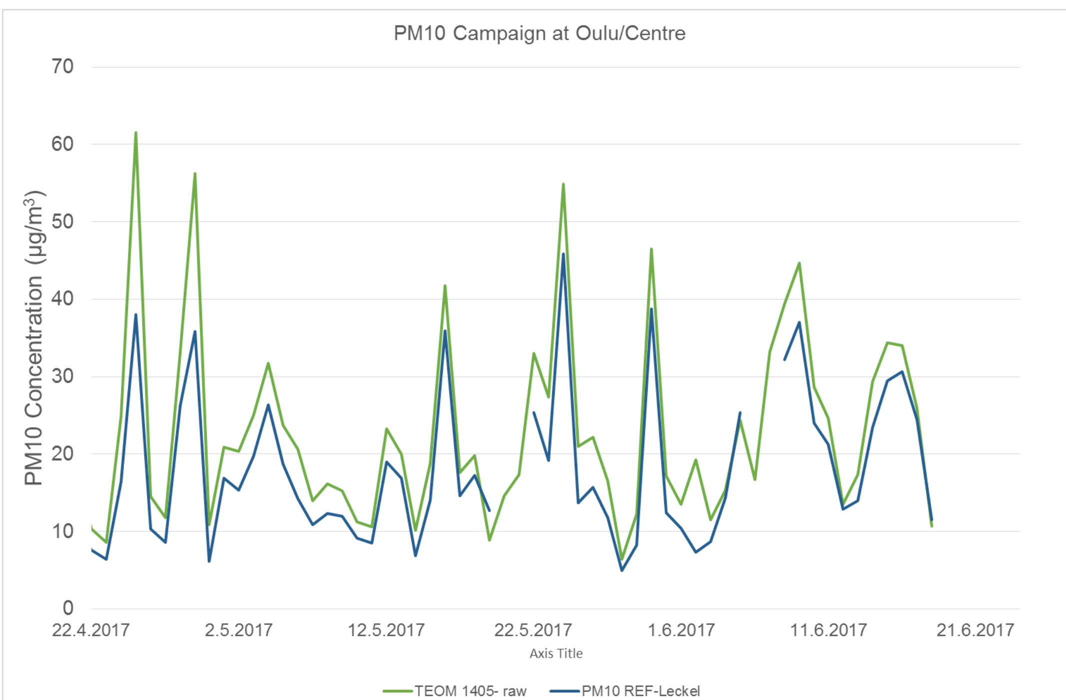

Figure 3.4. Time series of daily average PM10 mass concentration at Oulu/Centre.

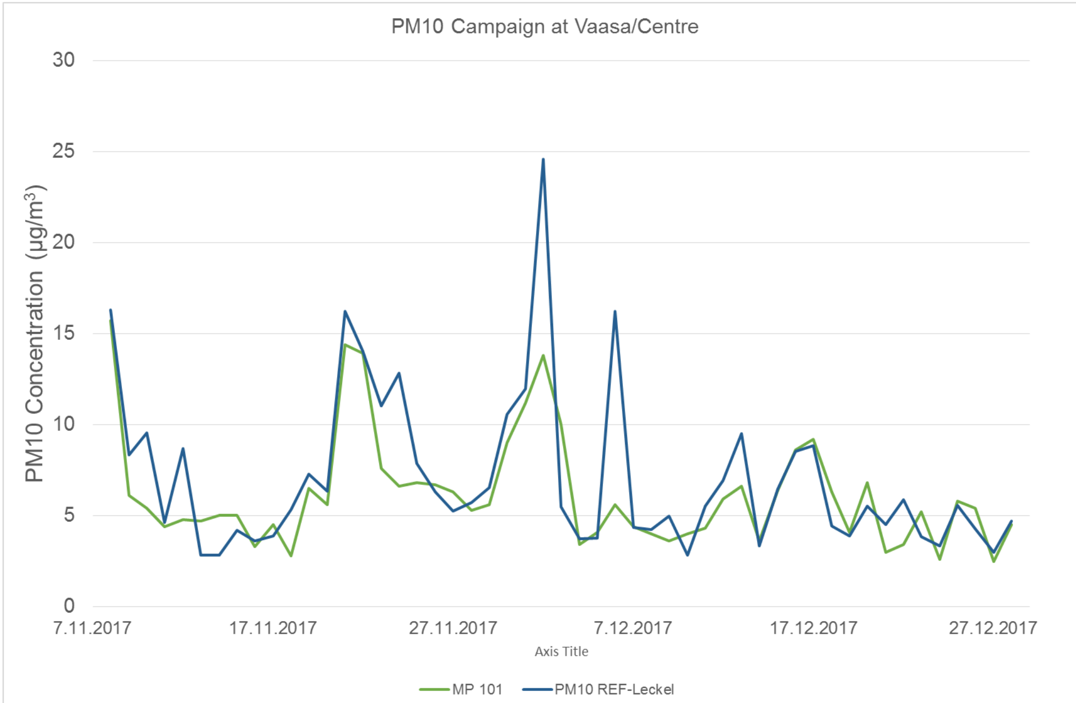

Figure 3.5. Time series of daily average PM10 mass concentration at Vaasa/Keskusta.

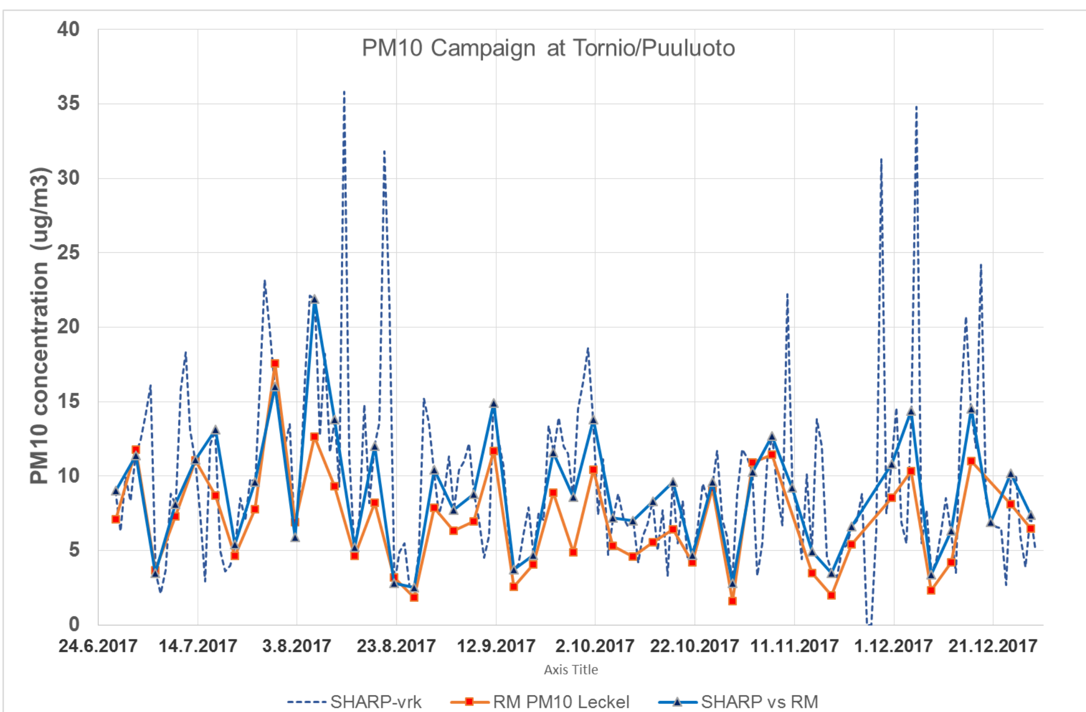

Figure 3.6. Time series of daily average PM10 mass concentration at Tornio/Puuluoto. The dotted line is for SHARP as daily values while lines with markers are daily values when verification took place (every 3rd day).

3.2. Verification results for PM_{10}

In the following, data for each paired comparison of AMS against the RM is analyzed with help of the equivalence software (Beijk et al. 2018). The local air quality networks had different practices in applying the calibration factors based on the DoE results in Kuopio: at some of the sites, the measurement results were not corrected whereas at some sites the calibration equation was employed (see Table 2.3). Therefore, the original results from the sites were first analyzed as they were (Raw data), and then reanalyzed to make the verification complete (Calibrated data) with two options for the calibration equation: full correction (slope and intercept) and slope through origin. Results from all the calculations are shown in Tables 3.1 – 3.4 for the AMS (Network/site , AMS with indication of how the results were treated (raw/calib). When the site AMS has been corrected, the calibration equation is shown in the last line in the bottom for each AMS. More detailed results and regression figures are presented in Annex 1. The red font indicates that the slope and/or intercept differ significantly from 1 and/or zero, respectively, or the uncertainty exceeds the critical value of 25 % as required by DQO. In the latter case, the instrument fails (Fail) to meet the requirement. When the instrument pass (Pass) the requirements either with full calibration equation or with slope correction the lower of the uncertainty associated with calibration correction, should be selected.

Table 3.1. The test results for TEOM 1405 by Thermo Scientific. At Etelä-Karjala/Mansikkala and at Oulu/keskusta the raw signal is used. At HSY/Mäkelänkatu the TEOM 1405 is corrected with the calibration function obtained in Kuopio. In case of TEOM 1405D no correction of signal is made.

Verification test PM_{10}	Criteria	Etelä-Karjala/Mansikkala TEOM 1405 raw	Oulu/keskusta TEOM 1405 raw	HSY/Mäkelänkatu TEOM 1405 calib	HSY/Mäkelänkatu TEOM 1405D
Concentration range	µg/m³	0 - 75	0 - 55	0 - 90	0 - 90
Raw data					
Slope	significant (Yes/No)	1,2270	1,148	1,1465	1,1931
Intercept	significant (Yes/No)	-0,5	2,0	-3,43	1,05
Expanded relative uncertainty	≤ 25%	44,6 %	38,6 %	18,10 %	25,00 %
Fail/Pass	≤ 25%	Fail	Fail	Pass	Fail
Calibrated data					
Calibration: equation		0,815y + 0,375	0,874y + -1,707	0,872y + 2,992	0,838y + 3,291
Expanded relative uncertainty	≤ 25%	10,8%	7,8 %	8,75 %	9,10 %
Fail/Pass	≤ 25%	Pass	Pass	Pass	Pass
Calibration: slope through origin		0,83y	0,808	0,982	0,955
Expanded relative uncertainty	≤ 25%	9,3%	10,3 %	15 %	16 %
Fail/Pass	≤ 25%	Pass	Pass	Pass	Pass
Calibration equation				0.868y - 2.068	

Table 3.2. The test results for MP101 by Environnement S.A at Naantali and at Vaasa. The raw signal of MP101 is corrected by calibration function (slope through origin) from DoE in Kuopio (at Naantali the slope correction was 0.91 instead of 0.938).

Verification test PM_{10}	Criteria	Turku/Naantali MP-101 calib	Vaasa/keskusta MP-101 calib	Kuopio site/Tasavallankatu MP-101 calib
Concentration range	µg/m³	0 - 35	0 - 20	0 - 75
Raw data				
Slope	significant (Yes/No)	1,0531	0,8926	0,97982
Intercept	significant (Yes/No)	-0,6447	0,2866	-0,70160
Expanded relative uncertainty	≤ 25%	10,4 %	20,7 %	13,0 %
Fail/Pass	≤ 25%	Pass	Pass	Pass
Calibrated data				
Calibration: equation			1,12y + -0,321	
Expanded relative uncertainty	≤ 25%		11,7 %	
Fail/Pass	≤ 25%		Pass	
Calibration: slope through origin			1,077y	
Expanded relative uncertainty	≤ 25%		8,6 %	
Fail/Pass	≤ 25%		Pass	
Calibration equation		0.91y	0,938y	0.938y

Table 3.3. The test results for Grimm 180. At Turku/NaHantali and at HSY/Mäkelänkatu the Grimm 180 is corrected with the calibration function (slope and intercept) and SHARP 5030 at Tornio/Puuluoto is corrected with slope correction according to the DoE in Kuopio.

Verification test PM_{10}	Criteria	Turku/Naantali Grimm 180 (FMI) calib	HSY/Mäkelänkatu Grimm calib	Tornio/Puuluoto SHARP 5030 calib
Concentration range	µg/m³	0 - 50	0 - 100	0 - 15
Raw data				
Slope	significant (Yes/No)	1,037	1,126	1,2350
Intercept	significant (Yes/No)	-0,3	-4,5	0,1248
Expanded relative uncertainty	≤ 25%	9,1 %	16,0 %	47,80 %
Fail/Pass	≤ 25%	Pass	Pass	Fail
Calibrated data				
Calibration: equation		0,964y + 0,248	0,888y + 3,998	0,81y + -0,101
Expanded relative uncertainty	≤ 25%	13,7 %	13,7 %	15,10 %
Fail/Pass	≤ 25%	Pass	Pass	Pass
Calibration: slope through origin		0,982y	1,051y	0,799y
Expanded relative uncertainty	≤ 25%	7,6 %	23,7 %	8,5 %
Fail/Pass	≤ 25%	Pass	Pass	Pass
Calibration equation		0.855y + 2.139	0.855y + 2.139	1,319

Table 3.4. The test results for FH62-IR, Osiris and APM-2 from HSY/Mäkelänkatu. Results of FH62-IR are given both raw, and corrected with the calibration correction used by the network. Osiris and APM-2 results are given without any correction.

Verification test PM_{10}	Criteria	HSY/Mäkelänkatu FH62-IR calib	HSY/Mäkelänkatu FH62-IR raw	HSY/Mäkelänkatu Osiris raw	HSY/Mäkelänkatu APM-2 raw
Concentration range	µg/m³	0 - 100	0 - 100	0 - 100	0 - 100
Raw data					
Slope	significant (Yes/No)	1,2108	0,9299	0,9051	0,5990
Intercept	significant (Yes/No)	-0,6644	0,2121	-3,8164	1,9244
Expanded relative uncertainty	≤ 25%	39,9 %	13,8 %	34,7 %	73,1 %
Fail/Pass	≤ 25%	Fail	Pass	Fail	Fail
Calibrated data					
Calibration: equation		0,826y + 0,549	1,075y + -0,228	1,105y + 4,216	1,669y + -3,213
Expanded relative uncertainty	≤ 25%	4,6 %	4,9 %	6,8 %	15,5 %
Fail/Pass	≤ 25%	Pass	Pass	Pass	Pass
Calibration: slope through origin		0,843y	1,066y	1,31y	1,486y
Expanded relative uncertainty	≤ 25%	5,0 %	4,6 %	6,8 %	15,8 %
Fail/Pass	≤ 25%	Pass	Pass	Pass	Pass
Calibration equation		1.300y - 0.904			

All results for PM_{10} verification from sites in this study and the DoE study in Kuopio are shown in Figures 3.7 to 3.13. In the figures the results are presented without any additional corrections of measured signal except factors installed by the manufacturer. Figure 3.7 shows the raw results of TEOM 1405 with the installed correction by the manufacturer (y = 1.03*original signal + 3 µg/m^3) at sites from Kuopio, Oulu, Etelä-Karjala and from two sites in Helsinki, Mäkelänkatu and Kumpula. In Kumpula the DoE study was conducted in 2007-08. In addition of TEOM 1405, also results of TEOM 1405D are presented in the figure. Those TEOMs which were corrected with the calibration function based on the DoE study, see in Table 2.3, were recalculated as raw results in this figure. The inlet as well as the heating temperature of the sampling tube was the same for all TEOMs. Figure 3.8 shows the raw results of MP-101 at three sites, Turku/Naantali, Vaasa/Centre and Kuopio/Tasavallankatu. The Kuopio/Tasavallankatu site took part in the DoE study in Kuopio as a site analyzer (i.e. candidate method) while the first two sites are included in the verification study. In Figure 3.9 the results of Grimm 180 are presented from DoE in Kuopio, Turku/Naantali and Tampere/Epilä. In this case the Grimm 180 is the same AMS i.e. owned by FMI. In Figure 3.10 the results of FH62-IR are presented from DoE in Kuopio and for HSY/Mäkelänkatu. In Figure 3.11 the results of SHARP 5030 are presented from DoE in Kuopio and for Tornio. In Figure 3.12 the results of Osiris are presented from DoE in Kuopio and in HSY/Mäkelänkatu while in Figure 3.13 the results of APM-2 are presented for HSY/Mäkelänkatu.

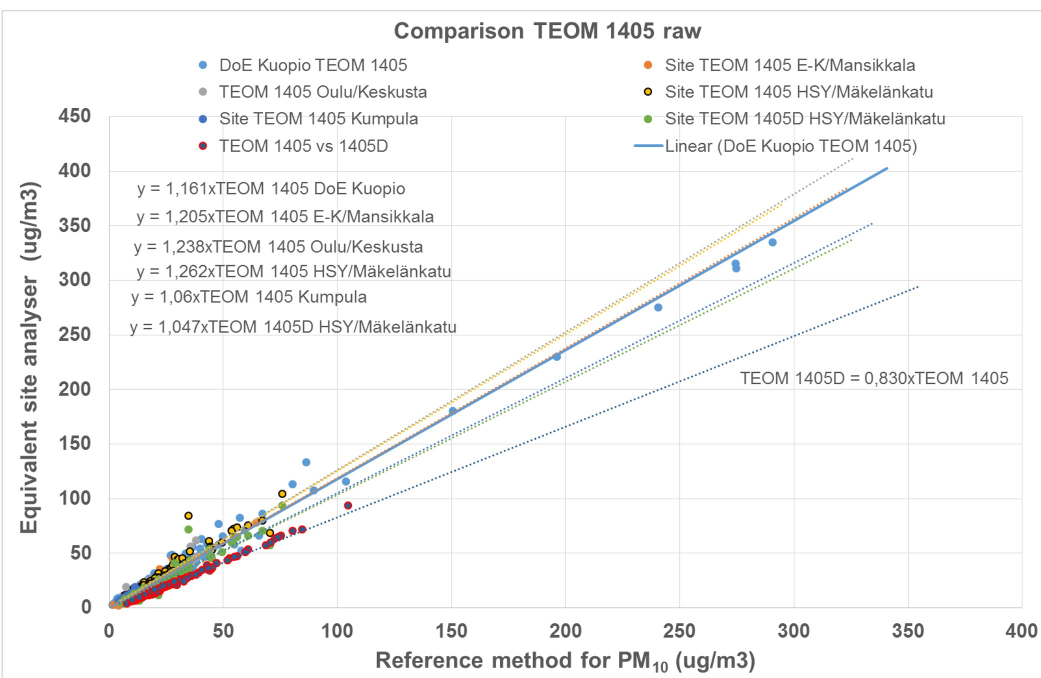

Figure 3.7. Raw results of TEOM 1405 at different sites in verification of PM_{10} against the reference method.

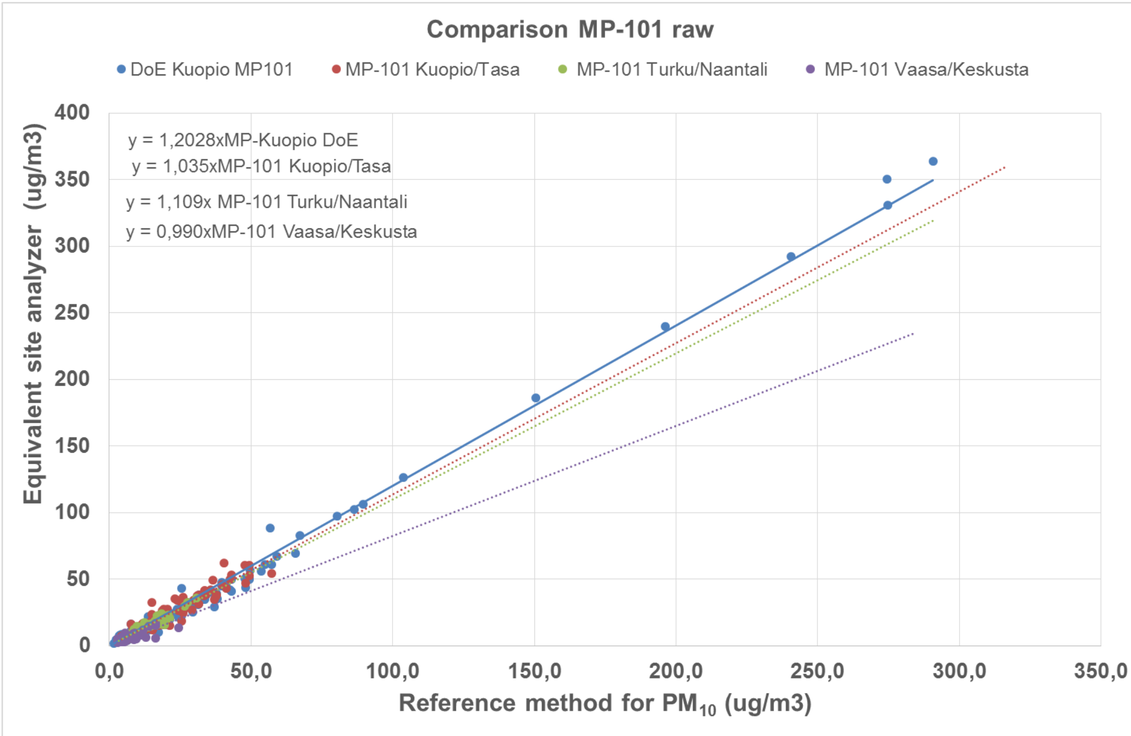

Figure 3.8. Raw results of MP-101 at three sites in verification of PM_{10} against the reference method.

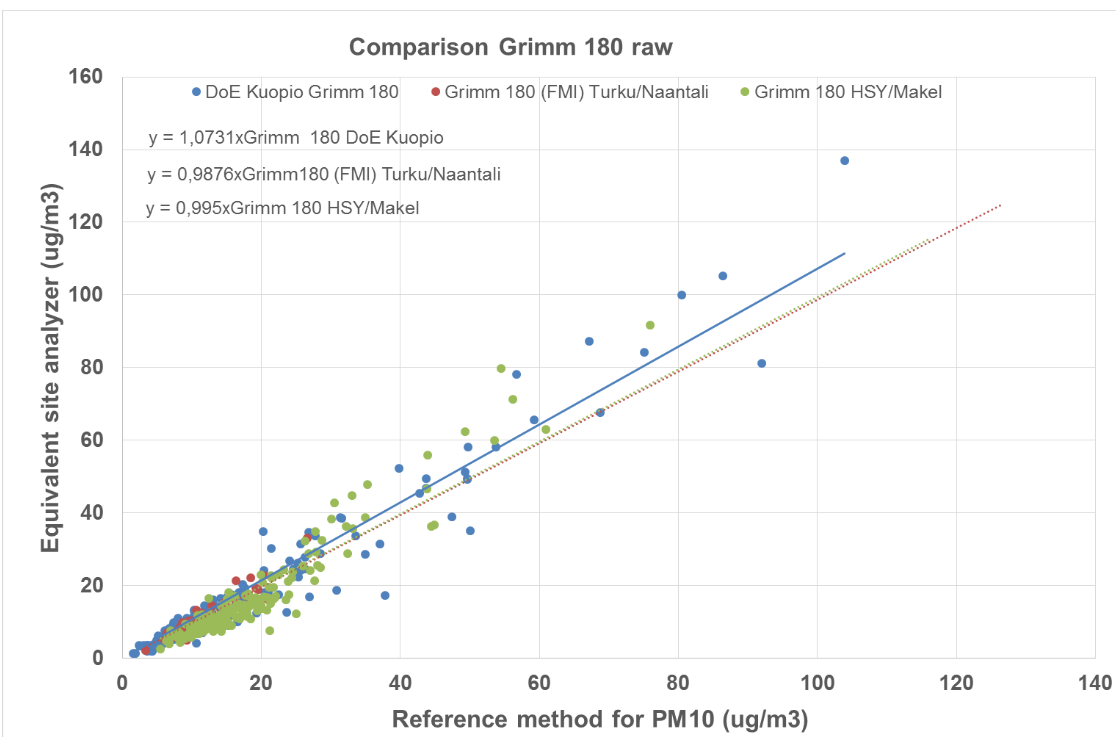

Figure 3.9. Raw results of Grimm 180 at three sites in verification of PM_{10} against the reference method.

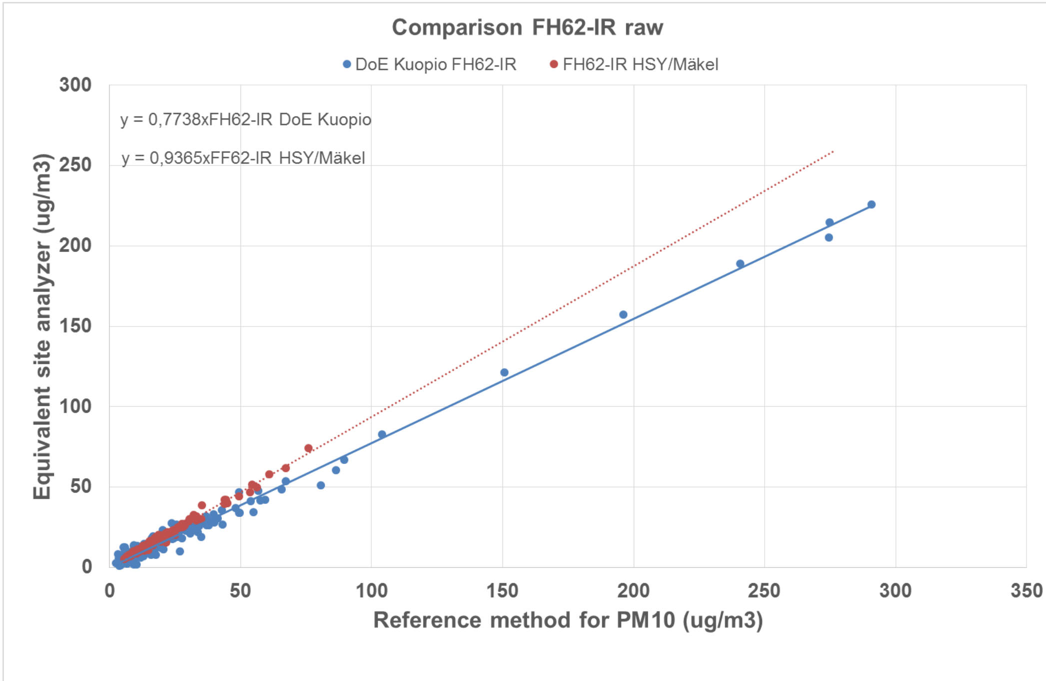

Figure 3.10. Raw results of FH62-IR at DoE in Kuopio and at HSY/Mäkelänkatu verification against the reference method.

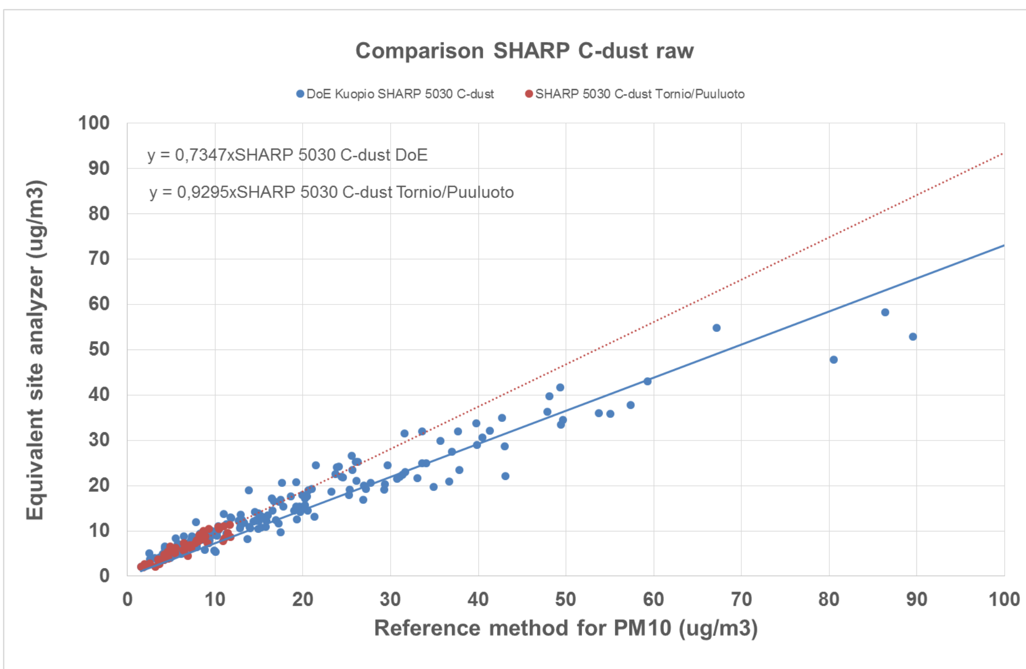

Figure 3.11. Raw results of SHARP C-dust at DoE in Kuopio and at Tornio/Puuluoto verification of PM_{10} against the reference method.

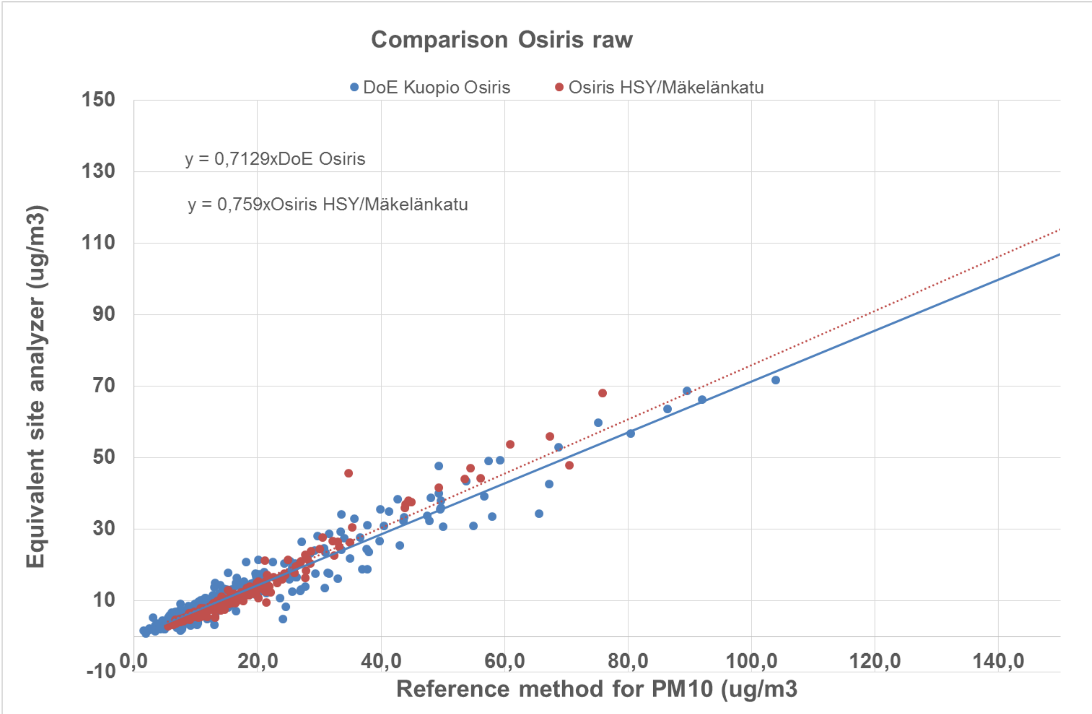

Figure 3.12. Raw results of Osiris at DoE in Kuopio and at HSY/Mäkelänkatu verification of PM_{10} against the reference method.

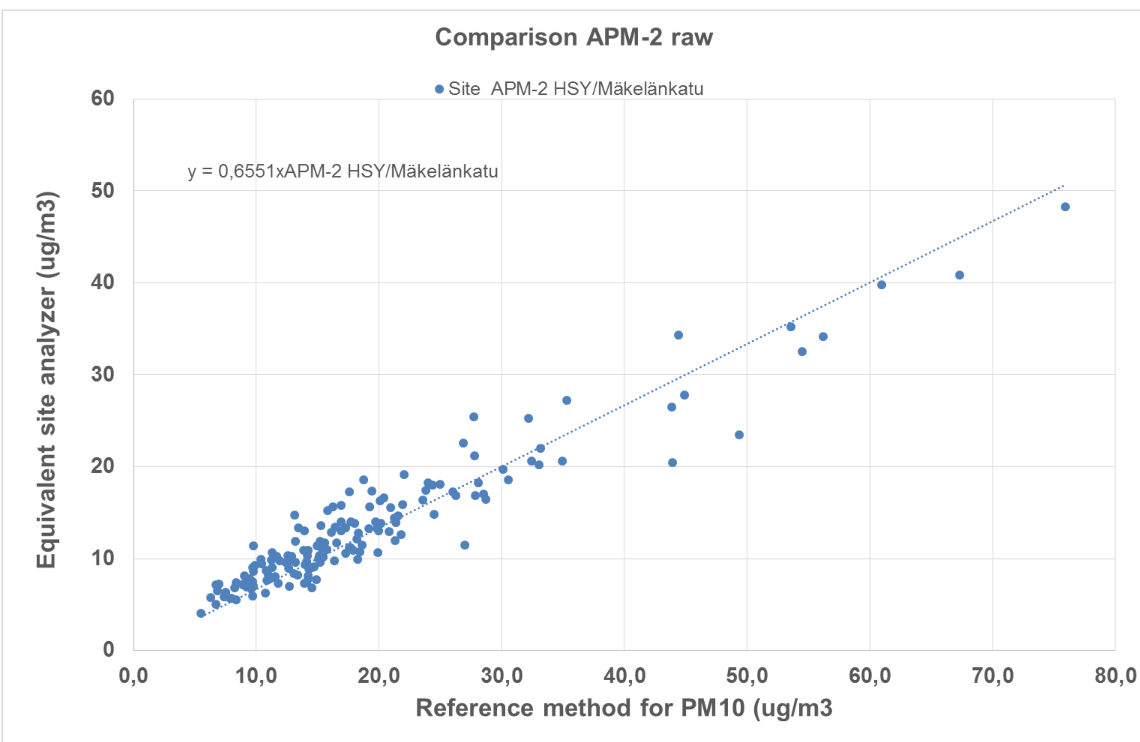

Figure 3.13. Raw results of APM-2 at HSY/Mäkelänkatu verification of PM_{10} against the reference method.

3.3. Time series of individual $PM_{2.5}$ verification test

The duration of the verification test for $PM_{2.5}$ measurements were 8 weeks for all sites i.e. at Tampere/Epilä, at HSY/Mäkelänkatu and at HSY/Kallio, which is the only site according to which the Average Exposure Index (AEI) is determined for the whole Finland. The verification at Virolahti failed because of a sampling error. Due to the error the data covered only 27 days which is less than what is needed for the calculation of the results for one campaign as stated in GDE. Therefore, the results from Virolahti were discarded. The time series of $PM_{2.5}$-verifications are presented as daily averages in Figures 3.14 – 3.16.

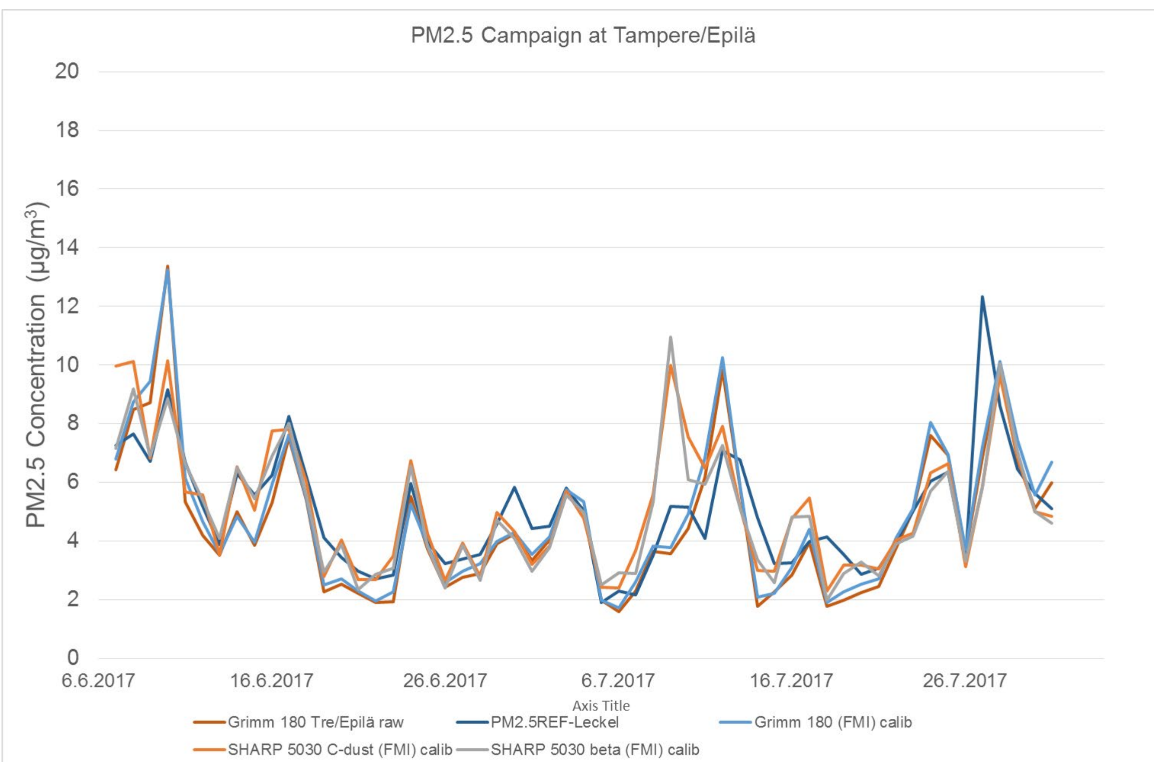

Figure 3.14. Time series of daily average $PM_{2.5}$ mass concentration at Tampere/Epilä.

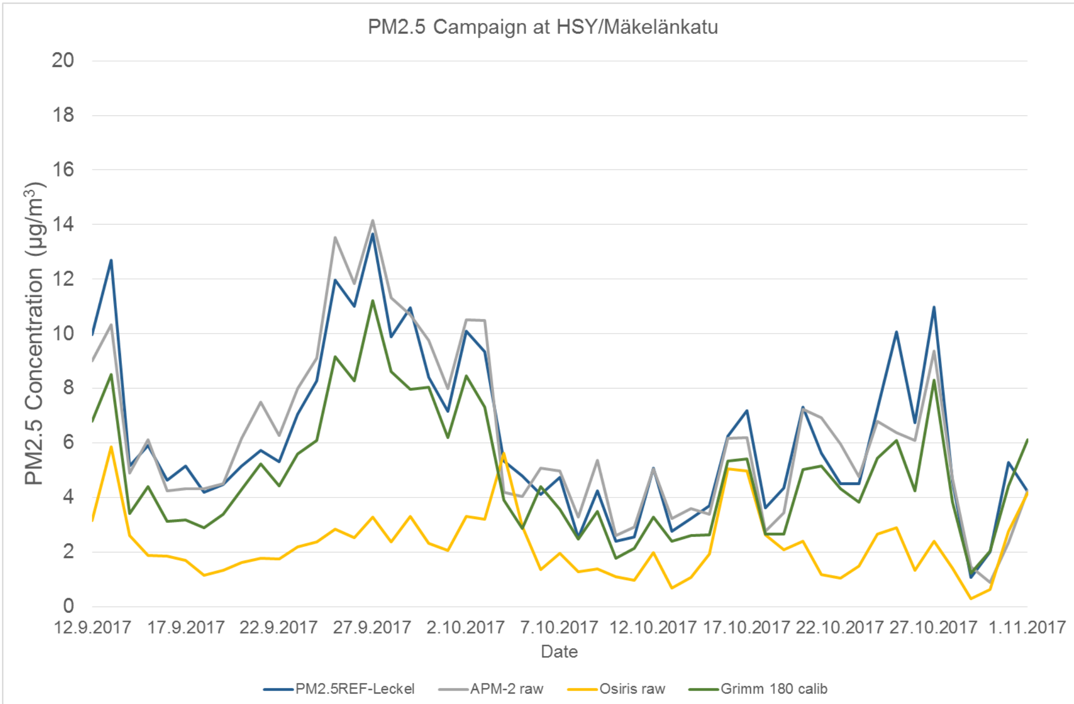

Figure 3.15a. Time series of daily average $PM_{2.5}$ mass concentration at HSY/Mäkelänkatu.

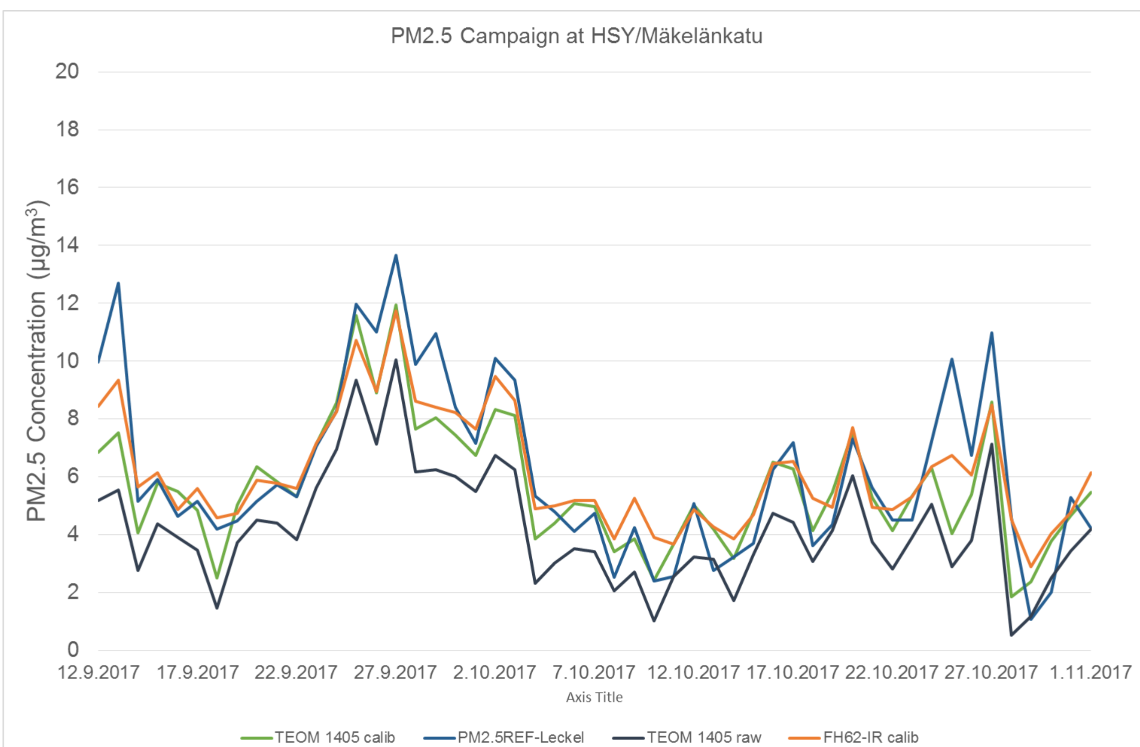

Figure 3.15b. Time series of daily average $PM_{2.5}$ mass concentration at HSY/Mäkelänkatu.

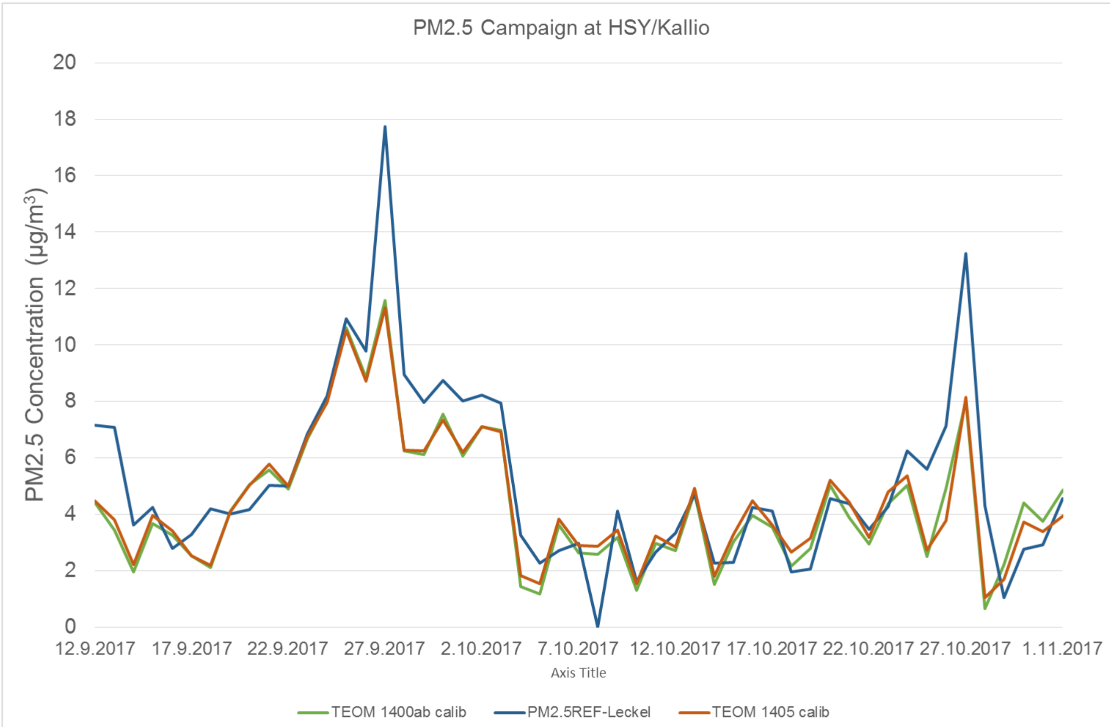

Figure 3.16. Time series of daily average $PM_{2.5}$ mass concentration at HSY/Kallio.

3.4. Verification results for $PM_{2.5}$

The verification data for each paired comparison of AMS against the RM is analyzed with help of the equivalence software as in chapter 3.2. Also in case of $PM_{2.5}$ measurements, the local air quality networks had different practices in applying the calibration factors based on the DoE results in Kuopio as was the case with PM_{10} measurements: at some of the sites, the measurement results were not corrected whereas at some sites the calibration equation was employed (see Table 2.3). Results from all the calculations are shown in Tables 3.5 – 3.8. The reader is referred to chapter 3.2 for clarification in order to be able to analyze the results in the tables. More detailed results and regression figures are presented in Annex 2.

Table 3.5. The test results of TEOM 1405 and TEOM 1405D for PM2.5 at HSY/Mäkelänkatu. The raw signal of TEOM 1405 is corrected by calibration function from DoE in Kuopio while signal from TEOM 1405D is not corrected.

Verification test $PM_{2.5}$	Criteria	HSY/Mäkelänkatu TEOM 1405 calib	HSY/Mäkelänkatu TEOM 1405D
Concentration range	µg/m³	0 - 20	0 - 20
Raw data			
Slope	significant (Yes/No)	0,7265	0,6842
Intercept	significant (Yes/No)	1,35	0,074
Expanded relative uncertainty	≤ 25%	45,80 %	62,80 %
Fail/Pass	≤ 25%	Fail	Fail
Calibrated data			
Calibration: equation		1,376y + -1,86	1,462y + 0,11
Expanded relative uncertainty	≤ 25%	10,80 %	8,30 %
Fail/Pass	≤ 25%	Pass	Pass
Calibration: slope through origin		1,094y	1,44y
Expanded relative uncertainty	≤ 25%	31,0 %	8,4 %
Fail/Pass	≤ 25%	Fail	Pass
Calibration equation		1.009y - 1.681	

Table 3.6. The test results of TEOM 1400ab and TEOM 1405 for PM2.5 at HSY/Kallio. The raw signal of TEOM 1400ab is corrected by calibration function from DoE in Helsinki while TEOM 1405 is corrected from DoE in Kuopio.

Verification test $PM_{2.5}$	Criteria	HSY/Kallio TEOM 1400ab calib	HSY/Kallio TEOM 1405 calib
Concentration range	µg/m³	0 - 20	0 - 20
Raw data			
Slope	significant (Yes/No)	0,7698	0,6887
Intercept	significant (Yes/No)	0,4753	0,9064
Expanded relative uncertainty	≤ 25%	43,4 %	56,50 %
Fail/Pass	≤ 25%	Fail	Fail
Calibrated data			
Calibration: equation		1,299y + -0,618	1,452y+ -1,316
Expanded relative uncertainty	≤ 25%	13,9%	13,60 %
Fail/Pass	≤ 25%	Pass	Pass
Calibration: slope through origin		1,202y	1,209y
Expanded relative uncertainty	≤ 25%	13,2%	21 %
Fail/Pass	≤ 25%	Pass	Pass
Calibration equation		1.25y + 1.56	1.009y - 1.681

Table 3.7. The test results of two Grimm 180 (site and IL/REF) and SHARP 5030 in Tampere/Epilä site. The raw signal of Grimm 180 from the site in Tampere/Epilä is not corrected by calibration function from DoE in Kuopio while signals from the other Grimm 180 (IL/REF) and SHARP 5030 are corrected..

Verification test $PM_{2.5}$	Criteria	Tampere/Epilä Grimm 180 raw	Tampere/Epilä Grimm 180 (FMI)calib	Tampere/Epilä SHARP C-dust (FMI)calib	Tampere/Epilä SHARP beta (FMI)calib
Concentration range	µg/m³	0 - 20	0 - 20	0 - 20	0 - 20
Raw data					
Slope	significant (Yes/No)	1,0599	1,1079	1,0631	0,9554
Intercept	significant (Yes/No)	-0,8701	-0,8674	-0,2702	0,0524
Expanded relative uncertainty	≤ 25%	7,6 %	16,6 %	12,40 %	9,20 %
Fail/Pass	≤ 25%	Pass	Pass	Pass	Pass
Calibrated data					
Calibration: equation		0,943y + 0,821	0,903y + 0,783	0,941y + 0,254	1,047y + -0,055
Expanded relative uncertainty	≤ 25%	14,1%	14,9 %	16,20 %	12,20 %
Fail/Pass	≤ 25%	Pass	Pass	Pass	Pass
Calibration: slope through origin		1,104y	1,048y	0,984y	1,037y
Expanded relative uncertainty	≤ 25%	30,1%	28,3 %	10,7 %	6 %
Fail/Pass	≤ 25%	Fail	Fail	Pass	Pass
Calibration equation			0,78y	0,854y+1,187	0,971y

Table 3.8. The test results for optical methods in HSY/Mäkelänkatu and for beta attenuation method. At Mäkelänkatu Grimm 180 and FH 62-IR are corrected according to DoE from Kuopio while APM-2 and Osiris are not corrected. Additionally the FH62-IR have also analyzed with no correction at the right column.

Verificationtest $PM_{2.5}$	Criteria	HSY/Mäkelänkatu Grimm 180 calib	HSY/Mäkelänkatu APM-2 raw	HSY/Mäkelänkatu Osiris raw	HSY/Mäkelänkatu FH 62-IR calib	HSY/Mäkelänkatu FH 62-IR raw
Concentration range	µg/m³	0 - 20	0 - 20	0 - 20	0 - 20	0 - 20
Raw data						
Slope	significant (Yes/No)	0,7555	1,0945	0,2616	0,6562	0,7760
Intercept	significant (Yes/No)	0,1129	-0,4149	0,6477	2,1370	0,4770
Expanded relative uncertainty	≤ 25%	48,0 %	16,80 %	143,00 %	54,5 %	41,5 %
Fail/Pass	≤ 25%	Fail	Pass	Fail	Fail	Fail
Calibrated data						
Calibration: equation		1,324y + -0,149	0,914y + 0,379	3,822y + -2,476	1,524y + -3,256	1,288y - 0,614
Expanded relative uncertainty	≤ 25%	7,4%	10,50 %	177,70 %	6,7%	7,2%
Fail/Pass	≤ 25%	Pass	Pass	Fail	Pass	Pass
Calibration: slope through origin		1,298y	0,964y	2,867y	1,053y	1,19y
Expanded relative uncertainty	≤ 25%	4,4%	11 %	58 %	46,8%	11,1%
Fail/Pass	≤ 25%	Pass	Pass	Fail	Fail	Pass
Calibration equation		0.747y + 0,532			0.850y + 1.709	

All results for $PM_{2.5}$ verification from sites in this study and the DoE study in Kuopio are shown in Figures 3.17 to 3.21. In the figures the results are presented without any additional corrections of measured signal except factors installed by the manufacturer as was shown in figures 3.7 – 3.13 for PM_{10} verification.

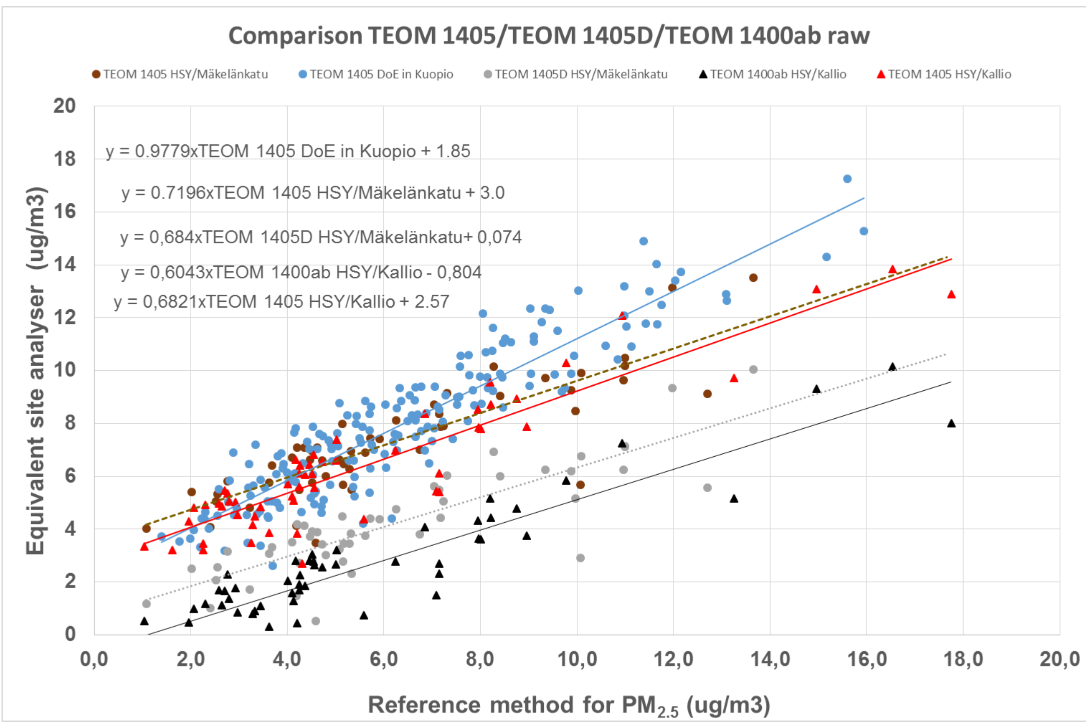

Figure 3.17. Raw results of TEOM 1405, TEOM 1405D and TEOM 1400ab at sites of HSY/Mäkelänkatu and HSY/Kallio in verification of $PM_{2.5}$ against the reference method.

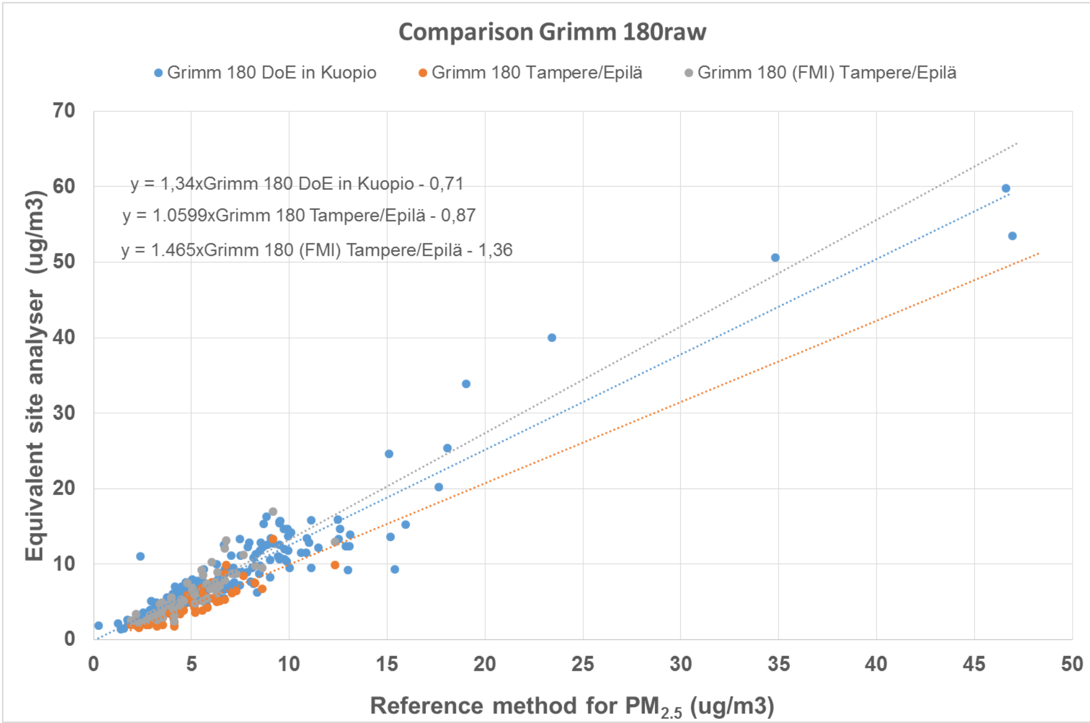

Figure 3.18. Raw results of Grimm 180 at sites of DoE in Kuopio and at Tampere/Epilä in verification of $PM_{2.5}$ against the reference method.

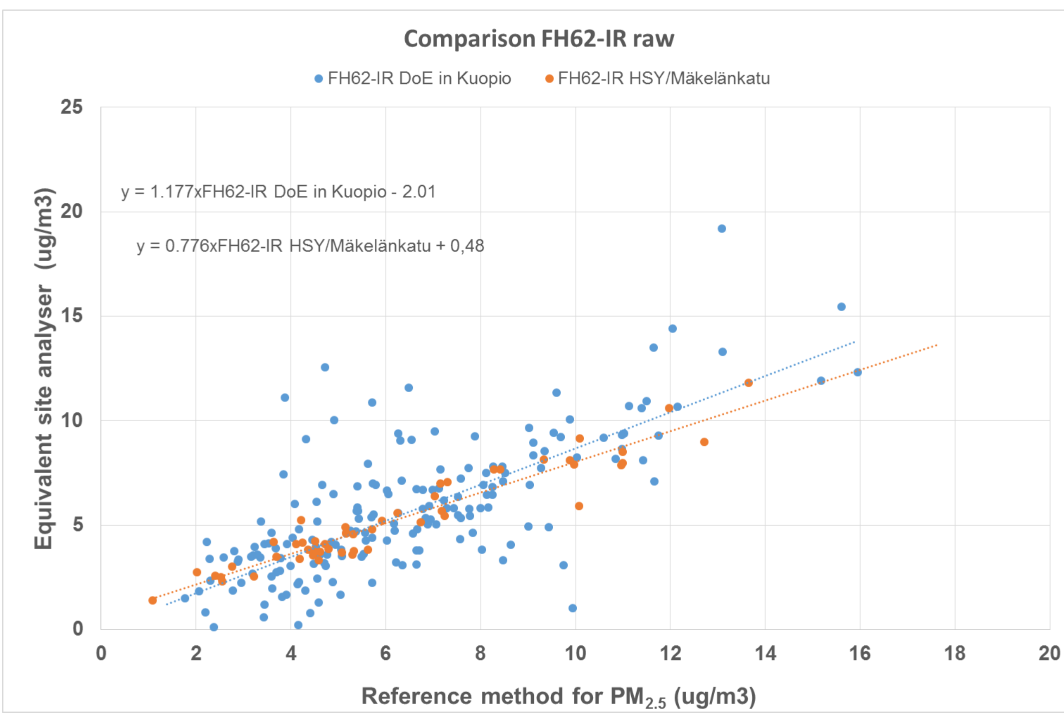

Figure 3.19. Raw results of FH62-IR at sites of DoE in Kuopio and at HSY/Mäkelänkatu in verification of $PM_{2.5}$ against the reference method.

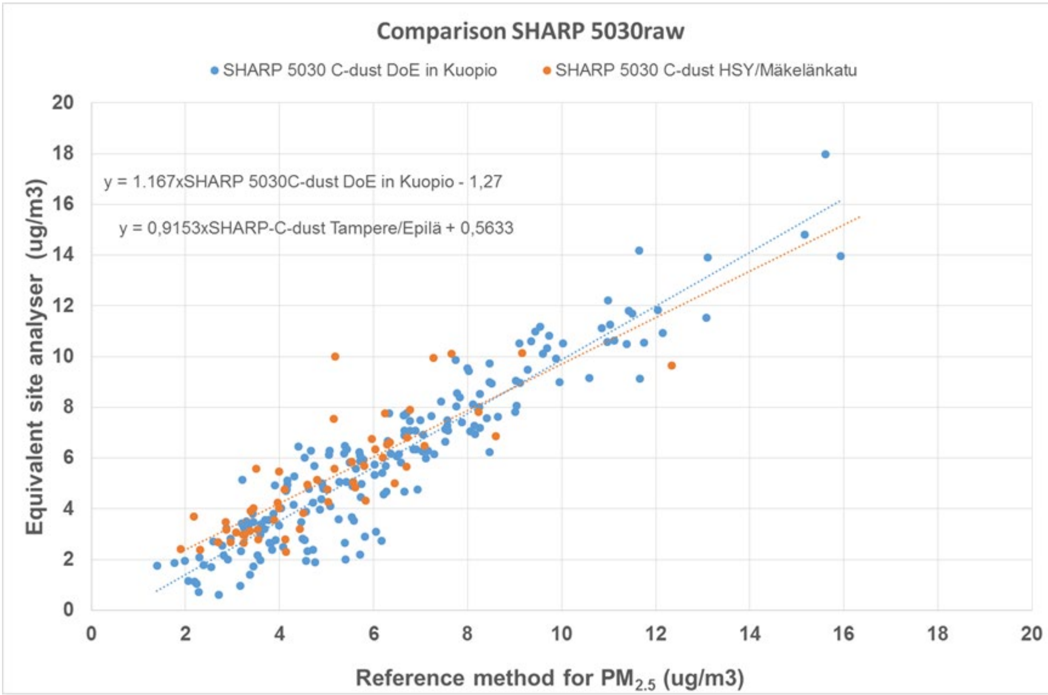

Figure 3.20. Raw results of SHARP 5030 at sites of DoE in Kuopio and at HSY/Mäkelänkatu in verification of $PM_{2.5}$ against the reference method.

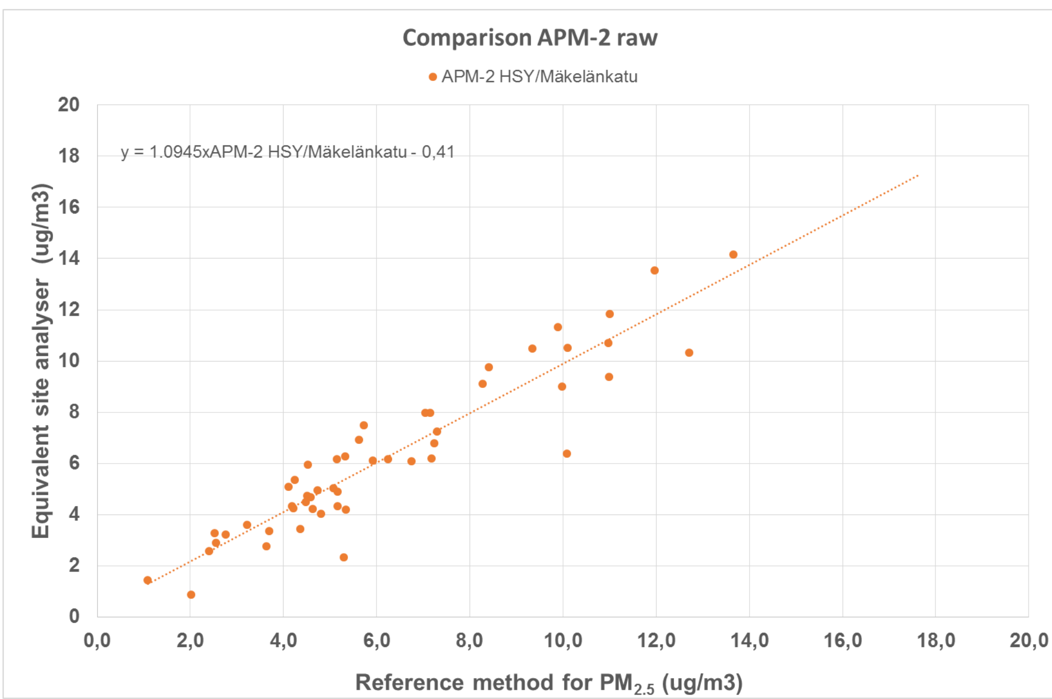

Figure 3.21. Raw results of APM-2 at HSY/Mäkelänkatu in verification of $PM_{2.5}$ against the reference method.

3.5. Recommendation for the common calibration factors for continuous PM-analyzers.

The calibration equations for the continuous PM-analyzers obtained in the DoE in Kuopio are presented in Table 2.4 for PM_{10} measurements and in Table 2.5 for $PM_{2.5}$ measurements. The operators of the air quality networks are free to select any of the calibration equations from those tables to fit best for the purpose: taken into account of seasonal effect, concentration range and location of the measurement station. In addition of the possibility for free of choice it has been proposed by operators of the local air quality to prepare a table for common calibration equations for the automated PM-analyzers. For such purpose table 3.9 present calibration equations taken from Tables 2.4 and 2.5 for PM_{10} and $PM_{2.5}$ measurements.

Table 3.9. Calibration equations for PM_{10} and $PM_{2.5}$ measurements for the automated PM-analyzers.

Equivalent PM-analyzer	PM10	U(%)	PM2.5	U(%)
BAM 1020	0,947	12,6%	1,100y + 0,733	7,4%
GRIMM 180	0,975	13,0%	0,780	12,3%
SHARP 5030 C-dust	1,242	15,2%	0,998	24,9%
SHARP 5030 (beta)	1,278	11,8%	0,971	0,2%
FH 62 IR	1,247	15,2%	0,850y + 1,709	17,3%
TEOM 1405	0,848	14,4%	1,009y - 1,681	8,8 %
MP101M	0,938	8,4%	0,812y - 0,306	8,9%
OSIRIS	1,343	15,4%		

4. Summary and conclusion

Suitability tests that demonstrate whether the concentration ranges and the type of dust particles reveal the situation where the equivalence tests of AMS has been demonstrated are defined in the EN 16450 as QA/QC procedures. Though the verification tests that were conducted in this study do not follow accurately the procedure for the sampling period, described in the EN-standard, the results give an overall view where the tested AMS perform similarly or differently in various parts of Finland. The Grimm 180, based on optical method, showed different respond against the reference method at different location. The MP-101, based on beta attenuation method, and TEOM 1405, based on oscillation micro balance method, performed similarly across Finland. In case where comparison was made only at one site, e.g. FH62-IR, SHARP 5030 and Osiris, the results were only compared with the results from DoE in Kuopio. Of these AMS, the largest discrepancy between the site AMS and the DoE in Kuopio was observed with FH62-IR and SHARP 5030. The durations of the campaigns in this suitability study were mostly 8 weeks with two exceptions; one at HSY/Mäkelänkatu where PM_{10} comparison took 169 days and one in Tornio where the comparison took place every third day lasting six months (44 successful samples).

TEOM 1400/1405

This AMS is the most common instrument for continuous PM measurements at local air quality networks in Finland. Results in case of PM10 verifications at Etelä-Karjala/Mansikkala, Oulu/Keskusta and Helsinki/Mäkelänkatu with TEOM 1405 raw values (in Mäkelänkatu the corrected results have been recalculated as original setting by the factory) show very good agreement between each other (Table 3.1 and Figure 3.7). When combining verification results for TEOM 1405 raw results (without correction) from this study, the latest DoE study in Kuopio (2014-2015) and the previous DoE study in Helsinki (2007-2008), all the results can be corrected with the calibration equation (Figure A7a). This agrees reasonably well with the calibration equation for TEOM 1405 at DoE comparison in Kuopio (Table 2.3). When comparing the TEOM 1405 and TEOM 1405D (Table 3.1, Figure 3.7 and Figure A4g) there is a clear difference between the different models of TEOM. The scatter of results is small, which indicates clear bias between these two different models of TEOM rather than random deviation. The reason for the systematic difference was not able to solve in this study.

The verification tests of $PM_{2.5}$ (Table 3.5) were conducted in Helsinki at two different type of site: HSY/Mäkelänkatu and HSY/Kallio. The former is a clear traffic site whereas the latter is an urban background site. HSY/Kallio is also the site where the average exposure index (AEI) for $PM_{2.5}$ in Finland is calculated. The network chose to use the calibration equation to correct the results for TEOM 1405 from the DoE in Kuopio whereas the results from TEOM 1400ab were corrected based on the DoE in Helsinki (Walden et al. 2010). As can be seen, the $PM_{2.5}$ results for TEOM 1400ab are about 10 % higher than for TEOM 1405 (Figure A10c). There is also a clear difference between the results at HSY/Kallio and at HSY/Mäkelänkatu for TEOM 1405 (Table 3.5) which may be because of different PM sources affecting the measurements.

MP101

This AMS worked very well at DoE in Kuopio and also at the site in Kuopio/Tasavallankatu. In this study, the PM_{10} concentrations at Turku/Naantali and at Vaasa/Centre were very low throughout the verification test, showing slightly more scattering of results between the sites in Turku/Naantali and Vaasa/Keskusta than in Kuopio. The overall agreement between the sites in this verification fits well with the PM10 results for MP101 achieved in DoE comparison at Kuopio (Figure 3.8 and Figure A7b). There was no verification test with MP101 for $PM_{2.5}$ measurements.

Grimm 180

The AMS was tested for verification for PM_{10} and $PM_{2.5}$ measurements. For PM_{10} tests were conducted at one site in HSY/Mäkelänkatu and at Turku/Naantali where the instrument was not a site instrument but was provided by FMI. In case of $PM_{2.5}$ measurements tests were conducted at Tampere/Epilä and at HSY/Mäkelänkatu. Grimm 180 is based on the optical method, i.e. reflection of laser light from the surface of the particle. The reflection angles depend on the size of the particles and the mass of particle is calculated based on the volume and the density of particle, which is fixed through the calibration process. The mass concentration of particles detected by Grimm 180 is therefore influenced by the particle density that is linked to the source of the particles (long range transboundary, combustion process, resuspension e.g. from the road), but it also depends on the reflection properties of the laser light from the particle surface (reflection index), which depends on the environmental conditions i.e. moisture. The sampling tube of the instrument is equipped with Perma Pure Drier that turns on automatically when the relative humidity exceeds 50% but it causes some particle loss. Comparing the results in Figure 3.9, the verification results from Turku/Naantali and HSY/Mäkelänkatu coincide very well, but the scatter of results especially at HSY/Mäkelänkatu is rather large. At high concentration the results of Grimm 180 seem to be systematically overestimated, which may be because of different source of particles than at low concentration. The overall agreement with the results at the verification results and DoE in Kuopio is reasonably good (Table 2.3 and Figure A7c).

Verification test of Grimm 180 for $PM_{2.5}$ measurements was conducted at Tampere/Epilä and at HSY/Mäkelänkatu. At Tampere/Epilä, two different Grimm 180 took part, and the results of the site Grimm 180 were not corrected but the results of the Grimm 180 of the FMI were corrected. However, the slopes between the two Grimm 180 instruments against the reference method (Table 3.6) differ only 4% even though the correction factor for the results of FMI was 0.78. The reason for this can be the lowered measurement capability of the site instrument due to lack of calibration of the aerosol channel. Respond of the Grimm 180 for particle concentration at HSY/Mäkelänkatu show considerable underestimation against the results obtained with the reference method in Helsinki. The similar behavior is not met from both of the Grimm instruments in Tampere/Epilä. The respond of the Grimm for particle concentration is source dependent and is essential that Grimm 180 is calibrated with known size and density of particles at regular time intervals.

FH62-IR

FH62-IR was used at HSY/Mäkelänkatu for PM_{10} and $PM_{2.5}$ measurements. Difference between the results in DoE in Kuopio and at verification at HSY/Mäkelänkatu is considerable as shown in Figure 3.10 and in Table 3.4 and 3.7. Both instruments have been checked by regular intervals with the calibration foils provided by the manufacturer accordingly. There may be other technical reasons, e.g. sample flow rate, and aging of the beta source in FH62-IR. At DoE in Kuopio the age of the beta-source was 7 years whereas at HSY/Mäkelänkatu the beta-source of FH62-IR was considerably younger. The beta source in FH62-IR is Kr-85 with the half-life of 10.8 years. This means that the activity of the beta-source was decreased about one third from the original intensity with the older FH62-IR. However, the regular use of calibration foils should compensate the effect of decreasing beta-source but may cause increased deviation of the results. Applying the calibration factors from DoE in Kuopio at the verification study at HSY/Mäkelänkatu the respond is underestimated by almost 20% for PM_{10} (Table 3.4) whereas overestimated by 35% for $PM_{2.5}$ (Table 3.7). It is evident that for FH62-IR at HSY/Mäkelänkatu good agreement with the concentration values obtained with the reference method is achieved by correcting the raw data for PM_{10} measurements with the slope correction of 1.075 (Table 3.4) and $PM_{2.5}$ measurements with the slope correction of 1.19 (Table 3.7).

SHARP 5030

This instrument was used for PM10 measurements at Tornio/Puuluoto, which is not a fixed air quality site but was used for a campaign study. The sampling strategy differed from other campaigns; in this case the reference sampler operated every third day during a period of six months yielding 43 daily samples in total. The concentration range was very low compared to the range that was at the DoE in Kuopio (Figure 3.11). In this study only C-dust signal is used for the analysis of the results. The difference between the slopes in Tornio and at DoE in Kuopio is 20% for C-dust signal i.e. the signal from nephelometer is corrected with the beta-signal. From table 3.3 the discrepancy between the results obtained at DoE in Kuopio and at verification study at Tornio is considerably large. The instrument failed with the corrected results, but passed the test with small uncertainty with a new correction only for the slope. In case of PM2.5 verification at Tampere/Epilä (Table 3.6) SHARP 5030 achieved acceptable results as shown in table 3.6 both for C-dust and beta-signal.

Osiris

The instrument passed the DoE study in Kuopio for PM_{10} and achieved consistent results at HSY/Mäkelänkatu during the verification study with the DoE results (Figure 3.12 and Table 3.4). In case for $PM_{2.5}$ Osiris fail to meet the criteria in DoE in Kuopio and likewise it failed during this verification study.

APM-2

This instrument was not at the DoE in Kuopio and therefore calibration equation for DoE has not been used by the network (HSY). The verification results both for PM_{10} and $PM_{2.5}$ suggest a correction for the slope with an uncertainty that fulfills the uncertainty requirement (table 3.4 and 3.7). The verification study does not fulfill the requirements which are needed for complete DoE study. Therefore, the comparison with the test results obtained by TÜV was used as a supporting document (TÜV, 2014a). The calibration factor achieved for PM_{10} verification test is almost 50 % higher that the one reported by TÜV, see in chapter 2.7. For PM2.5 the verification results obtained in Helsinki/Mäkelänkatu is inside the variation of the results achieved from individual campaigns conducted by TÜV.

The results from the verification study conducted in various parts of Finland as intensive campaigns showed clearly that the calibration equations obtained from the DoE study in Kuopio can be used in other parts of Finland. The calibration equation can be a form like $X_{REF} = by + a$ or $X_{REF} = by$, where y is the signal from AMS in question and a and b are the intercept and slope. This applies when the AMS model is the same as in DoE study in Kuopio. This is clearly true in the case of tapered element oscillating microbalance method (TEOM 1400 a/b and 1405) and beta attenuation method (MP 101). The optical method is sensitive for the characteristics of the particle i.e. size, shape and density of particle. Also the environmental conditions e.g. moisture can change the refraction index of the particle and affects the detection of particle. Acceptable agreement was achieved between the verification results and the DoE results in Kuopio for Grimm 180. Osiris agreed well with the measurements of PM_{10} but not of $PM_{2.5}$. APM-2 agreed well with PM2.5 measurements with the results obtained from the DoE results reported by TÜV. In case of PM_{10} the verification results obtained for APM-2 showed almost 50% discrepancy between the results of individual campaigns with the DoE study obtained by TÜV. As a conclusion, the results reported by TÜV for $PM_{2.5}$ measurements are applicable in Finland but for PM_{10} measurements, the calibration factor obtained in this study shall be used. The SHARP 5030 was included at one site for

PM_{10} and at one site for $PM_{2.5}$. For $PM_{2.5}$, the calibration equations obtained at DoE in Kuopio are applicable, but in case of PM_{10} the results obtained in this study are more questionable because of the low concentration range. The conclusion in case of SHARP 5030 is, however, that the calibration equations achieved at DoE in Kuopio shall be used. The FH62-IR took part only in HSY/Mäkelänkatu where the results showed that the better agreement with the reference method is achieved by using the calibration factors obtained in this verification study for PM_{10} and for $PM_{2.5}$ than applying the calibration factors from the DoE in Kuopio. Even though the campaign was rather long (157 days) there is no general proof that the situation will hold at any other location in Finland. Therefore, the calibration factors obtained for FH62-IR in DoE in Kuopio are valid elsewhere in Finland. In case of TEOM 1405 and TEOM 1405D, there is a consistent difference between the results of both instruments obtained in the verification study. The observed difference does not allow the use of the calibration factors obtained for TEOM 1405 at the DoE in Kuopio to TEOM 1405D. Since the instrument has not been tested elsewhere e.g. by TÜV, there is no proof of equivalency for the instrument. The calibration equations obtained in DoE in Kuopio and presented in Tables 2.4 and 2.5 are applicable in different parts in Finland. The operators of the air quality networks are free to select any of the calibration factors to fit best for the purpose. However, to increase to homogeneity for the use of common calibration factors, results in Table 3.9 should be used.

Even though the requirements for the on-going verification tests according to EN 16450 and GDE are not mandatory according to EU directives, correct functioning of the AMS with respect to the reference method should be demonstrated at regular time basis. The verification study showed that in general the agreement between the site AMS and the DoE results in Kuopio agree reasonable well, and e.g. the seasonality had a large effect on some of the AMS at DoE in Kuopio which was not considered here. Test program for verifying the calibration factors of the AMS at their location including the seasonal behavior, should be planned and organized in the near future.

Yhteenveto ja johtopäätökset

Automaattisen hiukkasmittalaitteen vastaavuus eli ekvivalenttisuus vertailumenetelmään on osoitettava GDE-ohjeen mukaisilla vertailumittauksilla eli ekvivalenttisuustesteillä. Standardi EN 16450 edellyttää lisäksi vertailumittauksia eli soveltuvuustestejä, joilla voidaan osoittaa, että ekvivalenttisuustesteissä hyväksytty laite soveltuu käytettäväksi myös suunnitellussa mittausympäristössä Vaikka tässä tutkimuksessa tehty mittausohjelma ei täysin täytä standardin vaatimuksia, voidaan tulosten perusteella osoittaa, että tietyt laitteet toimivat samankaltaisesti ja toiset poikkeavasti eri puolella Suomea. Esimerkiksi optiseen menetelmään perustuvan laitteen, Grimm 180, tulokset vaihtelivat vertailumenetelmän tuloksia vastaan eri mittausympäristöissä, kun taas beta-säteilyn vaimenemiseen perustuvan MP-101:n tai värähtelevään mikrovaakaan perustuvan TEOM 1405:n tuloksissa ei paikkariippuvuutta havaittu. Niille laitteille, joita testattiin vain yhdellä asemalla, kuten FH62-IR, SHARP 5030 ja Osiris, saatujen soveltuvuustestien tulosten vertailu suoritettiin Kuopion tuloksiin. Soveltuvuustestien mittausten kesto oli yleensä kahdeksan viikkoa. Poikkeuksena tästä oli HSY/Mäkelänkadun PM_{10}-mittaus, joka kesti 169 vuorokautta, ja Tornion mittaus, joka kesti kuusi kuukautta, mutta näytteenkeräys suoritettiin vain joka kolmas päivä (yhteensä 44 näytettä).

TEOM 1400/1405

Tämä laite on yleisimmin Suomen ilmanlaadun mittausverkoissa käytetty jatkuvatoiminen hiukkasmittalaite. Etelä-Karjala/Mansikkalan, Oulu/Keskustan ja Helsinki/Mäkelänkadun asemilla PM10-vertailuissa TEOM 1405:n korjaamattomat tulokset ovat hyvin yhteneviä vertailumenetelmää vastaan (taulukko 3.1 ja kuva 3.7). Kun verrataan TEOM 1405:n korjaamattomia tuloksia tämän tutkimuksen sekä aikaisempien vastaavuuden osoittamiseen tehtyjen tutkimusten kesken (Kuopio 2014-2015 ja Helsinki 2007-2008), voidaan kaikki alkuperäiset tulokset korjata samalla kertoimella vertailumenetelmää vastaaviksi (kuva A7a). Tämä kerroin vastaa hyvin Kuopion vertailumittauksissa saatuja kalibrointikertoimia (taulukko 2.3). Verrattaessa TEOM 1405:n ja TEOM 1405D:n tuloksia keskenään (taulukko 3.1, kuva 3.7 ja kuva A4g) havaitaan systemaattinen ero tulosten välillä. Lisäksi molemmilla laitteilla tulosten sisäinen hajonta oli pientä. Näin ollen on ilmeistä, että laitemallien välillä on jokin systemaattinen ero, mitä tässä tutkimuksessa ei voitu selvittää.

TEOM-laitteiden soveltuvuustestit $PM_{2.5}$-mittauksissa (taulukko 3.5) toteutettiin kahdella eri asemalla Helsingissä, HSY/Mäkelänkadun ja HSY/Kallion asemilla. Ensin mainittu on puhtaasti liikenneasema, kun taas jälkimmäinen on kaupunkitausta-asema, jonka tulosten perusteella lasketaan myös keskimääräinen altistumisindikaattori. HSY korjaa $PM_{2.5}$-mittauksissa TEOM 1405:n tulokset käyttäen Kuopion korjauskertoimia, kun taas $PM_{2.5}$-mittausten rinnakkaislaitteen, TEOM 1400ab:n tulokset korjataan aiempien Helsingin vertailumittausten (Walden et al., 2010) perusteella. Lopputuloksena on, että korjauksen jälkeen TEOM 1400ab:n tulokset ovat 10 % korkeammat kuin TEOM 1405:n (kuva A10c). TEOM 1405:n tuloksissa on HSY/Kallion ja HSY/Mäkelänkadun asemilla poikkeavuutta vertailumenetelmää vastaan, mikä voi johtua hiukkasten erilaisista lähteistä.

MP101

MP-101 pärjäsi hyvin Kuopion vertailumittauksissa, kuten myös Kuopion oma MP-101 hiukkasanalysaattori Tasavallankadulla. Turku/Naantalin ja Vaasa/Keskustan asemien soveltuvuustesteissä PM_{10}-pitoisuustasot olivat hyvin alhaiset koko mittausjakson ajan, minkä seurauksena myös tulosten hajonta vertailumenetelmää vastaan oli suurempi näillä asemilla kuin Kuopion vertailutuloksissa. MP-101:n tulokset eri asemilla sopivat hyvin Kuopion vertailumittauksissa saatuihin tuloksiin (kuva 3.8 ja kuva A7b) PM_{10}-mittauksissa. MP-101 ei ollut mukana tässä $PM_{2.5}$-soveltuvuustestissä.

Grimm 180

Grimm 180 oli mukana sekä PM_{10}- että $PM_{2.5}$-soveltuvuustesteissä. PM_{10}-soveltuvuustestit toteutettiin kahdella eri asemalla, HSY/Mäkelänkadun ja Turku/Naantalin asemilla. Jälkimmäisessä tapauksessa oli käytössä Ilmatieteen laitoksen laite. $PM_{2.5}$-soveltuvuustestit toteutettiin Tampere/Epilän ja HSY/Mäkelänkadun asemilla. Grimm 180:n mittausmenetelmä perustuu optiseen menetelmään, ts.

laservalon taittumiseen hiukkasen pinnasta. Valon taittumiskulma riippuu hiukkasen koosta, ja hiukkasen massa voidaan laskea hiukkasen koon ja tiheyden avulla. Grimm 180:n määrittämä hiukkasten massapitoisuus riippuu hiukkasten tiheydestä, mikä riippuu edelleen hiukkasten lähteistä (polttoprosessi, resuspensio esimerkiksi tiestä, kaukokulkeuma). Valon taitekertoimen muuttuminen hiukkasten pinnalla esimerkiksi ilman kosteuden vaikutuksesta, muuttaa valon sirontaominaisuuksia. Tämän kompensoimiseksi laitteen keräysputki on varustettu Perma Pure -kuivaimella, joka käynnistyy automaattisesti, kun ilman suhteellinen kosteus ylittää 50 %. Toisaalta näytelinjan kuivaus aiheuttaa jossain määrin hiukkashävikkiä. Verrattaessa Turku/Naantalin ja HSY/Mäkelänkadun tuloksia on yhteensopivuus hyvä (kuva 3.9), mutta tulosten hajonta vertailumenetelmää vastaan on erityisesti HSY/Hämeenkadun mittauksissa melko suuri. Suurilla hiukkaspitoisuuksilla Grimm 180 näyttäisi yliarvioivan pitoisuutta verrattuna vertailumenetelmään, mikä voisi johtua mikä voisi johtua siitä, että hiukkaslähteet ovat erilaiset korkeissa ja alhaisissa pitoisuuksissa. Lopputuloksena voidaan kuitenkin todeta, että soveltuvuustestien tulokset sopivat hyvin yhteen Kuopion vertailumittaustulosten kanssa (taulukko 2.3 ja kuva A7c).

Grimm 180:n soveltuvuustesteissä Tampere/Epilän asemalla oli testattavana kaksi Grimm 180 -laitetta. Näistä toinen oli mittausaseman laite, jonka tuloksia ei oltu korjattu. Toinen laitteista oli Ilmatieteen laitoksen laite, jonka tulokset korjattiin Kuopion vertailumittausten tulosten perusteella. Vaikka Ilmatieteen laitoksen Grimm 180 tulokset korjattiin Kuopion mittausten perusteella (kulmakerroinkorjaus 0.78), erosivat molemmat laitteet vertailumenetelmästä vain 4 % (taulukko 3.6). Yksi mahdollinen selitys tässä havaittuun yllättävän pieneen eroon voisi olla mittausaseman laitteen heikentynyt toiminta, sillä sen optisen penkin kalibrointia ei ollut tehty valmistajalla. Ilmatieteen laitoksen laitteen optinen penkki oli kalibroitu laitevalmistajalla viimeksi Kuopion vertailumittausten yhteydessä. HSY/Mäkelänkadulla Grimm 180:n tulokset poikkeavat selvästi molempien Tampereen Grimm 180 -laitteiden tuloksista suhteessa vertailumenetelmään. On erityisen tärkeää, että jatkuvatoimisen hiukkasmittalaitteen tekninen toiminta on kunnossa, mikä voidaan varmistaa esimerkiksi kalibroimalla optinen penkki tunnetulla hiukkaskoolla ja hiukkastiheydellä säännöllisin aikavälein.

FH62-IR

FH62-IR oli mukana HSY/Mäkelänkadulla sekä PM_{10}- että $PM_{2.5}$-soveltuvuustesteissä. Verrattaessa FH62-IR:n HSY/Mäkelänkadun PM_{10}- ja $PM_{2.5}$-soveltuvuustestien tuloksia Kuopion vertailumittauksen tuloksiin, poikkeavat ne merkittävästi toisistaan (Kuva 3.10 ja taulukot 3.4 ja 3.7). Selvää syytä tähän poikkeamaan ei löydetty. Molemmissa mittauksissa laitteen toiminta tarkistettiin asianmukaisesti ja säännöllisin välein käyttäen laitevalmistajan toimittamia kalibrointiliuskoja. Mahdollisia teknisiä syitä poikkeamiin ovat esimerkiksi näytevirtaus ja radioaktiivisen lähteen ikä. Kuopion mittauksissa lähteen ikä oli 7 vuotta, mutta HSY/Mäkelänkadulla selvästi nuorempi. Molemmissa laitteissa oli samanlainen radioaktiivinen lähde, Kr-85, jonka puoliintumisaika on 10.8 vuotta. Kalibrointiliuskojen käyttö korjaa vaimentuneen lähteen vaikutuksen, mutta voi toisaalta aiheuttaa suurempaa hajontaa tuloksissa. Korjattaessa HSY/Mäkelänkadun mittausten FH62-IR:n tulokset Kuopion vertailutulosten kalibrointikertoimilla aliarvioi tehty korjaus pitoisuustasoja 20 %:lla PM_{10}-mittauksissa (taulukko 3.4) ja yliarvioi $PM_{2.5}$-mittaustuloksia 35 %:lla (taulukko 3.7). Näiden tulosten perusteella HSY/Mäkelänkadulla saavutetaan parempi yhteensopivuus vertailumenetelmää vastaan korjaamalla raakatulokset PM_{10}-mittauksissa kulmakertoimella 1.075 (taulukko 3.4) ja PM2.5-mittauksissa kulmakertoimella 1.19 (taulukko 3.7).

SHARP 5030

Tämä laite oli tässä soveltuvuustestissä mukana PM_{10}-mittauksissa vain Tornio/Puuluodon asemalla, sekä $PM_{2.5}$-mittauksissa HSY/Mäkelänkadun asemalla. Tornio/Puuluoto ei ole kiinteä ilmanlaadun mittausasema. Näytteenkeruu tapahtui joka kolmas päivä kuuden kuukauden aikana, jolloin näytteitä kertyi yhteensä 43 vuorokausinäytettä. Pitoisuustasot Torniossa olivat hyvin alhaiset verrattuna Kuopion vertailumittauksen pitoisuustasoihin (kuva 3.11). SHARP 5030:n tuottamasta datasta analysoitiin tässä tutkimuksessa C-dust -signaali, joka sisältää optisen signaalin (nefelometri) korjattuna beta-menetelmän signaalilla. Taulukon 3.3 tuloksista havaitaan, että poikkeama vertailumenetelmän tuloksiin on 20 %, kun SHARP 5030:n tulokset on korjattu Kuopion vertailun tuloksilla (taulukko 3.3). Torniossa käytetty SHARP 5030 ei läpäissyt vertailua Kuopiossa määritetyillä kalibrointikertoimilla, mutta pelkästään kulmakerrointa käyttämällä saatiin hyväksyttävä korjauskerroin pienellä epävarmuudella. SHARP 5030 oli mukana vertailussa myös Tampereella $PM_{2.5}$-mittauksissa, joissa tulokset olivat hyväksyttävät Kuopion kertoimilla sekä C-dust:n signaalilla että beta-signaalilla (taulukko 3.6).

Osiris

Tämä laite läpäisi Kuopion vertailumittaukset PM_{10}-mittauksissa ja saavutti samankaltaisen yhteensopivuuden tässä soveltuvuustestissä HSY/Mäkelänkadun asemalla, joskin pienemmällä korjauskertoimella (kuva 3.12 ja taulukko 3.4). $PM_{2.5}$-vertailussa HSY/Mäkelänkadulla Osiris ei läpäissyt testiä (taulukko 3.7), kuten ei myöskään Kuopiossa.

APM-2

Tämä laite ei ollut mukana Kuopion vertailumittauksessa ja sen vuoksi laitteelle ei ole kalibrointiyhtälöä laadittu. Soveltuvuustestit tehtiin PM_{10}-ja $PM_{2.5}$-mittauksille HSY/Mäkelänkadun asemalla. Tulosten analyysin perusteella saadut korjauskertoimet PM_{10}- ja $PM_{2.5}$-mittauksille läpäisevät epävarmuuskriteerin (taulukot 3.4 ja 3.7). Koska soveltuvuustesti ei täytä niitä vaatimuksia, joita yhdenvertaisuustestit edellyttävät, on tässä tapauksessa käytetty analysoinnin tukena TÜV:n tekemää testiraporttia (TÜV, 2014a). PM_{10}-mittauksille saatu korjauskerroin on lähes 50 % suurempi kuin TÜV:n testeissä saatu tulos, ks. kappale 2.7. $PM_{2.5}$-mittauksissa saatu tulos on puolestaan TÜV:n testeissä saatujen korjauskertoimien vaihteluvälien sisällä.

Jatkuvatoimisten hiukkasmittalaitteiden (AMS) soveltuvuustutkimus, joka suoritettiin intensiivimittauskampanjoin eri puolilla Suomea, osoitti selvästi, että kalibrointiyhtälöt, jotka on saatu Kuopion vertailumittausten tuloksista, ovat päteviä eri puolilla Suomea tehtävissä hiukkasmittauksissa. Kalibrointiyhtälö voi olla muotoa $X_{REF} = by + a$ *tai* $X_{REF} = by$, missä y on AMS:n mittaussignaali ja a ja b ovat leikkauspiste ja kulmakerroin. Kalibrointiyhtälöitä voidaan soveltaa laitteisiin, joiden malli on sama kuin Kuopiossa testatut laitemallit. Vastaavuus on hyvä erityisesti mikrovaa'an värähtelyyn perustuvissa laitteissa (TEOM 1400 ab ja TEOM 1405) sekä beta-säteilyn vaimenemiseen perustuvassa laitteessa (MP-101). Optinen menetelmän mittaustulos riippuu hiukkasten ominaisuuksista, kuten hiukkasten koosta, muodosta ja tiheydestä. Myös ympäristöolosuhteet, kuten kosteus, voivat muuttaa hiukkasten optista taitekerrointa ja vaikuttaa siten hiukkasten havainnointiin. Riittävä yhteensopivuus saavutettiin kuitenkin tämän soveltuvuustutkimuksen ja Kuopion vertailumittauksen välillä Grimm 180 -laitteelle. Osiris käyttäytyi PM_{10}-mittauksissa samalla tavalla kuin Kuopiossa ja se oli hyväksyttävä. Sen sijaan Osiris ei täyttänyt vaatimuksia $PM_{2.5}$-mittauksissa kuten ei myöskään Kuopion vertailumittauksissa. APM-2 oli $PM_{2.5}$-mittauksissa yhteensopiva vertailumenetelmän kanssa käytettäessä TÜV:n raportoimia DoE-tulosten kalibrointikertoimia. Sen sijaan PM_{10}-mittauksissa ero kalibrointikertoimessa TÜV:n raportoimiin tuloksiin oli 50 %. Tämän soveltuvuustestin mukaan TÜV:n raportoimia tuloksia voidaan siis käyttää APM-2 laitteessa $PM_{2.5}$-mittauksissa, mutta PM_{10}-mittauksissa on käytettävä tämän tutkimuksen tuloksia. SHARP 5030 oli vertailussa mukana yhdellä asemalla PM_{10}-mittauksissa ja yhdellä asemalla $PM_{2.5}$-mittauksissa. $PM_{2.5}$:n tapauksessa Kuopion vertailumittausten kalibrointikertoimet soveltuivat hyvin tämän tutkimuksen tuloksiin, mutta PM_{10}-vertailutulokset olivat ongelmallisia alhaisten pitoisuustasojen vuoksi. Johtopäätös tästä vertailusta on, että SHARP 5030:n tulokset korjataan Kuopion kalibrointituloksilla sekä PM_{10}- ja $PM_{2.5}$-mittauksissa. FH62-IR -laitteella saavutetaan parempi yhteensopivuus vertailumittausmenetelmän tuloksiin käyttäen tässä tutkimuksessa saatuja kalibrointikertoimia kuin Kuopion vertailussa saatuja kalibrointikertoimia. Tämä pätee ainakin HSY/Mäkelänkadun mittauksissa, sillä tuloksen yleispätevyyttä rajoittaa se, ettei vertailua pystytty toistamaan muilla asemilla. Johtopäätöksenä on, että Kuopion vertailumittausten tulokset ovat päteviä FH62-IR -laitteelle muualla Suomessa. Verrattaessa TEOM 1405:n ja TEOM 1405D:n tuloksia keskenään oli niiden välillä systemaattinen poikkeama, jota ei voitu selittää. Tästä syystä TEOM 1405:n kalibrointikertoimia ei voi käyttää TEOM 1405D:n tulosten korjaamiseen. Koska TEOM 1405D:tä ei myöskään ole testattu muualla esimerkiksi TÜV:n toimesta, laite ei täytä vertailumenetelmän vaatimusta hiukkasmittauksille. Kuopion vertailumittausten perusteella määritetyt kalibrointikertoimet eri pitoisuusalueille ovat käyttökelpoisia eri puolella Suomea tehtävissä mittauksissa ja ne ovat esitetty taulukoissa 2.4 ja 2.5. Mittausverkkojen vastuuhenkilöt voivat valita näistä tuloksista parhaiten käyttökohteeseen soveltuvan kalibrointiyhtälön. Taulukkoon 3.9 on kerätty kalibrointiyhtälöt taulukoista 2.4 ja 2.5, joita tulisi käyttää yhtenäisinä kalibrointiyhtälöinä mittaustulosten korjaamiseksi Suomessa.

Tässä tutkimuksessa tehdyt vertailumittaukset hyväksyttyjen hiukkasmittauslaitteiden toiminnasta eri puolella Suomea ovat pakollisia EN 16450 standardin mukaan, mutta vaatimus ei ole direktiivissä kansallisessa lainsäädännössä (Ympäristönsuojelulaki 527/2014, Valtioneuvoston asetus ilmanlaadusta 79/2017), eikä niin muodoin ole velvoittava. Tämän tutkimuksen tulokset hyväksyttyjen hiukkasmittalaitteiden toiminnasta vertailumenetelmää vastaan eri puolella Suomea olivat pääosin hyviä. Kuitenkin todettiin myös poikkeavuuksia, joita ei pystytty selvittämään eikä tässä tutkimuksessa myöskään voitu huomioida vuodenaikojen vaihtelun osuutta, minkä taas Kuopion vertailumittauksissa todettiin vaihtelevan suurestikin eräillä laitetyypeillä. Nyt pitäisikin luoda hiukkasmittalaitteiden jatkuvien vertailujen toteuttamiseksi testausohjelma, jossa huomioitaisiin myös vuodenaikojen vaihtelu.

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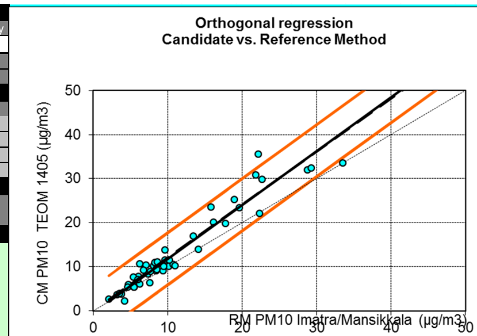
Annex 1. Verification results of PM10 measurements

In the following figures the site data has been analyzed as it has been at the site i.e. corrected according to calibration equation or not corrected.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m³	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405			Active
Filter 2	REF Instrument	Leckel 47/50			*Ignore*
Filter 3	Orientation	OK			Active
Filter 4	Site	matra/Mansikkala			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		**OK**		
RAW DATA			**RESULTS AFTER CALIBRATING**		
Regression	**0,815y + 0,375**		N (Spring)	#VALUE!	n
Regression (i=0)	**0,83y**		N (Summer)	#VALUE!	n
N	49	n	N (Fall)	#VALUE!	n
			N (Winter)	#VALUE!	n
Outliers	2	n	Outliers	1	n
Outliers	4,1	%	Outliers	2,0	%
Mean CM	14,63	µg/m3	Mean CM	12,14	µg/m3
Mean RM	12,30	µg/m3	Mean RM	12,30	µg/m3
Number of RM > UAT	2	n	Number of CM > UAT	1	n
Number of RM > LV	1	n	Number of CM > LV	1	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,2269**	significant	**Slope b**	1,0144	
Uncertainty of b	0,0346		Uncertainty of b	0,0287	
Intercept a	**-0,4603**		**Intercept a**	-0,3374	
Uncertainty of a	0,5585		Uncertainty of a	0,4634	
r^2	0,962		r^2	0,962	
Slope b forced through origin	**1,205**	significant			
Uncertainty of b (forced)	0,0222				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	1,817	µg/m3	**Calibration**	**(y+0,000) / 1,205**	
Uncertainty of calibration (forced)	1,109	µg/m3	Uncertainty of calibration	1,109	µg/m3
Random term	2,4620	µg/m3	Random term	2,2906	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	10,8830	µg/m3	Bias at LV	0,3838	µg/m3
Combined uncertainty	11,1580	µg/m3	Combined uncertainty	2,3226	µg/m3
Expanded relative uncertainty	**44,6322%**	**fail**	**Expanded relative uncertainty**	**9,2903%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



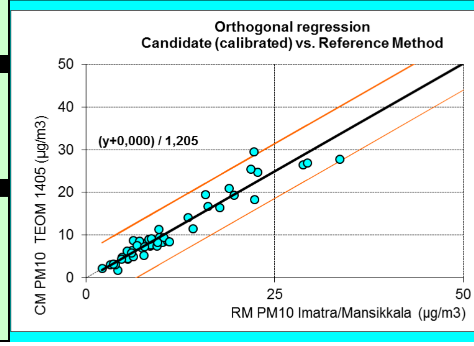


Figure A1. Verification results in Etelä-Karjala/Mansikkala for TEOM 1405 PM_{10} measurements. Data has not been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m^3	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	

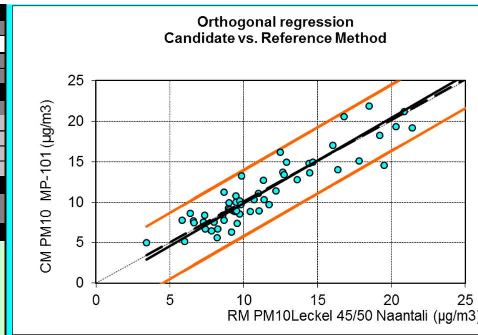
DATA SELECTION				
	Column	Value	Exclude instead of exclusive?	Status
Filter 1	CM-Instrument	MP-101		Active
Filter 2	REF Instrument	Leckel 47/50		Active
Filter 3	Orientation	OK		Active
Filter 4	Site	Naantali		Active

CALIBRATION SETTING		
Calibration based on:	SLOPE TROUGH ORIGIN	OK

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**0,95y + 0,612**		N (Spring)	#VALUE!	n
Regression (i=0)	**0,991y**		N (Summer)	#VALUE!	n
N	60	n	N (Fall)	#VALUE!	n
			N (Winter)	#VALUE!	n
Outliers	1	n	Outliers	1	n
Outliers	1,7	%	Outliers	1,7	%
Mean CM	12,10	µg/m3	Mean CM	11,99	µg/m3
Mean RM	12,10	µg/m3	Mean RM	12,10	µg/m3
Number of RM > UAT	1	n	Number of CM > UAT	1	n
Number of RM > LV	0	n	Number of CM > LV	0	n

REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**1,0531**		**Slope b**	1,0435	
Uncertainty of b	0,0411		Uncertainty of b	0,0408	
Intercept a	**-0,6447**		**Intercept a**	-0,6339	
Uncertainty of a	0,5465		Uncertainty of a	0,5418	
r^2	0,911		r^2	0,911	
Slope b forced through origin	**1,009**	significant			
Uncertainty of b (forced)	0,0169				

EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	2,127	µg/m3	**Calibration**	**(y+0,000) / 1,009**	
Uncertainty of calibration (forced)	0,844	µg/m3	Uncertainty of calibration	0,844	µg/m3
Random term	1,6448	µg/m3	Random term	1,8337	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	2,0080	µg/m3	Bias at LV	1,5409	µg/m3
Combined uncertainty	2,5956	µg/m3	Combined uncertainty	2,3951	µg/m3
Expanded relative uncertainty	**10,3824%**	***pass***	**Expanded relative uncertainty**	**9,5805%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



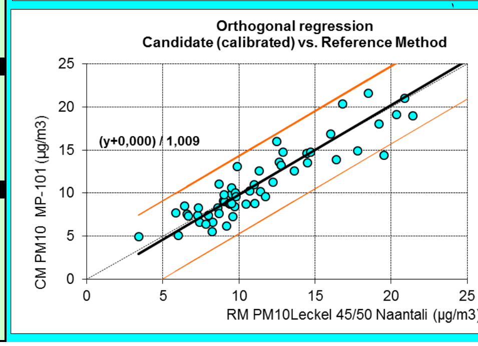


Figure A2. Verification results in Naantali for MP-101 PM_{10} measurements. Data has been corrected according to modified correction term from DoE from Kuopio i.e. the correction for the slope has been 0.91 instead of 0.938.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m^3	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	

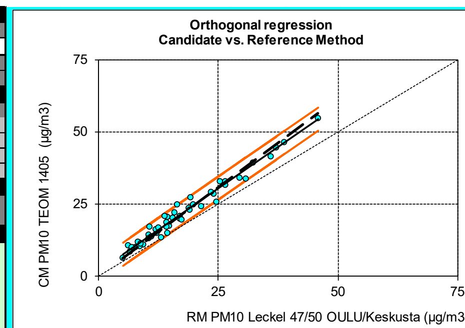
DATA SELECTION				
	Column	Value	Exclude instead of exclusive?	Status
Filter 1	CM Instrument	TEOM 1405		Active
Filter 2	RM Instrument	Leckel 47/50		Active
Filter 3	Orientation	OK		Active
Filter 4	Site	OULU/Keskusta		Active

CALIBRATION SETTING		
Calibration based on:	SLOPE TROUGH ORIGIN	OK

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**0,874y + -1,743**		N (Spring)	#VALUE!	n
Regression (i=0)	**0,81y**		N (Summer)	#VALUE!	n
N	49	n	N (Fall)	#VALUE!	n
			N (Winter)	#VALUE!	n
Outliers	2	n	Outliers	0	n
Outliers	4,1	%	Outliers	0,0	%
Mean CM	22,09	µg/m3	Mean CM	17,90	µg/m3
Mean RM	17,56	µg/m3	Mean RM	17,56	µg/m3
Number of RM > UAT	6	n	Number of CM > UAT	5	n
Number of RM > LV	0	n	Number of CM > LV	0	n

REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**1,1447**	significant	**Slope b**	0,9248	significant
Uncertainty of b	0,0263		Uncertainty of b	0,0213	
Intercept a	**1,9950**	significant	**Intercept a**	1,6594	significant
Uncertainty of a	0,5240		Uncertainty of a	0,4245	
r^2	0,975		r^2	0,975	
Slope b forced through origin	**1,234**	significant			
Uncertainty of b (forced)	0,0145				

EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,417	µg/m3	**Calibration**	**(y+0,000) / 1,234**	
Uncertainty of calibration (forced)	0,726	µg/m3	Uncertainty of calibration	0,726	µg/m3
Random term	1,5978	µg/m3	Random term	1,4292	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	9,2278	µg/m3	Bias at LV	-2,1026	µg/m3
Combined uncertainty	9,3651	µg/m3	Combined uncertainty	2,5423	µg/m3
Expanded relative uncertainty	**37,4604%**	**fail**	**Expanded relative uncertainty**	**10,1694%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



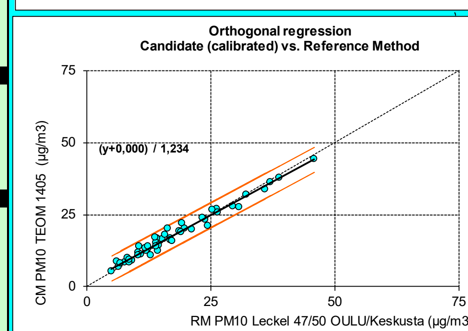
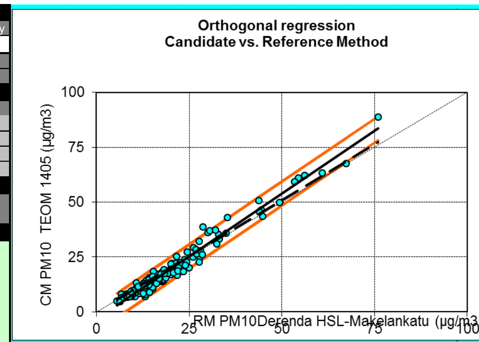


Figure A3. Verification results in Oulu/Keskusta for TEOM 1405 PM_{10} measurements. Data has not been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m³	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405			Active
Filter 2	REF Instrument	Derenda			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSL-Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,872y + 2,992		N (Spring)	62	n
Regression (i=0)	0,982y		N (Summer)	85	n
N	163	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	4	n	Outliers	1	n
Outliers	2,5	%	Outliers	0,6	%
Mean CM	18,50	µg/m3	Mean CM	19,13	µg/m3
Mean RM	19,13	µg/m3	Mean RM	19,13	µg/m3
Number of RM > UAT	19	n	Number of CM > UAT	20	n
Number of RM > LV	6	n	Number of CM > LV	6	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,1465**	significant	**Slope b**	0,9978	
Uncertainty of b	0,0162		Uncertainty of b	0,0141	
Intercept a	**-3,4302**	significant	**Intercept a**	0,0428	
Uncertainty of a	0,3623		Uncertainty of a	0,3160	
r^2	0,968		r^2	0,968	
Slope b forced through origin	**1,018**	significant			
Uncertainty of b (forced)	0,0100				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,886	µg/m3	**Calibration**	**(y+3,430) / 1,146**	
Uncertainty of calibration (forced)	0,502	µg/m3	Uncertainty of calibration	0,886	µg/m3
Random term	2,3265	µg/m3	Random term	2,1874	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	3,8947	µg/m3	Bias at LV	-0,0691	µg/m3
Combined uncertainty	4,5367	µg/m3	Combined uncertainty	2,1884	µg/m3
Expanded relative uncertainty	**18,1467%**	**pass**	**Expanded relative uncertainty**	**8,7538%**	**pass**
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



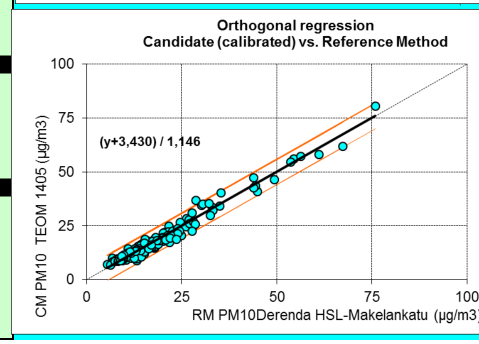
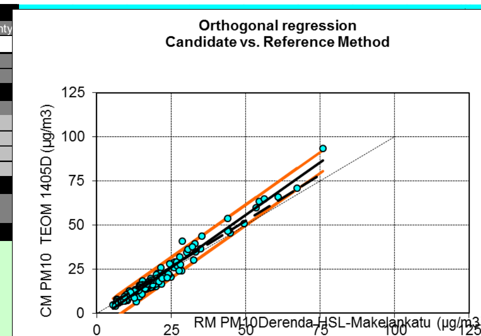


Figure A4a. Verification results in HSY/Mäkelänkatu for TEOM 1405 PM_{10} measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m³	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405D			Active
Filter 2	REF Instrument	Derenda			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSL-Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,838y + 3,291		N (Spring)	62	n
Regression (i=0)	0,955y		N (Summer)	85	n
N	163	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	3	n	Outliers	2	n
Outliers	1,8	%	Outliers	1,2	%
Mean CM	18,90	µg/m3	Mean CM	18,05	µg/m3
Mean RM	19,13	µg/m3	Mean RM	19,13	µg/m3
Number of RM > UAT	19	n	Number of CM > UAT	20	n
Number of RM > LV	6	n	Number of CM > LV	7	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,1931**	significant	**Slope b**	1,1389	significant
Uncertainty of b	0,0173		Uncertainty of b	0,0165	
Intercept a	**-3,9260**	significant	**Intercept a**	-3,7336	significant
Uncertainty of a	0,3879		Uncertainty of a	0,3706	
r^2	0,966		r^2	0,966	
Slope b forced through origin	**1,047**	significant			
Uncertainty of b (forced)	0,0110				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,949	µg/m3	**Calibration**	**(y+0,000) / 1,047**	
Uncertainty of calibration (forced)	0,549	µg/m3	Uncertainty of calibration	0,549	µg/m3
Random term	2,5059	µg/m3	Random term	2,4471	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	5,7268	µg/m3	Bias at LV	3,2093	µg/m3
Combined uncertainty	6,2511	µg/m3	Combined uncertainty	4,0358	µg/m3
Expanded relative uncertainty	**25,0044%**	**fail**	**Expanded relative uncertainty**	**16,1432%**	**pass**
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



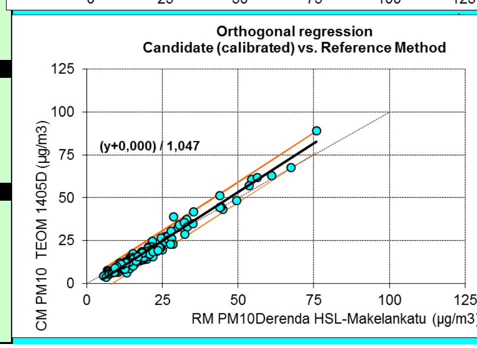
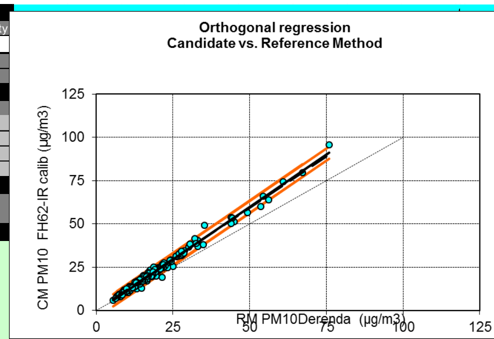


Figure A4b. Verification results in HSY/Mäkelänkatu for TEOM 1405D (dual model) PM_{10} measurements. The instrument was not at the DoE in Kuopio and therefore data is not corrected.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m3	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	FH62-IR-calib			Active
Filter 2	REF Instrument	Derenda			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSL-Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		
RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**0,826y + 0,549**		N (Spring)	63	n
Regression (i=0)	**0,843y**		N (Summer)	84	n
N	157	n	N (Fall)	10	n
			N (Winter)	0	n
Outliers	7	n	Outliers	3	n
Outliers	4,5	%	Outliers	1,9	%
Mean CM	22,82	µg/m3	Mean CM	19,25	µg/m3
Mean RM	19,40	µg/m3	Mean RM	19,40	µg/m3
Number of RM > UAT	19	n	Number of CM > UAT	19	n
Number of RM > LV	6	n	Number of CM > LV	6	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**1,2108**	significant	**Slope b**	1,0200	significant
Uncertainty of b	0,0105		Uncertainty of b	0,0089	
Intercept a	**-0,6644**	significant	**Intercept a**	-0,5406	significant
Uncertainty of a	0,2388		Uncertainty of a	0,2014	
r^2	0,988		r^2	0,988	
Slope b forced through origin	**1,186**	significant			
Uncertainty of b (forced)	0,0055				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	0,578	µg/m3	**Calibration**	**(y+0,000) / 1,186**	
Uncertainty of calibration (forced)	0,276	µg/m3	Uncertainty of calibration	0,276	µg/m3
Random term	1,4047	µg/m3	Random term	1,1610	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	9,8734	µg/m3	Bias at LV	0,4610	µg/m3
Combined uncertainty	9,9729	µg/m3	Combined uncertainty	1,2492	µg/m3
Expanded relative uncertainty	**39,8914%**	**fail**	**Expanded relative uncertainty**	**4,9967%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



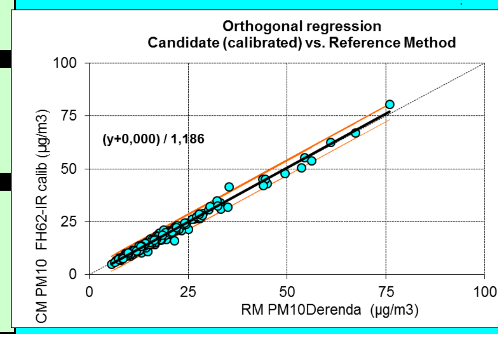
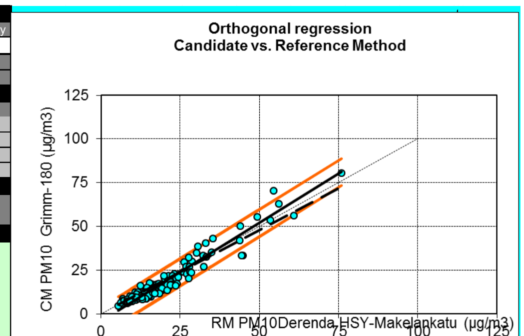


Figure A4c. Verification results in HSY/Mäkelänkatu for FH62-IR PM_{10} measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m3	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	Grimm-180			Active
Filter 2	REF Instrument	Derenda			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSL-Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		
RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**0,888y + 3,998**		N (Spring)	61	n
Regression (i=0)	**1,051y**		N (Summer)	85	n
N	162	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	6	n	Outliers	5	n
Outliers	3,7	%	Outliers	3,1	%
Mean CM	16,71	µg/m3	Mean CM	18,83	µg/m3
Mean RM	18,83	µg/m3	Mean RM	18,83	µg/m3
Number of RM > UAT	18	n	Number of CM > UAT	20	n
Number of RM > LV	5	n	Number of CM > LV	6	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**1,1264**	significant	**Slope b**	0,9948	
Uncertainty of b	0,0254		Uncertainty of b	0,0226	
Intercept a	**-4,5037**	significant	**Intercept a**	0,0979	
Uncertainty of a	0,5559		Uncertainty of a	0,4935	
r^2	0,918		r^2	0,918	
Slope b forced through origin	**0,952**	significant			
Uncertainty of b (forced)	0,0144				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,388	µg/m3	**Calibration**	**(y+4,504) / 1,126**	
Uncertainty of calibration (forced)	0,718	µg/m3	Uncertainty of calibration	1,388	µg/m3
Random term	3,5708	µg/m3	Random term	3,4388	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	1,8164	µg/m3	Bias at LV	-0,1620	µg/m3
Combined uncertainty	4,0063	µg/m3	Combined uncertainty	3,4426	µg/m3
Expanded relative uncertainty	**16,0250%**	***pass***	**Expanded relative uncertainty**	**13,7704%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



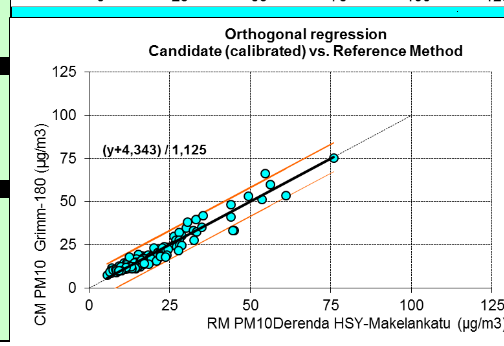
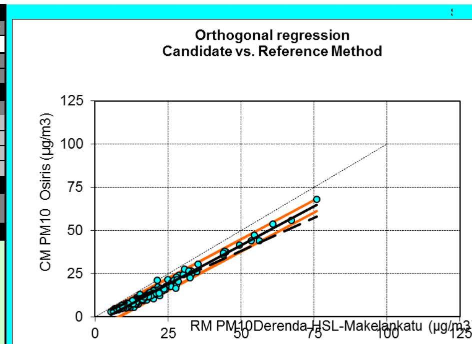


Figure A4d. Verification results in HSY/Mäkelänkatu for Grimm 180 PM_{10} measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m³	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	Osiris			Active
Filter 2	REF Instrument	Derenda			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSL-Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		
RAW DATA			**RESULTS AFTER CALIBRATING**		
Regression	**1,105y + 4,216**		N (Spring)	62	n
Regression (i=0)	**1,31y**		N (Summer)	85	n
N	163	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	5	n	Outliers	5	n
Outliers	3,1	%	Outliers	3,1	%
Mean CM	13,50	µg/m3	Mean CM	19,13	µg/m3
Mean RM	19,13	µg/m3	Mean RM	19,13	µg/m3
Number of RM > UAT	19	n	Number of CM > UAT	19	n
Number of RM > LV	6	n	Number of CM > LV	7	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,9051**	significant	**Slope b**	1,0011	
Uncertainty of b	0,0104		Uncertainty of b	0,0115	
Intercept a	**-3,8164**	significant	**Intercept a**	-0,0207	
Uncertainty of a	0,2341		Uncertainty of a	0,2587	
r^2	0,979		r^2	0,979	
Slope b forced through origin	**0,763**	significant			
Uncertainty of b (forced)	0,0086				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,573	µg/m3	**Calibration**	**(y+3,816) / 0,905**	
Uncertainty of calibration (forced)	0,429	µg/m3	Uncertainty of calibration	0,573	µg/m3
Random term	1,4086	µg/m3	Random term	1,6887	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-8,5604	µg/m3	Bias at LV	0,0334	µg/m3
Combined uncertainty	8,6755	µg/m3	Combined uncertainty	1,6891	µg/m3
Expanded relative uncertainty	**34,7020%**	**fail**	**Expanded relative uncertainty**	**6,7563%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



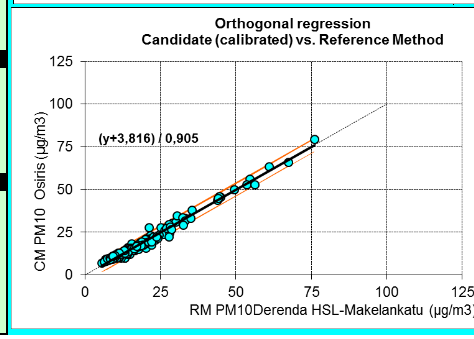
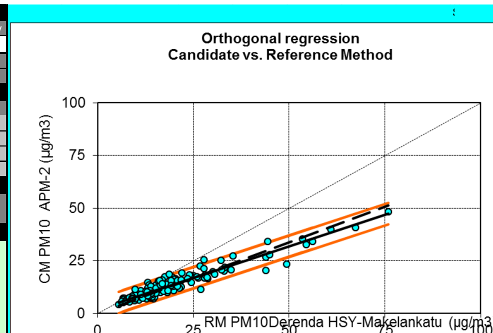


Figure A4e. Verification results in HSY/Mäkelänkatu for Osiris PM_{10} measurements. Data has not been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m³	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	APM-2			Active
Filter 2	REF Instrument	Derenda			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSL-Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		
RAW DATA			**RESULTS AFTER CALIBRATING**		
Regression	**1,67y + -3,01**		N (Spring)	60	n
Regression (i=0)	**1,496y**		N (Summer)	84	n
N	160	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	9	n	Outliers	22	n
Outliers	5,6	%	Outliers	13,8	%
Mean CM	13,28	µg/m3	Mean CM	19,16	µg/m3
Mean RM	19,16	µg/m3	Mean RM	19,16	µg/m3
Number of RM > UAT	19	n	Number of CM > UAT	20	n
Number of RM > LV	6	n	Number of CM > LV	7	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,5989**	significant	**Slope b**	1,0280	
Uncertainty of b	0,0160		Uncertainty of b	0,0267	
Intercept a	**1,8026**	significant	**Intercept a**	-0,5371	
Uncertainty of a	0,3597		Uncertainty of a	0,6005	
r^2	0,893		r^2	0,893	
Slope b forced through origin	**0,669**	significant			
Uncertainty of b (forced)	0,0092				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,877	µg/m3	**Calibration**	**(y-1,803) / 0,599**	
Uncertainty of calibration (forced)	0,462	µg/m3	Uncertainty of calibration	0,877	µg/m3
Random term	2,2941	µg/m3	Random term	4,0730	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-18,2518	µg/m3	Bias at LV	0,8645	µg/m3
Combined uncertainty	18,3954	µg/m3	Combined uncertainty	4,1637	µg/m3
Expanded relative uncertainty	**73,5815%**	**fail**	**Expanded relative uncertainty**	**16,6549%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



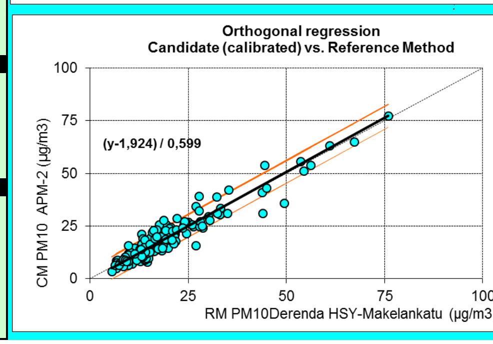


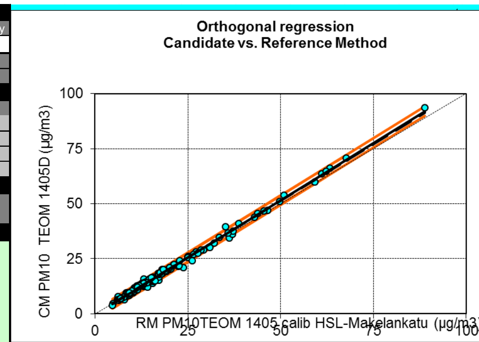
Figure A4f. Verification results in HSY/Mäkelänkatu for APM-2 PM_{10} measurements. The instrument was not at the DoE in Kuopio and therefore data is not corrected.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	μg/m3	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	

DATA SELECTION				
	Column	Value	Exclude instead of exclusive?	Status
Filter 1	CM-Instrument	TEOM 1405D		Active
Filter 2	REF Instrument	TEOM 1405 calib		Active
Filter 3	Orientation	OK		Active
Filter 4	Site	HSL-Makelankatu		Active

CALIBRATION SETTING		
Calibration based on:	SLOPE TROUGH ORIGIN	OK

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,962y + 0,33		N (Spring)	62	n
Regression (i=0)	0,973y		N (Summer)	85	n
N	163	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	7	n	Outliers	7	n
Outliers	4,3	%	Outliers	4,3	%
Mean CM	18,90	μg/m3	Mean CM	18,43	μg/m3
Mean RM	18,50	μg/m3	Mean RM	18,50	μg/m3
Number of RM > UAT	21	n	Number of CM > UAT	20	n
Number of RM > LV	7	n	Number of CM > LV	7	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,0399**	significant	**Slope b**	1,0131	significant
Uncertainty of b	0,0054		Uncertainty of b	0,0058	
Intercept a	**-0,3427**	significant	**Intercept a**	-0,3166	significant
Uncertainty of a	0,1230		Uncertainty of a	0,1315	
r^2	0,996		r^2	0,995	
Slope b forced through origin	**1,028**	significant			
Uncertainty of b (forced)	0,0032				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,296	μg/m3	**Calibration**	**(y+0,000) / 1,028**	
Uncertainty of calibration (forced)	0,160	μg/m3	Uncertainty of calibration	0,160	μg/m3
Random term	0,6296	μg/m3	Random term	0,7366	μg/m3
Additional uncertainty (optional)	0,00	μg/m3	Additional uncertainty (optional)	0,00	μg/m3
Bias at LV	1,6504	μg/m3	Bias at LV	0,3401	μg/m3
Combined uncertainty	1,7664	μg/m3	Combined uncertainty	0,8113	μg/m3
Expanded relative uncertainty	**7,0657%**	***pass***	**Expanded relative uncertainty**	**3,2451%**	***pass***
Ref sampler uncertainty	0,6700	μg/m3	Ref sampler uncertainty	0,6700	μg/m3
Limit value	50	μg/m3	Limit value	50	μg/m3



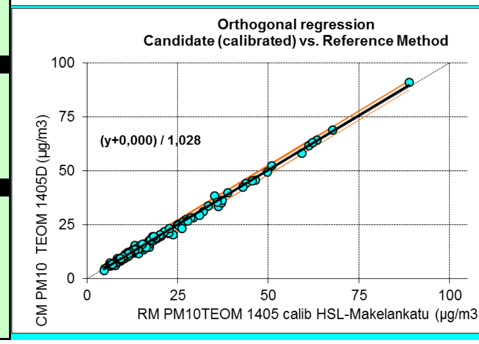


Figure A4g. Verification results in HSY/Mäkelänkatu for TEOM 1405 as DoE instrument and TEOM 1405D as candidate instrument in PM_{10} measurements.

GENERAL SETTINGS

Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	$\mu g/m^3$	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	

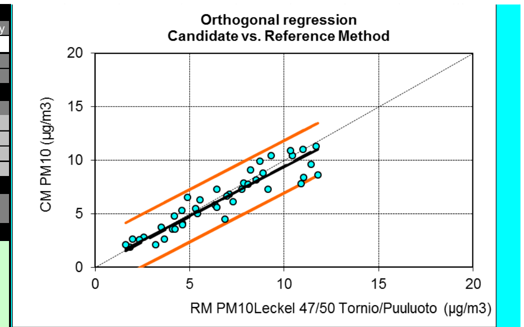
DATA SELECTION

	Column	Value	Exclude instead of exclusive?	Status
Filter 1	CM-Instrument	SHARP 5030 raw C		Active
Filter 2	REF Instrument	Leckel 47/50		Active
Filter 3	Orientation	OK		Active
Filter 4	Site	Tornio/Puuluoto		Active

CALIBRATION SETTING

Calibration based on:	SLOPE TROUGH ORIGIN	OK

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	1,091y + -0,245		N (Spring)	0	n
Regression (i=0)	1,058y		N (Summer)	15	n
N	42	n	N (Fall)	21	n
			N (Winter)	6	n
Outliers	0	n	Outliers	0	n
Outliers	0,0	%	Outliers	0,0	%
Mean CM	6,35	µg/m3	Mean CM	6,72	µg/m3
Mean RM	6,68	µg/m3	Mean RM	6,68	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,9168**		**Slope b**	0,9741	
Uncertainty of b	0,0541		Uncertainty of b	0,0572	
Intercept a	**0,2246**		**Intercept a**	0,2097	
Uncertainty of a	0,3950		Uncertainty of a	0,4179	
r^2	0,863		r^2	0,863	
Slope b forced through origin	**0,945**	significant			
Uncertainty of b (forced)	0,0223				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	2,731	µg/m3	**Calibration**	**(y+0,000) / 0,945**	
Uncertainty of calibration (forced)	1,115	µg/m3	Uncertainty of calibration	1,115	µg/m3
Random term	0,8131	µg/m3	Random term	1,4291	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-3,9336	µg/m3	Bias at LV	-1,0873	µg/m3
Combined uncertainty	4,0167	µg/m3	Combined uncertainty	1,7957	µg/m3
Expanded relative uncertainty	**16,0670%**	***pass***	**Expanded relative uncertainty**	**7,1828%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



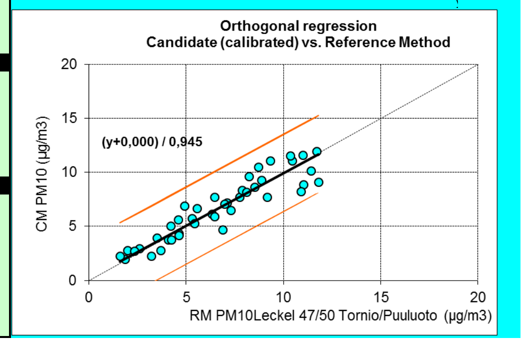


Figure A5. Verification results in Tornio/Puuluoto for SHARP PM_{10} measurements. Data was corrected according to DoE from Kuopio.

GENERAL SETTINGS

Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	$\mu g/m^3$	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	

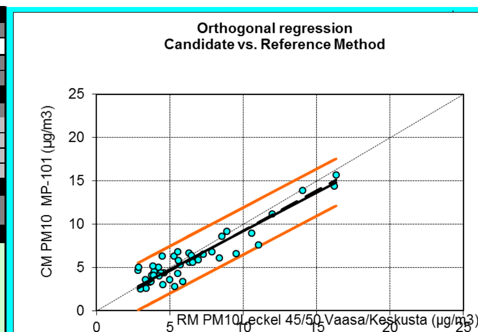
DATA SELECTION

	Column	Value	Exclude instead of exclusive?	Status
Filter 1	CM-Instrument	MP-101 calib		Active
Filter 2	REF Instrument	Leckel 47/50		Active
Filter 3	Orientation	OK		Active
Filter 4	Site	Vaasa/Keskusta		Active

CALIBRATION SETTING

Calibration based on:	SLOPE TROUGH ORIGIN	OK

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	1,12y + -0,321		N (Spring)	0	n
Regression (i=0)	1,077y		N (Summer)	0	n
N	42	n	N (Fall)	20	n
			N (Winter)	22	n
Outliers	0	n	Outliers	0	n
Outliers	0,0	%	Outliers	0,0	%
Mean CM	6,05	µg/m3	Mean CM	6,52	µg/m3
Mean RM	6,46	µg/m3	Mean RM	6,46	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,8926**	significant	**Slope b**	0,9673	
Uncertainty of b	0,0528		Uncertainty of b	0,0569	
Intercept a	**0,2866**		**Intercept a**	0,2732	
Uncertainty of a	0,3851		Uncertainty of a	0,4149	
r^2	0,862		r^2	0,862	
Slope b forced through origin	**0,928**	significant			
Uncertainty of b (forced)	0,0250				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	2,670	µg/m3	**Calibration**	**(y+0,000) / 0,928**	
Uncertainty of calibration (forced)	1,251	µg/m3	Uncertainty of calibration	1,251	µg/m3
Random term	0,9620	µg/m3	Random term	1,6495	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-5,0821	µg/m3	Bias at LV	-1,3637	µg/m3
Combined uncertainty	5,1723	µg/m3	Combined uncertainty	2,1402	µg/m3
Expanded relative uncertainty	**20,6893%**	***pass***	**Expanded relative uncertainty**	**8,5608%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



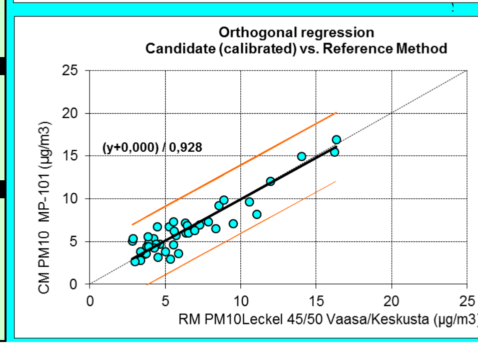
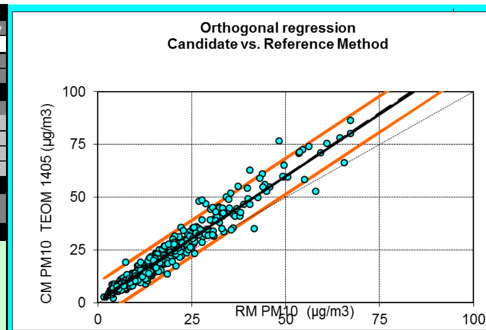


Figure A6. Verification results in Vaasa/Keskusta for MP-101 PM_{10} measurements. Data has been corrected according to the from DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m^3	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405			Active
Filter 2	REF Instrument				Ignore
Filter 3	Orientation	OK			Active
Filter 4	Site				Ignore
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,849y + -0,86		N (Spring)	#VALUE!	n
Regression (i=0)	0,836y		N (Summer)	#VALUE!	n
N	547	n	N (Fall)	#VALUE!	n
			N (Winter)	#VALUE!	n
Outliers	19	n	Outliers	13	n
Outliers	3,5	%	Outliers	2,4	%
Mean CM	24,08	µg/m3	Mean CM	20,13	µg/m3
Mean RM	19,58	µg/m3	Mean RM	19,58	µg/m3
Number of RM > UAT	74	n	Number of CM > UAT	72	n
Number of RM > LV	24	n	Number of CM > LV	26	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,1780**	significant	**Slope b**	0,9835	significant
Uncertainty of b	0,0060		Uncertainty of b	0,0050	
Intercept a	**1,0136**	significant	**Intercept a**	0,8707	significant
Uncertainty of a	0,2000		Uncertainty of a	0,1672	
r^2	0,986		r^2	0,986	
Slope b forced through origin	**1,196**	significant			
Uncertainty of b (forced)	0,0050				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,360	µg/m3	**Calibration**	**(y+0,000) / 1,196**	
Uncertainty of calibration (forced)	0,250	µg/m3	Uncertainty of calibration	0,250	µg/m3
Random term	3,7394	µg/m3	Random term	3,1125	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	9,9115	µg/m3	Bias at LV	0,0480	µg/m3
Combined uncertainty	10,5935	µg/m3	Combined uncertainty	3,1129	µg/m3
Expanded relative uncertainty	**42,3740%**	**fail**	**Expanded relative uncertainty**	**12,4516%**	**pass**
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



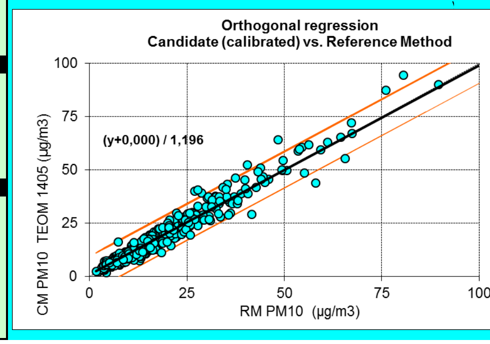
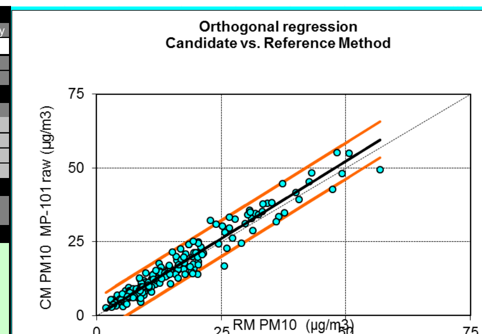


*Figure A7a. Verification results of TEOM 1405 for PM_{10} measurements at all sites in this study, DoE in Kuopio (2014-15) and DoE in Helsinki, Kumpula (2007-08). Data is recalculated as factory settings i.e. Y = 1.03*TEOM(original signal) + 3 µg/m^3.*

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m^3	50	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	MP-101 raw			Active
Filter 2	REF Instrument				Ignore
Filter 3	Orientation	OK			Active
Filter 4	Site				Ignore
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,952y + 0,121		N (Spring)	#VALUE!	n
Regression (i=0)	0,957y		N (Summer)	#VALUE!	n
N	203	n	N (Fall)	#VALUE!	n
			N (Winter)	#VALUE!	n
Outliers	5	n	Outliers	5	n
Outliers	2,5	%	Outliers	2,5	%
Mean CM	15,70	µg/m3	Mean CM	15,02	µg/m3
Mean RM	15,07	µg/m3	Mean RM	15,07	µg/m3
Number of RM > UAT	24	n	Number of CM > UAT	26	n
Number of RM > LV	2	n	Number of CM > LV	2	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,0502**	significant	**Slope b**	1,0041	
Uncertainty of b	0,0175		Uncertainty of b	0,0167	
Intercept a	**-0,1270**		**Intercept a**	-0,1137	
Uncertainty of a	0,3236		Uncertainty of a	0,3098	
r^2	0,944		r^2	0,944	
Slope b forced through origin	**1,045**	significant			
Uncertainty of b (forced)	0,0102				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,932	µg/m3	**Calibration**	**(y+0,000) / 1,045**	
Uncertainty of calibration (forced)	0,508	µg/m3	Uncertainty of calibration	0,508	µg/m3
Random term	2,6131	µg/m3	Random term	2,5435	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	2,3838	µg/m3	Bias at LV	0,0924	µg/m3
Combined uncertainty	3,5371	µg/m3	Combined uncertainty	2,5452	µg/m3
Expanded relative uncertainty	**14,1483%**	**pass**	**Expanded relative uncertainty**	**10,1808%**	**pass**
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



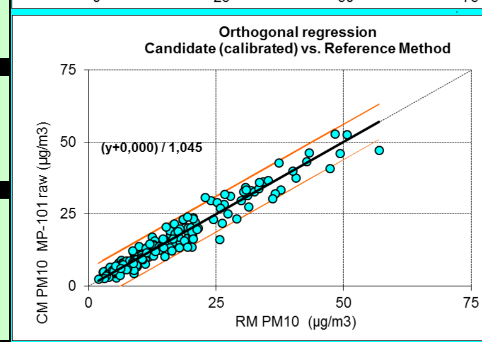


Figure A7b. Verification results of MP101 for PM_{10} measurements at sites in this study (Turku/Naantali, Vaasa/Keskusta) and from Kuopio (site MP-101 at Tasavallankatu).

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM10	µg/m^3	50		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	

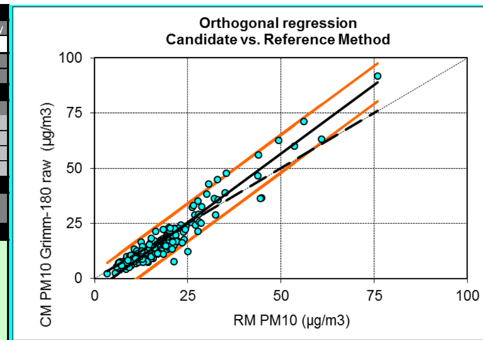
DATA SELECTION				
	Column	Value	Exclude instead of exclusive?	Status
Filter 1	CM Instrument	Grimm-180 raw		Active
Filter 2	RM Instrument			Ignore
Filter 3	Orientation	OK		Active
Filter 4	Site	DoE-Kuopio	Exclude	Active

CALIBRATION SETTING		
Calibration based on:	SLOPE AND INTERCEPT	OK

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,803y + 4,571		N (Spring)	116	n
Regression (i=0)	0,997y		N (Summer)	85	n
N	217	n	N (Fall)	16	n
			N (Winter)	0	n
Outliers	7	n	Outliers	4	n
Outliers	3,2	%	Outliers	1,8	%
Mean CM	15,21	µg/m3	Mean CM	16,78	µg/m3
Mean RM	16,78	µg/m3	Mean RM	16,78	µg/m3
Number of RM > UAT	17	n	Number of CM > UAT	20	n
Number of RM > LV	4	n	Number of CM > LV	5	n

REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**1,2458**	**significant**	**Slope b**	0,9895	
Uncertainty of b	0,0253		Uncertainty of b	0,0203	
Intercept a	**-5,6949**	**significant**	**Intercept a**	0,1754	
Uncertainty of a	0,4944		Uncertainty of a	0,3969	
r^2	0,910		r^2	0,910	
Slope b forced through origin	**1,003**	**significant**			
Uncertainty of b (forced)	0,0153				

EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,358	µg/m3	**Calibration**	**(y+5,695) / 1,246**	
Uncertainty of calibration (forced)	0,763	µg/m3	Uncertainty of calibration	1,358	µg/m3
Random term	3,7410	µg/m3	Random term	3,2549	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	6,5939	µg/m3	Bias at LV	-0,3472	µg/m3
Combined uncertainty	7,5811	µg/m3	Combined uncertainty	3,2733	µg/m3
Expanded relative uncertainty	**30,3246%**	**fail**	**Expanded relative uncertainty**	**13,0934%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	50	µg/m3	Limit value	50	µg/m3



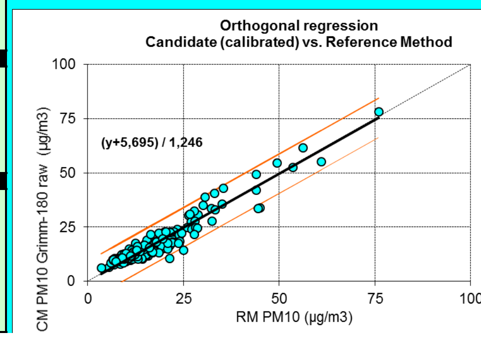
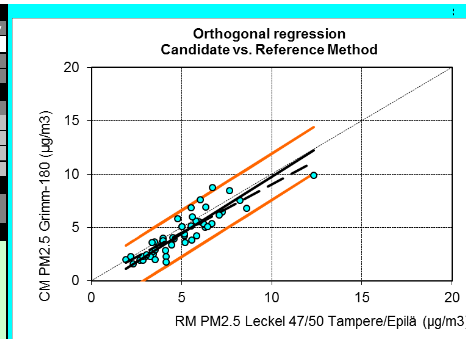


Figure A7c. Verification results of Grimm-180 for PM_{10} measurements at sites in this study (Turku/Naantali, HSY/Mäkelänkatu).

Annex 2. Verification results of $PM_{2.5}$ measurements

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m^3	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM Instrument	Grimm-180			Active
Filter 2	RM-Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	Tampere/Epilä			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		**OK**		
RAW DATA			**RESULTS AFTER CALIBRATING**		
Regression	**0,943y + 0,821**		N (Spring)	0	n
Regression (i=0)	**1,104y**		N (Summer)	53	n
N	53	n	N (Fall)	0	n
			N (Winter)	0	n
Outliers	2	n	Outliers	0	n
Outliers	3,8	%	Outliers	0,0	%
Mean CM	4,37	µg/m3	Mean CM	4,94	µg/m3
Mean RM	4,94	µg/m3	Mean RM	4,94	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,0599**		**Slope b**	0,9930	
Uncertainty of b	0,0667		Uncertainty of b	0,0629	
Intercept a	**-0,8701**	significant	**Intercept a**	0,0347	
Uncertainty of a	0,3529		Uncertainty of a	0,3329	
r^2	0,796		r^2	0,796	
Slope b forced through origin	**0,906**	significant			
Uncertainty of b (forced)	0,0236				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	2,032	µg/m3	**Calibration**	**(y+0,870) / 1,060**	
Uncertainty of calibration (forced)	0,709	µg/m3	Uncertainty of calibration	2,032	µg/m3
Random term	0,6634	µg/m3	Random term	2,1128	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	0,9283	µg/m3	Bias at LV	-0,1759	µg/m3
Combined uncertainty	1,1410	µg/m3	Combined uncertainty	2,1201	µg/m3
Expanded relative uncertainty	**7,6066%**	***pass***	**Expanded relative uncertainty**	**14,1342%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



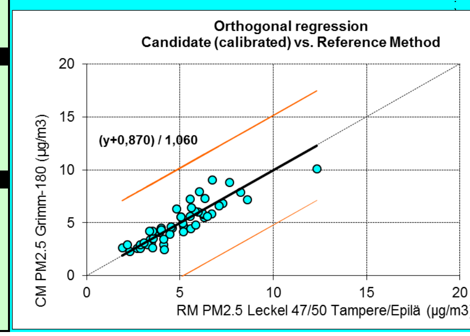
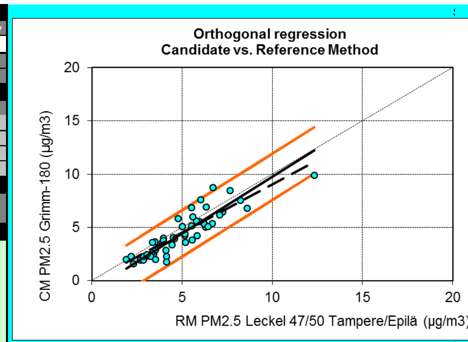


Figure A8a. Verification results in Tampere/Epilä for Grimm-180 (Tampere) in $PM_{2.5}$ measurements. Data has not been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m³	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM Instrument	Grimm-180			Active
Filter 2	RM-Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	Tampere/Epilä			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,943y + 0,821		N (Spring)	0	n
Regression (i=0)	1,104y		N (Summer)	53	n
N	53	n	N (Fall)	0	n
			N (Winter)	0	n
Outliers	2	n	Outliers	0	n
Outliers	3,8	%	Outliers	0,0	%
Mean CM	4,37	µg/m3	Mean CM	4,94	µg/m3
Mean RM	4,94	µg/m3	Mean RM	4,94	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,0599**		**Slope b**	0,9930	
Uncertainty of b	0,0667		Uncertainty of b	0,0629	
Intercept a	**-0,8701**	significant	**Intercept a**	0,0347	
Uncertainty of a	0,3529		Uncertainty of a	0,3329	
r^2	0,796		r^2	0,796	
Slope b forced through origin	**0,906**	significant			
Uncertainty of b (forced)	0,0236				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	2,032	µg/m3	**Calibration**	**(y+0,870) / 1,060**	
Uncertainty of calibration (forced)	0,709	µg/m3	Uncertainty of calibration	2,032	µg/m3
Random term	0,6634	µg/m3	Random term	2,1128	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	0,9283	µg/m3	Bias at LV	-0,1759	µg/m3
Combined uncertainty	1,1410	µg/m3	Combined uncertainty	2,1201	µg/m3
Expanded relative uncertainty	**7,6066%**	***pass***	**Expanded relative uncertainty**	**14,1342%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



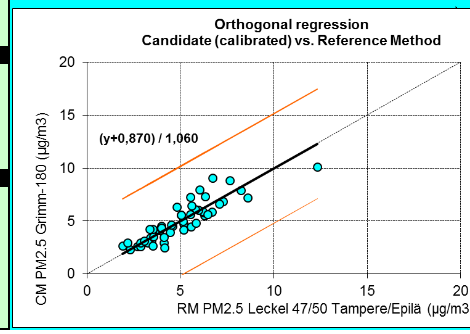
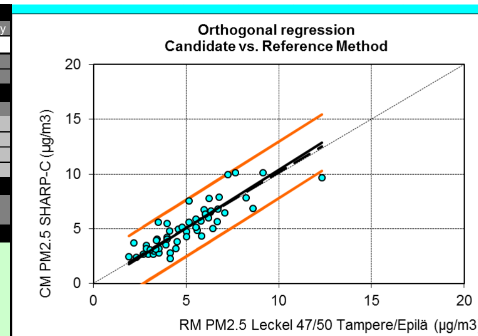


Figure A8b. Verification results in Tampere/Epilä for Grimm-180 (FMI) in $PM_{2.5}$ measurements. Data has not been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m³	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM Instrument	SHARP-C			Active
Filter 2	RM-Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	Tampere/Epilä			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,941y + 0,254		N (Spring)	0	n
Regression (i=0)	0,984y		N (Summer)	54	n
N	54	n	N (Fall)	0	n
			N (Winter)	0	n
Outliers	1	n	Outliers	0	n
Outliers	1,9	%	Outliers	0,0	%
Mean CM	5,10	µg/m3	Mean CM	5,02	µg/m3
Mean RM	5,05	µg/m3	Mean RM	5,05	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**1,0631**		**Slope b**	1,0438	
Uncertainty of b	0,0745		Uncertainty of b	0,0734	
Intercept a	**-0,2702**		**Intercept a**	-0,2525	
Uncertainty of a	0,4041		Uncertainty of a	0,3978	
r^2	0,740		r^2	0,740	
Slope b forced through origin	**1,016**	significant			
Uncertainty of b (forced)	0,0272				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	2,273	µg/m3	**Calibration**	**(y+0,000) / 1,016**	
Uncertainty of calibration (forced)	0,815	µg/m3	Uncertainty of calibration	0,815	µg/m3
Random term	0,8979	µg/m3	Random term	1,1952	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	1,6237	µg/m3	Bias at LV	1,0623	µg/m3
Combined uncertainty	1,8554	µg/m3	Combined uncertainty	1,5991	µg/m3
Expanded relative uncertainty	**12,3693%**	***pass***	**Expanded relative uncertainty**	**10,6605%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



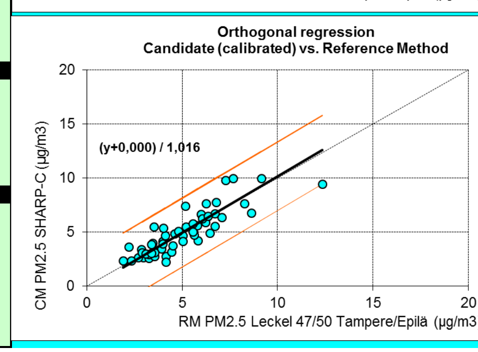
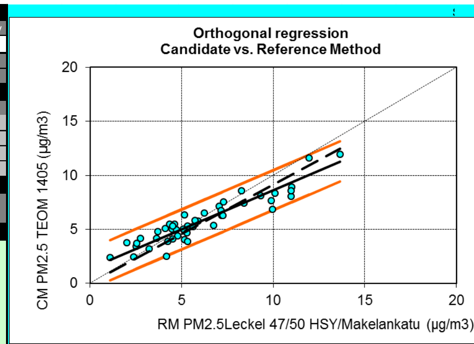


Figure A8c. Verification results in Tampere/Epilä for SHARP 5030 C-dust signal, in $PM_{2.5}$ measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m^3	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		
RAW DATA			RESULTS AFTER CALIBRATING		
Regression	1,376y + -1,86		N (Spring)	0	n
Regression (i=0)	1,094y		N (Summer)	0	n
N	47	n	N (Fall)	47	n
			N (Winter)	0	n
Outliers	1	n	Outliers	0	n
Outliers	2,1	%	Outliers	0,0	%
Mean CM	5,77	µg/m3	Mean CM	6,07	µg/m3
Mean RM	6,07	µg/m3	Mean RM	6,07	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	0,7265	significant	Slope b	1,0234	
Uncertainty of b	0,0406		Uncertainty of b	0,0558	
Intercept a	1,3517	significant	Intercept a	-0,1424	
Uncertainty of a	0,2721		Uncertainty of a	0,3745	
r^2	0,866		r^2	0,866	
Slope b forced through origin	0,914	significant			
Uncertainty of b (forced)	0,0225				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,247	µg/m3	Calibration	(y-1,352) / 0,727	
Uncertainty of calibration (forced)	0,674	µg/m3	Uncertainty of calibration	1,247	µg/m3
Random term	0,4345	µg/m3	Random term	1,5289	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-6,8521	µg/m3	Bias at LV	0,5610	µg/m3
Combined uncertainty	6,8658	µg/m3	Combined uncertainty	1,6285	µg/m3
Expanded relative uncertainty	45,7722%	fail	Expanded relative uncertainty	10,8570%	pass
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



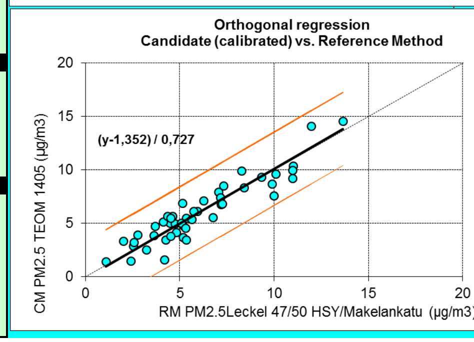
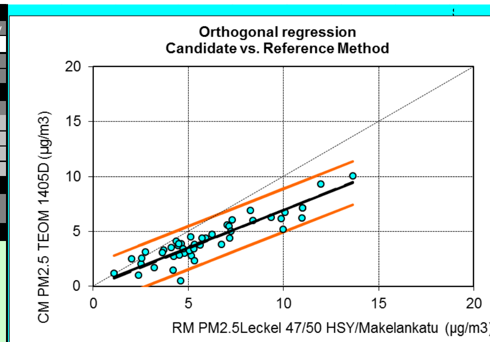


Figure A9a. Verification results HSY/Mäkelänkatu for TEOM 1405 in $PM_{2.5}$ measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m^3	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405D			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		
RAW DATA			RESULTS AFTER CALIBRATING		
Regression	1,462y + -0,109		N (Spring)	0	n
Regression (i=0)	1,44y		N (Summer)	0	n
N	48	n	N (Fall)	48	n
			N (Winter)	0	n
Outliers	1	n	Outliers	2	n
Outliers	2,1	%	Outliers	4,2	%
Mean CM	4,21	µg/m3	Mean CM	6,15	µg/m3
Mean RM	6,04	µg/m3	Mean RM	6,04	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	0,6842	significant	Slope b	1,0124	
Uncertainty of b	0,0430		Uncertainty of b	0,0622	
Intercept a	0,0744		Intercept a	0,0351	
Uncertainty of a	0,2867		Uncertainty of a	0,4150	
r^2	0,830		r^2	0,826	
Slope b forced through origin	0,694	significant			
Uncertainty of b (forced)	0,0182				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,320	µg/m3	Calibration	(y+0,000) / 0,694	
Uncertainty of calibration (forced)	0,547	µg/m3	Uncertainty of calibration	0,547	µg/m3
Random term	0,5218	µg/m3	Random term	1,1859	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-9,4011	µg/m3	Bias at LV	0,4056	µg/m3
Combined uncertainty	9,4156	µg/m3	Combined uncertainty	1,2533	µg/m3
Expanded relative uncertainty	62,7705%	fail	Expanded relative uncertainty	8,3554%	pass
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



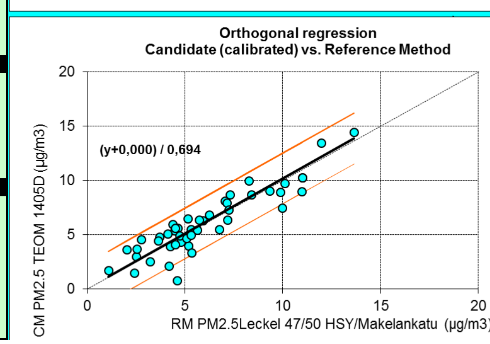
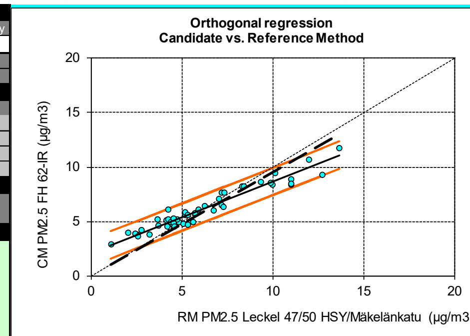


Figure A9b. Verification results in HSY/Mäkelänkatu for TEOM 1405D in $PM_{2.5}$ measurements. The instrument was not at the DoE in Kuopio and therefore data is not corrected.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	$\mu g/m^3$	30	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	FH 62-IR			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Mäkelänkatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		**OK**		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**1,524y + -3,256**		N (Spring)	0	n
Regression (i=0)	**1,053y**		N (Summer)	0	n
N	50	n	N (Fall)	50	n
			N (Winter)	0	n
Outliers	1	n	Outliers	0	n
Outliers	2,0	%	Outliers	0,0	%
Mean CM	6,17	µg/m3	Mean CM	6,14	µg/m3
Mean RM	6,14	µg/m3	Mean RM	6,14	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,6562**	significant	**Slope b**	1,0156	
Uncertainty of b	0,0260		Uncertainty of b	0,0396	
Intercept a	**2,1370**	significant	**Intercept a**	-0,0956	
Uncertainty of a	0,1769		Uncertainty of a	0,2696	
r^2	0,927		r^2	0,927	
Slope b forced through origin	**0,950**	significant			
Uncertainty of b (forced)	0,0230				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,800	µg/m3	**Calibration**	**(y-2,137) / 0,656**	
Uncertainty of calibration (forced)	0,691	µg/m3	Uncertainty of calibration	0,800	µg/m3
Random term	0,0000	µg/m3	Random term	0,9379	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-8,1762	µg/m3	Bias at LV	0,3714	µg/m3
Combined uncertainty	8,1762	µg/m3	Combined uncertainty	1,0088	µg/m3
Expanded relative uncertainty	**54,5081%**	**fail**	**Expanded relative uncertainty**	**6,7253%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



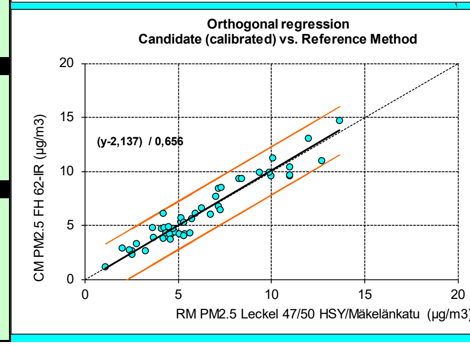
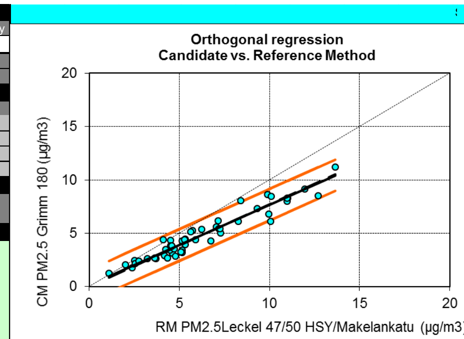


Figure A9c. Verification results in HSY/Mäkelänkatu for FH62-IR in $PM_{2.5}$ measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	$\mu g/m^3$	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	Grimm 180			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		**OK**		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**1,324y + -0,149**		N (Spring)	0	n
Regression (i=0)	**1,298y**		N (Summer)	0	n
N	50	n	N (Fall)	50	n
			N (Winter)	0	n
Outliers	2	n	Outliers	0	n
Outliers	4,0	%	Outliers	0,0	%
Mean CM	4,84	µg/m3	Mean CM	6,26	µg/m3
Mean RM	6,26	µg/m3	Mean RM	6,26	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,7555**	significant	**Slope b**	1,0111	
Uncertainty of b	0,0304		Uncertainty of b	0,0402	
Intercept a	**0,1129**		**Intercept a**	-0,0693	
Uncertainty of a	0,2103		Uncertainty of a	0,2784	
r^2	0,924		r^2	0,924	
Slope b forced through origin	**0,770**	significant			
Uncertainty of b (forced)	0,0131				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,935	µg/m3	**Calibration**	**(y-0,113) / 0,756**	
Uncertainty of calibration (forced)	0,392	µg/m3	Uncertainty of calibration	0,935	µg/m3
Random term	0,0000	µg/m3	Random term	1,0734	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-7,2209	µg/m3	Bias at LV	0,2628	µg/m3
Combined uncertainty	7,2209	µg/m3	Combined uncertainty	1,1051	µg/m3
Expanded relative uncertainty	**48,1393%**	**fail**	**Expanded relative uncertainty**	**7,3672%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



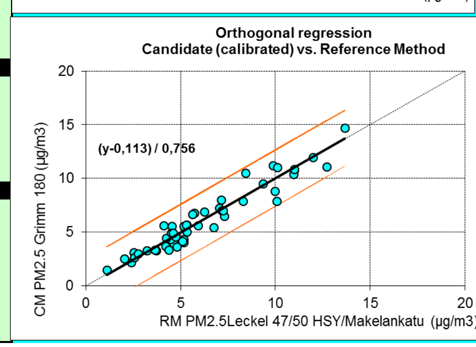
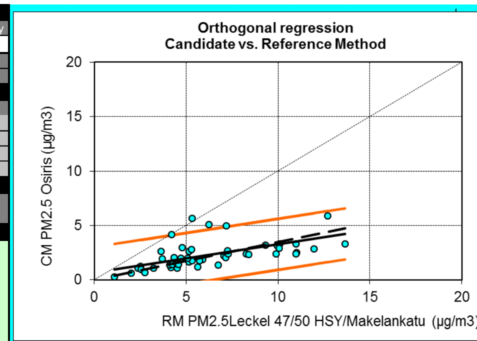


Figure A9d. Verification results in HSY/Mäkelänkatu for Grimm-180 in $PM_{2.5}$ measurements. Data has been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m^3	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	Osiris			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE TROUGH ORIGIN		OK		
RAW DATA			RESULTS AFTER CALIBRATING		
Regression	3,822y + -2,476		N (Spring)	0	n
Regression (i=0)	2,867y		N (Summer)	0	n
N	51	n	N (Fall)	51	n
			N (Winter)	0	n
Outliers	4	n	Outliers	14	n
Outliers	7,8	%	Outliers	27,5	%
Mean CM	2,27	µg/m3	Mean CM	6,52	µg/m3
Mean RM	6,22	µg/m3	Mean RM	6,22	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	0,2616	significant	Slope b	1,3203	significant
Uncertainty of b	0,0480		Uncertainty of b	0,1376	
Intercept a	0,6477		Intercept a	-1,6876	
Uncertainty of a	0,3304		Uncertainty of a	0,9474	
r^2	0,326		r^2	0,326	
Slope b forced through origin	0,349	significant			
Uncertainty of b (forced)	0,0216				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,477	µg/m3	Calibration	(y+0,000) / 0,349	
Uncertainty of calibration (forced)	0,649	µg/m3	Uncertainty of calibration	0,649	µg/m3
Random term	0,7648	µg/m3	Random term	3,5010	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-21,5033	µg/m3	Bias at LV	7,9206	µg/m3
Combined uncertainty	21,5169	µg/m3	Combined uncertainty	8,6599	µg/m3
Expanded relative uncertainty	143,4458%	fail	Expanded relative uncertainty	57,7325%	fail
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



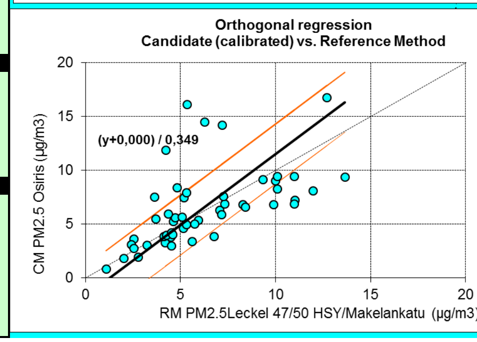
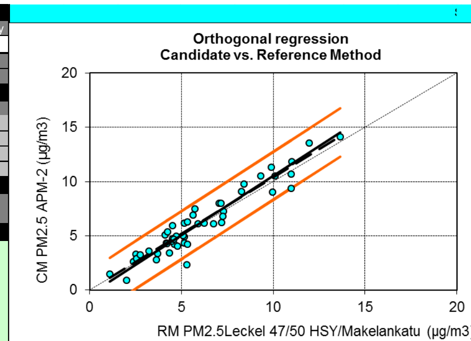


Figure A9e. Verification results in HSY/Mäkelänkatu for Osiris in $PM_{2.5}$ measurements. Data has not been corrected according to DoE from Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m^3	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	APM-2			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		
RAW DATA			RESULTS AFTER CALIBRATING		
Regression	0,914y + 0,379		N (Spring)	0	n
Regression (i=0)	0,964y		N (Summer)	0	n
N	49	n	N (Fall)	49	n
			N (Winter)	0	n
Outliers	2	n	Outliers	0	n
Outliers	4,1	%	Outliers	0,0	%
Mean CM	6,16	µg/m3	Mean CM	6,01	µg/m3
Mean RM	6,01	µg/m3	Mean RM	6,01	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	1,0945		Slope b	0,9956	
Uncertainty of b	0,0479		Uncertainty of b	0,0438	
Intercept a	-0,4149		Intercept a	0,0263	
Uncertainty of a	0,3176		Uncertainty of a	0,2901	
r^2	0,909		r^2	0,909	
Slope b forced through origin	1,038	significant			
Uncertainty of b (forced)	0,0201				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,471	µg/m3	Calibration	(y+0,415) / 1,094	
Uncertainty of calibration (forced)	0,603	µg/m3	Uncertainty of calibration	1,471	µg/m3
Random term	0,6804	µg/m3	Random term	1,5728	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	2,4200	µg/m3	Bias at LV	-0,1050	µg/m3
Combined uncertainty	2,5138	µg/m3	Combined uncertainty	1,5763	µg/m3
Expanded relative uncertainty	16,7589%	pass	Expanded relative uncertainty	10,5090%	pass
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



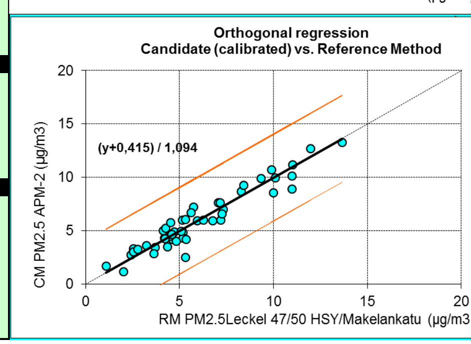
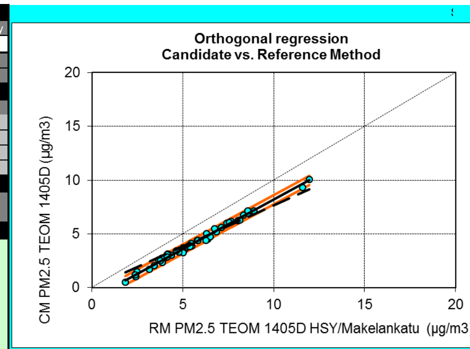


Figure A9f. Verification results from comparison in HSY/Mäkelänkatu for APM-2 in $PM_{2.5}$ measurements. The instrument was not at the DoE in Kuopio and therefore data is not corrected.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m³	30		0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	RM Instrument	TEOM 1405 cal			Active
Filter 2	CM Instrument	TEOM 1405D			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Makelankatu			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**1,085y + 1,117**		N (Spring)	0	n
Regression (i=0)	**1,307y**		N (Summer)	0	n
N	48	n	N (Fall)	48	n
			N (Winter)	0	n
Outliers	0	n	Outliers	0	n
Outliers	0,0	%	Outliers	0,0	%
Mean CM	4,21	µg/m3	Mean CM	5,68	µg/m3
Mean RM	5,68	µg/m3	Mean RM	5,68	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,9218**	significant	**Slope b**	1,0003	
Uncertainty of b	0,0120		Uncertainty of b	0,0130	
Intercept a	**-1,0300**	significant	**Intercept a**	-0,0018	
Uncertainty of a	0,0730		Uncertainty of a	0,0792	
r^2	0,992		r^2	0,992	
Slope b forced through origin	**0,765**	significant			
Uncertainty of b (forced)	0,0096				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	0,367	µg/m3	**Calibration**	**(y+1,030) / 0,922**	
Uncertainty of calibration (forced)	0,288	µg/m3	Uncertainty of calibration	0,367	µg/m3
Random term	0,0000	µg/m3	Random term	0,0000	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-3,3752	µg/m3	Bias at LV	0,0077	µg/m3
Combined uncertainty	3,3752	µg/m3	Combined uncertainty	0,0077	µg/m3
Expanded relative uncertainty	**22,5013%**	***pass***	**Expanded relative uncertainty**	**0,0516%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



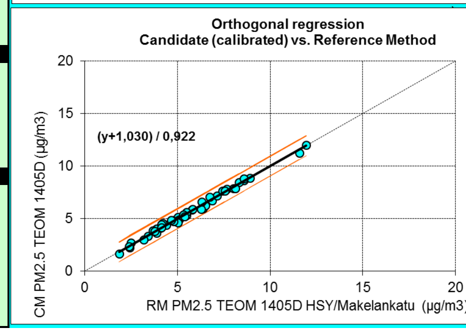
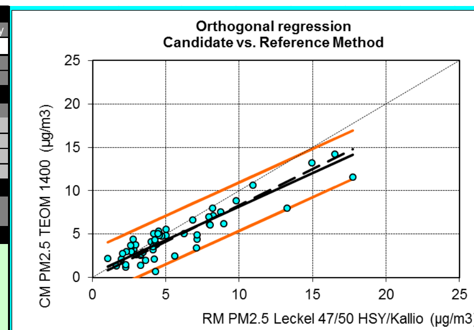


Figure A9g. Verification results from comparison in HSY/Mäkelänkatu for TEOM 1405 as DoE instrument and TEOM 1405D as candidate instrument in $PM_{2.5}$ measurements.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	µg/m³	30	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1400			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Kallio			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	**1,299y + -0,618**		N (Spring)	0	n
Regression (i=0)	**1,202y**		N (Summer)	0	n
N	55	n	N (Fall)	55	n
			N (Winter)	0	n
Outliers	1	n	Outliers	0	n
Outliers	1,8	%	Outliers	0,0	%
Mean CM	4,76	µg/m3	Mean CM	5,56	µg/m3
Mean RM	5,56	µg/m3	Mean RM	5,56	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			**REGRESSION RESULTS (CALIBRATED)**		
Slope b	**0,7698**	significant	**Slope b**	1,0253	
Uncertainty of b	0,0445		Uncertainty of b	0,0578	
Intercept a	**0,4753**		**Intercept a**	-0,1405	
Uncertainty of a	0,2954		Uncertainty of a	0,3838	
r^2	0,831		r^2	0,831	
Slope b forced through origin	**0,832**	significant			
Uncertainty of b (forced)	0,0255				
EQUIVALENCE TEST (RAW)			**EQUIVALENCE TEST (CALIBRATED)**		
Uncertainty of calibration	1,368	µg/m3	**Calibration**	**(y-0,475) / 0,770**	
Uncertainty of calibration (forced)	0,766	µg/m3	Uncertainty of calibration	1,368	µg/m3
Random term	1,0089	µg/m3	Random term	1,9880	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-6,4321	µg/m3	Bias at LV	0,6171	µg/m3
Combined uncertainty	6,5108	µg/m3	Combined uncertainty	2,0816	µg/m3
Expanded relative uncertainty	**43,4050%**	**fail**	**Expanded relative uncertainty**	**13,8772%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



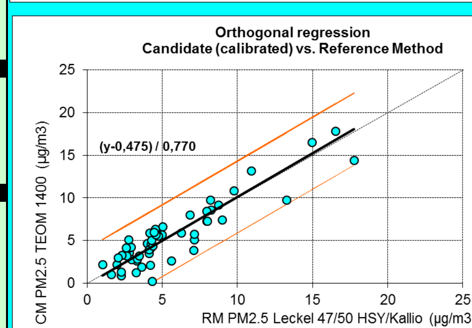
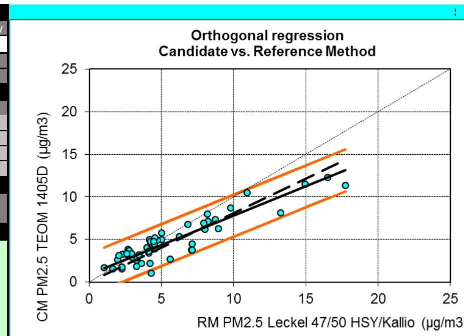


Figure A10a. Verification results in HSY/Kallio for TEOM 1400ab $PM_{2.5}$ measurements. Data has been corrected according to DoE from Helsinki.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	$\mu g/m^3$	30	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405D			Active
Filter 2	REF Instrument	Leckel 47/50			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Kallio			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	1,452y + -1,316		N (Spring)	0	n
Regression (i=0)	1,238y		N (Summer)	0	n
N	55	n	N (Fall)	55	n
			N (Winter)	0	n
Outliers	1	n	Outliers	1	n
Outliers	1,8	%	Outliers	1,8	%
Mean CM	4,74	µg/m3	Mean CM	5,56	µg/m3
Mean RM	5,56	µg/m3	Mean RM	5,56	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**0,6887**	significant	**Slope b**	1,0339	
Uncertainty of b	0,0394		Uncertainty of b	0,0572	
Intercept a	**0,9064**	significant	**Intercept a**	-0,1884	
Uncertainty of a	0,2613		Uncertainty of a	0,3794	
r^2	0,837		r^2	0,837	
Slope b forced through origin	**0,808**	significant			
Uncertainty of b (forced)	0,0247				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	1,209	µg/m3	**Calibration**	**(y-0,906) / 0,689**	
Uncertainty of calibration (forced)	0,742	µg/m3	Uncertainty of calibration	1,209	µg/m3
Random term	0,8308	µg/m3	Random term	1,8663	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-8,4322	µg/m3	Bias at LV	0,8280	µg/m3
Combined uncertainty	8,4730	µg/m3	Combined uncertainty	2,0417	µg/m3
Expanded relative uncertainty	**56,4866%**	**fail**	**Expanded relative uncertainty**	**13,6114%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



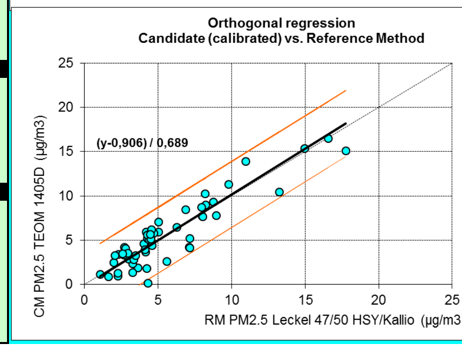
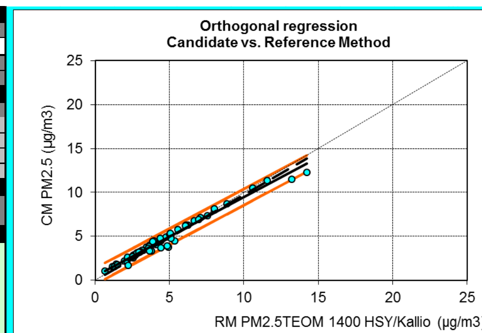


Figure A10b. Verification results in HSY/Kallio for TEOM 1405 $PM_{2.5}$ measurements. Data has been corrected according to DoE in Kuopio.

GENERAL SETTINGS					
Substance	Unit	Limit value	RM uncertainty	Confidence Level	Max Uncertainty
PM2.5	$\mu g/m^3$	30	0,67	0,975	25 %
	Spring	Summer	Fall	Winter	
Starting month:	3	6	9	12	
DATA SELECTION					
	Column	Value	Exclude instead of exclusive?		Status
Filter 1	CM-Instrument	TEOM 1405D			Active
Filter 2	REF Instrument	TEOM 1400			Active
Filter 3	Orientation	OK			Active
Filter 4	Site	HSY/Kallio			Active
CALIBRATION SETTING					
Calibration based on:	SLOPE AND INTERCEPT		OK		

RAW DATA			RESULTS AFTER CALIBRATING		
Regression	1,111y + -0,508		N (Spring)	0	n
Regression (i=0)	1,028y		N (Summer)	0	n
N	56	n	N (Fall)	56	n
			N (Winter)	0	n
Outliers	2	n	Outliers	0	n
Outliers	3,6	%	Outliers	0,0	%
Mean CM	4,70	µg/m3	Mean CM	4,72	µg/m3
Mean RM	4,72	µg/m3	Mean RM	4,72	µg/m3
Number of RM > UAT	0	n	Number of CM > UAT	0	n
Number of RM > LV	0	n	Number of CM > LV	0	n
REGRESSION RESULTS (RAW)			REGRESSION RESULTS (CALIBRATED)		
Slope b	**0,9001**	significant	**Slope b**	1,0012	
Uncertainty of b	0,0185		Uncertainty of b	0,0206	
Intercept a	**0,4572**	significant	**Intercept a**	-0,0057	
Uncertainty of a	0,1020		Uncertainty of a	0,1133	
r^2	0,977		r^2	0,977	
Slope b forced through origin	**0,972**	significant			
Uncertainty of b (forced)	0,0114				
EQUIVALENCE TEST (RAW)			EQUIVALENCE TEST (CALIBRATED)		
Uncertainty of calibration	0,565	µg/m3	**Calibration**	**(y-0,457) / 0,900**	
Uncertainty of calibration (forced)	0,342	µg/m3	Uncertainty of calibration	0,565	µg/m3
Random term	0,0000	µg/m3	Random term	0,2500	µg/m3
Additional uncertainty (optional)	0,00	µg/m3	Additional uncertainty (optional)	0,00	µg/m3
Bias at LV	-2,5391	µg/m3	Bias at LV	0,0308	µg/m3
Combined uncertainty	2,5391	µg/m3	Combined uncertainty	0,2519	µg/m3
Expanded relative uncertainty	**16,9275%**	***pass***	**Expanded relative uncertainty**	**1,6793%**	***pass***
Ref sampler uncertainty	0,6700	µg/m3	Ref sampler uncertainty	0,6700	µg/m3
Limit value	30	µg/m3	Limit value	30	µg/m3



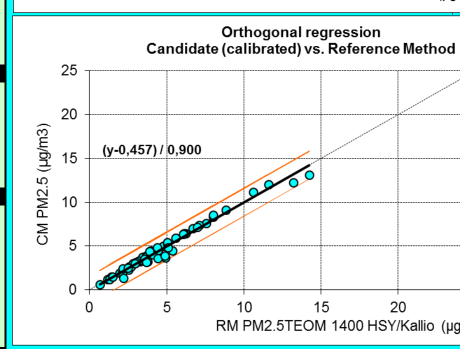


Figure Table 3.5c. Verification results in HSY/Kallio for TEOM 1400 as DoE instrument and TEOM 1405 as candidate instrument in $PM_{2.5}$ measurements.

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