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P. Panteliadis | Th. L. Hafkenscheid

Inter-laboratory comparison filter weighing 2010

GGD Amsterdam

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Panteliadis, P. [1],. Hafkenscheid, Th.L. [2]

[1] GGD Amsterdam Leefomgeving Luchtkwaliteit
[2] Rijksinstituut voor Volksgezondheid en Milieu, Centrum voor Milieumonitoring

Contact: Theo Hafkenscheid
Centrum voor Milieumonitoring
theo.hafkenscheid@rivm.nl

This study has been conducted at the own initiative of the participants in this comparison with the aim of checking the quality of reference measurements of particulate matter.

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Abstract

Inter-laboratory comparison filter weighings 2010

Reference measurements of particulate matter (PM) in ambient air are performed by sampling a known volume of air through a filter for 24 hours. By measuring the mass difference of the filter before and after sampling the concentration of particulate matter may be determined. For this purpose filters are weighed at least twice under strict conditions of temperature and relative humidity, as prescribed in European Standards EN 12341 and EN 14907.

In order to investigate whether application of this procedure – when applied by different laboratories – leads to comparable results, an inter-laboratory comparison has been conducted. For this purpose one pilot laboratory has sent sets of 12 filters (8 loaded, 4 blanks) to other participating laboratories. After having been weighed by participants the filters have been reweighed by the pilot laboratory.
In addition, the weighing conditions in participants' weighing rooms have been monitored using portable temperature/humidity meters. The monitoring results indicate that one laboratories has problems meeting the requirements for weighing conditions given in EN 12341 and EN 14907.

Evaluation of the results of the comparison shows that – when average results of the pilot laboratory are used as reference values and En scores are calculated using estimated weighing uncertainties – 45 out of 48 results correspond with the reference values.

From the results the inter-laboratory (reproducibility) uncertainty of the weighing results has been calculated and has been found to be 55 µg for a confidence level of 95 % for all filters; for loaded filters only, the uncertainty is 59 µg.

Key words: particulate matter, PM, reference measurements, filter weighing, comparability

Rapport in het kort

Inter-laboratorium vergelijking filterwegingen 2010

Referentie-metingen van fijnstof (PM) in buitenlucht vinden plaats door gedurende 24 uur een bekend volume lucht door een filter te zuigen. Door bepaling van het verschil in de massa van het filter voor en na dit proces kan de concentratie fijnstof worden berekend. Het filter wordt hiertoe minimaal tweemaal gewogen onder nauwkeurig bepaalde omgevingscondities (temperatuur, relatieve luchtvochtigheid). Een en ander is vastgelegd in de Europese normen EN 12341 en EN 14907.

Om te onderzoeken in hoeverre deze procedure bij verschillende meetinstanties tot vergelijkbare resultaten leidt, is een vergelijkend onderzoek verricht. Hierbij zijn door één laboratorium 12 verschillende filters (8 beladen, 4 blancos) toegezonden aan andere deelnemers aan het onderzoek. Na weging door deelnemers zijn de filters door het eerste laboratorium opnieuw gewogen. Tevens zijn gedurende de wegingen de omgevingscondities in de weegruimtes gevolgd m.b.v. draagbare temperatuur/vochtigheidsmeters. Hieruit blijkt dat één laboratorium problemen heeft om de eisen voor weegcondities gegeven in EN 12341 en EN 14907 te halen.

Evaluatie van de resultaten van het onderzoek laat zien dat - wanneer de gemiddelde weegresultaten van eerste meetinstantie als referentiewaarden worden genomen, en En-scores worden berekend aan de hand van geschatte meetonzekerheden – 45 van de 48 resultaten overeenkomen met de referentiewaarden bij een betrouwbaarheid van 95 %.

Uit de resultaten kan tevens de inter-laboratorium onzekerheid voor filterwegingen worden bepaald. Deze bedraagt 55 µg bij een betrouwbaarheid van 95 % wanneer resultaten voor alle filters worden gebruikt. Wanneer alleen resultaten voor beladen filters worden gebruikt bedraagt de onzekerheid 59 µg.

Trefwoorden: fijnstof, PM, referentie-metingen, filterweging, vergelijkbaarheid

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Contents

Summary

This report described the organization, results and evaluation of an inter-laboratory comparison for the weighing of filters used for sampling particulate matter in ambient air, held in February 2010. Determination of masses of filters is an essential part of the application of the European reference methods for the measurement of concentrations of PM_{10} and $PM_{2.5}$ in ambient air. The procedures for filter weighing are described in European Standards 12341 [1] and EN 14907 [2]. They comprise subsequent weighings under strict conditions of temperature and relative humidity of the weighing facilities.

This comparison is one of the activities organized by air monitoring networks in Belgium and the Netherlands for harmonization of monitoring methods.
Participants in the comparison are ISSeP, VMM, DCMR, RIVM and GGD Amsterdam (pilot laboratory).

The results of the comparison show that:

- Masses of loaded filters decrease in mass during the sequence “weighing by pilot – weighing by participant – reweighing by pilot”
- Masses of blank filters increase for Pall Tissuquartz but remain stable for Whatman QMA
- One participant has experienced difficulties with duplicate weighings resulting in exceedances of the criteria given in EN 14907
- Difference in results of participants and pilot laboratory are zero on average with no difference observed between loaded and blank filters
- One participant apparently has problems in keeping its weighing room conditions within the required ranges given in EN 12341 and EN 14907 (20 ± 1 °C; 50 ± 5 %RH).

Evaluation of the results based on En scores calculated relative to the results of the pilot laboratory reveals good performance of the laboratories on average, with only 3 out of 48 results exceeding the $En \leq 1$ criterion. For two laboratories the En scores indicate the presence of sources of systematic error.

By using normalized results the comparability of the results of participants mutually is observed to be good; most results correspond at a level of 95% probability.

When the normalized results are used to evaluate the method performance using ISO 5725 part2 statistics, the expanded uncertainty for reproducibility for all results – including those for blank filters – is found to be 55 μg. When using results for loaded filters only, the expanded uncertainty increases slightly to 59 μg.

Introduction

Determination of masses of filters is an essential part of the application of the European reference methods for the measurement of concentrations of PM_{10} and $PM_{2.5}$ in ambient air. The procedures for filter weighing are described in European Standards 12341 [1] and EN 14907 [2]. They comprise subsequent weighings under strict conditions of temperature and relative humidity of the weighing facilities.
Such conditions are essential in order to avoid significant changes in filter masses due to (de)sorption of water vapour – both by filter materials and particulate matter – and evaporation of semi-volatile constituents of particulate matter [3].

In order to investigate the comparability of the mass determination of filters – both loaded and blank filters – an inter-laboratory comparison has been conducted in February 2010. Participating laboratories are VMM (Antwerp, Belgium), ISSeP (Liège, Belgium), RIVM (Bilthoven, Netherlands), DCMR (Schiedam, Netherlands) and GGD Amsterdam (Amsterdam, Netherlands).

This report describes the organization, results and findings of this comparison.

Organization

Fourty-eight filters have been collected by the pilot laboratory (GGD Amsterdam) from various sources:

- 8 Whatman QMA quartz-fibre filters from a rural agricultural monitoring site (RIVM)
- 8 Whatman QMA quartz-fibre filters from a rural seaside monitoring site (RIVM)
- 8 Whatman QMA quartz-fibre filters from various urban monitoring sites (GGD)
- 8 blank Whatman QMA quartz-fibre filters (GGD)
- 8 Pall Tissuquartz-UP quartz-fibre filters from various monitoring sites (VMM)
- 8 blank Pall Tissuquartz-UP quartz-fibre filters (VMM).

Note All Whatman QMA filters have been preconditioned before use in accordance with the Netherlands Technical Agreement 8019. The preconditioning consists of exposure of the blank filters for a period of 3 weeks to air of 20 °C with a relative humidity close to 100 %RH.

All filters have been conditioned in the pilot laboratory's weighing facilities for at least 48 hours at 20 °C and 50% relative humidity (%RH). After the conditioning the filters have been subjected to four consecutive weighings, with a minimum interval of 24 hours between weighings. The mean results for all filters are used as the "mass before despatch".

Subsequently, the set of filters has been divided into four subsets of twelve, each containing two filters of the sources mentioned above, and despatched to the other participants together with a portable temperature/relative humidity sensors set to log readings every 10 minutes. Filters and sensors have been transported in cool boxes.
The sensors have been used to record temperatures and relative humidities in the participants' weighing facilities over a period enclosing the actual periods during which weighings have been performed.

RIVM, VMM and ISSeP have received and returned the cool boxes on February 1 and February 15, respectively. DCMR has received its cool box on February 9 and returned it on February 26.

All participants have stored, conditioned and weighed the filters in their own facilities according to the procedure described in [1] and [2]: conditioning for a minimum of 48 hours followed by a first weighing, conditioning again for a minimum of 24 hours followed by a second weighing.
The sensors have been placed next to the filters during the whole procedure.

After return filters and sensors have been placed in the pilot laboratory's weighing room. Filters have been reconditioned and reweighed twice following the prescribed conditions. The mean of the two weighing results has been used as the "mass after return".
The sensors have been calibrated in the weighing room by comparison of their readings with those of a calibrated dew point meter. Results of the calibrations have been used to correct the readings on despatch.

In Annex 1 the codes and sources of the filters and the codes of the sensors provided to the participants are given anonymously.

Results and evaluations

Results

The results of the weighings are presented anonymized in Annex 2 as follows:

- filter codes are given in the left hand column;
- the second and third columns give the weighing results of the pilot laboratory before and after despatch to participants;
- the fourth column gives the mean result that is used as the reference value;
- the fifth and sixth columns give the two weighing results of each participant;
- the seventh column gives the mean participant results
- the eighth column shows the difference between participants' mean and reference values.

From the results of the weighings performed by the pilot laboratory before and after despatch it is observed that for most loaded filters the mass after is lower than that before, the mean difference being 54 µg. Of the 16 blank filters 12 gained mass, the average gain being 11 µg. Pall Tissuquartz blank filters all gain mass, whereas Whatman QMA blanks on average do not gain mass.
The latter findings may be explained by the fact the Whatman QMA filters have been preconditioned at close to 100 %RH, whereas the Pall Tissuquartz filters have been used without prior treatment.

Differences between mean participants' results and reference values range from -163 µg to +55 µg.
The value of -163 µg is caused by the result of the second filter weighing performed by the participant: removal of the result of the second weighing reduces the difference to -39 µg.
On average, no significant difference in behaviour is found between loaded and blank filters.

Results marked in orange indicate a difference between consecutive weighings in excess of the requirements of EN 14907 (40 µg for blank filters, 60 µg for loaded filters).
These show that Lab 4 has had problems in keeping differences between duplicate weighings within required ranges.

Corrected results of measurements of temperatures and relative humidities in weighing facilities of participants are presented graphically in Annex 3 together with mean values observed during the periods of conditioning and weighing. Rectangles in the figures mark the periods of conditioning and weighing.
These show that Lab 1 has had problems in keeping its conditions within the requirements given in EN 12341 and EN 14907. Lab 1 has an average measured temperature of 17,4 °C that is constant over the period in which the conditionings and weighings have been performed.

Evaluation

Laboratory performance

For the evaluation of the results of the comparison the *En*-score model has been applied. The parameter *En* is calculated as follows [4]:

$$En = \frac{|x - x_{ref}|}{2 \cdot \sqrt{u_p^2 + u_{ref}^2}}$$

where

x = participant's result
x_{ref} = reference value
u_p = measurement uncertainty of participant's result
u_{ref} = measurement uncertainty of the reference value.

An En-score ≤ 1 is an indication of comparability of the participant's result and the reference value at a level of confidence of 95 %.

The mean results of the two weighings of each filter performed by the participants have been taken as values of x; the mean results of the weighings before and after performed by the pilot laboratory have been taken as reference values.

The measurement uncertainty of the values of x has been estimated based on the approach described in EN 14907 as follows:

$$u_x^2 = u_{cal}^2 + u_{zd}^2 + u_{buoy}^2 + u_{\Delta x}^2$$

where

u_{cal} = uncertainty in the calibration of the balance used for the weighings
u_{zd} = uncertainty due to zero drift of the balance
u_{buoy} = uncertainty due to differences in buoyancy
$u_{\Delta x}$ = uncertainty due to the difference between the two results used to calculate *x*.

The first 3 contributions have been calculated from the maximum criteria and default values given in EN 14907. The uncertainty due to the difference between the two weighing results has been calculated by assuming a uniform distribution as:

$$u_{\Delta x}^2 = \frac{(x_2 - x_1)^2}{12}$$

where x*1* and *x2* are the two participant's weighing results.

The uncertainty of the reference values is estimated similarly as

$$u_{ref}^2 = u_{cal}^2 + u_{zd}^2 + u_{buoy}^2 + u_{\Delta ref}^2$$

where $u_{\Delta ref}$ represents the uncertainty due to the difference in the weighing results of the pilot laboratory before and after the weighings of the participants.

The results of all calculations are given in Annex 4. These show that for all samples except for two for Lab 1 and one for Lab 4, En scores are ≤ 1, indicating correspondence with the reference values at 95% probability.
Further, all En scores for Lab 1 are positive, indicating a source of systematic error.
For Lab 3 eleven out of twelve En scores are negative, indicating a source of systematic error; however, the presence of this source does not lead to violation of the criterion En ≤ 1.

In the above way the comparability of the participant's results with the reference values is evaluated. In order to evaluate the mutual comparability of the results of all participants their results have been normalized to the reference values as follows:

$$x_n = \frac{x}{x_{ref}}$$

Uncertainties of the normalized results have been calculated by combining the relative uncertainties of reference values and participants results in quadrature. The normalized results and uncertainties are graphically displayed in Annex 4.

The figure shows that one result from Lab 4 does not compare with a number of results from Lab 1. Otherwise, all results are comparable within 95% probability.

Method performance

Uncertainty from differences

The uncertainty of the weighing method may be estimated from the differences of the results of participants and the pilot laboratory as follows:

$$u^2 = \frac{\sum_1^n \left(x_i - x_{ref,i}\right)^2}{2n}$$

where

x_i = participant's result for sample *i*
$x_{ref,i}$ = reference value for sample *i*
n = number of samples (48).

The resulting uncertainty is 34 µg.

When the aberrant result for one sample (-163 µg) is not taken into account the uncertainty reduces to 25 µg.

When using results for loaded filters only, the uncertainty is 39 µg and the expanded uncertainty (95% confidence) is 59 µg. Without the result for the one sample of -163 µg, these values reduce to 27 µg and 54 µg, respectively.

ISO 5725 approach

The availability of normalized measurement results permits the evaluation of the method performance by application of the statistics of ISO 5725 part 2 [5] by treating normalized results for one laboratory as replicate results. Calculation of statistical parameters yields the following results.

- Relative standard deviation of repeatability: 0,00021
- Between-laboratory relative standard deviation: 0,00014
- Relative standard deviation of reproducibility: 0,00025.

These results show that the weighing method used is quite robust: the ratio of reproducibility and repeatability standard deviations is < 2.

Using the mean mass of all filters the absolute statistics may be estimated to be:

- Standard deviation of repeatability: 0,028 mg
- Between-laboratory relative standard deviation: 0,020 mg
- Relative standard deviation of reproducibility: 0,034 mg.

The latter figure is in agreement with the figure obtained from the differences between participants results and reference values.

The expanded uncertainty (95% probability) for reproducibility of filter weighing obtained in this comparison is 69 µg.

However, this value is strongly influenced by the result for sample A16. The inclusion of this result leads to the exceedance of Mandel’s k-value at the 1% significance level. Elimination of this apparent outlier results in an uncertainty of 27 µg and an expanded uncertainty of 55 µg.

When using results for loaded filters only, the standard deviations increase slightly:

- Relative standard deviation of repeatability: 0,00023
- Between-laboratory relative standard deviation: 0,00017
- Relative standard deviation of reproducibility: 0,00029.

Using the mean mass of all filters the absolute statistics are calculated to be:

- Standard deviation of repeatability: 0,033 mg
- Between-laboratory relative standard deviation: 0,024 mg
- Relative standard deviation of reproducibility: 0,040 mg

The expanded uncertainty (95% probability) for reproducibility of weighing of the loaded filters in this comparison is 80 µg.

When – again – eliminating the result for sample A16, the following values are found:

- Standard deviation of repeatability: 0,015 mg
- Between-laboratory relative standard deviation: 0,026 mg
- Relative standard deviation of reproducibility: 0,029 mg

reducing the expanded uncertainty to 59 µg..

Conclusions

Laboratory performance

The results of the measurements of weighing facility conditions show that Laboratory 1 has problems in keeping its conditions within the ranges required by EN 12341 and EN 14907. Laboratories 2, 3 and 4 have conditions that are well within these ranges.

For Lab 1 the possible consequence is that all En scores are positive, with 2 exceeding the $En \leq 1$ criterion.
Lab 4 has problems in keeping results of duplicate weighings within the ranges required by EN 12341 and 14907; for one sample (A16) the difference is nearly 250 µg. Reweighing by the pilot laboratory has shown that this is not associated with loss of material from the filter. Most likely the second result for this sample is aberrant.

For Labs 2 and 3 all En scores are within the $En \leq 1$ criterion, although for Lab 3 a tendency towards negative En scores is noted.

When examining the mutual comparability of results for participants generally a good comparability is observed.

Method performance

The method performance, expressed as the reproducibility standard deviation of weighing results calculated according to ISO 5725 part 2 is 34 µg, leading to an expanded reproducibility uncertainty of 69 µg. When only results of loaded filters are used the expanded uncertainty increases slightly to 80 µg.

When eliminating the result for sample A16 the expanded uncertainties reduce to

- 55 µg for all samples
- 59 µg for loaded samples only.

References

[1] EN 12341: 1998. Air quality – Determination of the PM_{10} fraction of suspended particulate matter – reference method and field test procedure to demonstrate reference equivalence of measurement methods.

[2] EN 14907: 2005. Ambient air quality- Reference gravimetric measurement method for the demonstration of the $PM_{2,5}$ mass fraction of suspended particulate matter.

[3] CEN/TC 264 WG 15. Unpublished results.

[4] ISO 17043: 2010. Conformity assessment – general requirements for proficiency testing.

[5] ISO 5725:1994 part 2. Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.

Annex 1 –Filters and sensors supplied

Laboratory 1 – Sensor 3

Filter Code	*Source*	*PM mass (mg)*
A7	RIVM seaside	1,575
A8	RIVM seaside	1,255
A9	RIVM agricultural	1,410
A10	RIVM agricultural	1,329
B5	VMM	
B6	VMM	
B13	Pall Tissuquartz blank	
B14	Pall Tissuquartz blank	
C5	Whatman QMA blank	
C6	Whatman QMA blank	
C13	GGD urban	2,240
C14	GGD urban	1,132

Laboratory 2 – Sensor 2

Filter Code	*Source*	*PM mass (mg)*
A3	RIVM agricultural	2,161
A4	RIVM agricultural	1,446
A13	RIVM seaside	1,154
A14	RIVM seaside	1,370
B3	VMM	
B4	VMM	
B11	Pall Tissuquartz blank	
B12	Pall Tissuquartz blank	
C3	Whatman QMA blank	
C4	Whatman QMA blank	
C10	GGD urban	1,092
C12	GGD urban	2,882

Laboratory 3 – Sensor 4

Filter Code	*Source*	*PM mass (mg)*
A1	RIVM agricultural	1,530
A2	RIVM agricultural	2,000
A5	RIVM seaside	1,166
A6	RIVM seaside	1,392
B1	VMM	
B2	VMM	
B9	Pall Tissuquartz blank	
B10	Pall Tissuquartz blank	
C1	Whatman QMA blank	
C2	Whatman QMA blank	
C9	GGD urban	1,130
C11	GGD urban	1,847

Laboratory 4 – Sensor 1

Filter Code	*Source*	*PM mass (mg)*
A11	RIVM agricultural	1,209
A12	RIVM agricultural	1,447
A15	RIVM seaside	1,714
A16	RIVM seaside	2,100
B7	VMM	
B8	VMM	
B15	Pall Tissuquartz blank	
B16	Pall Tissuquartz blank	
C7	Whatman QMA blank	
C8	Whatman QMA blank	
C15	GGD urban	1,247
C16	GGD urban	0,563

Annex 2 – Results of weighings

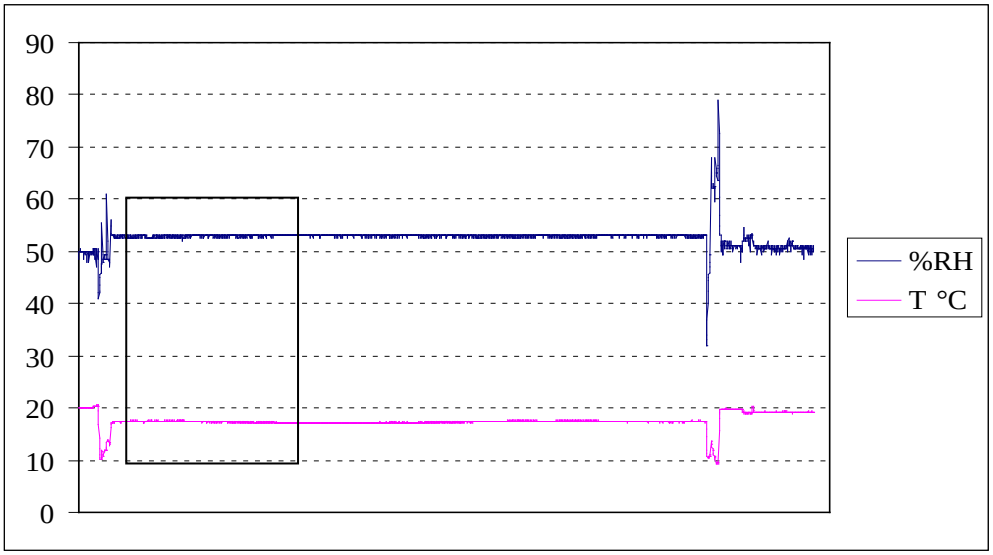
Results of weighings, all in mg.

Filter code	*Pilot*			*Participant*			*Difference part - pilot*
	Before	*After*	*Mean*	*Result 1*	*Result 2*	*Mean*	
A7	149,489	149,447	149,468	149,513	149,512	149,513	0,045
A8	147,543	147,504	147,524	147,563	147,565	147,564	0,040
A9	148,599	148,549	148,574	148,610	148,609	148,610	0,036
A10	148,283	148,232	148,257	148,295	148,295	148,295	0,038
B5	115,053	115,035	115,044	115,076	115,081	115,079	0,034
B6	107,371	107,364	107,367	107,400	107,396	107,398	0,031
B13	97,764	97,799	97,781	97,795	97,805	97,800	0,019
B14	99,395	99,429	99,412	99,430	99,431	99,431	0,019
C5	152,734	152,736	152,735	152,747	152,746	152,747	0,012
C6	152,362	152,371	152,367	152,377	152,378	152,378	0,011
C13	156,437	156,408	156,422	156,473	156,481	156,477	0,055
C14	150,063	150,045	150,054	150,090	150,088	150,089	0,035
A3	148,334	148,223	148,279	148,282	148,241	148,262	-0,017
A4	148,822	148,736	148,779	148,783	148,749	148,766	-0,013
A13	148,552	148,493	148,522	148,529	148,507	148,518	-0,004
A14	148,237	148,156	148,197	148,207	148,182	148,195	-0,002
B3	110,316	110,272	110,294	110,316	110,294	110,305	0,011
B4	111,621	111,567	111,594	111,622	111,587	111,605	0,011
B11	98,975	98,995	98,985	98,987	98,989	98,988	0,003
B12	98,173	98,187	98,180	98,181	98,185	98,183	0,003
C3	154,336	154,305	154,321	154,329	154,312	154,321	0,000
C4	154,216	154,207	154,212	154,217	154,206	154,212	0,000
C10	154,228	154,223	154,225	154,235	154,222	154,229	0,003
C12	150,623	150,519	150,571	150,607	150,560	150,584	0,013
A1	154,229	154,165	154,197	154,165	154,165	154,165	-0,032
A2	147,500	147,448	147,474	147,418	147,435	147,427	-0,047
A5	148,172	148,132	148,152	148,118	148,13	148,124	-0,028
A6	147,857	147,804	147,831	147,84	147,824	147,832	0,001
B1	113,603	113,553	113,578	113,543	113,543	113,543	-0,035
B2	112,340	112,331	112,335	112,309	112,316	112,313	-0,023
B9	98,588	98,592	98,590	98,571	98,567	98,569	-0,021
B10	98,570	98,582	98,576	98,562	98,566	98,564	-0,012
C1	153,014	152,995	153,005	152,989	152,991	152,990	-0,015
C2	153,563	153,542	153,552	153,54	153,539	153,540	-0,013
C9	151,760	151,722	151,741	151,734	151,746	151,740	-0,001
C11	147,174	147,093	147,133	147,126	147,122	147,124	-0,009

A11	147,945	147,853	147,899	147,892	147,930	147,911	0,012
A12	148,003	147,906	147,954	147,960	147,940	147,950	-0,004
A15	148,537	148,457	148,497	148,520	148,550	148,535	0,038
A16	148,876	148,797	148,837	148,798	148,550	148,674	-0,163
B7	116,062	116,017	116,039	116,071	116,040	116,056	0,017
B8	113,560	113,466	113,513	113,487	113,510	113,499	-0,014
B15	96,701	96,723	96,712	96,776	96,710	96,743	0,031
B16	98,135	98,176	98,156	98,226	98,160	98,193	0,037
C7	152,916	152,948	152,932	152,976	152,930	152,953	0,021
C8	154,113	154,138	154,126	154,211	154,110	154,161	0,035
C15	149,411	149,350	149,380	149,426	149,350	149,388	0,007
C16	150,343	150,344	150,344	150,411	150,350	150,381	0,037

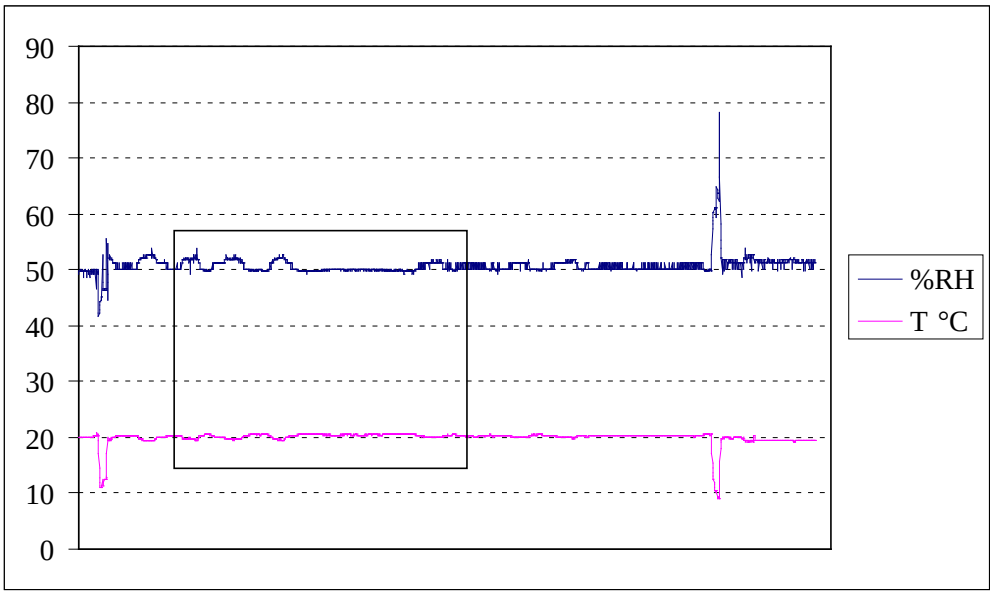
Annex 3 – Weighing room conditions

Laboratory 1



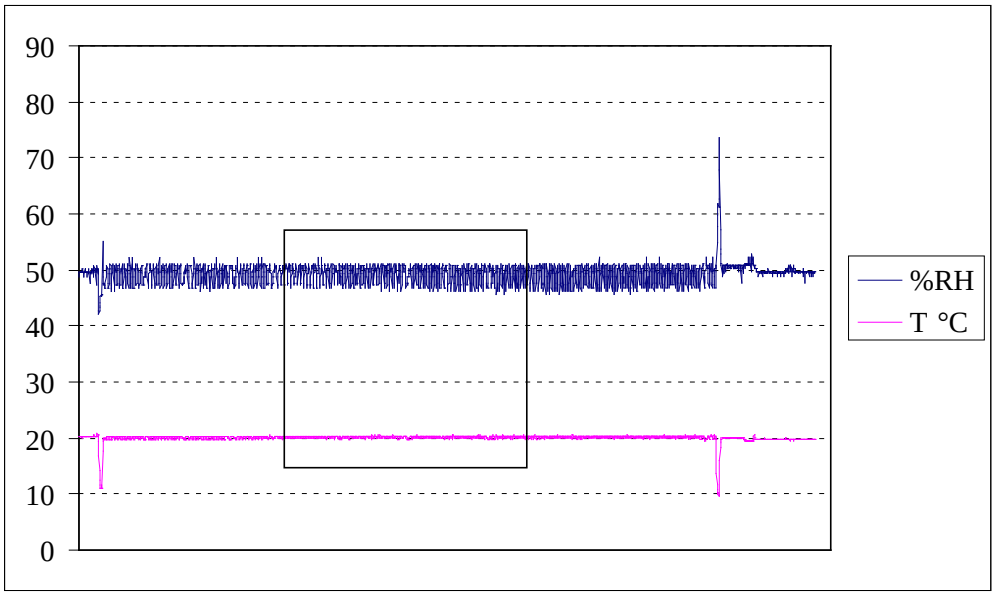
Mean temperature during conditioning and weighing: 17,4 °C
Mean relative humidity during conditioning and weighing: 52,9 %RH.

Laboratory 2



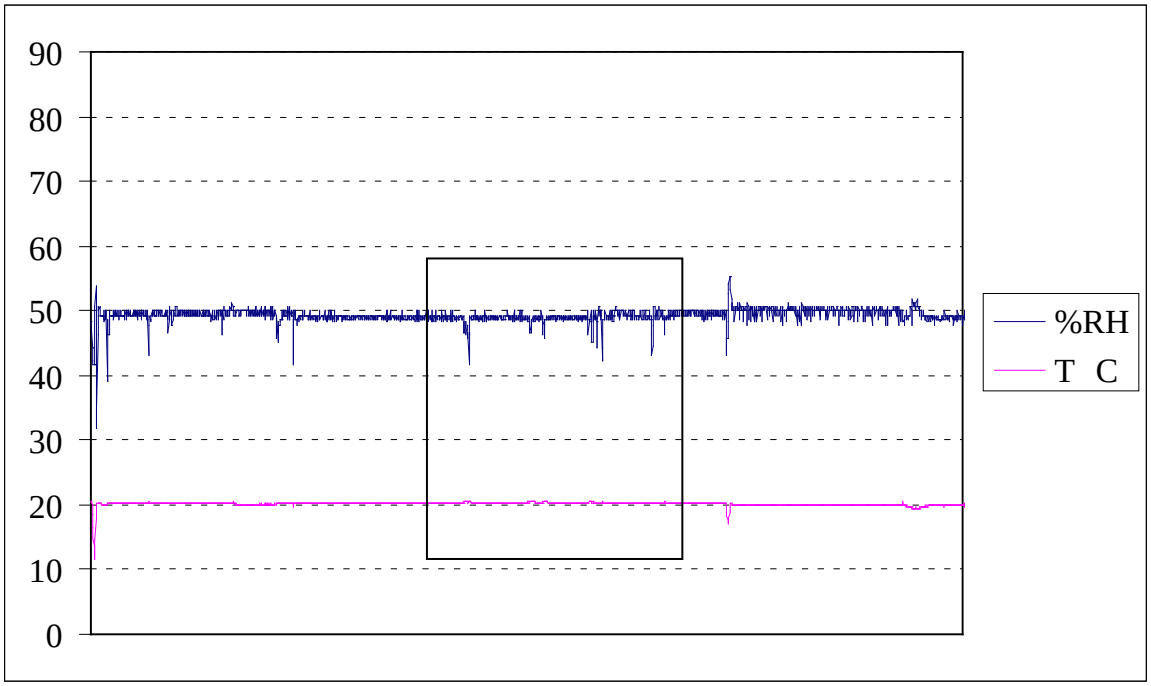
Mean temperature during conditioning and weighing: 20,3 °C
Mean relative humidity during conditioning and weighing: 50,5 %RH.

Laboratory 3



Mean temperature during conditioning and weighing: 20,1 °C
Mean relative humidity during conditioning and weighing: 49,1 %RH.

Laboratory 4



Mean temperature during conditioning and weighing: 20,2 °C
Mean relative humidity during conditioning and weighing: 49,1 %RH.

Annex 4 – Evaluation

Weighing results, uncertainties (in mg) and En scores.

Filter code	*Pilot*		*Participant*		*En score*
	Reference	*Uncertainty*	*Mean*	*Uncertainty*	
A7	149,468	0,018	149,513	0,013	1,02
A8	147,524	0,017	147,564	0,013	0,94
A9	148,574	0,019	148,610	0,013	0,77
A10	148,257	0,019	148,295	0,013	0,81
B5	115,044	0,014	115,079	0,013	0,90
B6	107,367	0,013	107,398	0,013	0,84
B13	97,781	0,016	97,800	0,013	0,45
B14	99,412	0,016	99,431	0,013	0,45
C5	152,735	0,013	152,747	0,013	0,32
C6	152,367	0,013	152,378	0,013	0,30
C13	156,422	0,015	156,477	0,013	1,36
C14	150,054	0,014	150,089	0,013	0,93
A3	148,279	0,035	148,262	0,018	-0,22
A4	148,779	0,028	148,766	0,016	-0,20
A13	148,522	0,021	148,518	0,014	-0,08
A14	148,197	0,027	148,195	0,015	-0,03
B3	110,294	0,018	110,305	0,014	0,24
B4	111,594	0,020	111,605	0,016	0,21
B11	98,985	0,014	98,988	0,013	0,08
B12	98,180	0,014	98,183	0,013	0,08
C3	154,321	0,016	154,321	0,014	0,00
C4	154,212	0,013	154,212	0,013	0,00
C10	154,225	0,013	154,229	0,013	0,09
C12	150,571	0,033	150,584	0,019	0,17
A1	154,197	0,022	154,165	0,013	-0,61
A2	147,474	0,020	147,427	0,014	-0,97
A5	148,152	0,017	148,124	0,013	-0,65
A6	147,831	0,020	147,832	0,014	0,03
B1	113,578	0,019	113,543	0,013	-0,75
B2	112,335	0,013	112,313	0,013	-0,62
B9	98,590	0,013	98,569	0,013	-0,58
B10	98,576	0,013	98,564	0,013	-0,33
C1	153,005	0,014	152,990	0,013	-0,39
C2	153,552	0,014	153,540	0,013	-0,33
C9	151,741	0,017	151,740	0,013	-0,01
C11	147,133	0,027	147,124	0,013	-0,15

Filter code	*Pilot*		*Participant*		*En score*
	Reference	*Uncertainty*	*Mean*	*Uncertainty*	
A7	147,899	0,030	147,911	0,017	0,17
A8	147,954	0,031	147,950	0,014	-0,06
A9	148,497	0,027	148,535	0,016	0,62
A10	148,837	0,026	148,674	0,073	-1,05
B5	116,039	0,018	116,056	0,016	0,34
B6	113,513	0,030	113,499	0,015	-0,21
B13	96,712	0,014	96,743	0,023	0,58
B14	98,156	0,018	98,193	0,023	0,65
C5	152,932	0,016	152,953	0,018	0,43
C6	154,126	0,015	154,161	0,032	0,50
C13	149,380	0,022	149,388	0,025	0,11
C14	150,344	0,013	150,381	0,022	0,73

Normalized results and expanded uncertainties