National Institute for Public Health
and the Environment
*Ministry of Health, Welfare and Sport*

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RIVM report 2022-0117
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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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# Synopsis


## Inter-laboratory comparison of particulate matter filter weighing 2022

Measurements of particulate matter ($PM_{10}$ and $PM_{2,5}$) in ambient air are performed by several air monitoring networks in Europe. These PM measurements are carried out by using filters in a monitoring device that ambient air passes through. Every filter is exposed to ambient air for 24 hours. The laboratories of the air monitoring networks calculate the concentration of PM by using the weight of the filters before and after exposure.

In order to investigate whether this weighing procedure – when applied by different laboratories – leads to similar results, a comparison between the laboratories is carried out every two to four years. The weighing results for 2022 were roughly similar.

The results show relatively small differences between the participating laboratories, and these are well within the limit values for PM measurements. This means there is a strong basis for comparing and exchanging PM measurements between the participating laboratories. The filters have to be weighed exactly as described in a European Standard (EN 12341). For example, temperature and relative humidity in the weighing rooms have to fall within specified value ranges. All but one of the participating laboratories matched these requirements.

In 2022, eight laboratories in Europe participated in this research. A total of 84 filters were compared. RIVM performs the measurements together with several air monitoring networks throughout the European Union.


Keywords: particulate matter, PM, reference measurements, filter weighing, inter-laboratory comparison

# Publiekssamenvatting

## Een vergelijking van de weging van fijnstoffilters door laboratoria in 2022

Verschillende luchtmeetnetten in Nederland en Europa meten de hoeveelheid fijnstof ($PM_{10}$ en $PM_{2,5}$) in de buitenlucht. Dit wordt gedaan met filters in een apparaat dat continu buitenlucht aanzuigt. Elk filter wordt na 24 uur vervangen. De laboratoria van de meetnetten wegen het filter voor en na de plaatsing. Hiermee wordt de concentratie fijnstof bepaald.

Elke twee tot vier jaar vergelijkt het RIVM het weegproces bij een aantal van deze laboratoria. Zo wordt gecontroleerd of de fijnstofconcentraties in de verschillende laboratoria overeenkomen. De resultaten van de wegingen waren in 2022 ongeveer gelijkwaardig.

Er waren kleine verschillen te zien die ruim binnen de grenzen vallen die voor fijnstofmetingen zijn bepaald. Dit betekent dat alle fijnstofmetingen onderling goed met elkaar overeenkomen en tussen de deelnemende meetnetten kunnen worden uitgewisseld. De laboratoria moeten de metingen volgens een Europees vastgestelde procedure doen (EN 12341). De weegkamers horen bijvoorbeeld een bepaalde temperatuur en luchtvochtigheid te hebben. Op één na voldeden alle deelnemende laboratoria aan deze procedure.

In 2022 deden acht laboratoria uit Europa mee aan de vergelijking. In totaal zijn 84 filters gemeten. Het RIVM doet de metingen samen met Nederlandse meetnetten en enkele lidstaten van de Europese Unie. Het RIVM is het nationaal referentielaboratorium voor luchtkwaliteitsmetingen in de buitenlucht en heeft daarom deze taak.

Kernwoorden: fijnstof, PM, referentie-metingen, filterweging, inter-laboratorium vergelijking

# Contents

# Summary

Reference measurements of particulate matter (PM) in ambient air are performed by sampling an accurately 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 can be determined. For this purpose, filters are weighed at least twice, both before and after sampling, under strict conditions of temperature and relative humidity, as described in European Standard EN 12341:2014.

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 twelve pre-weighed filters typically used for low-volume sampling (eight loaded, four blanks) to other participating laboratories. After having been weighed by participants, the filters have been reweighed by the pilot laboratory.

In addition, the temperatures and relative humidity values in the participants' weighing rooms have been monitored using portable temperature/humidity meters. The monitoring results indicate that one laboratory has problems in controlling the temperature and relative humidity in their weighing room.

Evaluation of the results of the comparison shows that – when average results of the pilot laboratory are used as assigned reference values and En numbers are calculated using estimated weighing uncertainties – all results meet the criterion for En to be ≤1.

From the results, the inter-laboratory (reproducibility) uncertainty of the weighing results has been calculated and has been found to be 0.057 mg for a confidence level of 95% for all filters. This corresponds to a relative uncertainty of 2.1% at the level of daily limit value for $PM_{10}$ (50 µg/m$^3$) and 3.4% at the level of a substitute daily limit value for $PM_{2,5}$ (30 µg/m$^3$).

# 1 Introduction

Determination of filter masses is an essential part of the application of the European reference methods for the measurement of $PM_{10}$ and $PM_{2,5}$ concentrations in ambient air. The procedures for filter weighing are described in European Standard EN 12341:2014 [1]. They comprise subsequent conditioning and weighing under prescribed temperature and relative humidity conditions at 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.

In order to investigate the comparability of the mass determination of both loaded and blank filters, an inter-laboratory comparison has been conducted in February to April, 2022. Participating laboratories, including their abbreviations and locations, are (in alphabetical order):

- DCMR Rijnmond Environmental Service (DCMR; Schiedam, the Netherlands);
- Environmental Research Laboratory of the National Centre for Scientific Research 'Demokritos' (EREL; Athens, Greece);
- Flanders Environment Agency (VMM; Antwerp, Belgium);
- National Institute for Public Health and the Environment (RIVM; Bilthoven, the Netherlands);
- Public Health Service of Amsterdam (GGD Amsterdam; Amsterdam, the Netherlands), pilot laboratory;
- Scientific Institute of Public Service (ISSeP; Liège, Belgium);
- South Limburg Regional Implementing Agency (RUDZL; Maastricht, the Netherlands);
- State Agency for Nature, Environment and Consumer Protection (LANUV; Essen, Germany).

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

# 2 Methods

The comparison is based on the weighing of filters typically used for low-volume sampling in accordance with EN 12341:2014 [1], with a diameter of 47 mm. 56 loaded filters and 28 blank filters have been collected by the pilot laboratory (GGD Amsterdam) from the following sources:

- 28 Whatman QMA quartz-fibre filters from rural monitoring sites (RIVM);
- 14 Whatman QMA quartz-fibre filters from urban background and traffic sites (RIVM);
- 14 Whatman QMA quartz-fibre filters from traffic sites (RIVM);
- 28 pre-conditioned blank Whatman QMA quartz-fibre filters (RIVM).

All filters have been conditioned in the pilot laboratory's weighing facilities for a minimum of 48 hours at (20 ± 1) °C and (47.5 ± 2.5)% relative humidity (% RH). After conditioning, the filters have been subjected to four consecutive weighings, with a minimum interval of 24 hours between weighings (from February 21$^{st}$ to March 1$^{st}$, 2022). When the results of the first and fourth weighings differ by less than 0.060 mg for loaded filters and 0.040 mg for blank filters, the mean results for all filters are used as the 'mass before despatch'.

Subsequently, from the set of filters, seven subsets of twelve filters have been prepared, each containing eight loaded filters and four blank filters from the sources mentioned above, and despatched to the other participants.

All participants have stored, conditioned, and weighed the filters in their own facilities according to the procedure described in [1] as follows; 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. If the two results differ by more than 0.040 mg for blank filters and 0.060 mg for sampled filters, the procedure for the second weighing is repeated for a third weighing and the average of the last two consecutive weighings are taken as the filter mass. If these requirements aren't met, the filters are not taken into account in this study.

In addition, all participants have been supplied with portable temperature/relative humidity sensors to log readings every minute. Filters and sensors have been transported to the participants in cool boxes. The sensors have been used to record temperatures and relative humidity values in the participants' weighing facilities over a period enclosing the actual conditioning and weighing periods.

After their return, filters and sensors have been placed in the pilot laboratory's weighing room. Filters have been reconditioned and reweighed four times following the prescribed conditions (from March 30$^{th}$ to April 11$^{th}$, 2022). When the results of the first and fourth weighings differ by less than 0.060 mg for loaded filters and 0.040 mg

for blank filters, the mean results for all filters are used as the 'mass after return'.

In Annex 1, the codes and (types of) PM loadings of the filters provided to the participants are given.

The sensors have been re-calibrated in the pilot laboratory’s weighing room by comparison of their readings with those of a calibrated dew-point meter. The results of the calibrations have been used to correct the readings.

# 3 Results and evaluations

## 3.1 Results

### *3.1.1 General*

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

- The left-hand column contains filter codes;
- the second and third columns contain the weighing results of the pilot laboratory before and after despatch to participants;
- the fourth column provides the mean result that is used as the reference value;
- the fifth and sixth columns contain the two weighing results of each participant;
- the seventh column present the third weighing result of each participant in case this was needed;
- the eighth column contains the mean participant results;
- the ninth column shows the difference between reference values and participants' mean results.

### *3.1.2 Results of the pilot laboratory*

As a criterion for calculating the mean mass before despatch for every filter, the first and fourth weighings had to differ by less than 0.060 mg for loaded filters and 0.040 mg for blank filters. For all filters, this criterion has been fulfilled. The same criterion applied to calculating the mean mass after return, for which all filters matched this criterion.

From the results of the weighings performed by the pilot laboratory before and after despatch, it is observed that, on average, the mass after return of the loaded filters is lower than it was before despatch (mean difference of -0.086 mg), whereas the mass for blank filters is on average almost the same (mean difference of -0.002 mg). The last (fourth) weighing of loaded filters before despatch also showed a (minor) decrease of mass, indicating that the filters were already losing volatiles during the five days they were stored in the pilot laboratory.

The mass changes of the loaded filters are plotted against the masses of PM originally determined on the filters in Figure 1. The relation observed between the mass change and the filter loading suggests some proportionality between the mass loss and the mass of PM on the filter. This may be an indication for losses of (semi-)volatile constituents of the PM.

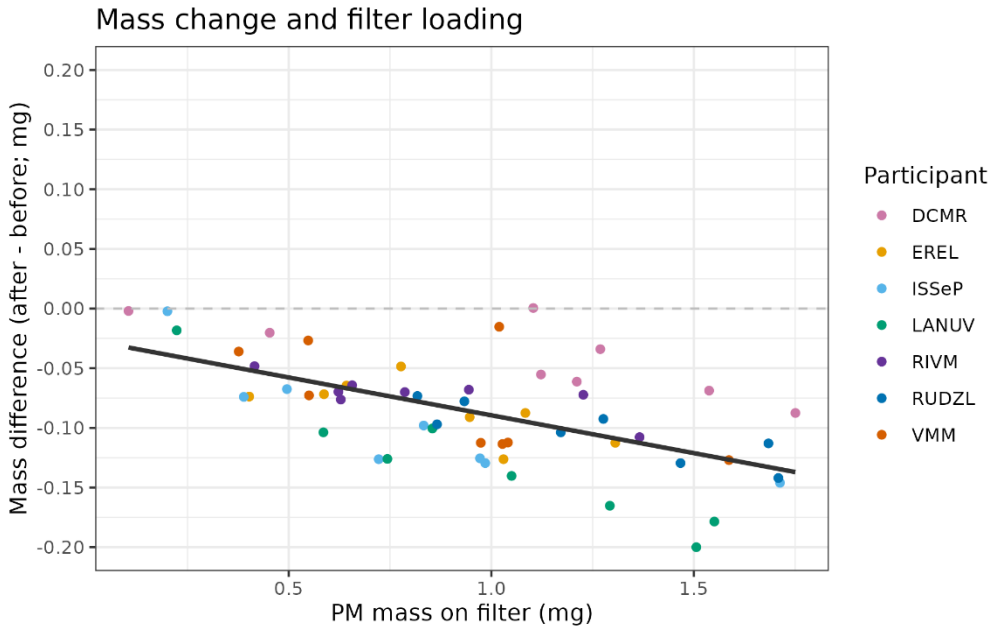



*Figure 1 Mass changes of sampled filters after return to the pilot laboratory.*

### *3.1.3 Results of the participants*

Differences between mean participants' results and reference values range from -0.014 mg to +0.124 mg, with an average of 0.021 mg.

Differences between two consecutive weighings are all within the requirements of EN 12341:2014 (≤0.040 mg for blank filters, ≤0.060 mg for sampled filters).

Corrected results of sensor measurements of temperatures and relative humidity values in weighing facilities of participants (one-hour average values) are presented graphically in Annex 3. They reveal that for the weighing facilities of most participating laboratories, the temperature is stable and relative humidity shows a small upward trend during the placement period of some sensors. Overall – with the exception of laboratory 2 – the mean average weighing room temperature and relative humidity values are within the requirements given in [1]. It is observed that measurements in the weighing room of laboratory 2 exhibit fluctuations and are on average below the minimum temperature and minimum relative humidity requirements.

Reports by participants confirm this trend and show that all weighings for this study – except for those in laboratory 2 – have (within the inherent uncertainties of the loggers) been performed at 45-50% RH and 19-21 °C.

## 3.2 Evaluation of the weighing results

### *3.2.1 Laboratory performance*

For the evaluation of the results of the comparison, the En number has been used. En is calculated as follows [2]:

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

where

$x_p$ is the participant's result;
$x_{ref}$ is the reference value;
$u_p$ is the measurement uncertainty of the participant's result;
$u_{ref}$ is the measurement uncertainty of the reference value.

An En number $\leq 1$ 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 consecutive weighings of each filter performed by the participants have been taken as values of $x_p$; 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 $x_p$ has been estimated according to the approach described in EN 12341:2014 as follows:

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

where

$u_{cal}$ is the uncertainty in the calibration of the balance used for the weighings;
$u_{zd}$ is the uncertainty due to zero drift of the balance;
$u_{buoy}$ is the uncertainty due to differences in buoyancy;
$u_{\Delta x,p}$ is the uncertainty due to the difference between the two weighing results of the participants.

The first three uncertainty contributions have been calculated from the maximum criteria and default values given in EN 12341:2014, resulting in a value of 0.0084 mg. The uncertainty due to the difference between the two weighing results of the participant has been calculated by assuming a uniform distribution as:

$$u_{\Delta x,p}^2 = \frac{\left(x_{p,2} - x_{p,1}\right)^2}{12}$$

where $x_{p,1}$ and $x_{p,2}$ are the participant's two weighing results.

The uncertainty of the reference values is estimated similarly as:

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

where $u_{\Delta x,ref}$ is the uncertainty due to the difference between the results of the pilot laboratory before and after despatch of the filters.

The uncertainty due to the difference between the two weighing results of the pilot laboratory has been calculated by assuming a uniform distribution as:

$$u^2_{\Delta x,ref} = \frac{\left(x_{ref,2} - x_{ref,1}\right)^2}{12}$$

where $x_{ref,1}$ and $x_{ref,2}$ are the weighing results before despatch and after return of the filters.

Because of potential differences in weighing room relative humidity values between participants and pilot laboratory, an additional (default) uncertainty contribution has been added based on the maximum criteria for blank and loaded filter masses included in EN 12341:2014:

- 0.060/√3 mg for loaded filters;
- 0.040/√3 mg for blank filters.

The results of all calculations are given in Annex 4. These show that for all results, En numbers are ≤ 1, indicating correspondence with the reference values at 95% probability.

*3.2.2 Method performance*

3.2.2.1 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:

$$u^2 = \frac{\sum_{1}^{n}\left(x_{i,p} - x_{i,ref}\right)^2}{2n}$$

where

$x_{i,p}$ is the participant's result for sample i;
$x_{i,ref}$ is the reference value for sample i;
n is the number of samples.

The resulting uncertainty is 0.023 mg.

When splitting the results between sampled and blank filters only, the uncertainty is 0.027 mg for sampled filters and 0.011 mg for blank filters.

Combining both uncertainties in quadrature may yield an indication of the uncertainty of a differential weighing. This results in an uncertainty of 0.029 mg and an expanded uncertainty (95% confidence) of 0.058 mg.

3.2.2.2 ISO 5725 part 2 approach

The availability of normalized measurement results permits the evaluation of the method performance by application of the statistics of

ISO 5725 part 2 [3] by treating normalized results for one laboratory as replicate results. Normalized results are calculated as follows:

$$x_{i,n} = \frac{x_{i,p}}{x_{i,ref}}$$

where

$x_{i,p}$ is the participant's result for sample i;
$x_{i,ref}$ is the reference value for sample i.

Calculation of ISO 5725 part 2 statistical parameters for results of this study yields the relative standard deviations shown in Table 1 – with a differentiation between results for loaded filters and blank filters, and all filters combined. Using the mean mass of all filters, the absolute statistics may be estimated by multiplying the relative standard deviations by these mean masses. The results show that the weighing method used is quite robust.

*Table 1 Relative standard deviations (RSD) and absolute standard deviations (SD) for loaded and blank filters and all filters combined.*

| | ***Loaded filters*** | ***Blank filters*** | ***All filters*** |
|---|---|---|---|
| ***Relative standard deviations*** | | | |
| Repeatability RSD | 0.00008 | 0.00004 | 0.00006 |
| Between-laboratory RSD | 0.00017 | 0.00009 | 0.00014 |
| Reproducibility RSD | 0.00019 | 0.00009 | 0.00016 |
| ***Absolute standard deviations*** | | | |
| Repeatability SD (mg) | 0.0114 | 0.0058 | 0.0095 |
| Between-laboratory SD (mg) | 0.026 | 0.013 | 0.021 |
| Reproducibility SD (mg) | 0.029 | 0.014 | 0.024 |

The relative standard deviations are comparable to those found in the previous comparison in 2018 [4].

In addition, the results are submitted to Mandel's *h* and *k* tests for outliers of mean values and standard deviations, respectively, and to Grubb's and Cochran's outlier tests.
A closer examination of the results of the ISO 5725 part 2 evaluation reveals that:

- For all normalized data, one result of Laboratory 1, three results of Laboratory 2 and six results of Laboratory 4 are marked as outliers of mean (99% probability), as indicated by Mandel's *h* statistics. These are indicated with a superscript *h* in Annex 2.
- For all data pooled, five results of Laboratory 2 and two results of Laboratory 7 are marked as outliers of precision (99% probability), as indicated by Mandel's *k* statistics, marked with a superscript *k* in Annex 4.
- One of the results of Laboratory 2 is marked as an outlier of precision (99% probability), as indicated by Cochran's test statistics, marked with an asterisk in Annex 4.

- No outliers of mean (99% probability) were found by conducting Grubb's tests for the single largest and smallest observations.

As some weighings from Laboratory 2 are marked as outliers in multiple test statistics and because all of these weighings have not been performed at 19-21 °C and most not at 45-50% RH, they will be discarded. The individual outliers from Laboratory 1, 4, and 7 could be explained by the fact that the results are obtained from filters from different sources and therefore they don't necessarily have the same PM composition. Probably a loss of volatiles or humidity was taking place during the five days of storage of the filters in the pilot laboratory, resulting in higher absolute losses for filters with higher PM masses. When omitting all the results of Laboratory 2 from the evaluation, the (relative) standard deviations as shown in Table 2 are obtained.

*Table 2 Relative standard deviations (RSD) and absolute standard deviations (SD) for loaded and blank filters and all filters combined, after removal of outliers.*

| | ***Loaded filters*** | ***Blank filters*** | ***All filters*** |
|---|---|---|---|
| ***Relative standard deviations*** | | | |
| Repeatability RSD | 0.00005 | 0.00004 | 0.00004 |
| Between-laboratory RSD | 0.00017 | 0.00009 | 0.00014 |
| Reproducibility RSD | 0.00018 | 0.00010 | 0.00015 |
| ***Absolute standard deviations*** | | | |
| Repeatability SD (mg) | 0.0069 | 0.0053 | 0.0064 |
| Between-laboratory SD (mg) | 0.025 | 0.013 | 0.021 |
| Reproducibility SD (mg) | 0.026 | 0.014 | 0.022 |

When using the reproducibility standard deviations after removal of the outlying results as measures of the uncertainties of weighing results of loaded and blank filters, the method uncertainty may be calculated by combining both results in quadrature:

$$u_m^2 = s_{R,l}^2 + s_{R,b}^2$$

where $s_{R,l}$ and $s_{R,b}$ are the reproducibility standard deviations for loaded and blank filter weighings, respectively.

The combination results in an uncertainty value of 0.029 mg and an expanded uncertainty (95% confidence) of 0.057 mg. This value is similar to the value obtained from differences in results between participants and pilot laboratory (0.058 mg).

# 4 Conclusions

*Organization*

The comparison involves the transport of filters to and from participating laboratories with filter weighings performed by the pilot laboratory before and after both transportations. It is observed that during this process the mass of loaded filters decreases on average, potentially due to losses of (semi)volatile constituents of particulate matter. Also, the fact that the sampled Whatman QMA filters have been preconditioned at high-relative humidity values may make losses of water an obvious cause of mass decrease.

The mass decreases are incorporated into the uncertainty budget used for the evaluation of laboratory performances.

*Laboratory performance*

Overall, the results of the laboratory performance evaluation are satisfactory. Evaluation using En numbers shows that all laboratories, even with outliers, meet the performance requirement of $En \leq 1$.

A study of the control of temperatures and relative humidity values in the weighing facilities of participants shows that all except one of the laboratories confirm with the requirements in European Standard EN 12341:2014 [1].

*Method performance*

The method performance, expressed as the reproducibility standard deviation of weighing results calculated according to ISO 5725 part 2 without outliers, is 0.022 mg. When results of loaded filters only are used, the reproducibility standard deviation increases slightly to 0.026 mg.

By combining uncertainties for the weighing of loaded and blank filters expressed as reproducibility standard deviations, an uncertainty of 0.029 mg results, leading to an expanded method uncertainty of 0.057 mg. When using this value to calculate the relative uncertainty contribution of the weighing process to the overall uncertainty of the measurement of PM, expressed at the limit values of $PM_{10}$ and $PM_{2,5}$, the following values are obtained (95% confidence):

- $PM_{10}$ at 50 µg/m$^3$ (daily limit value [5]): 2.1%;
- $PM_{10}$ at 45 µg/m$^3$ (daily air quality guideline level of the World Health Organization (WHO) [6]): 2.3%;
- $PM_{2,5}$ at 30 µg/m$^3$ (substitute daily limit value [7]): 3.4%;
- $PM_{2,5}$ at 15 µg/m$^3$ (daily guideline level of the WHO [6]): 6.9%.

These values suggest that the uncertainty contributions of the filter conditioning and weighing process as obtained in this study are relatively small, considering that the maximum allowed uncertainty for PM reference measurements is 25% [5].

# References

[1] European Committee for Standardization. EN 12341:2014. Ambient air – Standard gravimetric measurement method for the determination of the $PM_{10}$ or $PM_{2,5}$ mass concentration of suspended particulate matter. Brussels: CEN.

[2] International Organization for Standardization. ISO 13528:2015(Cor. 2016-10). Statistical methods for use in proficiency testing by interlaboratory comparison. Geneva: ISO.

[3] International Organization for Standardization. ISO 5725-2:2019(E). 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. Geneva: ISO.

[4] GGD Amsterdam (2018) Inter-laboratory comparison filter weighing 2018. Doc 18-1164. Amsterdam: GGD Amsterdam.

[5] European Parliament, Council of the European Union. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, Annex I – Annex XI. Official Journal of the European Union, L 152.

[6] World Health Organization (2021) WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, p. 74-97. Geneva: World Health Organization.

[7] European Committee for Standardization. EN 16450:2017. Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM10; PM2,5). Brussels: CEN.

# Annex 1 Filters supplied to each laboratory

*Laboratory 1 VMM*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A1 | $PM_{10}$ | 1.028 |
| A2 | $PM_{10}$ | 1.587 |
| A3 | $PM_{10}$ | 1.020 |
| A4 | $PM_{10}$ | 1.041 |
| A5 | $PM_{10}$ | 0.548 |
| A6 | $PM_{10}$ | 0.974 |
| A7 | $PM_{2,5}$ | 0.550 |
| A8 | $PM_{2,5}$ | 0.377 |
| B1 | blank | - |
| B2 | blank | - |
| B3 | blank | - |
| B4 | blank | - |

*Laboratory 2 EREL*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A9 | $PM_{10}$ | 1.306 |
| A10 | $PM_{2,5}$ | 0.643 |
| A11 | $PM_{10}$ | 0.947 |
| A12 | $PM_{2,5}$ | 1.084 |
| A13 | $PM_{10}$ | 0.777 |
| A14 | $PM_{2,5}$ | 0.403 |
| A15 | $PM_{2,5}$ | 0.587 |
| A16 | $PM_{10}$ | 1.030 |
| B5 | blank | - |
| B6 | blank | - |
| B7 | blank | - |
| B8 | blank | - |

*Laboratory 3 ISSeP*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A17 | $PM_{2,5}$ | 0.985 |
| A18 | $PM_{2,5}$ | 0.201 |
| A19 | $PM_{10}$ | 1.713 |
| A20 | $PM_{2,5}$ | 0.389 |
| A21 | $PM_{2,5}$ | 0.496 |
| A22 | $PM_{10}$ | 0.833 |
| A23 | $PM_{10}$ | 0.972 |
| A24 | $PM_{2,5}$ | 0.722 |
| B9 | blank | - |
| B10 | blank | - |
| B11 | blank | - |
| B12 | blank | - |

*Laboratory 4 LANUV*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A25 | $PM_{10}$ | 1.293 |
| A26 | $PM_{2,5}$ | 0.224 |
| A27 | $PM_{2,5}$ | 0.744 |
| A28 | $PM_{2,5}$ | 0.586 |
| A29 | $PM_{10}$ | 1.506 |
| A30 | $PM_{10}$ | 1.551 |
| A31 | $PM_{2,5}$ | 1.050 |
| A32 | $PM_{2,5}$ | 0.855 |
| B13 | blank | - |
| B14 | blank | - |
| B15 | blank | - |
| B16 | blank | - |

*Laboratory 5 DCMR*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A33 | $PM_{2,5}$ | 1.269 |
| A34 | $PM_{10}$ | 1.538 |
| A35 | $PM_{2,5}$ | 0.105 |
| A36 | $PM_{10}$ | 1.751 |
| A37 | $PM_{10}$ | 1.104 |
| A38 | $PM_{2,5}$ | 0.453 |
| A39 | $PM_{10}$ | 1.123 |
| A40 | $PM_{10}$ | 1.211 |
| B17 | blank | - |
| B18 | blank | - |
| B19 | blank | - |
| B20 | blank | - |

*Laboratory 6 RUDZL*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A41 | $PM_{2,5}$ | 1.172 |
| A42 | $PM_{10}$ | 0.818 |
| A43 | $PM_{2,5}$ | 0.866 |
| A44 | $PM_{10}$ | 1.684 |
| A45 | $PM_{10}$ | 1.467 |
| A46 | $PM_{10}$ | 1.709 |
| A47 | $PM_{2,5}$ | 0.934 |
| A48 | $PM_{2,5}$ | 1.277 |
| B21 | blank | - |
| B22 | blank | - |
| B23 | blank | - |
| B24 | blank | - |

*Laboratory 7 RIVM*

| ***Filter Code*** | ***PM type*** | ***PM mass (mg)*** |
|---|---|---|
| A49 | $PM_{10}$ | 0.945 |
| A50 | $PM_{2,5}$ | 0.629 |
| A51 | $PM_{10}$ | 1.366 |
| A52 | $PM_{2,5}$ | 0.657 |
| A53 | $PM_{2,5}$ | 0.416 |
| A54 | $PM_{2,5}$ | 0.623 |
| A55 | $PM_{2,5}$ | 0.787 |
| A56 | $PM_{10}$ | 1.227 |
| B25 | blank | - |
| B26 | blank | - |
| B27 | blank | - |
| B28 | blank | - |

# Annex 2 Results of weighings in this study

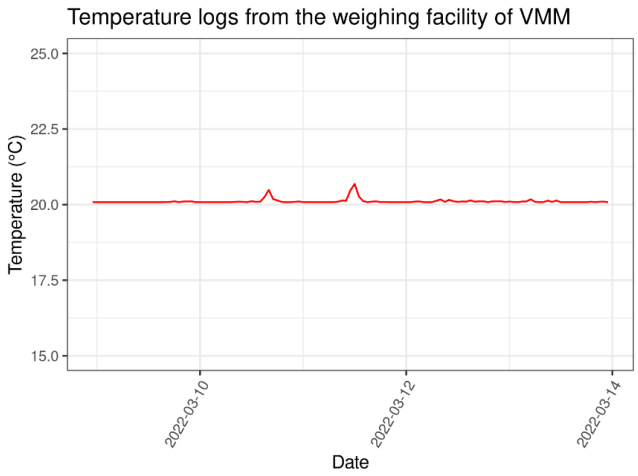
| Filter Code | Pilot | | | Participant | | | | Difference |
|---|---|---|---|---|---|---|---|---|
| | Before | After | Mean | First | Second | Third | Mean | |
| A1 | 149.782 | 149.668 | 149.725 | 149.717 | 149.704 | | 149.710 | 0.014 |
| A2 | 148.184 | 148.057 | 148.120 | 148.129[h] | 148.114 | | 148.122 | -0.002 |
| A3 | 145.381 | 145.366 | 145.374 | 145.378 | 145.369 | | 145.373 | 0.000 |
| A4 | 149.184 | 149.072 | 149.128 | 149.131 | 149.120 | | 149.126 | 0.002 |
| A5 | 147.051 | 147.025 | 147.038 | 147.025 | 147.009 | | 147.017 | 0.021 |
| A6 | 151.046 | 150.933 | 150.989 | 150.989 | 150.975 | | 150.982 | 0.007 |
| A7 | 147.158 | 147.086 | 147.122 | 147.118 | 147.106 | | 147.112 | 0.010 |
| A8 | 148.816 | 148.780 | 148.798 | 148.807 | 148.787 | | 148.797 | 0.000 |
| B1 | 146.416 | 146.423 | 146.419 | 146.421 | 146.421 | | 146.421 | -0.002 |
| B2 | 147.529 | 147.537 | 147.533 | 147.547 | 147.546 | | 147.547 | -0.014 |
| B3 | 143.326 | 143.339 | 143.332 | 143.333 | 143.328 | | 143.331 | 0.002 |
| B4 | 148.302 | 148.286 | 148.294 | 148.298 | 148.296 | | 148.297 | -0.003 |
| | | | | | | | | |
| A9 | 150.211 | 150.099 | 150.155 | 150.035 | 150.085 | 150.040[h] | 150.063 | 0.092 |
| A10 | 147.996 | 147.931 | 147.963 | 147.915[h] | 147.945 | | 147.930 | 0.033 |
| A11 | 147.253 | 147.162 | 147.207 | 147.145 | 147.140 | | 147.143 | 0.065 |
| A12 | 149.121 | 149.033 | 149.077 | 149.030 | 149.070 | | 149.050 | 0.027 |
| A13 | 144.100 | 144.051 | 144.076 | 144.050 | 144.035 | | 144.043 | 0.033 |
| A14 | 148.156 | 148.082 | 148.119 | 148.125 | 148.090 | | 148.108 | 0.011 |
| A15 | 147.122 | 147.051 | 147.086 | 147.110 | 147.070 | | 147.090 | -0.004 |
| A16 | 150.245 | 150.119 | 150.182 | 150.165 | 150.090[h] | 150.150 | 150.120 | 0.062 |
| B5 | 149.142 | 149.127 | 149.134 | 149.135 | 149.115 | | 149.125 | 0.009 |
| B6 | 146.382 | 146.373 | 146.377 | 146.355 | 146.350 | | 146.353 | 0.025 |
| B7 | 149.277 | 149.265 | 149.271 | 149.255 | 149.245 | | 149.250 | 0.021 |
| B8 | 148.111 | 148.092 | 148.102 | 148.100 | 148.100 | | 148.100 | 0.001 |
| | | | | | | | | |
| A17 | 147.899 | 147.770 | 147.834 | 147.817 | 147.813 | | 147.815 | 0.019 |
| A18 | 147.375 | 147.373 | 147.374 | 147.362 | 147.364 | | 147.363 | 0.011 |
| A19 | 146.840 | 146.694 | 146.767 | 146.746 | 146.742 | | 146.744 | 0.023 |
| A20 | 149.957 | 149.883 | 149.920 | 149.895 | 149.897 | | 149.896 | 0.024 |
| A21 | 149.008 | 148.940 | 148.974 | 148.957 | 148.958 | | 148.958 | 0.017 |
| A22 | 149.039 | 148.941 | 148.990 | 148.987 | 148.992 | | 148.990 | 0.001 |
| A23 | 146.915 | 146.790 | 146.853 | 146.831 | 146.831 | | 146.831 | 0.022 |
| A24 | 146.790 | 146.664 | 146.727 | 146.700 | 146.701 | | 146.701 | 0.026 |
| B9 | 146.802 | 146.812 | 146.807 | 146.794 | 146.799 | | 146.797 | 0.010 |
| B10 | 147.599 | 147.603 | 147.601 | 147.594 | 147.596 | | 147.595 | 0.006 |
| B11 | 149.112 | 149.111 | 149.111 | 149.120 | 149.121 | | 149.121 | -0.009 |
| B12 | 148.164 | 148.145 | 148.154 | 148.153 | 148.157 | | 148.155 | -0.001 |

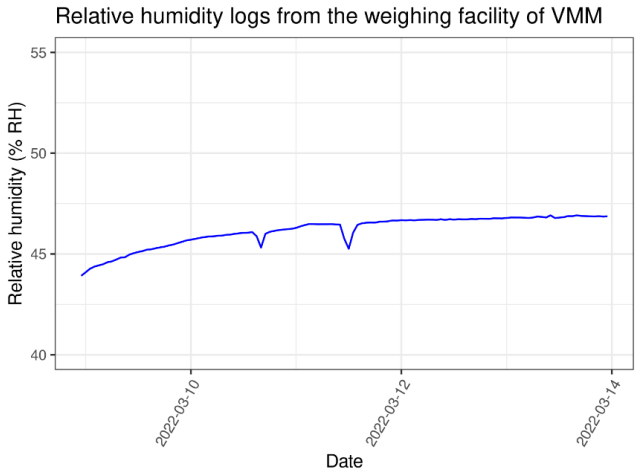
All weighing results are in milligrams. The difference is calculated by subtracting the mean weighing result of the participant laboratory by the mean weighing result of the pilot laboratory.

[h] Outlier as indicated by Mandel's *h* statistics (99% probability).

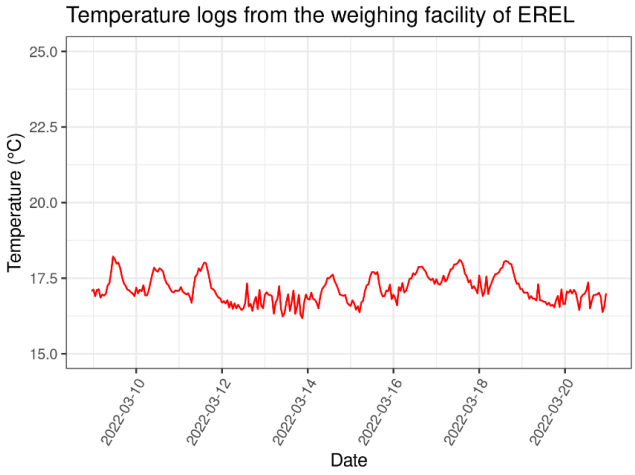
| Filter Code | Pilot | | | Participant | | | | Difference |
|---|---|---|---|---|---|---|---|---|
| | Before | After | Mean | First | Second | Third | Mean | |
| A25 | 149.664 | 149.498 | 149.581 | 149.505 | 149.507 | | 149.506 | 0.075 |
| A26 | 147.851 | 147.832 | 147.841 | 147.826 | 147.821 | | 147.824 | 0.018 |
| A27 | 149.548 | 149.422 | 149.485 | 149.434 | 149.431 | | 149.433 | 0.052 |
| A28 | 147.379 | 147.276 | 147.327 | 147.277 | 147.272 | | 147.275 | 0.053 |
| A29 | 149.864 | 149.664 | 149.764 | 149.657[h] | 149.643[h] | | 149.650 | 0.113 |
| A30 | 151.737 | 151.558 | 151.647 | 151.529[h] | 151.517[h] | | 151.523 | 0.124 |
| A31 | 148.076 | 147.936 | 148.006 | 147.933 | 147.924[h] | | 147.929 | 0.078 |
| A32 | 144.282 | 144.181 | 144.231 | 144.169 | 144.158 | | 144.164 | 0.068 |
| B13 | 148.295 | 148.278 | 148.286 | 148.267 | 148.268 | | 148.268 | 0.019 |
| B14 | 144.626 | 144.610 | 144.618 | 144.594 | 144.600 | | 144.597 | 0.021 |
| B15 | 147.488 | 147.469 | 147.478 | 147.453 | 147.460 | | 147.457 | 0.022 |
| B16 | 141.993 | 141.966 | 141.979 | 141.942[h] | 141.950 | | 141.946 | 0.033 |
| | | | | | | | | |
| A33 | 144.825 | 144.791 | 144.808 | 144.801 | 144.800 | | 144.801 | 0.007 |
| A34 | 147.106 | 147.037 | 147.072 | 147.052 | 147.049 | | 147.051 | 0.021 |
| A35 | 148.723 | 148.721 | 148.722 | 148.719 | 148.719 | | 148.719 | 0.003 |
| A36 | 150.056 | 149.969 | 150.012 | 149.991 | 149.988 | | 149.990 | 0.023 |
| A37 | 146.882 | 146.883 | 146.882 | 146.877 | 146.875 | | 146.876 | 0.006 |
| A38 | 148.876 | 148.856 | 148.866 | 148.860 | 148.859 | | 148.860 | 0.006 |
| A39 | 149.565 | 149.510 | 149.537 | 149.522 | 149.522 | | 149.522 | 0.015 |
| A40 | 149.116 | 149.055 | 149.085 | 149.064 | 149.078 | | 149.071 | 0.014 |
| B17 | 146.539 | 146.563 | 146.551 | 146.550 | 146.552 | | 146.551 | 0.000 |
| B18 | 147.421 | 147.435 | 147.428 | 147.424 | 147.425 | | 147.425 | 0.003 |
| B19 | 148.455 | 148.471 | 148.463 | 148.457 | 148.459 | | 148.458 | 0.005 |
| B20 | 146.379 | 146.400 | 146.389 | 146.386 | 146.387 | | 146.387 | 0.002 |
| | | | | | | | | |
| A41 | 146.840 | 146.737 | 146.788 | 146.764 | 146.765 | | 146.765 | 0.024 |
| A42 | 146.519 | 146.445 | 146.482 | 146.461 | 146.462 | | 146.462 | 0.020 |
| A43 | 147.177 | 147.080 | 147.128 | 147.119 | 147.123 | | 147.121 | 0.007 |
| A44 | 145.420 | 145.307 | 145.363 | 145.344 | 145.354 | | 145.349 | 0.014 |
| A45 | 149.243 | 149.114 | 149.178 | 149.148 | 149.142 | | 149.145 | 0.033 |
| A46 | 148.624 | 148.482 | 148.553 | 148.531 | 148.528 | | 148.530 | 0.024 |
| A47 | 147.051 | 146.973 | 147.012 | 147.008 | 147.012 | | 147.010 | 0.002 |
| A48 | 148.938 | 148.846 | 148.892 | 148.890 | 148.889 | | 148.890 | 0.002 |
| B21 | 146.460 | 146.470 | 146.465 | 146.463 | 146.469 | | 146.466 | -0.001 |
| B22 | 148.331 | 148.269 | 148.300 | 148.267 | 148.275 | | 148.271 | 0.029 |
| B23 | 147.402 | 147.428 | 147.415 | 147.419 | 147.429 | | 147.424 | -0.009 |
| B24 | 146.905 | 146.913 | 146.909 | 146.913 | 146.924 | | 146.919 | -0.010 |
| | | | | | | | | |
| A49 | 148.303 | 148.235 | 148.269 | 148.245 | 148.254 | | 148.250 | 0.019 |
| A50 | 148.671 | 148.595 | 148.633 | 148.599 | 148.616 | | 148.608 | 0.025 |
| A51 | 146.500 | 146.392 | 146.446 | 146.419 | 146.439 | | 146.429 | 0.017 |
| A52 | 147.577 | 147.512 | 147.544 | 147.517 | 147.536 | | 147.527 | 0.018 |
| A53 | 147.054 | 147.006 | 147.030 | 147.003 | 147.016 | | 147.010 | 0.021 |
| A54 | 148.771 | 148.701 | 148.736 | 148.709 | 148.720 | | 148.715 | 0.021 |
| A55 | 148.517 | 148.447 | 148.482 | 148.453 | 148.466 | | 148.460 | 0.023 |
| A56 | 150.442 | 150.370 | 150.406 | 150.372 | 150.396 | | 150.384 | 0.022 |
| B25 | 146.752 | 146.761 | 146.756 | 146.730 | 146.743 | | 146.737 | 0.020 |
| B26 | 146.806 | 146.805 | 146.805 | 146.778 | 146.791 | | 146.785 | 0.021 |
| B27 | 148.003 | 147.998 | 148.000 | 147.976 | 147.984 | | 147.980 | 0.020 |
| B28 | 146.451 | 146.454 | 146.453 | 146.423 | 146.445 | | 146.434 | 0.019 |

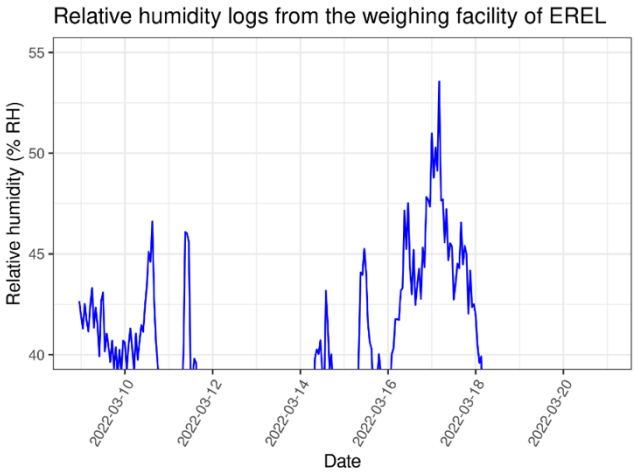
# Annex 3 Weighing room conditions of every participant



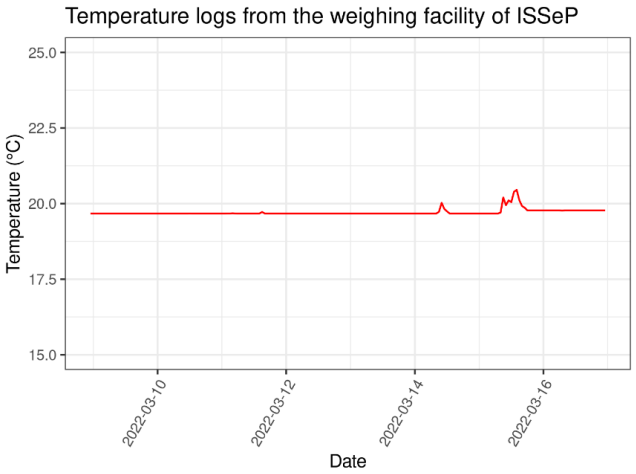



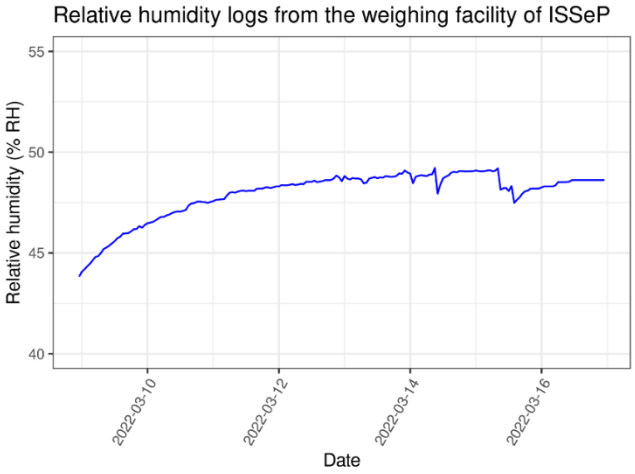

*Weighing room conditions of laboratory 1*



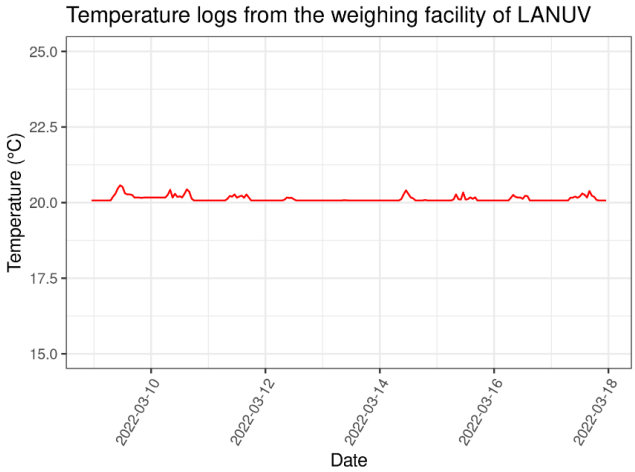



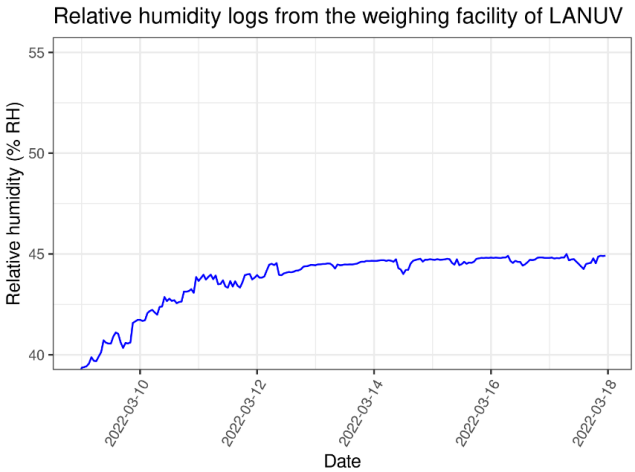

*Weighing room conditions of laboratory 2*



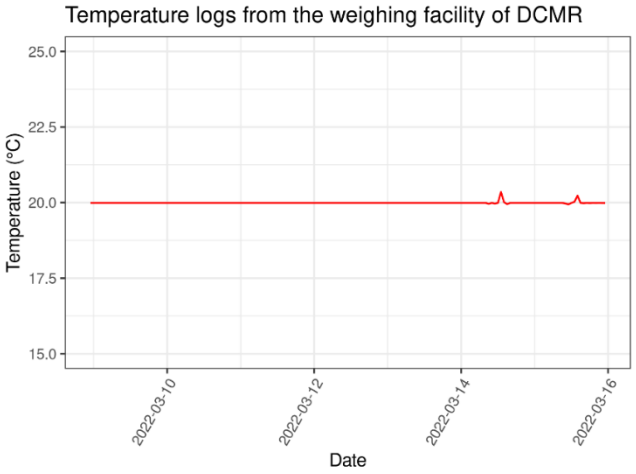



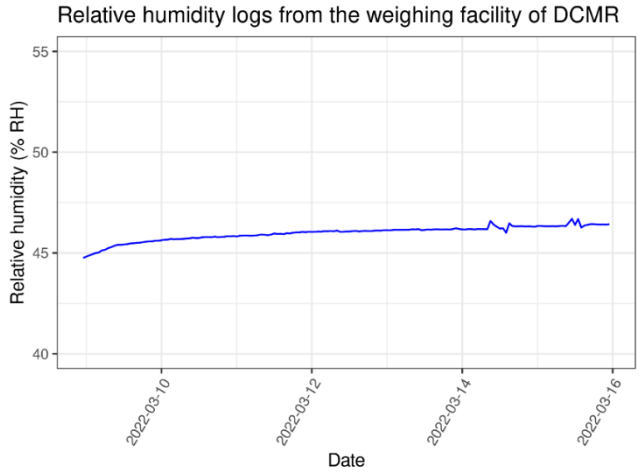

*Weighing room conditions of laboratory 3*



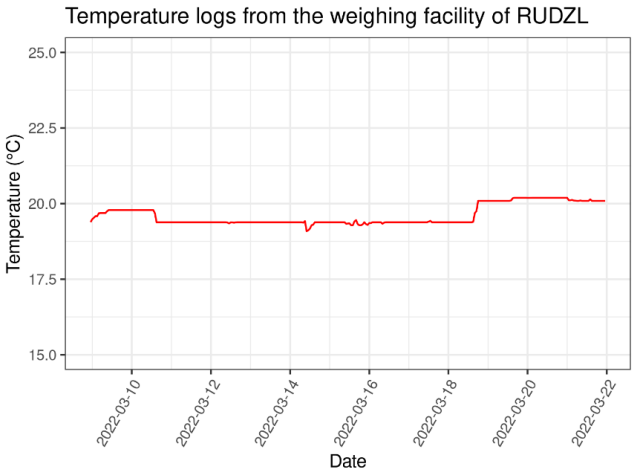



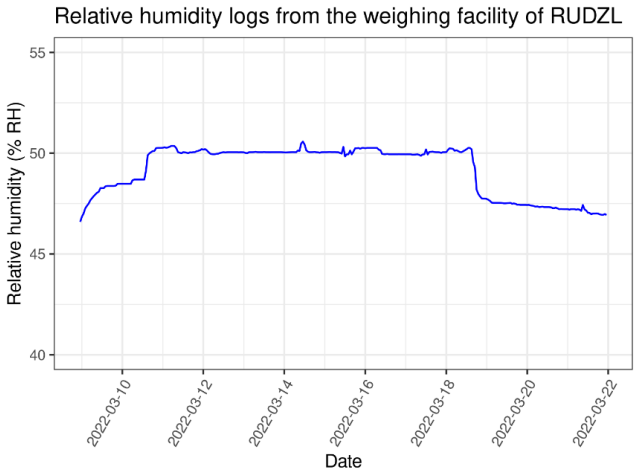

*Weighing room conditions of laboratory 4*



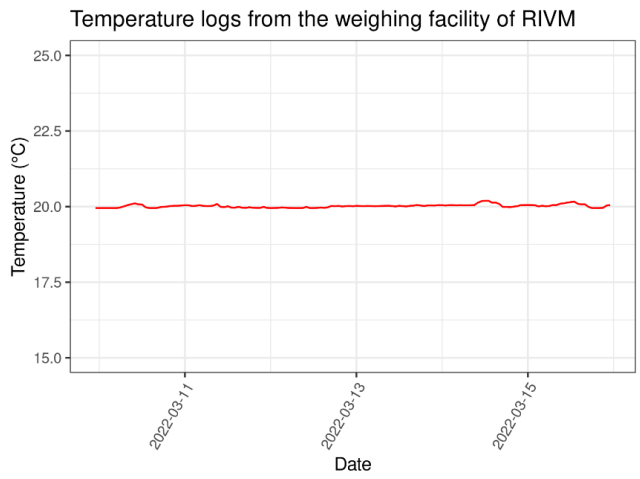



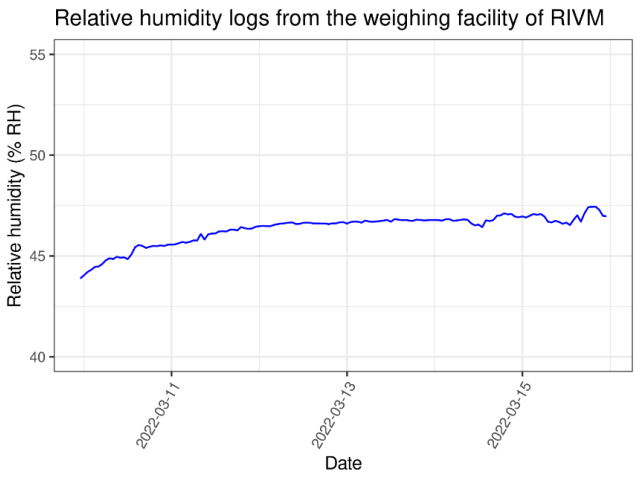

*Weighing room conditions of laboratory 5*




*Weighing room conditions of laboratory 6*




*Weighing room conditions of laboratory 7*

# Annex 4 Laboratory performance evaluation

| *Filter code* | *Pilot* | | *Participant* | | *En number* |
|---|---|---|---|---|---|
| | *Mean* | *Uncertainty* | *Mean* | *Uncertainty* | |
| A1 | 149.725 | 0.034 | 149.710 | 0.009 | 0.15 |
| A2 | 148.120 | 0.038 | 148.122 | 0.009 | 0.02 |
| A3 | 145.374 | 0.009 | 145.373 | 0.009 | 0.00 |
| A4 | 149.128 | 0.033 | 149.126 | 0.009 | 0.02 |
| A5 | 147.038 | 0.011 | 147.017 | 0.009 | 0.28 |
| A6 | 150.989 | 0.034 | 150.982 | 0.009 | 0.07 |
| A7 | 147.122 | 0.023 | 147.112 | 0.009 | 0.12 |
| A8 | 148.798 | 0.013 | 148.797 | 0.010 | 0.00 |
| B1 | 146.419 | 0.009 | 146.421 | 0.008 | 0.03 |
| B2 | 147.533 | 0.009 | 147.547 | 0.008 | 0.27 |
| B3 | 143.332 | 0.009 | 143.331 | 0.008 | 0.03 |
| B4 | 148.294 | 0.009 | 148.297 | 0.008 | 0.05 |
| | | | | | |
| A9 | 150.155 | 0.034 | 150.063[k] | 0.015 | 0.91 |
| A10 | 147.963 | 0.020 | 147.930 | 0.012 | 0.40 |
| A11 | 147.207 | 0.028 | 147.143 | 0.008 | 0.72 |
| A12 | 149.077 | 0.027 | 149.050[k,*] | 0.014 | 0.29 |
| A13 | 144.076 | 0.016 | 144.043 | 0.009 | 0.42 |
| A14 | 148.119 | 0.023 | 148.108[k] | 0.013 | 0.13 |
| A15 | 147.086 | 0.022 | 147.090[k] | 0.014 | 0.04 |
| A16 | 150.182 | 0.037 | 150.120[k] | 0.019 | 0.57 |
| B5 | 149.134 | 0.009 | 149.125 | 0.010 | 0.17 |
| B6 | 146.377 | 0.009 | 146.353 | 0.008 | 0.47 |
| B7 | 149.271 | 0.009 | 149.250 | 0.009 | 0.40 |
| B8 | 148.102 | 0.010 | 148.100 | 0.008 | 0.03 |
| | | | | | |
| A17 | 147.834 | 0.038 | 147.815 | 0.008 | 0.18 |
| A18 | 147.374 | 0.008 | 147.363 | 0.008 | 0.15 |
| A19 | 146.767 | 0.043 | 146.744 | 0.008 | 0.20 |
| A20 | 149.920 | 0.023 | 149.896 | 0.008 | 0.29 |
| A21 | 148.974 | 0.021 | 148.958 | 0.008 | 0.20 |
| A22 | 148.990 | 0.029 | 148.990 | 0.008 | 0.01 |
| A23 | 146.853 | 0.037 | 146.831 | 0.008 | 0.21 |
| A24 | 146.727 | 0.037 | 146.701 | 0.008 | 0.26 |
| B9 | 146.807 | 0.009 | 146.797 | 0.008 | 0.20 |
| B10 | 147.601 | 0.008 | 147.595 | 0.008 | 0.12 |
| B11 | 149.111 | 0.008 | 149.121 | 0.008 | 0.18 |
| B12 | 148.154 | 0.010 | 148.155 | 0.008 | 0.01 |

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

[k] Outlier as indicated by Mandel's *k* statistics (99% probability).

* Outlier as indicated by Cochran's test statistics (99% probability).

| Filter code | Pilot | | Participant | | En number |
|---|---|---|---|---|---|
| | Mean | Uncertainty | Mean | Uncertainty | |
| A25 | 149.581 | 0.048 | 149.506 | 0.008 | 0.62 |
| A26 | 147.841 | 0.010 | 147.824 | 0.008 | 0.24 |
| A27 | 149.485 | 0.037 | 149.433 | 0.008 | 0.51 |
| A28 | 147.327 | 0.031 | 147.275 | 0.008 | 0.56 |
| A29 | 149.764 | 0.058 | 149.650 | 0.009 | 0.83 |
| A30 | 151.647 | 0.052 | 151.523 | 0.009 | 0.98 |
| A31 | 148.006 | 0.041 | 147.929 | 0.009 | 0.71 |
| A32 | 144.231 | 0.030 | 144.164 | 0.009 | 0.72 |
| B13 | 148.286 | 0.010 | 148.268 | 0.008 | 0.36 |
| B14 | 144.618 | 0.010 | 144.597 | 0.008 | 0.39 |
| B15 | 147.478 | 0.010 | 147.457 | 0.009 | 0.41 |
| B16 | 141.979 | 0.011 | 141.946 | 0.009 | 0.61 |
| | | | | | |
| A33 | 144.808 | 0.013 | 144.801 | 0.008 | 0.10 |
| A34 | 147.072 | 0.022 | 147.051 | 0.008 | 0.25 |
| A35 | 148.722 | 0.008 | 148.719 | 0.008 | 0.03 |
| A36 | 150.012 | 0.027 | 149.990 | 0.008 | 0.26 |
| A37 | 146.882 | 0.008 | 146.876 | 0.008 | 0.09 |
| A38 | 148.866 | 0.010 | 148.860 | 0.008 | 0.09 |
| A39 | 149.537 | 0.018 | 149.522 | 0.008 | 0.19 |
| A40 | 149.085 | 0.020 | 149.071 | 0.009 | 0.18 |
| B17 | 146.551 | 0.011 | 146.551 | 0.008 | 0.00 |
| B18 | 147.428 | 0.009 | 147.425 | 0.008 | 0.06 |
| B19 | 148.463 | 0.010 | 148.458 | 0.008 | 0.09 |
| B20 | 146.389 | 0.010 | 146.387 | 0.008 | 0.05 |
| | | | | | |
| A41 | 146.788 | 0.031 | 146.765 | 0.008 | 0.25 |
| A42 | 146.482 | 0.023 | 146.462 | 0.008 | 0.24 |
| A43 | 147.128 | 0.029 | 147.121 | 0.008 | 0.08 |
| A44 | 145.363 | 0.034 | 145.349 | 0.009 | 0.14 |
| A45 | 149.178 | 0.038 | 149.145 | 0.008 | 0.32 |
| A46 | 148.553 | 0.042 | 148.530 | 0.008 | 0.22 |
| A47 | 147.012 | 0.024 | 147.010 | 0.008 | 0.02 |
| A48 | 148.892 | 0.028 | 148.890 | 0.008 | 0.03 |
| B21 | 146.465 | 0.009 | 146.466 | 0.008 | 0.03 |
| B22 | 148.300 | 0.020 | 148.271 | 0.009 | 0.46 |
| B23 | 147.415 | 0.011 | 147.424 | 0.009 | 0.17 |
| B24 | 146.909 | 0.009 | 146.919 | 0.009 | 0.18 |
| | | | | | |
| A49 | 148.269 | 0.021 | 148.250 | 0.009 | 0.23 |
| A50 | 148.633 | 0.024 | 148.608 | 0.010 | 0.30 |
| A51 | 146.446 | 0.032 | 146.429[k] | 0.010 | 0.17 |
| A52 | 147.544 | 0.020 | 147.527 | 0.010 | 0.22 |
| A53 | 147.030 | 0.016 | 147.010 | 0.009 | 0.26 |
| A54 | 148.736 | 0.022 | 148.715 | 0.009 | 0.26 |
| A55 | 148.482 | 0.022 | 148.460 | 0.009 | 0.27 |
| A56 | 150.406 | 0.022 | 150.384 | 0.011 | 0.25 |
| B25 | 146.756 | 0.009 | 146.737 | 0.009 | 0.38 |
| B26 | 146.805 | 0.008 | 146.785 | 0.009 | 0.39 |
| B27 | 148.000 | 0.008 | 147.980 | 0.009 | 0.39 |
| B28 | 146.453 | 0.008 | 146.434[k] | 0.010 | 0.35 |

**RIVM**
Committed to *health and sustainability*