Swiss Agency for the Environment, Forests and Landscape (SAEFL)

PM10-Correction Models for Teom and Betameter Measurements

Comparative PM10 measurements,

in cooperation with the air pollution control agencies of the

Cantons of AG, GR, LU, ZH,

City of Zurich

EMPA Dübendorf

Summary of main report

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1. Introduction

PM10 air quality standards: in 1998, air quality standards for PM10 particulate matter (finely dispersed airborne particles with an aerodynamic diameter of less than 10 µm) were included in the Ordinance on Air Pollution Control (OAPC 1998). Subsequently, PM10 concentration has been measured at several points in Switzerland.

Measurement methods: operators of measurement networks have access to a range of measuring instruments based on different principles that are available on the market today. In Switzerland, high volume samplers (HVS), Teom and Betameter instruments are mainly used. The manually operated, gravimetric HVS accords with the reference method recently specified by the European Committee for Standardization in the EN 12341 standard (CEN 1999). The Teom and Betameter instruments measure continuously. These methods do not however accord with the reference method, and it is therefore necessary either to demonstrate equivalence with the reference method or to correct the measured values using suitable procedures. In the winter season, Teom measurements are systematically lower than parallel measurements obtained with an HVS. Results from the Betameter lie both above and below those of the HVS.

Comparative measurements: in 1999, the Swiss Agency for the Environment, Forests and Landscape brought together the comparative measurements available at the time in Switzerland in a report and interpreted these as far as this was possible (SAEFL 1999). It transpired that – as in other countries – there were systematic differences particularly between HVS and Teom, but that insufficient data were available to establish generally valid correction functions. At that time, the specialist agencies, which were planning more conclusive comparative measurements, decided to coordinate their tests, to record the results in a database, and evaluate these jointly. The idea behind the comparative measurements was to establish correction functions for average daily values from the Teom and Betameter equipment, and thereby to achieve equivalence with the reference method, or at least to achieve good agreement between the HVS data and the Teom and Betameter measurements at the niveau of the OAPC parameters. The present report presents the outcome of this cooperation.

2. Measurement program, procedure and quality assurance

Locations, PM10 instruments, measured variables: PM10 concentration was measured simultaneously with various instruments ('comparative measurements') at seven Swiss air pollution measurement stations in the Central Lowlands (Swiss Plateau) and in the Alps. Each station was equipped with an HVS instrument (DHA 80, Digitel Elektronik AG) and at least one Teom (1400AB Rev. B, Rupprecht & Patashnik Co) or Betameter instrument (Eberline-Betastaubmeter FH62 I-R). In addition to PM10, further gaseous pollutants and meteorological parameters were measured, which were needed for the development of analytical models. The measurement period extended from June 1999 to April 2001. Standard instrument settings were laid down and all of the (valid) measured data corrected to reference conditions ($T = 9\,°C = 282\ K$ and $p = 950\ hPa$) and recorded in a database.

In the report, the above measurement stations are treated as **reference stations** (further reference stations may be added later as mentioned in the Recommendations) and these must fulfill the following conditions: (1) parallel measurements over at least a full year, and (2) instrument settings as in the previous PM10 comparative test. The validity of the correction functions is monitored by specialists at the reference stations. These also compare the results with other reference stations and make their own data available for function optimization.

Measurement periods:

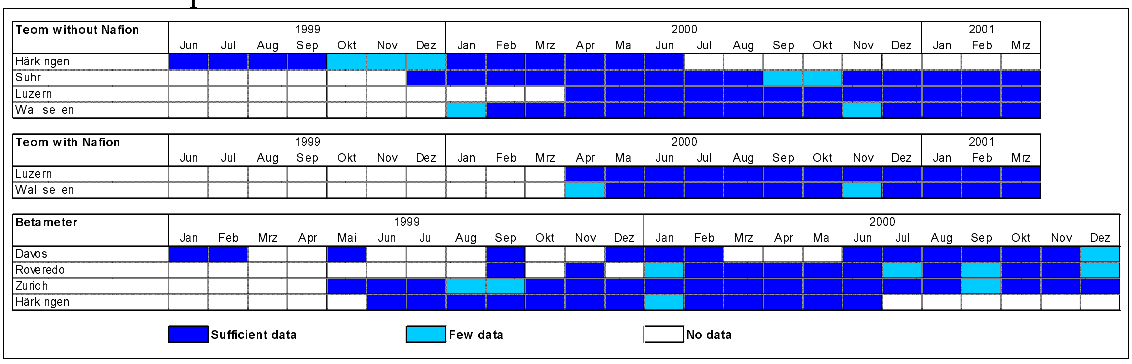

Fig. 1 Measurement periods and data availability.

Procedure: specification of common instrument settings and laboratory analysis methods, recording of measurement data, plausibilisation, conversion of the measured data to $T = 9$ °C (282 K) and $p = 950\ hPa$, recording in database, joint evaluation and interpretation.

Terminology for correction functions: the measured PM10 values based on HVS (symbol Y) are the values to be specified (target variable). This is achieved approximately by use of regression and periodic functions (symbol Y_{Mod}, *'Mod'* being an index for the function type). The other measured values – mainly of course those of PM10 from the Teom and Betameter instruments – are the determining (or explaining) variables, symbols: X= PM10 Teom/Betameter, T= temperature, N= NO_X.

Correction functions: in the evaluation, numerous regression and periodic functions were tested. Only the successful ones are included in the report. *This should not be taken to mean that the development of analytical functions had terminated at the time of writing the present report.* Some of the analytical models that were analyzed, but not included, consider further pollutants and meteorological parameters (pressure, humidity), and also include transformed variables (e.g. logarithmic pollutant concentrations).

All the determining variables are included in the analysis as *daily average values*[1].

Abb.(index *Mod*)	Function type	Function Y_{Mod}
RG1	Linear regression	$Y_{RG1} = a_0 + a_1 * X$
RG2	Linear regression	$Y_{RG2} = a_0 + a_1 * X + a_2 * T$
RG3	Linear regression	$Y_{RG3} = a_0 + a_1 * X + a_3 * N$
RG4	Linear regression	$Y_{RG4} = a_0 + a_1 * X + a_2 * T + a_3 * N$
RG0	Linear regression	$Y_{RG0} = a_1 * X$
Per (periodical)	Non-linear regression	$Y_{Per} = \{A + B * \sin[2 * \pi * (t - t_0 - C)/365)]\} * X$

Tab. 1: Types of correction functions.

Quality assurance: the interlaboratory test carried out by Cercl'Air in 2000 in Basel on PM10 measurements with HVS showed that the repeatability standard deviation is still very large (Cercl'Air, 2001). It is apparent that the EN 12341 standard still allows considerable variability in laboratory analysis methods, equipment settings and set-up, which may affect the measured results. Defining more specific recommendations on the performance of measurements and quality assurance is therefore a priority task.

1 To obtain valid daily average values, at least 24 valid half-hourly values are required on a particular day.

3. Correction functions for Teom measurements

Fig. 2 shows scatter plots for the Suhr Bärenmatte measuring station (exposed to traffic) in the Central Lowlands. In the figure at top left, the uncorrected Teom data (without Nafion) are compared with the HVS measurements. At top right, the Teom values have been corrected using the RG1 regression function, i.e. with PM10 as unique regression variable. At bottom left, the temperature is included as a further determining variable (RG2), leading to an improvement in the correlation (and in the coefficient of determination R^2) from 0.84 to 0.92. At bottom right, a periodic function is shown, in which the deviation between HVS and Teom is approximated by a sinusoidal oscillation with a period of one year.

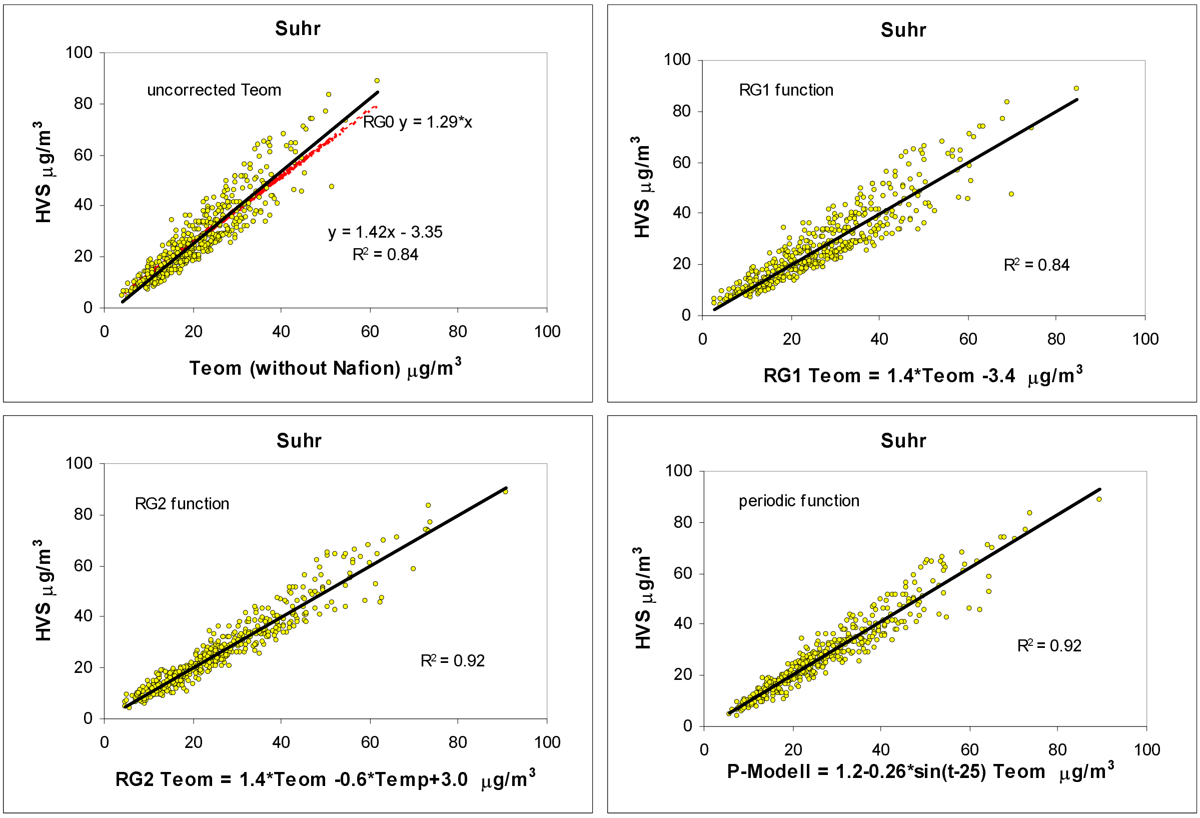

Fig. 2 *Results of the regression analyses for Suhr Bärenmatte (measurement period: December 99 to March 2001, N=478). The dashed line in the figure at top left is for the RG0 function.*

The results are typical of all the Teom measurements. The following are characteristic of stations with Teom instruments:

- The **PM10** measurement with Teom is of course the most important determining variable for HVS. Inclusion of the **temperature** leads to a considerable improvement in the correlation. However, **NO_x** has no significant effect. Neither are the other gaseous pollutants **CO, O_3 and SO_2 ,** nor the meteorological parameters **pressure** and **relative humidity,** relevant as determining variables.
- Comparison of Teom **with or without Nafion:** all the results show that the measurement data from Teom with Nafion lie closer to HVS than those without Nafion. Although this statement is not necessarily valid for individual daily values, it does apply to all observed totalities.
- None of the functions tested fulfill the requirements of **EN 12341** that **R^2** ≥ **0.95**. The calculated values lie in the range 0.63-0.92
- The functions are nevertheless appropriate for conversion of the Teom data to OAPC parameters. All of the functions provide *average values* that correspond well with the average HVS values. For the determination of the *number of days in which the average 24 h value of 50 µg/m³ is exceeded,* the functions display specific differences. The *periodic function* provides the best approximation to the number of days with exceedance.
- The function parameters vary only slightly between the various station locations, enabling *site-independent functions for the Central Lowlands* to be defined (since parallel measurements with Teom/HVS have till now only been performed in the Central Lowlands, it is not known to what extent the functions may also apply to Alpine stations and south of the Alps).

The following table provides an evaluation of the Central Lowlands functions for OAPC parameters. It shows the average values and the number of days > 50 µg/m³ for HVS and Teom instruments (column: 'measured values'), the corrected values (column: 'corrected values') and the deviations of the corrected values from HVS (column: 'deviation from HVS'). Although the functions prove very satisfactory for average values, there are significant differences for the number of days > 50 µg/m³. The periodic function displays the smallest deviations. The RWTÜV function is an RG1 function from a German comparative measurement, and has been occasionally used in Switzerland.

OAPC statistics	Parameters		Measured val. *Y*		Corrected values Y_{Mod}					Deviations from HVS				
			HVS	Teom	Per	RG0	RG1	RWTÜV	RG2	Per	RG0	RG1	RWTÜV	RG2
Luzern	Average val.	μg/m³	23.0	17.8	22.5	22.4	22.2	21.5	21.7	-0.4	-0.5	-0.7	-1.5	-1.3
	No. of days	>50μg/m³	11	2	9	3	4	4	7	-2	-8	-7	-7	-4
Suhr	Average val.	μg/m³	27.1	21.4	28.6	27.1	27.0	26.6	28.1	1.5	0.0	-0.1	-0.4	1.0
	No. of days	>50μg/m³	39	5	42	20	20	23	33	3	-19	-19	-16	-6
Härkingen	Average val.	μg/m³	25.4	21.1	25.2	26.7	26.5	26.2	25.5	-0.3	1.2	1.1	0.7	0.0
	No. of days	>50μg/m³	20	3	18	12	12	15	16	-2	-8	-8	-5	-4
Wallisellen	Average val.	μg/m³	20.8	16.4	21.1	20.7	20.5	19.5	21.3	0.3	-0.1	-0.3	-1.3	0.5
	every 2nd day	>50μg/m³	5	0	6	2	2	4	5	1	-3	-3	-1	0
all	Average val.	μg/m³			Root sum of deviations squared =					1.6	1.3	1.4	2.2	1.8
	No. of days	>50μg/m³			Root sum of deviations squared =					4	22	22	18	8

Tab. 2: Comparison of the Central Lowlands functions for Teom without Nafion.

Assessment:

- For Teom instruments, satisfactory correction functions may be found and specified. Simple linear functions such as RG0 and RG1 are well suited to the calculation of yearly average values. For the calculation of the number of days exceeding 50 μg/m³, the RG0 and RG1 functions provide an improvement, and this can be further raised using an RG2 function, which takes account of the temperature. However, the periodic model is best suited for inclusion of the temperature, since this accounts for the seasonal differences between Teom and HVS. Indeed, where parallel Teom and HVS measurements for a whole year are available at a particular measuring station, a reliable local correction function may be derived.
- It was found that the differences between local correction functions are small, at least for the Central Lowlands. Site-independent functions have therefore been included in the present publication. **These can be applied to stations for which parallel measurements are not available.**
- Measurements using Teom instruments equipped with the Nafion dryer system lie closer to HVS than those without Nafion. However, the differences are still so great that a correction is necessary. For this, the same correction functions may be used as for Teom without Nafion, whereby, however, different values apply to the regression coefficients.

Comparative measurements have also been carried out in recent years in other countries (EC PM 2001, Green 2001, Sen Stadt 2001). The results are comparable with

Swiss observations. So far, the functions presented abroad have not treated multiple regression, i.e. only linear and non-linear regression was carried out with PM10 as unique determining variable. In order to model the annual fluctuations, seasonally adjusted functions were introduced, and these may be regarded as an approximation to the periodic and RG2 functions applied in Switzerland (with temperature as supplementary determining variable). It was also found that significant – unexplained – differences exist, not only between the Teom and reference instruments, but also between the reference instruments themselves.

4. Correction functions for Betameter measurements

While the Teom measurements are generally lower than the HVS values, the Betameter measurements display both higher and lower values, but also partly correspond well with HVS. At some stations, the difference between Betameter and HVS fluctuates during the year as for Teom, but not at others. Indeed, the correction functions derived for Betameter instruments generally appear to be more site-dependent than for Teom. This raises a question that must remain unanswered in the present analysis.

As with Fig. 2, Fig. 3 shows scatter plots for both Betameter and HVS at the Stampfenbachstrasse in Zurich. The uncorrected measurements themselves correlate strongly with HVS ($R^2 = 0.93$), the correlation being stronger than for the Teom measurements in Suhr corrected using the periodic function! By using the RG2 function, the correlation can be slightly improved ($R^2 = 0.94$), thereby falling just short of the requirements of EN12341. In Zurich, the average value and number of days > 50 $\mu g/m^3$ using the Betameter are over predicted in comparison to HVS. Using a correction function (RG1, RG2), both parameters can be adjusted to correspond well with those of HVS. At the other sites with Betameter instruments, the situation is not as simple as in Zurich, and here, the deviations are not coherent.

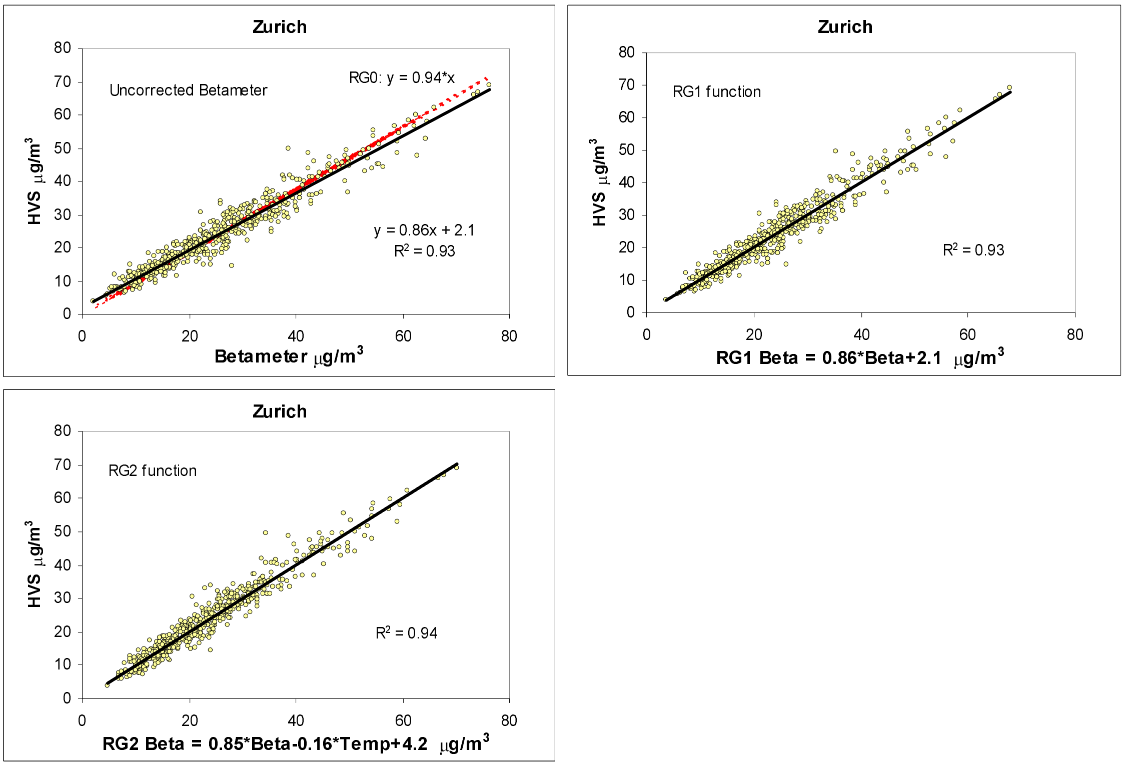

Fig. 3 *Results of the regression analyses for Stampfenbachstrasse in Zurich (measurement period December 99 to March 2001, N=478). The dashed line at top left is for the RG0 function.*

Conclusion from the analyses of the 4 Betameter stations (Zurich, Härkingen, Davos, Roveredo): in the Central Lowlands, the uncorrected Betameter data lie closer to HVS than those for Teom. Further improvements may be achieved with site-specific functions. For the assessment of PM10 exposure according to OAPC, the average values from Betameter measurements can be adjusted well to the reference average value for HVS using both the RG1 and RG2 regression functions. Concerning the number of exceedances, these functions perform somewhat worse than for Teom. However, the models approximate the number of exceedances better than without correction. An exception is the Härkingen station, where the models improve the average values but worsen the number of exceedances. Härkingen is also an exception in that here, the relationship HVS/Betameter displays a clear annual oscillation. Thus for Härkingen, the periodic function gives the best results, whereas this is not true of the other three sites. The measurements now available do, however, at least permit a relationship to be identified between the two Central Lowlands sites in Zurich and Härkingen, and also between the two Alpine sites in Davos and Roveredo. For this reason, Central Lowlands and Alpine functions were established (each based on two sites), whereby, however, the statistical basis for these was weaker than for Teom (for which the Central Lowlands could be based on four sites).

The following table gives an evaluation for the Central Lowlands and Alpine functions for OAPC parameters in the same way as Tab. 2. The average values and the number of days > 50 µg/m^3 for HVS and Betameter instruments are entered along with the corrected values.

OAPC statistics	Parameters		Measured values		Central Lowlands functions			
			HVS	Betameter	RG0	RG 1	RG 2	Periods
Zurich	Average val.	µg/m^3	24.1	25.6	24.1	24.4	24.3	25.0
	No. of days	>50µg/m^3	15	28	24	21	24	33
Härkingen	Average val.	µg/m^3	26.3	27.3	25.6	25.8	25.8	26.6
	No. of days	>50µg/m^3	29	21	16	14	16	24

OAPC statistics	Parameters		Measured values		Alps functions		
			HVS	Betameter	RG0	RG 1	RG 2
Roveredo	Average val.	µg/m^3	25.9	21.7	28.1	26.6	26.1
	No. of days	>50µg/m^3	14	7	25	9	10
Davos	Average val.	µg/m^3	13.7	7.9	10.2	12.6	13.2
	No. of days	>50µg/m^3	0	0	2	1	1

Tab. 3: *Betameter: comparison between measured and average values for the Central Lowlands functions applied to the Zurich and Härkingen sites. Ditto for the Alps functions applied to Roveredo and Davos.*

In the literature, significantly fewer evaluations of Betameter/HVS are available than for Teom/HVS. In an investigation carried out in Berlin (Sen Stadt 2001), the relationship between HVS and Betameter measurements changed significantly at different filter service lives (which, however, is not the subject of comparative Betameter/HVS measurements, but rather of comparisons between Betameters themselves). In the Swiss comparative measurements, the filter service life parameter was not standardized, and had indeed been set differently by the measurement network operators.

5. Conclusions, recommendations and future perspectives

5.1. Conclusions

In the earlier SAEFL publications on comparative PM10 measurements, it had not then been possible to derive correction functions. In comparison to the earlier work, the coordinated comparative tests over the last two years represent a major step forward. It is now possible to derive **excellent site-specific correction functions for Teom and satisfactory functions for Betameter instruments,** with which the OAPC parameters can be approximated based on the reference procedure. Indeed, for the Teom instrument, **site-independent** functions are now available, at least for the Central Lowlands. For the Betameter instruments, site-independent functions have also been proposed, but the statistical basis for these is still relatively weak.

5.2. Recommendations for the choice of function

The functions recommended in the following are to be used with this parameterization only if the instrument settings correspond with those of the reference stations (Appendix A1). For other settings, the parameters given are not optimal.

Teom measurements: the periodic model is principally recommended:

- Advantages: good estimate of the yearly average value, very good estimate of the number of days > 50 $\mu g/m^3$, independently of the choice of reference variables, physically justified, interpretable parameters, good statistical quality (coefficient of determination), may be simplified to RG0 for calculating the yearly average value.
- Disadvantages: choice of a reference date (21.03.XX) of the measurement year, calculation somewhat more complicated than for simple regression (inclusion of the date in the formula).

Function	Central Lowlands periodic functions	RG0 approximation
Teom **without** Nafion dryer	$Y_{Per}(t) := X(t) * \left[1.27 - 0.30 * \sin\left(2 * \pi * \frac{t - t_0 - 7.8d}{365}\right)\right]$	$Y_{RG0} = 1.27 * X$
Teom **with** Nafion dryer	$Y_{Per}(t) := X(t) * \left[1.17 - 0.23 * \sin\left(2 * \pi * \frac{t - t_0 - 15.3d}{365}\right)\right]$	$Y_{RG0} = 1.17 * X$
Suitability	Estimation of yearly average and number of exceedances of 50 µg/m^3 of Teom daily average values X(t)	For estimating yearly average from measured yearly average Teom X only
Note	Symbols: t = date, t_0 = 21 March of the measurement year, (d=day)	

Tab. 4: *Recommended periodic functions for the Central Lowlands for Teom measuring instruments.* ***The recommended functions are independent of the reference values*** *and apply both to the previous (T = 9 °C, p = 950 hPa) and for future (T = 20 °C, p = 1013 hPa) reference values.*

Measured Betameter values: different correction functions are recommended for the Central Lowlands and the Alps as follows:

Central Lowlands: RG0 function

- Advantages: good estimate of the yearly average value, very simple function, independent of the choice of reference values, interpretable parameters.
- Disadvantages: fairly good estimate of the number of days > 50 µg/m^3, no physical interpretation, fairly good statistical properties.

Alps: RG2 function

- Advantages: good estimate of the yearly average value, the best of all alternatives seen from a statistical point of view
- Disadvantages: dependent on the choice of reference values, only applicable if Betameter and temperature measurements available.

Function	Central Lowlands	Alps
Betameter: previous reference values **9°C, 950 hPa**	$Y_{RG0} = 0.938 * X$	$Y_{RG2} = 1.041 * X - 0.161 * T + 5.451$
Betameter: future reference values **20°C, 1013 hPa**	$Y_{RG0} = 0.938 * X$	$Y_{RG2} = 1.041 * X - 0.165 * T + 5.493$
Suitability	For yearly average and number of days > 50 µg/m^3	For yearly average and number of days > 50 µg/m^3
Notes	The RG0 functions are independent of reference conditions.	The RG2 functions are dependent of the reference conditions. The regression coefficients a_0 and a_2 therefore differ.

Tab. 5: Recommended Central Lowlands and Alpine functions for Betameter instruments. In the Central Lowlands, the RG0 function is the same for all reference values. In the Alps, a difference must be made.

5.3. Further recommendations

Verification of correction functions

The recommended functions were derived from measured data from **all** the reference stations. If more data had been available, the data set could have been divided into two parts before performing the regression analysis, the first part being used to establish the function parameters and the other to verify the functions. For Teom without Nafion, to which most of the measurements applied, this procedure was chosen for determining the Central Lowlands functions. A more rigorous verification of the functions is pending and needs to be carried out with future data from the reference stations or – better still – with data from other stations.

HVS

Comparative tests such as the interlaboratory test in Basel, and the comparative series in Berlin, have shown that even for reference instruments, it was not easy to establish strong correlations. For flow calibration, laboratory analysis and filter procedures, further standardization work is therefore necessary. Initial steps in this direction have been undertaken in the standardization guidelines of the EMPA, in-LUFT and OSTLUFT (all the standardization guidelines are obtainable on request).

It is also desirable to quantify the measurement uncertainties of the reference method. This would offer an opportunity to assess the quality of a correction function (this is optimal when the deviation from HVS is lower than the measurement uncertainty).

Teom

In future, it is to be expected that an increasing number of Teom instruments will be fitted with Nafion dryers. As this system did not come onto the market until the present investigation had started, only two stations were equipped with it. To increase the reliability of the proposed site-independent functions, data from further sites are desirable. Also, no comparative measurements with Teom instruments (with or without Nafion dryers) are available from Alpine regions, so that no assessment is possible there.

All results presented in the present report are based on an evaluation of daily average values. However, it would also be possible to perform regression analyses with half-hourly values[2]. Particularly for Teom measurements, this approach could be worthwhile, since the fluctuations in daily average temperatures are responsible for the greater part of the deviation between Teom and HVS. However, the temperature variations during the day are themselves large and are neglected in the method used here.

Betameter

To what extent the characteristics of the Grisons data may be applied to other Alpine sites is not known. To determine this, further comparative measurements in the Alps would be required. Also, the dependency of the measurements on the filter life cycle needs to be checked for one or two Swiss sites.

Statistics

In common with the analyses cited from abroad, and as usual for reference methods, the present study assumes that the target variable based on HVS is precisely measurable, i.e. has no scatter. Thus all of the regression analyses are performed under the assumption that only the Teom and Betameter measurements are subject to error. In fact, however, the HVS measurements themselves are uncertain, as the interlaboratory test in 2000 in Basel clearly showed (Cercl'Air 2001). If, however, both the variables in a regression are subject to random errors ('errors in variables'), steeper linear regression functions prove better. The optimum inclination depends on the relationship between the scatter in the measurement errors. An initial test was

2 This method produces different results only if non-linear functions are used.

performed using the data for the Lucerne station. The number of exceedances is higher for the errors-in-variables function.

When the number of days exceeding 50 µg/m^3 is used as the criterion for function quality, this focuses attention one-sidedly on the high concentration values. To obtain a better function assessment procedure from a statistical point of view, not only should the model values > 50 µg/m^3 be counted but also probability methods should be more generally applied. The corrected values are random variables with a corresponding probability distribution. Thus in addition to counting the exceedance of the average value (= corrected value), that of neighboring values should also be counted, whereby the prediction quality (probability prediction) would vary. With this (more complex) procedure, all the functions discussed here could be assessed in more depth. For the moment, the question whether this method would lead to a different order of priority among the functions must remain open.

Function development

To permit the recommended functions to be verified, and if necessary modified, the comparative tests will be continued at certain stations. Data from these, as well as data from new comparative tests at further stations, will need to be recorded in the existing database.

In the present study, only a few of the proposed functions could be considered. The comparative tests of PM10 in Switzerland and abroad will be continued, and this will permit further experience to be gained with differences in measurement methods, finally allowing the analytical procedures to be standardized.

Recommendations of the EC Working Group on particulate matter

The draft of the final report on 'Guidance to Member States on PM10 Monitoring and Intercomparisons with the Reference Method' (EC PM 2001) was published recently (27 August, 2001). It contains a wide range of results from comparative measurements using Teom/HVS and Betameter/HVS, and makes recommendations on procedure.

Qualitatively, the results are similar to the Swiss results. For conversion purposes, RG0 and RG1 functions are recommended with seasonal, or even monthly, fitting where this is required by the comparative measurements. This amounts in effect to applying a periodic function. In certain countries, significant differences appear between the regression coefficients. The report therefore contains comprehensive and practical recommendations on the performance of comparative measurements. To monitor the stability of the correction functions, these should not be carried out once only, but repeatedly at intervals. As long as countries perform no comparative measurements of their own, the working group recommends using a correction factor of 1.3 for both Teom and Betameter instruments. Basically, each country or region should carry out comparative tests at at least two sites in order to establish correction functions, on the basis of which the Teom and Betameter measurements are corrected.

The proposed correction factor of 1.3 is almost identical to the factor of 1.27,[3] recommended in the present report for Teom measurements (without Nafion) (Tab. 4). This corresponds to the RG0 approximation to the periodic function[4]. At this level of approximation, the results in Switzerland and abroad are in good agreement. The factor of 1.3 is also recommended for Betameter measurements by the EC working group. However, the Swiss Betameter measurements display large differences from one site to another, the correction factors varying between 0.9 and 1.4.

5.4. Future perspectives

HVS interlaboratory test: on 24 –31 October 2001, the Cercl'Air working group on quality assurance will carry out an interlaboratory test with HVS in Dübendorf. This will enable the repeatability standard deviation to be determined. Also, the volumetric flow rate will be determined with a certified Rotameter, and the airtightness of the entire system and the filters checked.

Teom: In-LUFT will clarify how best to correct the (half-)hourly Teom measurements so that they may be accessed online on the Internet and via SMS.

3 1.17 for Teom with Nafion. For this, the EC working has (still) not issued any recommendations.

4 The periodic function reduces to the RG0 function if the annual period with HVS/Teom is neglected.

Appendix

A.1 Measurements: instrument settings and standard conditions

Instrument settings

Detailed information on setting HVS, Teom and Betameter instruments are to be found in the main report, Appendix 1. Standard working guidelines are also available for this, and these may be obtained from EMPA in Dübendorf, in-LUFT in Lucerne and OSTLUFT in Zurich.

Reference conditions

All of the measured data used in the comparative test were corrected to the (still) valid Swiss standard conditions (Temperature T = 9°C = 282 K, ambient pressure p = 950 hPa). These are soon to be altered to accord with European recommendations for gaseous air pollutants (T = 20°C = 293 K, p = 1013 hPa according to guideline 1999/30/EC of 22.04.99). For particles, no reference conditions have been defined[5]. These are important, since they may partly influence the parameterization of the correction functions.

A2. Notes on statistics

The mathematical and statistical assumptions for regression analyses (normal distribution and independency of the residuals) are only partly fulfilled for the functions analyzed. Although the residuals have a bell-shaped profile, they display differing skewness and narrow peaks (leptokurtic). The chi squared test gives a normal distribution in some cases, but not in others. Furthermore, the residuals display more or less autocorrelation, and thus are not independent. The independence improves in moving from RG1 to RG2 and to the periodic functions. In consequence, the errors determined in the regression coefficients are unreliable. To obtain more suitable conditions, robust methods must be applied and autoregressive functions used. It is

5 In EN 12341 'Determination of PM10 fraction in suspended particulates, reference method, etc.', standard conditions are specified (1013 hPa, 273 K). However, these only apply to certification of the equivalence of PM10 instruments, and not to the publication of measured data and their comparison with the impact thresholds.

possible that the normal distribution and independence of the residuals could be improved by an extended regression analysis ('errors-in-variables').

A3. Details of analytical evaluations

The main report (Appendix A3) provides further results of the statistical evaluations. Thus the number of days with exceedances, apart from those of 50 µg/m^3, are also quoted for 35 µg/m^3, 40 µg/m^3 up to 60 µg/m^3 for all measured and corrected values.

A4. Optimum functions for reference stations

The main report also contains optimum functions for the Davos, Härkingen, Lucerne, Roveredo, Suhr, Wallisellen and Zurich reference stations.

A5. Interlaboratory test on filter weighing

During the comparative test, a simple interlaboratory test for filter weight measurement was performed. In this, 10 HVS filters (of which 5 were uncharged and 5 charged with an exposure time of 24 h) were measured in all the laboratories. In the weight measurements, fictive particle charges were calculated from the difference between charged and uncharged filters, and the repeatability standard deviation determined. This lay between 1.2% and 1.9% of the average value. In the interlaboratory test in 2000 in Basel, in which 8 HVS instruments were included, the reference standard deviation was 16% of the average value. Although the experimental set-up is not the same for the interlaboratory test in Basel and in the filter weight measurement test, the above difference suggests that **filter weight measurement contributes only marginally to the total uncertainty of an HVS measurement.** The new HVS interlaboratory test in Dübendorf will provide more precise answers to this question.

Abbreviations

AfU GR	Environmental Protection Agency of the Canton of Grisons (Amt für Umwelt des Kantons Graubünden)
AfU LU	Environmental Protection Agency of the Canton of Lucerne (Amt für Umweltschutz des Kantons Luzern)
AUS AG	Environmental Protection Agency of the Building Department of the Canton of Aargau (Abteilung Umweltschutz des Baudepartements Kanton Aargau)
AWEL ZH	Office for Waste Management, Water, Energy and Air of the Canton of Zurich (Amt für Abfall, Wasser, Energie und Luft des Kantons Zürich)
SAEFL	Swiss Agency for the Environment, Forests and Landscape
EMPA	Swiss Federal Laboratories for Materials Testing and Research
HVS	High volume sampler
in-LUFT	Intercantonal air pollution monitoring network, environmental protection agencies of the six Cantons of Central Switzerland in collaboration with the Canton of Aargau (Das interkantonale Luftmessnetz)
OAPC	Ordinance on Air Pollution Control
LVS	Low volume sampler
NABEL	National Air Pollution Monitoring Network
CO	Carbon monoxide
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides: sum of NO and NO_2
O_3	Ozone
SO_2	Sulfur dioxide
PM10	Fine particulates (finely dispersed airborne particulates with an aerodynamic diameter <10 µm)
UGZ ZH	Environmental and Health Protection Agency of the City of Zurich
WRAC	Wide range aerosol classifier

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