Measuring protocol wind tunnels

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Air Quality

Version july 2013

Introduction

The Dutch Road Authority (Rijkswaterstaat) has taken the initiative to establish a harmonised method defining a minimum required comparability of measurement results from different wind tunnel facilities. This is due to the lack of a standardised method for air quality research in wind tunnels.

> This measuring protocol aims to harmonise the various methods employed during air quality research in wind tunnels in the Netherlands.

The following parties have contributed to this measuring protocol (alphabetic order):

- DNW
- DNV KEMA
- Peutz
- RIVM - Rijksinstituut voor Volksgezondheid en Milieu
- RWS- DWW Rijkswaterstaat – Dienst Weg- en Waterbouwkunde
- TNO
- TU-Delft Faculteit Werktuigbouwkunde
- University of Hamburg - EWTL Environmental Wind Tunnel Laboratory
- Von Karman Instituut (België)

The present document represents the Dutch 'state-of-the-art' reached after roughly two years of discussions, testing and benchmarking by experts from all three Dutch wind tunnels. Professor Bernd Leitl of the Meteorologisches Institut of the Universität Hamburg participated in the discussions as an outside expert.

The protocol is (almost by definition) never finished. Presently, according to professor Leitl, there are some open issues that should still be addressed:

- The overall structure of the protocol is perhaps not perfect - a new user might miss a more clear separation of
  1. administrative/normative background
  2. physical backgrounds
  3. reference quantities / parameters
  4. implementation of the protocol in a step by step example

- There are many parts reflecting the individual concerns of particular wind tunnel laboratories during the first round of drafting the protocol. A lot of consensus has been built among the potential users in the present version. The present draft should be checked for items that have already been agreed on and common standards should be defined as strict as possible.

- In order to reach the intended agreement of results from different wind tunnels within 10...15%, either a very similar test set-up or a very detailed documentation of the test data will be vital. Whereas the latter is extending test efforts and costs, the former must be precisely defined by the wind tunnel modelers within the scope of the protocol.

In the summer of 2013 the wind tunnels of Peutz and TNO are operated in accordance with this protocol.

By request of the Dutch ministry of Infrastructure and the Environment the wind tunnel protocol is published as a report of the National Institutes for Public Health and the Environment (RIVM). The RIVM is, however, not responsible for the content of the protocol, it was only one of the parties involved in drafting the protocol.

Contents

1 Scope

This measuring protocol focuses on wind tunnel research for improvement of the ambient air quality along motorways for PM_{10} and NO_2. Specific criteria are set for the set-up and realisation of dispersion measurements in wind tunnels.

This measuring protocol is to be applied to wind tunnel studies, concerning traffic induced air pollution in urban and rural surroundings for:

- The effect of screens
- The effect of elevated and lowered roads, road coverings and tunnel outlets

This wind tunnel research shall be performed in an atmospheric boundary layer wind tunnel or in a conventional wind tunnel facility specifically adapted for modelling flow and dispersion phenomena within the lower atmospheric boundary layer.

This measuring protocol sets **additional** criteria for air quality research in wind tunnels. The criteria set in the NEN 8100 and CUR 103 are mandatory in any case as long as no other specific criteria or additional criteria are specified in this measuring protocol.
This is because the NEN and CUR apply to wind tunnel measurements in general and do not specifically cover air quality measurements.

2 Normative references

NEN 8100	–	Windhinder en windgevaar in bebouwde omgeving
CUR 103	–	Aanbeveling 103. Windtunnelonderzoek. Civieltechnisch Centrum Uitvoering Research en Regelgeving
VDI 3783/12	–	Environmental Meteorology. Physical modelling of flow and dispersion processes in the atmospheric boundary layer. Application of wind tunnels. December 2000.
RBL 2007	–	Regeling Beoordeling Luchtkwaliteit 2007, Staatscourant 13 november 2007, 220, pagina 21.

If relevant, the last version of the before specified documents applies.

3 Characterisation of the wind field in the wind tunnel

3.1 Approach flow

In the scale model, the atmospheric boundary layer is simulated as approach flow with the following similarity:

$$\left[\frac{\bar{u}(z)}{u_{ref}}\right]_{Model} = \left[\frac{\bar{u}(z)}{u_{ref}}\right]_{Full\ scale}$$

In which,

$\bar{u}(z)$	-	time averaged wind velocity at height z
u_{ref}	-	average wind velocity at reference height

3.2 Choice of the roughnes length for the approach wind field

Depending on the location of the field site to be tested/evaluated, one of the four full-scale roughness classes has to be chosen from table 1.

Based on the desired model scale, the approach flow conditions to be modelled can be derived from length scales provided for one roughness class in table 1.
The wind tunnel roughness of the approach flow field shall be established up to the model under test (e.g. screen) and on the whole turn table.

Table 1. Roughness lengths, profile exponents and zero displacements (according to VDI 3783 Part 12, table 2)

Parameter		Roughness class			
		Slightly rough	Moderately rough	Rough	Very rough
Terrain type		Ice, snow, sand, water surface	Grassland, farmland	Suburban areas, parks	Inner cities, dense forest
Full scale roughness length	z_0 [m]	10^{-5} ... $5 \cdot 10^{-3}$	$5 \cdot 10^{-3}$ ... 10^{-1}	0,1 ... 0,5	0,5 ... 2
Full scale displacement height	d_0 [m]	≈ 0	≈ 0	≈ 0,75· h[1])	≈ 0,75·h[1])
Power law exponent	a	0,08 ... 0,12	0,12 ... 0,18	0,18 ... 0,24	0,24 ...

[1]) h is the mean height of vegetation and buildings, in m

3.3 Measurement and documentation of the wind field

3.3.1 Number of parameters and measuring position

The following parameters of the boundary layer upstream of the model must be measured and documented:

- Mean wind speed profiles
- Mean turbulence intensity profiles (longitudinal, transversal and vertical)
- Characteristic longitudinal turbulence length scale for at least one relevant height above the floor of the wind tunnel (preferably at screen height/average building height etc., L_{UX}[1])
- Spectral distribution of longitudinal turbulent kinetic energy for at least one height from the floor of the wind tunnel to the the ground (S_{uu}[2])

Horizontal measuring positions (XY-plane)

These data should be provided for different positions inside the wind tunnel. Three profiles as function of the height (the Z-direction) and upstream of the model (positions as given in figure 1 and 2). Furthermore two profiles as function of the height on the turning table for rural or flat areas at the same position as the centre profile which is the closest to the model (see figure 2).

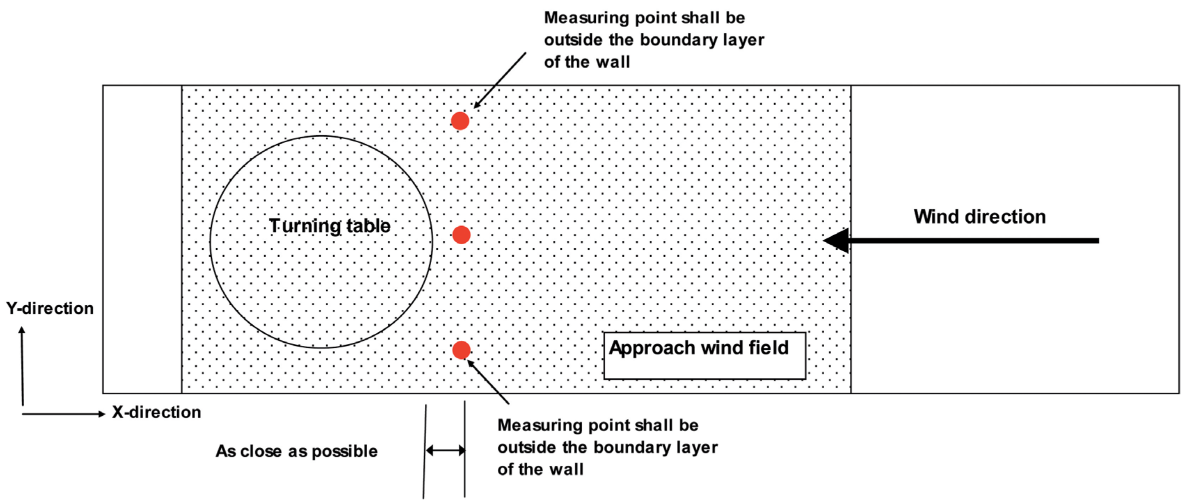
The profiles (in the Z-direction) should be measured from positions as low as possible/at least at average building/obstacle height/screen height, but higher than 1.5 times the height of the roughness elements used for boundary layer modelling. This is in order to ensure local independence and representativeness of the results.

Also the measuring positions at both sides of the tunnels shall be outside the boundary layer of the side walls of the tunnel (if applicable).

The roughness length parameter z_o can be derived from a semi-logarithmic plot of the measured wind profile(s). Alternatively, the roughness length may be calculated from fitting a logarithmic wind profile to the measured data, also incorporating a measured value of the friction velocity u*.

Consistent modelling of the appropriate power law exponent, displacement height and roughness length within one approach flow class must be documented. As additional quality criterion the power law exponent/roughness length ratio can be used (Counihan, 1975[3]).

Figure 1 Measuring positions for the wind characterization for urban surroundings.

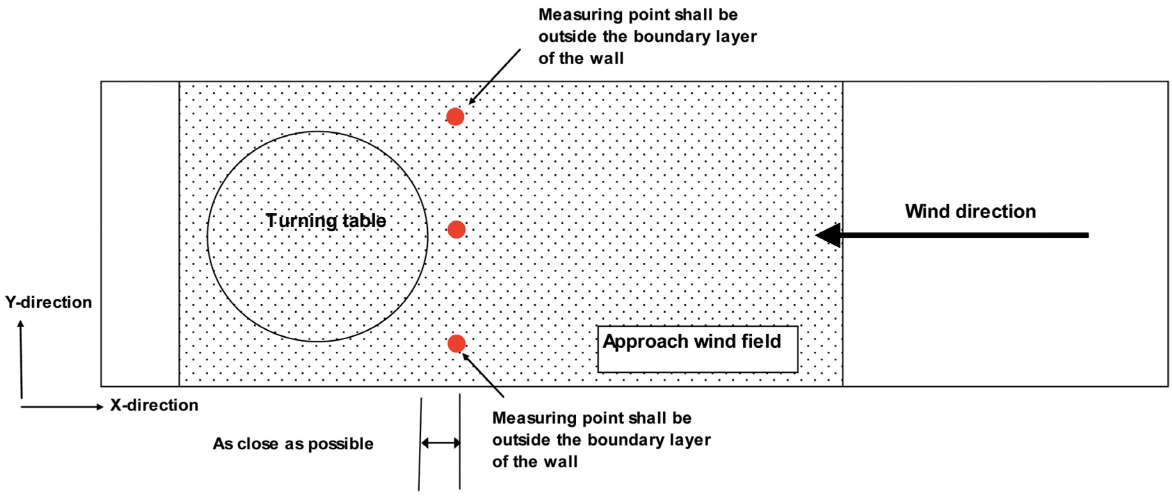


[1] L_{UX} is the longitudinal turbulence length scale and is described on page 9 in VDI 3783 part 12.

[2] S_{UU} is the spectral distribution of longitudinal turbulent kinetic energy and is described on page 8 in VDI 3782 part 12. A frequency range from about 0,1 Hz to about 100 – 1000 Hz is in general sufficient. Based on the experience of the wind tunnel institutes or specific conditions in the wind tunnel this frequency range can be extended to cover the spectrum.

[3] Counihan, J. 1975: Adiabatic atmospheric boundary layers: a review and analysis of data from the period 1980-1972. Atmospheric Environment, Vol. 9, 871-905. Pergamon.

Figure 2 Measuring positions for the wind characterization for rural or flat surroundings.



3.3.2 Frequency of the characterization of the wind field and vertical measuring positions

New approach flow with unknown characteristics
For each new approach wind field with an unknown roughness length the wind field has to be characterized minimally at each indicated measuring position in the X, Y-plane in 4.2.1. At each measuring position in the X, Y-plane the parameters have to be measured in the vertical plane at minimally 10 points sufficiently distributed over the vertical axis (in the Z-direction). Vertical measurement profiles shall cover at least a height range of up to 4 times the average height of obstacles surrounding the test site.

Approach flow with previously measured and documented roughness characteristics
Before a new series of tests in a previously completely documented model boundary layer flow, the assumed approach flow conditions shall be verified by test measurements. The wind speed profile shall be checked at one or more representative measuring positions in the X, Y-plane and at minimal three vertical points (in the Z-direction). Verification measurements shall cover the entire height range expected/intended to be covered by subsequent flow/dispersion measurements. The results of these measurements have to be compared to historical measurements and have to be reported.

3.3.3 Documentation of the wind field

In each report for a wind tunnel air quality research project the characterization of the wind field shall be documented.

4 Test model requirements

4.1 Model scale

The model scale should be chosen by the laboratory according to their best practices and relevant wind tunnel constraints. The model scale must be the same as for the modelled roughness length in the approach field. In addition, the model scale must reflect the desired spatial resolution of flow and concentration measurements and the corresponding spatial resolution of the measurement equipment applied during the test. Typical model scales are expected to be in the order of 1:400 up to 1:200.

Note: As air quality measurements have to be performed in general at a height of 1.50 m (full scale); the accuracy of this position should be taken in account. When assuming a positioning accuracy and size of the suction nozzle of about 1 mm, then at a scale of 1:500 this equals to 500 mm or 0.5 m at full scale, which is a relative large deviation with respect to the measuring height of 1.50m.

The surroundings should be defined according to the model scale defined previously and the diameter of the turning table.

Buildings and/or models that are expected to influence the surroundings are supposed to be on the turning table. If an important obstacle falls just outside the turning table and should be relevant for the study, it ought to be added on the side of the turning table.

Note: A rule of thumb indicates that the influence distance of an obstacle on the mean flow and dispersion field is about 10 times its height. Concentration fluctuations however can be measured at even larger distances.

The rationale for the choice of the scaling and scaling details shall be provided in the test report.

Note: Contributions of road parts that are outside the turning table and are not modelled in the wind tunnel, but that have an influence on the measured concentrations, have to be accounted for by calculation (please refer to chapter 9 for this).

4.2 Tunnel outlets and coverings

Prior to the performance of air quality measurements at tunnel outlets and coverings, the wind tunnel institutes should discuss with the customer how to model tunnel outlet emissions (such as the speed and direction of the vehicle induced draught at the tunnel outlets, the amount of ventilation air through ventilation chimneys and so on).

Note: In general traffic induced turbulence is important at tunnel outlets and at low wind speeds.

4.3 Traffic induced turbulence

Traffic induced turbulence must be taken into account based on the experience and general practice of the wind tunnel institutes.

In general, emissions from road traffic shall be modelled as emissions from a continuously emitting line source with a uniform release rate along the source (if inhomogeneous emission modelling is not explicitly required). As part of the documentation of the experimental setup, evidence must be given that the line source applied in the model provides an uniform release and that the source is not influenced by the local pressure field produced by nearby obstacles, such as building structures, topography or screens.

The way traffic induced turbulence is taken into account in the wind tunnel shall be described in the report.

4.4 Model roughness

In case of smooth objects (such as coverings) the requirements and reporting as given in the CUR 103 (paragraph 6.3.2) shall be followed.

4.5 Modelled green

If trees, bushes and other green are expected to have a significant effect on dispersion results, the aerodynamic effect of green shall be modelled explicitly. When green is considered in the wind tunnel model, model trees and model bushes should in principle provide the same aerodynamic behaviour/aerodynamic roughness as expected at full scale.

Modelled green is to be applied based on the expertise and general practice of the wind tunnel institutes. The amount and permeability of the modelled green is to be reported.

> *Note: This paragraph should be revised as soon as agreement on model approach has been achieved. Otherwise greenery will be one of the key factors for deviating model results.*

5
Tracer gas

5.1 Choice of tracer gas

The choice of tracer gas is up to the expertise of the wind tunnel institutes and depends among others on the lower detection limit and the dynamic range of the measuring equipment and the atmospheric background concentrations.

The buoyancy of the tracer gas shall not effect its dispersion. The choice of the tracer gas shall be reasoned and reported. If a non-neutrally buoyant trace gas is used, the independence of results from possible buoyancy effects must be verified and documented over the entire range of possible/intended release rates at the measurement position closest to the emission source. If a mixture of a non-buoyant trace gas is used for emission modelling, the mixing ratio, effective density of the mixture as well as the means ensuring a perfect mixture of the released gases must be documented.

> *Note: It is recommended to take health and safety aspects regarding the use of the tracer gas into consideration.*

5.2 Tracer gas injection

The tracer gas must be injected uniformly and constant along the modelled road. The implemented line source must ensure a proper initial spread of the modelled pollutant to comply with the underlying line source concept. As reference release height range, the average wake height of vehicles can be used. An experimental verification of the initial distribution of trace gas by means of vertical concentration profile measurements is desirable.

Pressure driven release devices must be evaluated/verified regarding a homogeneous release character, even under locally varying static pressure conditions within a wind tunnel model. At least, the pressure drop across the line source must be documented for the entire range of source strengths. If a pressure correction for non-uniform release conditions is applied, the correction procedure must be documented.

> *Note: Use of a line source to generate a uniform concentration field on the modelled road is highly recommended.*

Measures shall be in place to either correct for the amount of tracer gas injected or by controlling the amount of tracer gas flow (e.g. by mass flow controllers, a fixed pressure drop and so on) and proof shall be given that each injection point emits the same amount of tracer gas independent of the pressure behind obstacles. Vertical plumes at the injection points should be avoided. The procedure shall be reported.

5.3 Tracer gas background

Atmospheric background concentration of the applied tracer gas limits the lowest detection level of the measurements.

The measuring results shall not be influenced by the presence or accumulating background level of the tracer gas. The way how this influence is taken into account is to be reported.

> *Note: It is strongly recommended that the lowest concentration level measured is at least ten times higher than the atmospheric background level. Accumulation of tracer gas in closed wind tunnels could influence the measuring results.*

5.4 Source strength independency

The independency of the source strength of the tracer gas on the results is to be checked and reported. This is performed by measurements with the double or half amount of injected tracer gas at a minimum of three measuring positions at one specific wind speed and at a wind direction perpendicular to the screen.

> *Note: The double/half-criterion could be replaced by a statement that the 3 source strength must cover the entire range of applied source flow rates.*

6 Test conditions

6.1 Effect of screens

Only in the case of determination of the ***effect*** of screens, tests shall be performed with a reference situation and a planned situation. The reference situation could be no screen or an existing screen and the planned situation could be a (new) screen or a higher screen.

6.2 Measuring locations

The scaled height where the measurements have to be performed, shall be in accordance to the current air quality legislation (RBL, 2007) and shall be reported.

The number of measuring points in the horizontal plane is dependent on the points where the highest concentrations are to be expected. This should be judged by the wind tunnel institutes. This can be done by first performing measurements in a coarse grid and then in a finer grid in order to determine the points with highest concentrations.

6.3 Wind speeds and directions

Tests should be made at the appropriate wind speed selected by the wind tunnel institutess using this protocol.

Measurements will be made for a number of equally distributed wind directions (30 degrees).
The following wind directions shall be applied as a minimum:

- in case of a symmetrical test model and in open terrain 0 – 90°
- in case of a non-symmetrical test model and in open terrain 0 – 180°
- in urban areas 0 – 360°

Further refinement between the mentioned directions should be carried out if the measured pollutant concentrations show a strong dependency regarding wind direction.

The wind tunnel institutes should provide proof in the report that the results are independent of the wind speed (Reynolds independent), at least for the typical range of wind speeds to be used during the dispersion test series. This performed by measurements at a minimum of three measuring points at a wind direction perpendicular to the screen and at a significant lower and a significant higher wind speed.

6.4 Repetitions of measurements

As part of the quality assurance procedure the wind tunnel institutes should decide which and how many measurements have to be repeated. It is strongly recommended to repeat the measurements after the largest possible time span (e.g. repetition of measurements after a weekend and without removing the test model from the turning table in the wind tunnel).

Note: The above recommendation is hard to fulfil and might be replaced by a less demanding test.

Note: In general performing repeated measurements on the same day with the same measurement set-up and with the same operators, will show lower uncertainties then when the measurements are repeated on different days after disassembling and reassembling exactly the same model on the turning table. The bandwidth of results from those tests reveal a more realistic uncertainty of the total test procedure. By repeating measurements after a number of days by reassembling the model set-up in the wind tunnel, could be part of the total quality assurance procedure of the wind tunnel institutes. By this procedure a realistic uncertainty of the total test procedure can be determined.

6.5 Description of measurement procedure

A general description of the way the measurements are carried out shall be described in the report, so that the reader could form an idea of how the test results were obtained.

7 Measuring equipment

7.1 General requirements

All measurements shall be performed with measuring equipment that has valid calibrations (this in accordance with CUR 103 paragraph 6.4). Equipment shall be calibrated as necessary to maintain an adequate measurement accuracy. At least once per year and as often as is necessary to maintain the measurement accuracy specified. It is strongly recommended to record the calibration data in a control chart and base the appropriate calibration frequency on this control chart. For all measuring equipment the uncertainty shall be known. It is strongly recommended to determine the uncertainty of measuring equipment according to the "Guide of expression of uncertainty of measurements" (NVN-EN 13005) or according to the NEN-ISO 14956.

7.2 Turbulence

Turbulence shall be measured with a suitable and appropriate measuring method for the longitudinal, transversal and vertical spectral distribution of the wind fluctuations. The method and reasoning for the choice of the method is to be reported.

Note: Turbulence can usually be measured with a hot wire anemometer for the longitudinal, transversal and vertical spectral distribution of the wind fluctuations. However, hot wire anemometry works properly only in moderately turbulent boundary layer flows. Often, the commonly accepted turbulence levels will be exceeded.

7.3 Gas analysis

The gas analysis shall be performed with an instrument which is capable of measuring the concentrations with sufficient accuracy at each individual measuring range. The deviation of the linearity of the instrument shall be less than 1% of the full scale of each range.

Note: The requirement for a linear response may not be necessary – it is more important that sufficient measurement accuracy and sensitivity is ensured over the entire range of concentrations to be measured.

The calibration gas can be either purchased commercially or can be prepared by the wind tunnel institutes itself. The calibration gas shall have an uncertainty of less than 2% of the guaranteed gas concentration.

Calibration of the instrument with calibration gas shall be performed at the beginning of each series of measurements. Regular checks with calibration gas during the measurements shall be performed to ensure proper readings. When the readings of these checks are within the range of >2% and <10% of the calibration gas value then the instrument shall be readjusted or the previous measurements shall be numerically corrected. When readings of the checks are >10% of the calibration gas value than the results of the previous measurements shall be rejected.

Note: The underlying uncertainties should be such that the desired overall uncertainty of the wind tunnel results is not exceeded.

The sampling frequency or time at each sampling point shall be such that the concentration fluctuations are sufficiently averaged. The standard deviation in the average concentration due to concentration fluctuations shall be less than (preferably) 1% of the average concentration.

Note: When as an example the concentration is measured at 2 second intervals and the standard deviation of these 2 second concentration readings is 1.5 ppm at a level of 30 ppm then one needs $n = \{(1.5/30)/(1\%/100)\}^2 = 25$ *samples or 25 x 2 = 50 seconds of averaging time.*

7.4 Suction nozzle

The suction velocity in the suction nozzle shall be less or equal to the local wind velocity in order to avoid dilution or averaging effects at the measuring position.

The wind tunnel institutes should give proof by means of a verification experiment that the appropriate suction flow has been chosen for the model set-up and type of suction nozzle chosen.

7.5 Tracer gas injection equipment

The total uncertainty of the equipment for controlling and measuring the amount of tracer injected at each point shall be known within 2%. In paragraph 6.2 more details are given about the way how the tracer gas injection should be applied.

8
Data processing

8.1 Calculation of concentration coefficient

The concentration coefficient is defined as:

$$C^* = \frac{c \cdot u_{ref} \cdot L_{ref}^n}{Q} \quad \text{with} \quad C^*_{model} = C^*_{fullscale}$$

where

c - measured concentration (mass concentration [kg/m³] or volume ratio [-])

u_{ref} - reference wind velocity in [m/s]

L^n_{ref} - reference length in [m]

Q - source emission (mass flow [kg/s] or volume flow [m³/s])

n - exponent (source type specific, see table 2)

Table 2 Values of exponent n.

type of source	emission mass flow	emission volume flow	Exponent n
point source	m/t	L³/t	2
line source	m/t/L	L³/t/L	1

8.2 Calculation of traffic induced turbulence and road contributions

The way how traffic induced turbulence is taken into account is to be described.
Contributions of road parts that are outside the turning table and that are not modelled in the wind tunnel, but have an influence on the measured concentrations must be accounted for by calculation. Contributions of road parts outside the turning table equivalent to a full scale length of 500m shall be taken into account. The way how these contributions are accounted for shall be described in the report.

8.3 Calculation of screen effect and yearly average values

In case of determining the screen effect, the screen effect is to be calculated from the measuring results.
The screen effect is calculated as:

$$\textit{Screen effect } (\%) \textit{ at } x \textit{ meters} = \left(1 - \frac{\textit{Concentration behind screen at } x \textit{ meters}}{\textit{Concentration without screen at } x \textit{ meters}}\right) x\, 100\%$$

Using the concentration coefficient determined from the wind tunnel measurements the yearly average concentration for NO_2 and PM_{10} shall be computed in accordance to the calculation procedure that is described in the “Regeling Beoordeling Luchtkwaliteit” (RBL, 2007).

9 Reporting

Besides the general standard project details and the required reporting details according to the CUR 103 chapter 10, at least the following details regarding the dispersion modelling shall be included in the report to the customer:

- Choice of roughness length of the approach wind field
- Rationale for choice of scaling
- Characterization of the wind field
- Stability of the wind speed during the tests
- How traffic induced turbulence is taken into account
- Corrective calculation procedure for traffic induced turbulence made available to customer
- Model roughness (applicable on smooth and round objects such as coverings)
- The use and way of application of modelled green
- The way how emissions of tunnel outlets/coverings are modelled
- Applied tracer gas, tracer gas injection procedure and the way how measures are taken to avoid measurements close to the background concentration
- Proof of source strength independency
- Proof of wind speed (Reynolds) independency
- Description of measuring procedure
- Uncertainty of the measuring equipment
- Uncertainty of the total test procedure

A full list of details that have to be reported is given in Annex B.

10 Uncertainty of the method (statistical data)

To be added at a later stage.

11 Quality control

The wind tunnel institutes should have their own quality control in place for the performance and documentation of projects and measurements.

In general quality control for wind tunnel tests consists of two main parts.

The first is the control of the quality in the set-up and performance of the wind tunnel tests. This relates to daily measurement quality and focuses on how measurements and control of these measurements are being performed.

The second part focuses on the quality of maintaining the wind tunnel and measuring equipment. This relates to the long-term quality. This involves proper maintenance of the wind tunnel, yearly calibrations of the measuring equipment, regular performance of wind field measurements and repetitions of measurements.

Quality control shall also be in accordance to the NEN 8100, for which a description of a quality document is required each five years.

As already indicated in paragraph 8.1 the uncertainty of the measuring equipment and measuring procedure shall be known. Therefore the determination of the uncertainty should be part of the quality control.

ANNEX A (Normative)

Tests to be performed

In tables A.1 and A.2 the specific tests are summarized that need to be performed as a minimum during an air quality research project in wind tunnels

Table A.1 Tests to be performed during an air quality dispersion project.

Type of measurement	Test conditions	
Characterization of wind field	New approach field	At various points in the horizontal plane and at least 10 points in the vertical plane (4.3.2)
	Known approach field	At one or more points in the horizontal (X,Y) plane and at least 3 points in the vertical plane (4.3.2)
Concentration measurements	Situations (when the effect of screens have to be determined)	Present and planned
	Wind directions	Minimum of 4 or 7 or 12 sectors (see paragraph 7.3)
	Number of wind speeds	At least one
	Measuring height	According to RBL, 2007
	Density of measuring grid : to determine points with highest concentrations	Up to expertise of wind tunnel institutes
	Checks of calibration	Frequency depending on stability of the instrument
Wind speed independency	Wind speed	Lowest and highest
	Wind direction	Perpendicular to screen
	Measuring positions	3 (minimum)
Source strength independency	Wind speed	Same as during concentration measurements
	Wind direction	Perpendicular to screen
	Measuring positions	3 (minimum)
	Source strength	Double or half as during concentration measurements

Table A.2 Tests to be performed for long-term quality control.

Type of measurement	Minimum frequency
Wind field & turbulence	Each time before a series of tests is performed at one or more points in the horizontal (X,Y) plane and at minimal three vertical points (in the Z-direction)
Repetitions of measurements	At the largest possible time span when a model is placed in a tunnel. The number of measurements is to be decided by the wind tunnel institutes
Calibration of measuring equipment	At least once per year
Appropriate suction flow	Once for the suction nozzles used

ANNEX B (Normative)

Data to be reported

Table B.1 Data to be reported (when applicable)

Items	According to reference
General aspects	
General information	CUR 103 paragraph 10.1
Description of the wind tunnel	CUR 103 paragraph 10.2
Basic information of screen and surroundings	CUR 103 paragraph 10.3
Scale model	
Description of model and surroundings	CUR 103 paragraph 10.4/10.5 NEN 8100 annex C.2.3/4/5
Calculation and rationale for choice of scaling	Protocol paragraph 5.1 NEN 8100 annex C.2.1
Emission of tunnel outlets and coverings	Protocol paragraph 5.2
Proof of homogeneous concentration field	Protocol paragraph 5.3
Description of the modelling of traffic induced turbulence	Protocol paragraph 5.3
Model roughness	Protocol paragraph 5.4
Modelled green	Protocol paragraph 5.5 NEN 8100 annex C.2.6
Wind tunnel	
Modelled boundary layer	CUR 103 paragraph 10.6 NEN 8100 annex C.2.2 and C.4.1
Results of measuring data of wind profile and turbulence intensity data	Protocol paragraph 4.3.1 and 4.3.2
Tracer gas	
Type of tracer gas	Protocol paragraph 6.1
Procedure of tracer gas injection	Protocol paragraph 6.2
Background levels or measures against accumulation	Protocol paragraph 6.3
Proof of source strength independency	Protocol paragraph 6.4
Test conditions	
Test conditions, measuring results, proof of Reynolds independency and measuring procedure	Protocol chapter 7
The way how traffic induced turbulence is taken into account	Protocol paragraph 5.3
Stability of the tunnel wind speed during the tests	NEN 8100 annex C.4.4
Height of measurements and locations	Protocol paragraph 7.2
Wind speed and directions	Protocol paragraph 7.3
Measuring equipment	
Description of measuring equipment	CUR 103 (where applicable) NEN 8100 annex C.4.5 Protocol paragraph 8.1, 8.2, 8.3
Uncertainty of measuring equipment	NEN 8100 annex C.4.5 Protocol chapter 8.1
Uncertainty of measuring results	Protocol chapter 7.4
Data processing	
The way traffic induced turbulence is taken into account	Protocol paragraph 9.2
The way how roads outside the turning table are taken into account	Protocol paragraph 9.2
Calculation of the screen effect	Protocol chapter 9.3
Description of procedure or reference to calculation procedure to yearly averages	Protocol chapter 9 3

ANNEX C (Informative)

Checklist for air quality dispersion projects

The following items could be checked when starting an air quality dispersion project

General aspects
- **Customer details**
- **Definition of the project and details**

Scaling and model aspects

Choice of roughness length

Measurements of the wind field

Tracer gas and dosing
- **Choice of tracer gas**
- **Dosing and design of line source**

Test conditions
- **Number of wind sectors**
- **Number and height of measuring points**

Measuring equipment
- **Suitable and calibrated equipment**

Data processing
- **Effect of roads outside the turning table**
- **Traffic induced turbulence**
- **Effect of screens**
- **Yearly averages**

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Dit is een uitgave van:

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DNV KEMA
Peutz
RIVM - Rijksinstituut voor Volksgezondheid en Milieu
RWS- DWW Rijkswaterstaat – Dienst Weg- en Waterbouwkunde
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