# Odour dispersion modelling in Austria

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Two classes of dispersion models are currently used for (regulatory) odour dispersion, namely Gauss and Lagrange models. These models generally predict time-averaged concentrations, often over one hour. Therefore, the models have to be adopted somehow to cope with short-term odour peaks which can be smelled by the human nose. Over the last years, the authors have developed an approach where the short-term peaks are parameterized according to atmospheric stability ("peak-to-mean" factors). This approach is used with the Austrian Odour Dispersion Model AODM, based on the Austrian regulatory Gauss model, and described here in detail. With the German Lagrange model LASAT as well as with the AUSTAL 2000 model, a factor 4 is used independent of the distance from the source and the meteorological conditions to account for short-term peak concentrations. The models predict the separation distance between odour sources and the adjacent residential area to protect it from excessive odour nuisance. Besides the description of the approach in AODM, the meteorological input data to run the model are of importance. An example of separation distances for a fictitious livestock unit is added.

## 1. Introduction

Environmental odour is a main nuisance besides noise and air pollution. Caused by urban sprawl, the annoyance potential due to industrial, agricultural and municipal odour sources is growing tremendously. Besides abatement technologies for the release of odourous substances, the application of separation distances between odour sources and residential area is an appropriate method to reduce nuisance. Separation distances can be obtained from dispersion models. Such models predict the ambient odour concentration on an hourly or half-hourly basis. This time series of concentration values allows a calculation of the percentage of the time in a year during which the threshold odour concentration will be exceeded. This can be compared to a tolerated exceedence probability depending on the land-use category. Combinations of threshold odour concentrations and tolerated exceedence probabilities are called odour impact criteria. An overview of various national odour impact criteria can be found in Sommer-Quabach et al. (2014).

Two pre-requisites are necessary to run this procedure: a transformation of the mean values calculated by the models to short-term concentrations relevant for human odour perception, and the appropriate meteorological input, i.e. representative wind and stability information for the site under investigation.

For Austria, to determine the short-term peak concentrations required for the assessment of odour perception, the authors developed a peak-to-mean approach depending on atmospheric stability; this algorithm is used in the Austrian Odour Dispersion Model (AODM), the regulatory Austrian Gauss model, and a description has been published already in Schauberger et al. (2000) and Piringer et al. (2007); in Piringer et al. (2014), the latest version is described in detail. With the German

Citation: Piringer M., Knauder W., Petz E., Schauberger G. (2015): Odour dispersion modelling in Austria. Austrian Contributions to Veterinary Epidemiology. Vol. 8, 27-34.

Lagrange model LASAT, a factor 4 is used independent of the distance from the source and the meteorological conditions to account for short-term peak concentrations (Janicke et al., 2004; Janicke Consulting, 2013). The discrepancy of the two concepts is discussed in Schauberger et al. (2012).

Dispersion models need mainly wind and stability information as meteorological input data. Whereas the use of wind data, either based on measurements or from meteorological pre-processors, is often straightforward, on-site representative stability information is more difficult to obtain. An overview on methods to determine discrete stability classes can be found e.g. in Piringer et al. (2004; Section 4.6) and Piringer & Schauberger (2013).

The structure of the paper is as follows: Section 2 presents a brief description of the models used, the peak-to-mean approach, and the model input data. The results and a discussion are presented in Section 3. Section 4 contains a summary and a brief outlook on current developments.

## 2. Material and methods

### 2.1 Brief description of the models used

The Austrian odour dispersion model (AODM; Piringer et al., 2007; Piringer et al., 2013; Schauberger et al., 2002) estimates mean ambient concentrations by the Austrian regulatory dispersion model and transforms these to instantaneous values depending on the stability of the atmosphere (Section 2.2). The model has been validated internationally with generally good results ((Baumann-Stanzer & Piringer, 2011; Piringer & Baumann-Stanzer, 2009). The regulatory model is a Gaussian plume model applied for single stack emissions and distances from 100 m up to 15 km. Plume rise formulae used in the model are a combination of formulae suggested by Carson & Moses (1969) and Briggs (1975). The model uses a traditional discrete stability classification scheme with dispersion parameters developed by Reuter (1970).

The dispersion model LASAT (Janicke Consulting, 2013) simulates the dispersion and the transport of a representative sample of tracer particles utilizing a random walk process (Lagrangian simulation). It computes the transport of passive trace substances in the lower atmosphere (up to heights of about 2000 m) on a local and regional scale (up to distances of about 150 km). A number of physical processes, including time dependencies, are simulated, such as transport by the mean wind field, dispersion in the atmosphere, sedimentation of heavy aerosols, deposition on the ground (dry deposition), washout of trace substances by rain and wet deposition, first order chemical reactions. The quality of the results achievable by Lagrangian models mainly depends on the wind field they are based on. A simplified version of LASAT is offered free of charge (AUSTAL2000, http://www.austal2000.de) which is favoured by German guide lines (GOAA, 2008; TA Luft, 2002). LASAT uses the Klug-Manier stability classification scheme (TA Luft, 2002). Like AODM, LASAT has been evaluated using test data sets for different applications (see www.janicke.de).

### 2.2 The Austrian peak-to-mean approach

The peak-to-mean concept in the AODM is based on a relationship by Smith (1973), where the peak-to-mean factor $\psi_0 = C_p / C_m$ is given by:

$$\frac{C_p}{C_m} = \left(\frac{t_m}{t_p}\right)^a \qquad (1)$$

with the mean concentration $C_m$ calculated for an integration time of $t_m$ (1800 s) and the peak concentration $C_p$ for an integration time of $t_p$ (5 s). The exponent *a* depends on atmospheric stability. The maximum peak-to-mean factor $\psi_0$ valid near the odour source varies between approx. 3 (stable conditions) and 55 (very unstable conditions). For the reduction of the peak-to-mean ratio with distance due to turbulent mixing, an exponential attenuation function (Mylne & Mason, 1991; Mylne, 1992) is used:

$$\Psi = 1 + (\Psi_0 - 1)\exp\left(-0.7317\frac{T}{t_L}\right) \quad (2)$$

where $T = x/u$ is the time of travel with the distance *x* and the mean wind speed *u,* $t_L$ is a measure of the Lagrangian time scale (Mylne, 1992).

The time scale $t_L$ is taken to be equal to $\sigma^2/\varepsilon$ where $\sigma^2 = \frac{1}{3}\left(\sigma_u^2 + \sigma_v^2 + \sigma_w^2\right)$ is the variance of the wind speed taken as the mean of the variance of the three wind components *u, v,* and *w*, respectively, and $\varepsilon$ is the rate of dissipation of the turbulent energy using the following approximation:

$$\varepsilon = \frac{1}{k\,z}\left(\frac{\sigma_w}{1.3}\right)^3 \quad (3)$$

where $k$ = 0.4 is the von Karman constant and $z$ = 2 m is the height of the receptor, the human nose.

A relationship between the standard deviations of the three wind components and the mean wind speed *u* was proposed by Robins (1979) and is given in Tab. 1. For $\sigma_u/u$ and $\sigma_v/u$, no change with stability is assumed. Deviating from Robins (1979), $\sigma_w/u$ is taken in the AODM to be stability-dependant, assuming an increasing importance of $\sigma_w$ compared to *u* in unstable conditions.

*Table 1: Ratios of the standard deviations of the three wind components* ($\sigma_u$, $\sigma_v$ and $\sigma_w$) *to the horizontal wind velocity u depending on the stability of the atmosphere (Robins, 1979).*

| Stability class | | $\sigma_u/u$ | $\sigma_v/u$ | $\sigma_w/u$ |
|---|---|---|---|---|
| 2 | very unstable | 0.2 | 0.2 | 0.3 |
| 3 | unstable | 0.2 | 0.2 | 0.2 |
| 4 | neutral | 0.2 | 0.2 | 0.1 |
| 5 | slightly stable | 0.2 | 0.2 | 0.1 |
| 6 | stable | 0.2 | 0.2 | 0.1 |
| 7 | very stable | 0.2 | 0.2 | 0.1 |

The resulting peak-to-mean attenuation curves are presented in Fig. 1. For classes 2 and 3, the peak-to-mean factors, starting at rather high values near the source, rapidly approach 1 with increasing distance. This is in agreement with the premise that vertical turbulent mixing can lead to short periods of local high ground-level concentrations, whereas the ambient mean concentrations are low. For class 4, the decrease of the peak-to-mean ratio is more gradual with increasing distance, because vertical mixing is reduced and horizontal diffusion is dominating the dispersion process. The peak-to-mean ratio in 100 m is then about 4. The curve for class 5 is similar to that of class 4, with reduced absolute values. For classes 6 and 7 (identical curves due to identical $\psi_0$ values), the peak-to-mean ratio exceeds 2 only near the source. The grey horizontal line denotes the overall factor 4 of the German TA-Luft (2002). This factor clearly dominates from 100 m onwards. This has strong implications on the resulting separation distances, as will be shown in Section 3.

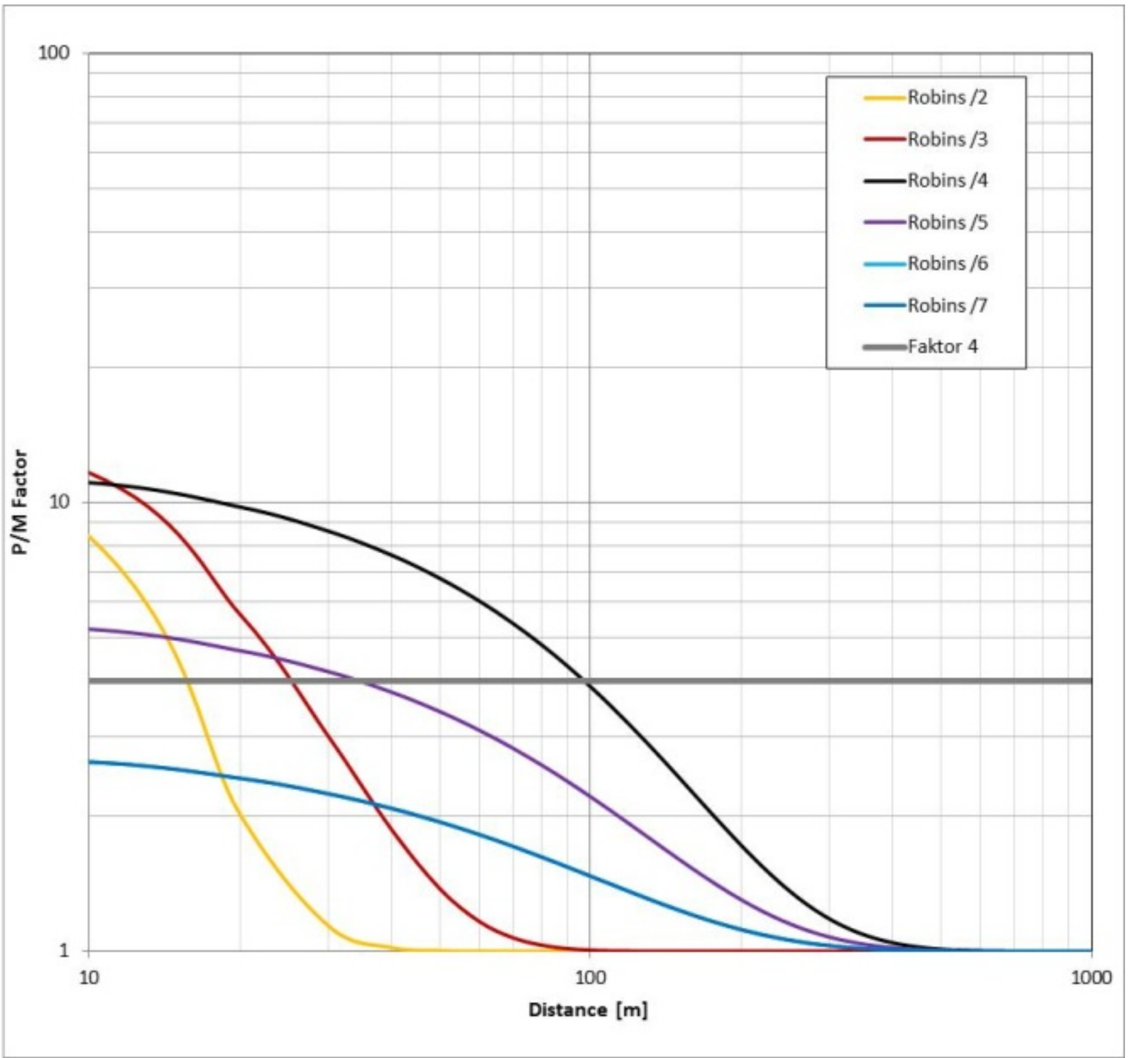


*Figure 1: Peak-to-mean ratios depending on the distance from the source for different atmospheric stabilities (classes 2 to 7, definition see Tab. 1) and the overall factor 4 of the German TA-Luft.*

### 2.3 Site and emissions

Separation distances have been calculated for the site Kittsee east of Vienna near Bratislava (17.070° E and 48.109 N at 136 m asl.). The site is within flat terrain, mainly farmland. Kittsee can experience high wind speeds, mainly from northwesterly directions, often associated with frontal systems and storms. The secondary maximum of wind directions is from northeast, in contrast to a lot of other meteorological stations in the area. This is explained by a topographical deflection of the regional flow in the area caused by the southernmost tip of the Carpathian mountains in the region of Bratislava north of the site. These wind directions show on average lower wind speeds as they are mainly observed in anti-cyclonic conditions.

For all model runs, the same source data are used (Tab. 2). The source is assumed non-buoyant, i.e. the effective stack height is equal to the physical stack height. As for the AODM and LASAT runs the same emissions, the same meteorological input data and the same peak-to-mean attenuation curves are used, the resulting separation distances depend on the different model physics and differences in the schemes to determine atmospheric stability only.

*Table 2: Source data for dispersion calculations*

| | | |
|---|---|---|
| Stack height | [m] | 8.0 |
| Stack diameter | [m] | 2.7 |
| Outlet air velocity | [m $s^{-1}$] | 3.0 |
| Volume flow rate | [$m^3$ $h^{-1}$] | 60 000 |
| Temperature | [°C] | 20 |
| Odour emission rate | [$ou_E s^{-1}$] | 5 200 |

## 3. Results and discussion

Direction-dependent separation distances are calculated for two odour impact criteria used in Austria: 1 $ou_E$/m3 and 3 % exceedence probability, representative for recreation areas (high odour protection), 1 $ou_E$/m3 and 8 % exceedence probability, representative for residential areas mixed with commercial activity (low odour protection). They are shown as isolines in Fig. 2, encompassing the area of exceedence of the given thresholds. The larger the area, the more unfavourable is the odour impact criterion. In Fig. 2, the AODM results are compared to the factor 4-model of TA-Luft (2002) applied with LASAT.

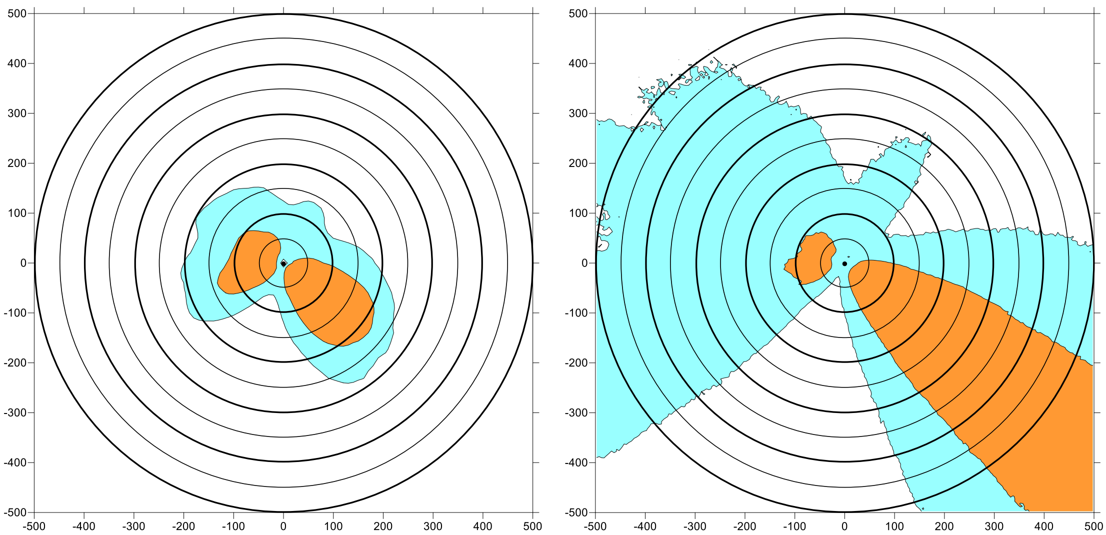


*Figure 2: Direction-dependent separation distances [m] with (left) AODM, peak-to-mean ratios from Fig.1, and (right) LASAT, factor 4, for 1 $ou_E$/m3 and 3 % (blue) and 8 % (orange) exceedence probability for Kittsee.*

Comparing the left and the right panel in Fig. 2, large differences in the separation distances can be seen. The application of an overall factor 4 over all distances and stability conditions clearly leads to very large, partly unrealistic separation distances. The shape of the separation distances is strongly influenced by the wind directions in Kittsee, and the elongation towards SE is due to the fact that north-westerly winds coincide with the highest wind speeds, on average. Allowing for an exceedence probability of 3 %, this elongation is much more pronounced for LASAT, where the separation distance towards SE well exceeds 500 m, compared to only 280 m for

AODM. Also towards the west, LASAT calculates far larger separation distances compared to AODM, for an exceedence probability of 3 %. For 8 %, however, the area of exceedence then is similar to AODM.

Apart from the use of the factor 4 with LASAT, another reason for the discrepancy of separation distances between AODM and LASAT originates from the different stability schemes used with the two models. Stability classes in Austria are determined with the Reuter (1970) scheme, those in Germany with the Klug-Manier scheme (TA-Luft, 2002). In both schemes, stability classes are determined as a function of half-hourly mean wind speed and a combination of sun elevation angle, cloud base height and cloud cover. In the Reuter (1970) scheme, classes 2 and 3 can occur only during daytime, classes 5 to 7 only at night. Class 4 can occur day and night. Klug-Manier classes are numbered from I to V and are classified according to atmospheric stability as follows: Stability classes V and IV comprise very unstable and unstable conditions. They do not occur during nighttime. Class V occurs only between May and September in Central Europe. Stability classes III/2 and III/1 are classified as neutral. III/2 occurs predominantly at daytime, III/1 predominantly at nighttime and during sunrise and sunset. Stability classes II and I comprise stable and very stable conditions, mostly, but not exclusively at night.

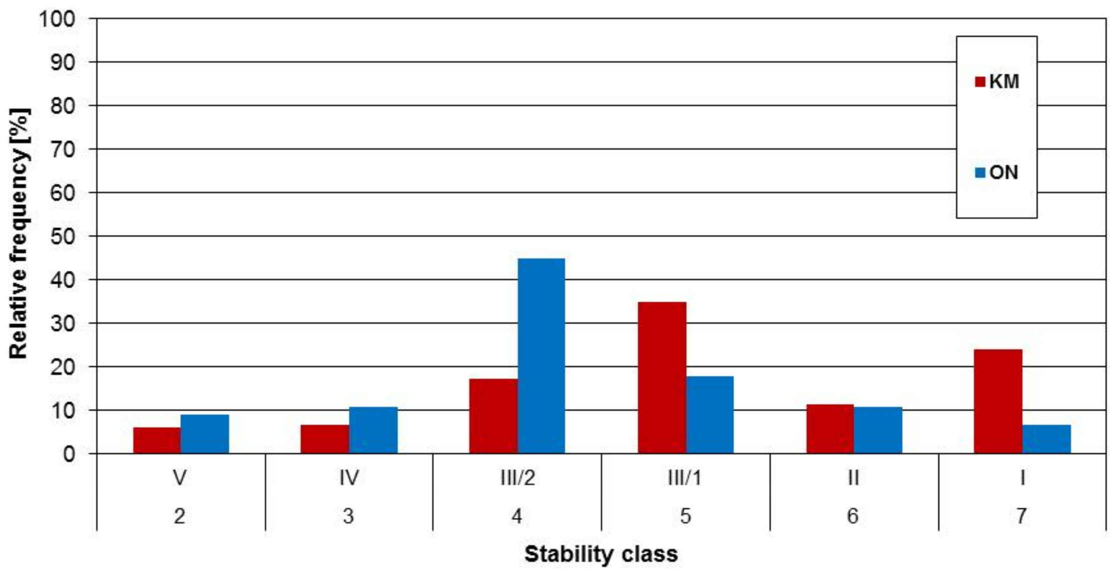


*Figure 3: Relative frequency of stability classes in Kittsee; KM = Klug-Manier (TA-Luft, 2002); ON = Reuter (1970).*

The Reuter (1970) scheme used in the AODM delivers about twice as many unstable situations for Kittsee compared to the Klug-Manier scheme (TA-Luft, 2002), whereas the latter calculates much more neutral and stable cases (Fig. 3). Thus, the large separation distances for NW wind calculated by LASAT are supported by the neutral and stable conditions which often occur with NW wind; only at shorter distances, the unstable classes 2 and 3 are relevant which are mainly observed with easterly winds. As unstable situations are very seldom in the Klug-Manier scheme, LASAT calculates similar separation distances compared to AODM for an exceeding probability of 8 % west of the odour source.

## 4. Conclusions and outlook

Separation distances to protect the neighbourhood from odour nuisance have been calculated with two models, the Gaussian Austrian Odour Dispersion Model AODM and the Lagrange particle diffusion model LASAT. Short-term peak odour concentrations have been calculated with the peak-to-mean ratios of Fig. 1 for AODM and with the factor 4 for LASAT. The same emission (Tab. 2) and meteorological data have been used, but atmospheric stability is determined differently from these data (Section 3). Differences in the resulting separation distances are then both due to the different peak-to-mean concepts and to the different atmospheric stability schemes used with the models. The results are demonstrated for Kittsee, a rural site in the Eastern flatlands of Austria near Bratislava.

The maximum of the separation distances occurs for NW wind and is thus stretching south-east; this can be explained by the fact that the main wind direction in Kittsee is also associated with the highest average wind speed and predominantly neutral to stable dispersion conditions. In this case, LASAT delivers unrealistically large separation distances, caused by the factor 4 and the stability scheme with LASAT which calculates far more neutral and stable situations occurring with NW wind than the AODM stability scheme. Allowing for an exceedence probability of 8 %, LASAT calculates similar separation distances as AODM for easterly winds, as these are mainly associated with unstable conditions, which are very seldom in the LASAT stability scheme compared to AODM.

Currently, a coupling of the peak-to-mean approach developed for AODM to LASAT is undertaken which is stimulated, apart from the large discrepancies in separation distances between LASAT and AODM with the current peak-to-mean ratios, also by the wider range of applicability of LASAT. It is commonly accepted that Gauss models can be used in flat terrain without nearby obstacles; Lagrange models have a broader range of applicability, including built-up areas and moderate topography.

**References**

Baumann-Stanzer, K. & Piringer, M. (2011). Validation of regulatory micro-scale air quality models: modelling odour dispersion and built-up areas. World Review of Science, Technology and Sust. Development, 8, 203-213.

Briggs, G. A. (1975). Plume rise predictions. Lectures on air pollution and evironmental impact analysis. AMS Report, Boston.

Carson, J. E. & Moses, H. (1969). Validity of several plume rise formulas. Air Pollution Control Assn-J, 19, 862-866.

GOAA (2008). Detection and Assessment of Odour in Ambient Air. Guideline on Odour in Ambient Air (GOAA).

Janicke Consulting (2013). Dispersion model LASAT. Reference/Working Book for Version 3.3.

Janicke, L., Janicke, U., Ahrens, D., Hartmann, U. & Müller, W.J. (2004). Development of the Odour Dispersion Model AUSTAL2000G in Germany. Environmental Odour Management, VDI-Berichte 1850, 411-417.

Mylne, K. R. (1992). Concentration fluctuation measurements in a plume dispersing in a stable surface layer. Boundary-Layer Meteorology, 60, 15-48.

Mylne, K. R. (1992). Concentration fluctuation measurements in a plume dispersing in a stable surface layer. Boundary-Layer Meteorology, 60, 15-48.

Mylne, K. R. & Mason, P.J. (1991). Concentration fluctuation measurements in a dispersing plume at a range of up to 1000m. Quarterly Journal of the Royal Meteorological Society, 117, 177-206.

Piringer, M. & Baumann-Stanzer, K. (2009). Selected results of a model validation exercise. Adv Sci Res, 3, 13-16.

Piringer, M. & Schauberger, G. (2013). Dispersion modeling for odour exposure assessment.. In V. Belgiorno, V. Naddeo & T. Zarra (Eds.), Odour Impact Assessment Handbook (Volume , pp. 125-176). Wiley.

Piringer, M., Joffre, S., Baklanov, A., Burzynski, J., Christen, A., Deserti, M., De Ridder, K., Emeis, S., Karppinen, A., Mestayer, P., Middleton, D., Tombrou, M., Baumann-Stanzer, K., Bonafè, G., Dandou, A., Dupont, S., Ellis, N., Grimmond, S., Guilloteau, E., Martilli, A., Masson, V., Oke, T., Prior, V., Rotach, M. & Vogt, R. (2004). The Urban Surface Energy Budget and Mixing Height in European Cities: Data, Models and Challenges for Urban Meteorology and Air Quality. Final Report of Working Group 2 of COST 715-Action.

Piringer, M., Knauder, W., Petz, E. & Schauberger, G. (2014). Use of Ultrasonic Anemometer Data to Derive Local Odourrelated Peak-to-mean Concentration Ratios. Chemical Engineering Transactions, 40, 103-108.

Piringer, M., Petz, E., Groehn, I. & Schauberger, G. (2007). A sensitivity study of separation distances calculated with the Austrian Odour Dispersion Model (AODM). Atmospheric Environment, 41, 1725-1735.

Piringer, M., Petz, E., Groehn, I. & Schauberger, G. (2013). Corrigendum to "A sensitivity study of separation distances calculated with the Austrian Odour Dispersion Model (AODM)" [Atmos. Environ. 41 (2007) 1725-1735]. Atmospheric Environment, 67, 461-462.

Reuter, H. (1970). Die Ausbreitungsbedingungen von Luftverunreinigungen in Abhängigkeit von meteorologischen Parametern. Arch. Met. Geoph. Biokl. A,, 19, 173-186.

Robins, A. G. (1979). Development and structure of neutrally simulated boundary layers. J. Industrial Aerodynamics, 4, 71 - 100.

Schauberger, G., Piringer, M. & Petz, E. (2000). Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM). Atmospheric Environment, 34, 4839-4851.

Schauberger, G., Piringer, M. & Petz, E. (2002). Calculating Direction-dependent Separation Distance by a Dispersion Model to avoid Livestock Odour Annoyance. Biosyst Eng, 82, 25-37.

Schauberger, G., Piringer, M., Schmitzer, R., Kamp, M., Sowa, A., Koch, R., Eckhof, W., Grimm, E., Kypke, J. & Hartung, E. (2012). Concept to assess the human perception of odour by estimating short-time peak concentrations from one-hour mean values. Reply to a comment by Janicke et al.. Atmospheric Environment, 54, 624-628.

Smith, M. E. (1973). Recommended guide for the prediction of the dispersion of airborne effluents. ASME, New York.

TA Luft (2002). Erste Allgemeine Verwaltungsvorschrift zum Bundes–Immissionsschutzgesetz. (Technische Anleitung zur Reinhaltung der Luft - TA Luft).