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MODIFICATION OF A GAUSS DISPERSION MODEL FOR THE ASSESSMENT OF ODOUR SENSATION IN THE VICINITY OF LIVESTOCK BUILDINGS

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ABSTRACT

The concentration of odoriphores can be handled like other volatile pollutants. The dispersion of airborne emissions can be described by dispersion models (eg Gaussian model). To apply a dispersion model to odour emissions, the odour concentration and the volume flow of the outlet air have to be known. The emission model is based on a steady-state balance of the sensible heat fluxes to calculate the indoor temperature and the related volume flow of the ventilation rate. By a simple model of the odour release the odour flow is assessed. The dispersion model calculates half hour mean concentrations. The sensation of odour, however, depends on the momentary odour concentration and not on a mean value over a long time of integration. Therefor the concentration fluctuation has taken into account. By the concept of the peak-to-mean ratio the calculated mean value is transformed to the expected peak concentration. The change of the variability of the mean concentration is expressed as a function of the time of travel, and the Lagrangian time scale which describes the turbulent diffusion, strongly depending on the stability of the atmosphere. The mean concentration of the dispersion model is modified by an amplification function depending on the stability, wind velocity and the distance. The highest amplifications can be expected for very unstable conditions with low wind velocity.

INTRODUCTION

Livestock farming is increasingly confronted with questions of environmental protection because of different kinds of pollutants brought into the atmosphere. One of them is odour which is a very important component because the acceptance of livestock farming in the vicinity can decrease due to an increase in odour sensation (Schiffman, 1998).

The concentration of odoriphores can be handled like other volatile pollutants and can be measured by an olfactometer in odour units per volume (OU m^{-3}). One odour unit per qubicmeter is defined as the concentration of odoriphores which results in an odour sensation by at least half of the members of a panel (CIGR, 1994).

The odour sensation is triggered by the odour stimulus and characterised by intensity and frequency. To predict these parameters it is necessary to consider short-term fluctuations of odourant concentrations at the receptor point. Odour sensation can only be observed if the odourant concentration is higher than the odour threshold of the substances. Due to fluctuations an odour sensation can take place even if the mean odourant concentration is lower than the odour threshold.

Previous investigations of the present authors concentrated on a comparison of the shape of the different power functions used by various guidelines to calculate the separation distance between livestock farms and residential areas with that derived via a Gauss model to conclude that the latter shows a stronger dependence from the odour emission than suggested by the guidelines (Piringer and Schauberger, 1999) as well as on the development and test of a steady-state balance model to calculate the indoor climate of livestock buildings (Schauberger et al., 1999, 2000ba). No diurnal variation of the odour emission was assumed in these publications. This paper

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investigates the diurnal and annual variations of the sensation distance of livestock farms depending on the appropriate variations of the odour emission as well as the ambient meteorological conditions. This will be achieved with a model based on three modules, the first calculating the odour emission of the livestock building, the second calculating ambient odour concentrations, and the third taking into account the conversion to instantaneous concentrations.

MATERIAL AND METHOD

Odour emission model

The emission model is based on a steady-state balance of the sensible heat fluxes to calculate the indoor temperature and the related volume flow of the ventilation system. The corresponding odour flow is assessed by a simple model of the odour release. The model has been described extensively in Schauberger et al. (1999 and 2000ba).

Dispersion model and meteorological conditions

The concentration of odoriphores can be handled like other volatile pollutants. The odour concentration of the centre line of the plume is calculated by the Austrian regulatory dispersion model (ÖNorm M 9440, 1992/96; Kolb, 1981) by making use of a statistics of stability classes representative for the Austrian flatlands north of the Alps. The model has been validated internationally with generally good results (e.g. Pechinger and Petz, 1995).

Assessment of the expected maximum concentration in an interval of an breath

The regulatory model calculates half hour mean concentrations. The sensation of odour, however, depends on the momentary odour concentration and not on a mean value over a long time of integration. Smith (1973) gives the following relationship:

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

with the mean concentration C_m calculated for an integration time of t_m and the peak concentration C_p for an integration time of t_p. Smith (1973) suggests the following values of the exponent u depending on the stability of the atmosphere: 0.35 (SC=4), 0.52 (SC=3) and 0.65 (SC=2). Using t_m = 1800 s (calculated half-hour mean value) and t_p = 5 s (duration of a single breath), the following peak-to-mean factors, depending on atmospheric stability, are derived by a quadratic function based on the values of Smith (1973): 43.25 (SC=2), 20.12 (SC=3), 9.36 (SC=4), 4.36 (SC=5), 1.00 (SC=6) and 1.00 (SC=7).

These values are only valid close to the odour source. Due to turbulent mixing, the peak-to-mean ratio is reduced with increasing distance from the source. Mylne and Mason (1991) analysed the fluctuation of the plume concentration and developed the following relationship: The peak-to-mean ratio in equation (1) is modified by an exponential attenuation function of T/t_L, where $T=x/u$ is the time of travel with the distance x and the mean wind speed u, and t_L is a measure of the Lagrangian time scale (Mylne, 1992):

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

where Ψ_0 is the peak-to-mean factor calculated in equation 1.

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

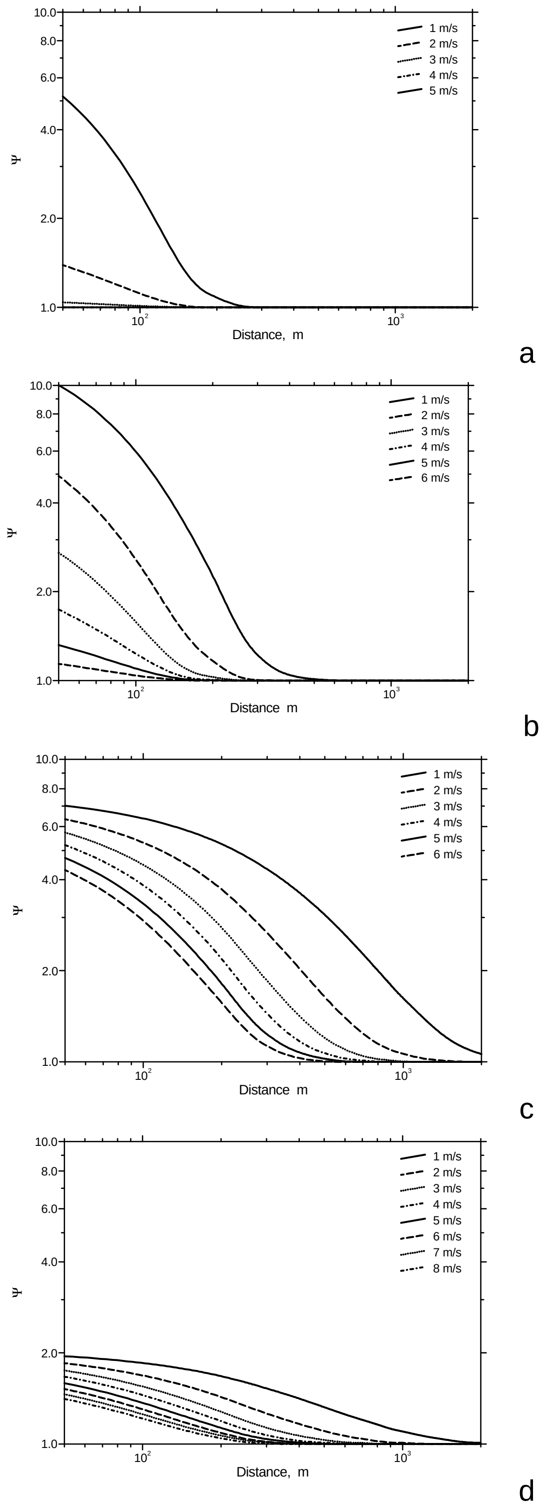

Figure 1. Dependence of the attenuation function Ψ of the peak to mean ratio with distance for stability class (SC) 2 (a), 3 (b), 4 (c) and 5 (d) for all classes of wind velocity which occur at Wels (see also Tab. 2 and 3)

$$e = \frac{1}{kz}\left(\frac{s_w}{1.3}\right)^3 \qquad (3)$$

where $k = 0.4$ is the von Karman constant and $z = 2$m is the height of the receptor, the human nose. The ratio of the variances of the three components u, v and w to the horizontal windspeed u depending on the stability of the atmosphere (Schauberger et al., 2000b) . For stability classes 6 and 7 no change of the peak-to-mean ratio is assumed. For σ_u / u and σ_v / u, values are taken from (Robins, 1979), and no change with stability is assumed. σ_w / u is taken to be stability-dependant, using our long-term Sodar experience which suggests an increasing importance of σ_W compared to u in unstable conditions.

Table 4. Variance of the three components of the wind u, v and w as a function of the stability of the atmosphere (details see text)

Class of stability	Variance of the wind velocity		
	s_u / u	s_v / u	s_w / u
2	0.2	0.2	0.3
3	0.2	0.2	0.2
4	0.2	0.2	0.1
5	0.2	0.2	0.1

The peak concentration C_p is calculated by the following equation:

$$C_p = C_m \cdot \Psi \qquad (4)$$

The approach leading to equation 4 assures a gradual decrease of the peak to mean – ratio with increasing distance, wind speed and stability, as can be seen from Fig. 1. For classes 2 and 3, Ψ, starting at rather high values near the source and at low wind speeds, rapidly approaches 1 with increasing wind speed and distance. This is in agreement with ideas that vertical turbulent mixing in weak winds then locally can lead to short periods of 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 wind speed and distance, because vertical mixing is reduced and horizontal diffusion is dominating the dispersion process. This is even more the case for class 5, when the peak to mean – ratio never exceeds 2. Compared to uncorrected peak to mean–values the damping is most effective for class 2 and decreases with increasing class number.

The problem of odour regulation is summarised by Nicell (1994) discussing the whole chain of odour sensation (detection 1 OU/m^3), discrimination (3 OU/m^3), unmistakable perception (5 OU/m^3, complaint level), and as a last step the degree of annoyance. Following this definition, three distances were calculated using these limit values, named sensation distance, discrimination distance, and complaint distance, by linear interpolation of the odour concentration calculated for discrete 41 distances between 50 m and 2000b m.

RESULTS

The sensation distance(Fig. 2), 1 OU/m^3, does not show a strong variation over the year. There is, however, a tendency of lower sensation distances in the summer months compared to the winter months. This is caused by generally lower wind speeds during summer and about ten times higher occurrence of stability class 2 which leads to high concentrations in the vicinity of the source. The sensation distance varies between about 90 and 450 m, the discrimination distance between about 80 and 250 m, and the distance of annoyance between 40 and almost 200 m for the livestock husbandry investigated. The higher the threshold, the smaller the range of distances, as expected. The distributions show several peaks, but none of the distance intervals occurs at frequencies above 10 %. For the sensation distance, the main peak occurs at rather large distances, which is probably caused by cases of high wind speeds and stability class 4 which occur frequently, but do not show exceedances of the discrimination or the annoyance levels. The latter show two distinct peaks at low and middle distances. The peaks at low distances are probably caused by a combination of stability class 2 and weak winds, giving rise to the highest odour concentrations near the source. The peaks at greater distances are most probably caused by stable situations (SC 6 and 7). The dependence of the threshold distance on the stability class can more clearly be seen from the example in Fig. 3 (see also Fig. 5), where odour concentration with distance is displayed for selected half-hours on September 8, 1992, with a large variety of stability conditions, ranging from SC=2 (very unstable) to SC=7 (very stable).

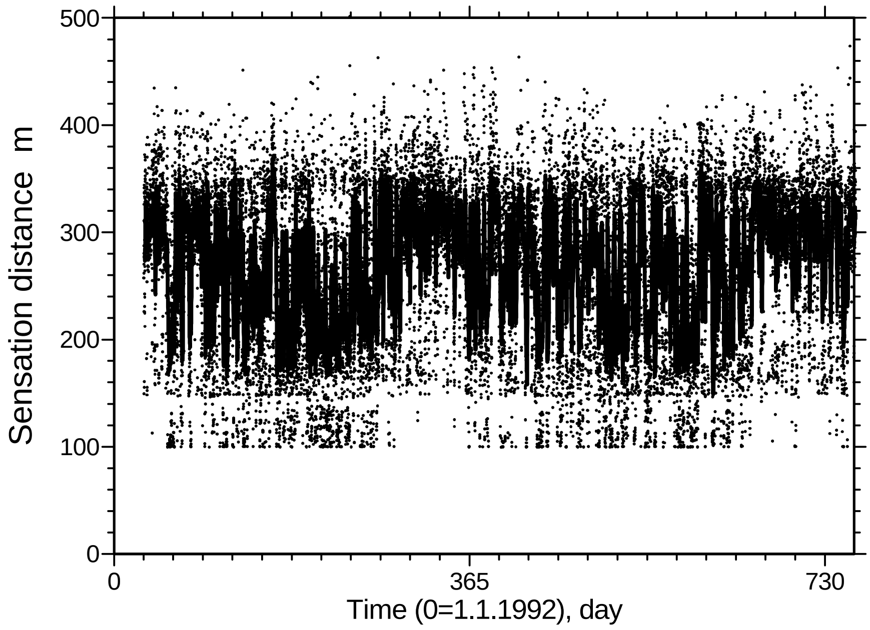

Figure 2. Calculated sensation distance (odour threshold 1 OU/m³). Each point represents a half hour mean value, calculated by the time series of meteorological elements at Wels. The line shows the smoothed average (over 24 hours) to eliminate the diurnal variation.

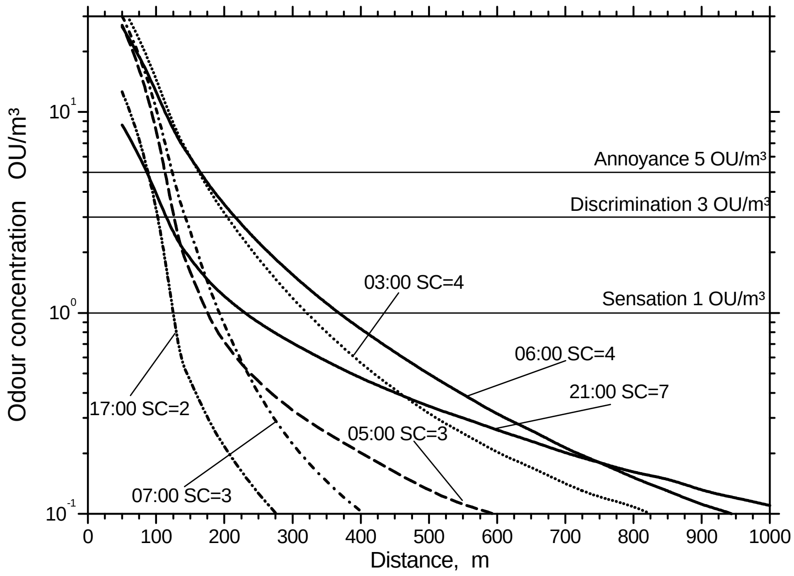

Figure 3. Calculated odour concentration as a function of the distance for September 8, 1992. On this day, the stability of the atmosphere varied between class SC=2 (very unstable) and class SC=7 (very stable) (see also Fig. 5).

Obviously, wind velocity and stability of the atmosphere are not homogeneously distributed over the wind directions. In Fig. 4, these two parameters are analysed. The dominant effect for low sensation distances to occur, which are most interesting for the environmental impact of the livestock building, is the stability. For unstable (SC 2 and 3) and very stable conditions (SC 6 and 7) combined with low wind velocity, the minimum sensation distances can be observed. From the occurrence frequencies of these classes, such minimum sensation distances can occur during daytime (high insulation) as well as during nocturnal radiative cooling situations.

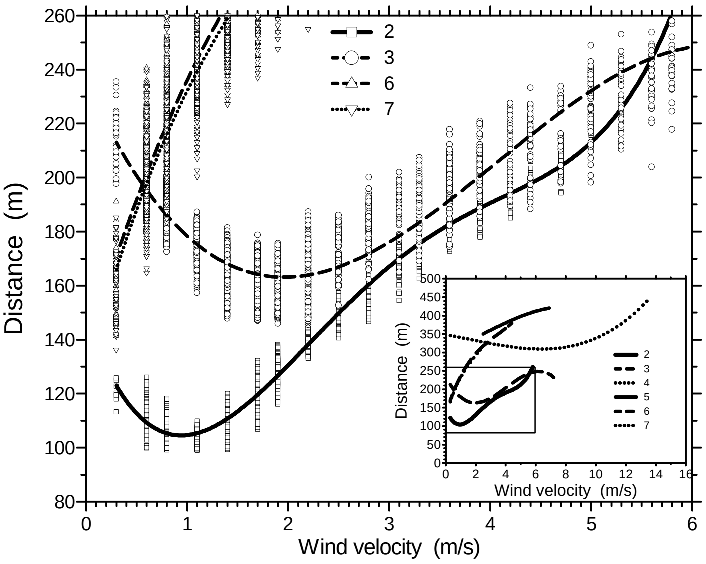

Figure 4. Influence of wind velocity and stability of the atmosphere on the distance of sensation (1 OU/m³).The small panel shows the fit of a polynom of 4th order without the data points for all classes of stability which occur at Wels.

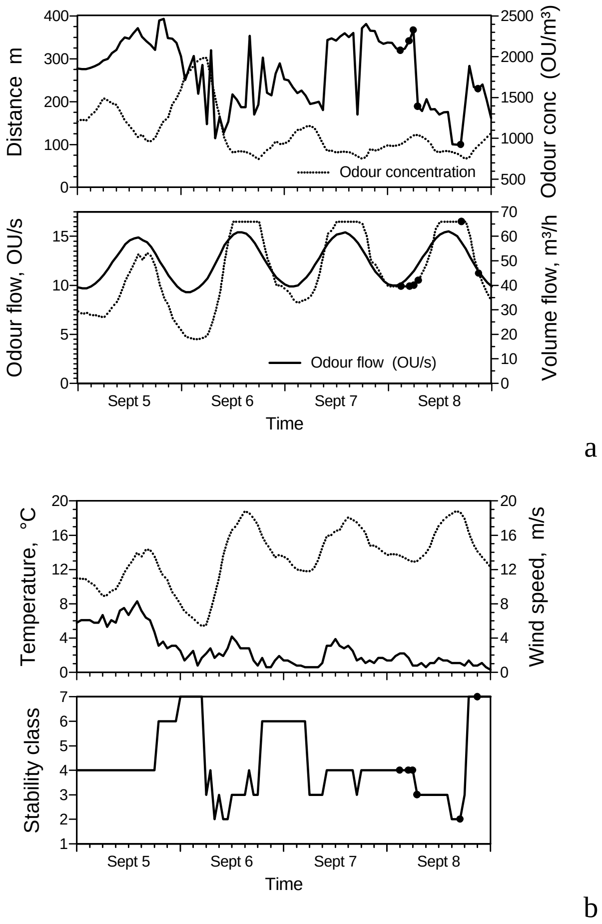

Figure 5. Emission and meteorological situation between September 5 and 8, 1992. The points highlight the time of the day where the odour concentration as a function of distance is drawn in Fig. 3) (a) Calculated ———— sensation distance in m and - - - - - - odour concentration in OU/m³ (upper panel); ———— odour flow in OU/s and - - - - - -, volume flow in m³/h (lower panel) per animal. (b) Ambient conditions: - - - - - outdoor air temperature in °C); ———— wind speed in m/s (upper panel); stability class of the boundary layer (lower panel).

DISCUSSION AND CONCLUSIONS

The dynamic Austrian odour dispersion model (AODM) consists of three modules: the first calculates the odour emission of the livestock building, the second estimates ambient concentrations, and the third takes into account the conversion to instantaneous values.

The odour emissions module is described in detail by Schauberger et al. (1999 and 2000ba). The consideration of the diurnal variation of the odour emission is the most important feature of this module. Since odour is mainly released by the animals, by polluted surfaces and by the feed, the diurnal variation of the emission is assumed to be in phase with animal activity.

The use of the Gaussian regulatory model ÖNorm M 9440 (1992/96) as the second module to calculate odour concentration imposes some restrictions to the generalization of the results achieved. The model is applicable only in flat terrain. Building influence on the dispersion as well as the influence of low-level capping inversions on the concentrations are not considered. The model is reliable only for wind velocity equal to or above 1 m/s and is advised to be applied for distances equal to or larger than 100 m. Treating more complex meteorological or topographic conditions, more elaborate dispersion models have to be used. The restrictions are, however, not very severe because a lot of large livestock farms in Austria are situated in rather flat terrain. Concentrations during calm wind conditions could be considered in a first step according to ÖNorm M 9440 (1992/96) by multiplying by 1.5 the concentration for 1 m/s and the appropriate stability class.

Since the sensation of odour depends on the momentary concentration rather than on a mean value calculated by the Gauss model over a longer period of integration, proper values of the peak-to-mean ratio have to be determined. The importance of the instantaneous concentration is discusses by Mylne (1988) for a non-linear dose response relationship of Chlorine as a toxic substance. For odour a similar situation is given: First the odour threshold has to be succeeded to receive a sensation of odour, secondly odour intensity goes with the logarithm of the concentration (e. g Misselbrook et al., 1993). Use of equation 1 does only take into account for the dependence on atmospheric stability, but not for the damping of the peak-to-mean ratio with increasing distance and wind speed. This is achieved by an attenuation function (equation 2) which depends on travel time and a measure of the Lagrangian time scale (Mylne, 1992). The result is given in Fig. 1 which shows that, with increasing wind speed and distance, a peak-to-mean ratio of 1 is more rapidly approached for stability classes 2 and 3 than for 4 and 5. This is in accordance with ideas of decreasing vertical turbulent mixing with increasing static stability of the atmosphere and increasing wind speed. Uncertainties arise in the necessary determination of the variances of the three wind components depending on stability. The values given there are seen as a first guess, and more investigations will be necessary to properly assess a possible dependance on stability of the variances of the horizontal wind components as well as a final determination of the stability dependence of the variance of the vertical wind by measurements with ultrasonic anemometers.

The Gauss model, extended by the peak-to-mean module, has been used to calculate the sensation, discrimination and annoyance distances for the scenario. Annual and diurnal variations as well as the influence of selected meteorological parameters have been investigated. For the configuration chosen, the distances for the three odour levels lie in a relatively narrow range (within 500 m). Qualitatively, this is in overall agreement with various national guidelines, discussed by Piringer and Schauberger (1999). The approach chosen is judged to give satisfactory results. The dependence on meteorological parameters shows the expected behaviour, i.e. lower distances occur during the summer months compared to the cold season due to lower wind speeds and far more frequent unstable situations. Overall, the results indicate a stronger dependence of the distances from meteorological conditions than from odour emission parameters.

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REFERENCES

1. CIGR Commission International du Génie Rural 1994. Aerial environment in animal housing - concencentration in and emission from farm buildings. CEMAGREF, Rennes
2. Kolb, H. 1981. Ein normatives Modell zur Simulierung der Ausbreitung von Schadstoffen in der Atmosphäre unter besonderer Berücksichtigung der Verhältnisse in Österreich. [A regulative model to simulate the dispersion of pollutants in the atmosphere for the situation in Austria]. Publ. 29. Abteilung für Theoretische Meteorologie, University Vienna, Vienna
3. Misselbrook, T.H., Clarkson, C.R., Pain, B.F. 1993. Relationship between concentration and intensity of odour for pig slurry and broiler houses. J of Agricultural Engineering Research 55: 163-169
4. Mylne, K.R. 1988. Concentration fluctuation measurements of a tracer plume at up to 1 km range in the atmosphere. 9th Symp. on Turbulence and Diffusion, Roskilde, p168-171.
5. Mylne, K.R. 1992. Concentration fluctuation measurements in a plume dispersing in a stable surface layer. Boundary-Layer Meteorology60, 15-48.
6. Mylne, K.R., Mason P.J. 1991. Concentration fluctuation measurements in a dispersing plume at a range of up to 1000m. Quart. J Royal Meteorol Soc. 117, 177-206.
7. Nicell, J. A. 1994. Development of the odour impact model as a regulatory strategy. Int. J. Environment and Pollution 4, 124-138.
8. ÖNorm M 9440 1992/1996. Ausbreitung von luftverunreinigenden Stoffen in der Atmosphäre; Berechnung von Immissionskonzentrationen und Ermittlung von Schornsteinhöhen [Dispersion of pollutants in the atmosphere – calculation of the ambient air concentrations and determination of stack heights]. Österreichisches Normungsinstitut, Vienna
9. Pechinger, U., Petz, E. 1995. Model evaluation of the Austrian Gaussian plume model ON M 9440: comparison with the Kincaid dataset. Int. J. Environment and Pollution 5, 338 - 349.
10. Piringer, M., Schauberger, G 1999. Comparison of a Gaussian Diffusion Model with Guidelines for Calculating the Separation Distance between Livestock Farming and Residential Areas to Avoid Odour Annoyance. Atmospheric Environment, 33 2219–2228
11. Robins, A. G. 1979. Development and structure simulated neutrally simmulated boudary layers. J. Ind. Aerodyn. 4, 71-100.
12. Schauberger, G., Piringer, M., Petz, E. 1999. Diurnal and annual variation of odour emission of animal houses: a model calculation for fattening pigs. Journal of Agricultural Engineering Research 74, 251-259
13. Schauberger, G., Piringer, M., Petz, E. 2000ba. Steady-state balance model to calculate the indoor climate of livestock buildings demonstrated for fattening pigs. International Journal of Biometeorology, 43, 154-162
14. Schauberger, G., Piringer, M., Petz, E. 2000bb. Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM). Atmos Environ, in press
15. Schiffman, S. S. 1998. Livestock Odors: implications for human health and well-being. Journal of Animal Science 76, 1343 - 1355
16. Smith, M.E. 1973. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. ASME, N.Y.