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Assessment of the odour concentration in the near-field of small sources

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Abstract

For small odour sources with a stack height of about the 2.5-fold of the building height a simple empirical assessment of the odour concentration is presented. The relevant near field dispersion is characterised by a disturbed plume due to the building structure. Some dispersion models can only be applied outside this disturbance zone which can be estimated by about 10 to 20 fold of the reference length of the building.

First the adaptation of dispersion models is discussed which mimics odour sensation of humans. For an assessment of the maximum expected odour concentration for an integration time of one single breath (about 5 seconds) a correction factor is introduced. Then two box models are presented which can be applied in the near field. In the transient zone, where Gaussian dispersion models can be applied too, the results of the near-field box models show a conservative estimation of the odour concentration. In some administrative procedures there is a need for such empirical models to reduce costs. Nevertheless this approach has to be seen as a first guess and doesn't want to substitute more sophisticated methods.

Introduction

In administrative procedures, small odour sources place the expert however also the authority in many cases in front of the problem of the proportionality. Small sources can be livestock buildings, snack-rooms, small businesses and so on. From the complexity of geometry and meteorological situation, micro-scale models would be appropriate. In many cases the necessary application cannot not be justified through the expenses.

In the following we present a method to assess the odour concentration in the near field of a building. The near field is the zone where the source structure directly affects plume dispersion and structure. The near field is typically 10 to 20 times the reference length, often estimated by the building height or width [1,2].

First we discuss the adaptation of dispersion models to mimic the odour sensation of humans due to their non-linear dose-response relationship. Second we present a simplified method to calculate odour concentration in the near field of buildings, based on box models.

Adaptation of dispersion models for the odour perception of humans

Most dispersion models are calculating mean values for an integration time of 30 to 60 minutes (eg [3]). For odour sensation the relevant integration time is about the duration of one single breath (about 5s). Therefore the fluctuations of the odour concentration has to be taken into account.

For the assessment of the expected maximum concentration at a receptor point a correction factor $F_{P/M}$ can be used, which is defined by the concentration for an integration time of the dispersion model and the concentration for an integration time of one single breath, often called peak-to-mean ratio. The maximum expected concentration for a single breath C_P can be calculated by

$$C_P = F_{P/M}\, C \tag{1}$$

with the concentrations of the dispersion model C and a distance depending factor $F_{P/M}$. Close to the source a factor $F_{P/M}{}^0$ is calculated by [4], which has to be attenuated as a function of distance

$$F_{P/M}^0 = \left(\frac{t_m}{t_P}\right)^a \tag{2}$$

with the exponent a of the power function, depending on the stability of the atmosphere (Tab. 1), the integration time for the mean value t_m = 1800 s (depending on the used dispersion model between t_m = 1800 s and 3600 s) and the short time integration time t_P, here assumed as t_P = 5 s as duration of a single breath.

Tab. 1: Exponent a of Eq. 2, to assess the short term concentration C_P as a function of the stability classes of the atmosphere SC (ÖNorm [3] and Pasquill) and the correspondent peak-to-mean factors $F_{P/M}{}^0$

SC		State of Texas[1]		Smith[2]		AODM[3]	
		a	$F_{P/M}{}^0$	a	$F_{P/M}{}^0$	a	$F_{P/M}{}^0$
2	A	0.68	54.74	0.65	45.88	0.640	43.25
3	B	0.55	25.47	0.52	21.34	0.510	20.12
4	C	0.43	12.57	0.52	21.34	0.380	9.36
5	D	0.30	5.85	0.35	6.58	0.250	4.36
6	E	0.18	2.88	-	-	0.000	1.00
7	F	0.18	2.88	-	-	0.000	1.00

[1] [5]; [2] [4]; [3] [7]

The former TA Luft guide line selected a constant correction factor $F_{P/M}$=10. In this respect it has to taken into mind that the Gaussian dispersion model, which was used with this correction factor, is limited to distances above 100 m. A recently presented version of the dispersion model for odour (AUSTAL2000G), which has to be used in accordance to TA Luft 2002 (AUSTAL 2000, www.austal2000.de) is using a constant factor 4 [6].

For a simplified assessment we suggest an interpolation between the correction factor close to the source $F_{P/M}{}^0$ and at a distance above 100m $F_{P/M,max}$. The constant value above 100 m can be selected according to the TA Luft ($F_{P/M,max}$ = 10) or by a less conservative approach according to the ODIF or AUSTAL200G model ($F_{P/M,max}$ = 4). Beside this two constant values a more sophisticated attenuation function can be used, which is based on the travel time of the pollution and the Lagrangian time scale describing the stability of the atmosphere [7]. Fig. 1 depicts the correction factor $F_{P/M}$ calculated for the exponent a used in the State of Texas (Tab. 1, [5]) and a maximum value of 4 (ODIF or AUSTAL2000G model) as an example.

The correction factor $F_{P/M}$ for distances below 100m can be calculated by

$$F_{P/M} = \begin{cases} F_{P/M}{}^0 - \left(F_{P/M}{}^0 - F_{P/M,\max}\right)\left(e^{\ln 2\, 10^{-6} x^3} - 1\right) & for\ x \le 100m\ and\ F_{P/M}{}^0 > F_{P/M,\max} \\ F_{P/M,\max} & for\ x \le 100m\ and\ F_{P/M}{}^0 \le F_{P/M,\max} \\ F_{P/M,\max} & for\ x > 100m \end{cases} \tag{3}$$

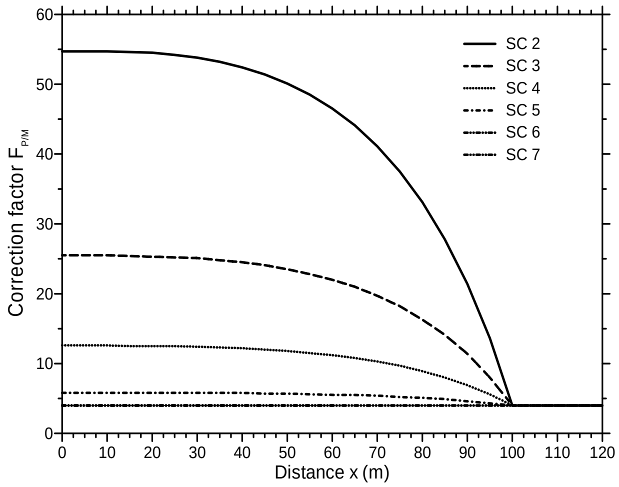


Fig. 1: Correction factor $F_{P/M}$ as a function of the distance from the source x (m). The graph shows a maximum for stability class SC = 2 and a value $F_{P/M,max}$ = 4 according to ODIF or AUSTAL 2000G.

The ratio between emission concentration C_e and the perception threshold of 1 OU/m³ lies in the range between 100 and 10 000. This means, that in the close vicinity of odour source the expected dilution can be below this ratio. Therefore the maximum expected odour concentration is limited by the odour emission concentration.

$$C_P = \min\left(C\,F_{P/M}, C_e\right) \quad (4)$$

Dispersion models for the near field

In the close vicinity of buildings and other obstacles close to a stack, plume dispersion is disturbed. For flat areas the dilution process can be solved relatively simple (eg Gaussian models). For complex terrain due to bluff bodies like buildings and other obstacles the wind-field itself is changed in the near field but also the spatial distribution of turbulence. Here we want to give an overview how to treat building effects.

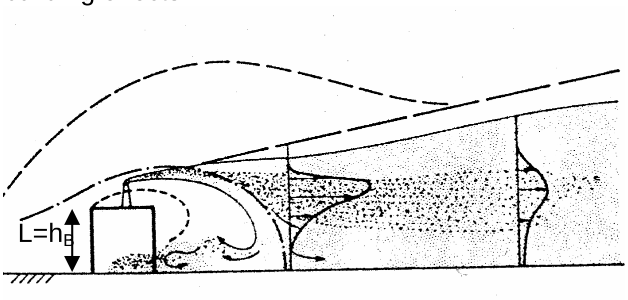


Fig. 2: Schematic view of the building effect in the leeward. The reference length L (in this case the building height h_B) characterises the size of the recirculation zone (after [8])

The dilution process in the close vicinity of buildings is strongly depending on the scale. In Fig. 2 the influence of a building is schematically shown. The cavity zone is characterised by the re-circulation. Behind there is the down-wash zone. The size of the building effect can be assessed by the reference length L.

The reference length L can be expressed by the building height h_B and the crosswind width h_A according to ÖNorm [3].

$$L = \min\left(h_A, h_B\right) \quad (5)$$

In the near field various model concepts are in use (Fig. 3). Box models need only few input information, therefore they can be used easily as a first estimation. The Gaussian concept can be adopted for the near field by an interpolation scheme, taking into account building and downwash effects (eg regulatory dispersion model in The Netherlands).
An other modification is the virtual source. It is based on the idea, that the source is split into two different plums to simulate the extra dispersion which is caused by the building effect. Initially this was achieved by shifting the location of the source upwind, to model the broadening of the plume due to the building effect [9,10]. More complex models (micro-scale non-hydrostatic models, eg MISKAM) were not included in this overview.

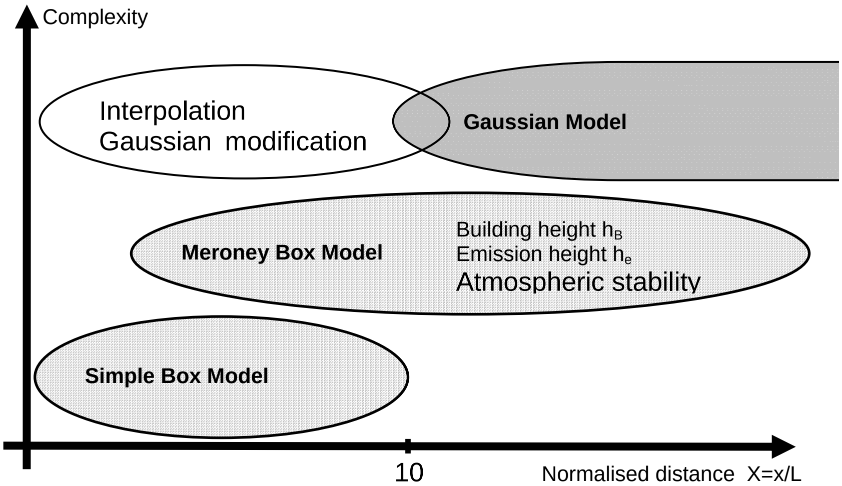


Fig. 3: Model concepts in the near field of a building

For a box model it is assumed that the concentration C inside the cavity zone can be expressed by

$$C = \frac{K\,Q}{u\,A_B} \qquad (6)$$

with a dimensionless concentration coefficient K, odour concentration C (OU/m³), wind velocity u (m/s), building area cross section A_B, which can be expressed by $A_B = L^2$, and the source strength Q (OU/s).

Simple box model
For the simple box model two areas can be distinguished [8], depending on the normalised distance X = x/L. For distances closer than x/L = 2.5 a constant concentration coefficient is assumed, which means, that inside the cavity zone a constant odour concentration is expected. In the range between x/L = 2.5 and 10 the concentration coefficient and therefore also the concentration C goes with the inverse square of the normalised distance. For distances above x/L = 10 this model cannot be applied (see also Fig. 3). For the concentration coefficient K (for x/L<2.5) various values are in use, in the range between 0.5 and 5.0 [8]. For higher distances values between 4 and 20 can be found in literature. For a maximum estimation we selected a value of 3.0. For distances x/L ≥ 2.5 a coefficient was selected that the function show a smooth behaviour for the limit value of x/L = 2.5 by

$$K = \left| \begin{array}{ll} 3.0 & \text{for } \frac{x}{L} < 2.5 \\ 18.75\left(\frac{x}{L}\right)^{-2} & \text{for } 2.5 \le \frac{x}{L} \le 2.5 \end{array} \right. \qquad (7)$$

with the distance x (m) in wind direction from the source and the reference length L (m).

Meroney box model

In the previous concept only the reference length L as a source depending parameter was used. In the following assessment of the concentration coefficient K, based on Meroney [8], also the ratio of stack height h_e and the building height h_B is used. Fig. 4 shows the influence of the stack height compared to the building height. Only when the emission height h_e is 2.5 times above the building height it can be supposed that the emission lies outside of the building influence.

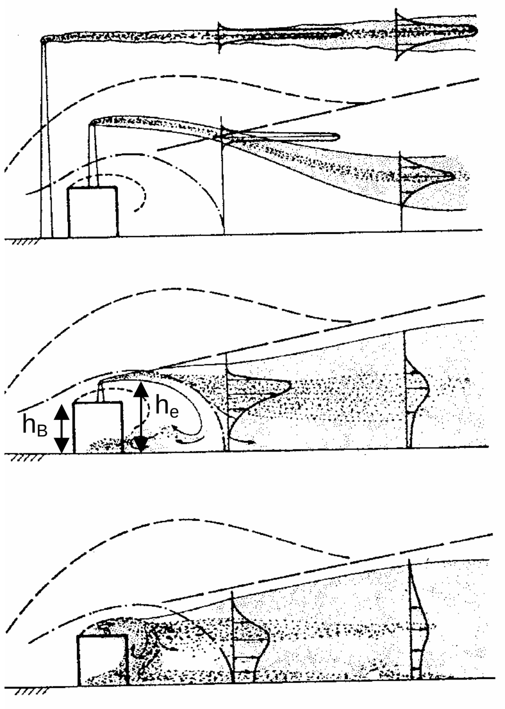


Fig. 4: Influence of the height of the odour emission h_e compared to the building height h_B [after [8])

The assessment of K is based on a modification of the dispersion parameters σ_x and σ_z of the Gaussian dispersion model. The modification is based on the broadening of the plume due to the building effect, parameterised by the cross-section of the building A_B

$$K_0 = \frac{A_B}{\pi \sigma_y \sigma_z + c A_B} \tag{8}$$

with an empirical constant c (between c=0.5 and 2.0).
To take into account the size of the re-circulation zone and the entrainment into this zone the ratio between emission height h_e and building height h_B is introduced. For a maximum of the ratio h_e/h_B=2.5 the concentration coefficient $K_{2.5}$ is calculated by

$$K_{2.5} = K_0 \exp\left[-\frac{1}{2} \left(\frac{6.25}{\frac{\sigma_z^2}{A_G} + \frac{1}{\pi}} \right) \right] \tag{9}$$

Then the concentration coefficient K can be calculated by the ratio h_e/h_B

$$K = K_{2.5} \left(\frac{K_{2.5}}{K_0} \right)^{\left[\left(\frac{h_e / h_B}{2.5} \right)^2 - 1 \right]} \tag{10}$$

The dispersion parameters, σ_x and σ_y, used in this paper are based on the ÖNorm [3].

Example

In the following example we apply the simple box modes and the Meroney box model to a typical small odour source. We selected an isolated building with a building height h_B of about 5 m, an emission height h_e of about 6 m. The odour source was estimated by an odour flow rate Q = 420 OU/s and an emission concentration C_e = 300 OU/m³ (Fig. 5)

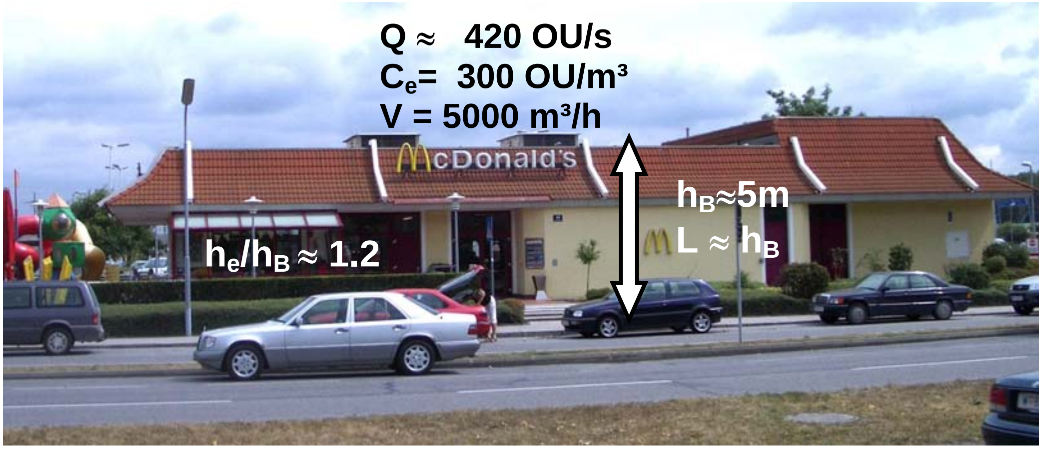


Fig. 5: Example of an isolated building as a small odour source with typical parameters.

The odour concentration was calculated by the two box models. For distances x>100m we assume, that beyond this distance the Gaussian model can be applied. The presented results were calculated for an wind velocities of 1, 3, and 5 m/s.

In Fig. 6 the odour concentration was calculated by the Meroney box model for all stability classes 2 to 7 and a wind velocity of u=1 m/s. Below a distance of L=10, the maximum value over all stability classes (thick line in Fig. 6) is dominated by SC=2 (unstable), for higher distances by SC=7 (very stable).

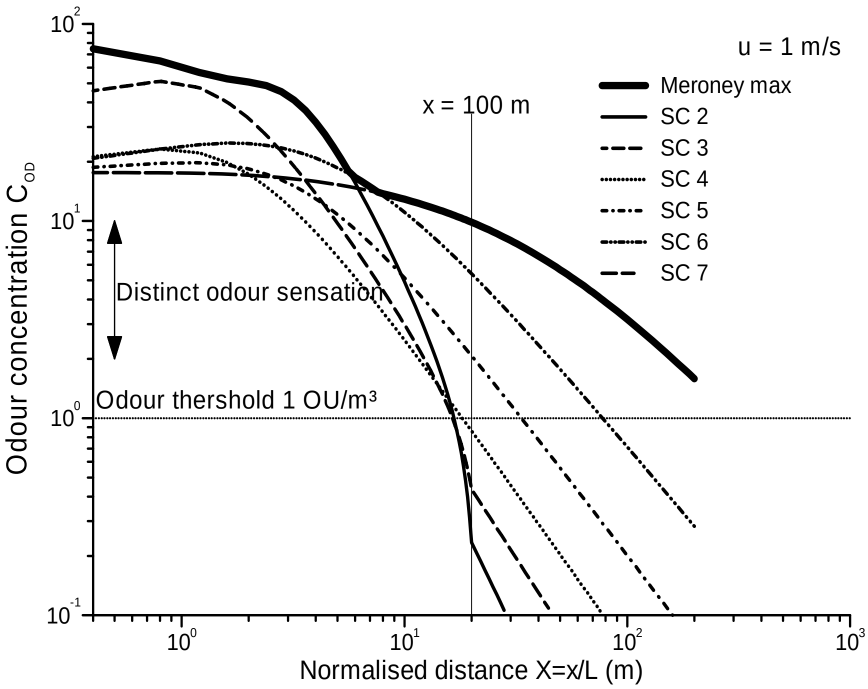
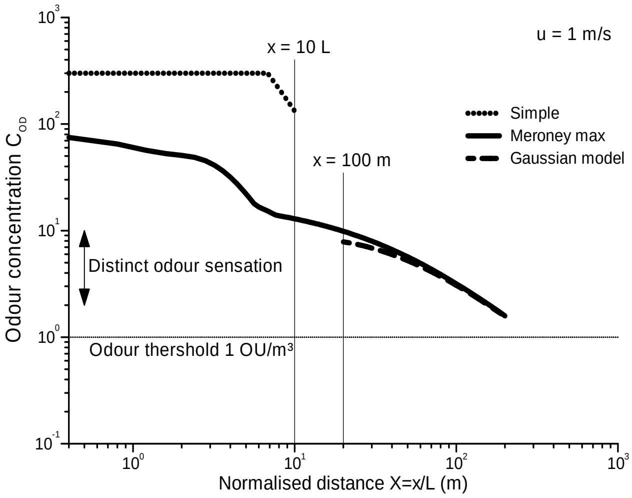
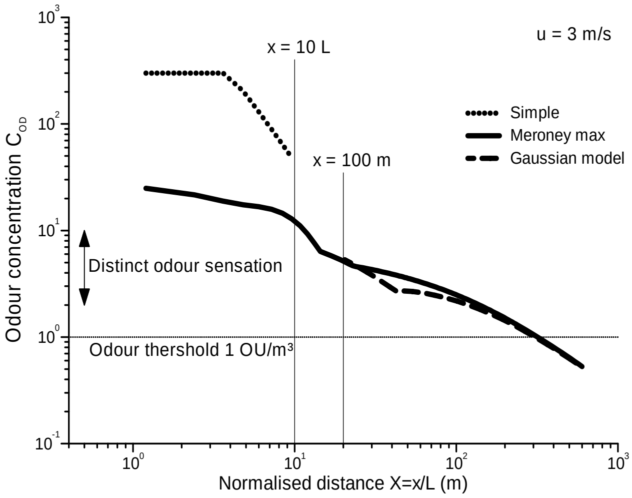


Fig. 6: Odour concentration calculated by the Meroney box model for a wind velocity of 1 m/s.

In Fig. 7 the calculation for the simple box model, the Meroney model, and the odour concentration calculated by the Gaussian model was depicted. For a wind velocity of u =1 m/s and 3m/s the simple model shows a plateau which is caused by the fact, that the ambient odour concentration is limited by the odour emission concentration. At the upper limit of the model domain (L = 10 or x = 50 m) and u =1 m/s, the odour concentration is assessed by the simple box model with C = 139 UO/m³, which is about the 10 fold of the Meroney model. The upper level of distinct odour sensation (C = 10 OU/m³) is reached at a distance of 20 L, which means x = 100 m. At distances above 100 m, the odour concentration calculated by the Gaussian model shows a close agreement with the Meroney assessment.
By using a wind statistics (wind direction and wind velocity) or a dispersion climatology (stability classes and wind velocity) these results can be used to assess the annoying potential for a certain distance. Therefore the exceedance probability for a certain threshold can be used. In general an odour threshold of 1 OU/m³ is selected. The exceedance probability for this threshold depends on the protection level which has to be archived. For Germany an exceedance probability of 10% (90-precentile) is assumed for residential areas.



a



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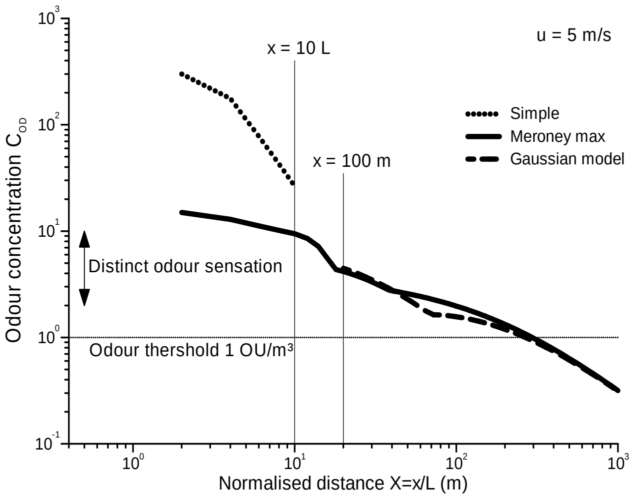

c

Fig. 7: Odour concentration calculated by the simple box model (Eq. 7), the Meroney box model and by the Gaussian model (distance > 100 m) for a wind velocity of 1 m/s (a), 3 m/s (b), and 5 m/s.

Discussion and Conclusions

Small odour sources have to be evaluated in many cases to assess the odour annoyance in the vicinity of the emission. Especially for administrative procedures, consultants and expert witness have sometimes to accept restrictions concerning the costs. In this paper we summarise methods which can be used in a multi-step approach. To consider the sensation characteristics of humans, we suggest an adaptation of the presented models by a peak-to-mean approach, as it is used for regulatory dispersion models. As a first guess, the odour concentration can be calculated by a simple box model or the Meroney box model. If the calculated odour concentration exceeds the pre-selected limit values, more sophisticated solutions can be applied.

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