

SUPPLEMENTARY MATERIAL

Summary and Evaluation of the Odour Regulations Worldwide

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Odour Impact Criteria

There are two groups of odour impact criteria (OIC) used in various jurisdictions. The first group is common in the Anglo-American countries with high threshold/low exceedance probability; the second group with low threshold/high exceedance is based on investigations in Germany. Even if both approaches show empirical evidence, the advantages/disadvantages have to be discussed. The first group of OIC is based on investigations of the annoyance, which were determined by a survey of highly annoyed people and compared with the results of a dispersion model (Miedema and Ham, 1988; Miedema et al., 2000; Noordeggraaf and Bongers, 2007).

The empirical evidence of the second group of OIC with low threshold and high exceedance probability (Germany and Austria) is also based on investigations of the annoyance which were determined by a

survey of (highly) annoyed people and the odour exposure determined by field investigations according to EN 16841 Part 1 and VDI 3940 Part 1 (Steinheider et al. 1993, Both et al. 2004, Sucker et al. 2008). Also, hedonic tone and odour intensity were taken into account in these investigations. The main finding is that with the exceedance of an odour frequency of 10% a significant nuisance in residential areas is combined. Because field investigations only make sense if the odour source already exists, a comparison of the frequency of odour perception by the method of field inspections (EN 16841-1, 2016; VDI 3940 Part 1, 2006) with calculations of dispersion models (Hartmann, 2006; Müller and Riesewick, 2013; Ranzato et al., 2012) were carried out. For this comparison, it is necessary to consider the conversion of the hourly mean odour concentration to an odour concentration relevant to the odour perception in the field. By field inspection using a panellist, a grid area has to be visited at least 52 or 104 times, which are randomly distributed over half a year or one year. With this kind of field inspection, it is possible to detect an odour frequency in the range of 10% and above with good accuracy. Because of methodological restrictions, lower odour frequency than 2% or less cannot be detected by this method, which means that model calculations using such small exceedance probabilities cannot be checked by this empirical approach. But in practice, these low frequencies are not relevant.

For a low exceedance probability of $p_T = 2\%$ or less, only a few distinct meteorological situations will contribute to the separation distance. For $p_T = 0.1\%$ according to 9 h per year (West Australia), the only 9 highest values of the ambient odour concentration are used to determine the separation distance. This means that for each wind direction, at least nine hours per year of a certain meteorological situation with a very low dilution can be found, which leads to a nearly circular separation distance. Therefore the meteorological situation has a low influence on the direction-depending separation distance. In contrast, for a high exceedance probability in the range of 10 to 20%, nearly all stability classes contribute to the separation distance, as could be shown by Schaubberger et al. (2006, Figures 4-6).

Table S1 below summarizes the examples of considering the FIDOL factors: intensity, hedonic tone, odor character, and nuisance in selected odour regulations.

Table S1: Odour impact criteria (OIC) of various jurisdictions defined by the odour concentration threshold C_T^* ($\text{ou}\cdot\text{m}^{-3}$) for the corresponding integration time of the ambient concentration and the exceedance probability p_T (in %). The ambient odour concentration is determined either by the integration time or the peak-to-mean factor F .

| Country | Ambient Odour Concentration | | Odour Impact Criteria C_T^* / p_T ($\text{ou}\cdot\text{m}^{-3} / \%$) | Protection Level | Source/ Reference |
|---------|---|---------------------|--|------------------|----------------------|
| | Integration time of the ambient concentration | Peak-to-Mean factor | | | |
| | | | | | |

| | | | | | |
|-----------------|-----|---|--|---|--|
| Germany | 1s | No peak to mean factor If the hourly mean exceeds $0.25 \text{ ouE}\cdot\text{m}^{-3}$ the hour is counted as an odour hour) | Limit values defined as odour hours per year (odour hours/8760) 0.02 0.10 0.15 0.15 | Irrelevance criterion Residential and mixed areas | GOAA (2008) |
| | 1 h | | Annoyance factors (Limit values to be multiplied by the annoyance factor) 0.5 1.5 0.75 0.5 0.5 0.5 | Commercial and industrial areas Villages (only for livestock odour) Pleasant odours poultry fattening pigs milking cows Fattening bulls horses | |
| Austria | 5 s | variable # | 1 / 8 and 5 / 3 | residential areas | ÖAW (1994) |
| Ireland | 1 h | 1 | 4.3 / 2 | residential areas / pig | Sheridan et al. (2004); EPA Ireland, (2001); Hayes et al. (2006) |
| | | | 1.5 / 2 | pure residential areas / pig, target value | |
| | | | 3 / 2 | residential areas / pig, planned farms | |
| | | | 6 / 2 | rural areas, pig, old farms | |
| | | | 9.7 / 2 | residential areas, poultry | |
| | | | 6 / 2 | residential areas, poultry | |
| Belgium | 1 h | 1 | 6 / 2 | pigs | Nicolas et al. (2008) |
| | | | 10 / 2 | poultry | |
| The Netherlands | 1h | 1 | | Suggested limit values, to be approved locally | Yang and Hobson (2000) |
| | 1h | 1 | 5 / 2 1.5 / 2 0.5 / 2 | Upper limit existing situations, Upper limit new situations Safe target for new sources | |

| | | | | | |
|----------------------------|-------|-----|---|--|-------------------------------------|
| | | | 1 / 0.5 2 / 0.1 10 / 0.01 | Suggested limit values for new (highly) intermittent sources | |
| | | | 0.5 / 2 1.5 / 2 1.0 / 2 3.5 / 2 | Specific Branche limit values, example: STP new facilities, densely populated existing facilities, densely populated new facilities, sparsely populated existing facilities, sparsely populated | |
| Denmark | 1 min | 7.8 | 5 to 10 / 1 | residential areas | Mahin (2001), Olesen et al. (2005) |
| | | | 10 to 30 / 1 | industrial and rural areas | |
| Hungary | 1 h | 1 | 0.6 to 1.2 / 2 | | Cseh et al. (2010) |
| France | 1 h | 1 | Odour flow as a function of emission height | Food and beverage industries (previously different industries) | Arrêté (2003, 2008, 2012) |
| | | | 5 / 2.0 | Composting plant | |
| | | | 5 / 0.5 at 3 km | New animal by-product processing plants | |
| | | | 5 / 2.0 at 3 km based on dispersion result if not C<1000 per source | Existing animal by-product processing plants | |
| | | | C<5 at 500m if people are living in this area | Solvent industries Other authorized activities | |
| Italy (province of Trento) | 3s | 2.3 | 1 / 2.0 2 / 2.0 3 / 2.0 | Residential areas x > 500 m 200 m ≤ x ≤ 500 x < 200 m | Provincia Autonoma di Trento (2012) |
| | | | 2 / 2.0 3 / 2.0 4 / 2.0 | Non-residential ar x > 500 m 200 m ≤ x ≤ 500 x < 200 m | |
| Australia Queensland | | 10 | 5 / 2.0 | stacks | Environmental Protection Agency |
| | | 5 | 5 / 0.5 | ground-level or down-washed plumes | |

| | | | | | |
|---------------------------------|--------|------|--|---|--|
| | | | | | Queensland (2004) |
| Australia New South Wales | 3 s | * | $C_T = f(D) / 1$ | C_T ($\text{ou}\cdot\text{m}^{-3}$) depends on the population density D ($1\cdot\text{km}^{-2}$); $C_T = -(\log D - 4.5)/0.6$ | Wallis and Cadee (2008) |
| Australia West Australia | 3 min | ‡ | 2 / 0.5 4 / 0.1 | | Wallis and Cadee (2008) |
| Australia Victoria | 3 min | ‡ | 4 / 0.1 | | Wallis and Cadee (2008) |
| Australia Queensland | | 2 | 2.5 / 0.5 | residential areas | Wallis and Cadee (2008) |
| Australia South Australia | 3 min | ‡ | $CT = f(D) / 0.1$ | C_T ($\text{ou}\cdot\text{m}^{-3}$) depends on the population density D ($1\cdot\text{km}^{-2}$); $C_T = -(\log D - 4.5)/0.6$ | Wallis and Cadee (2008) |
| New Zealand | 1 h | 1 | 1 / 0.5 2 / 0.5 5 / 0.5 5 to 10 / 0.5 | high sensitivity /unstable and semi unstable high sensitivity / stable moderate sensitivity low sensitivity | Ministry for the Environment New Zealand (2003) |
| USA Pennsylvania | 2 min | 2 | 4 / 0.57 | residential with highway | |
| USA California | 1 h | 1 | 4 / 1.1 | industrial with some residential and highway | |
| USA Pennsylvania | 1 h | 1 | 20 / 1.1 | residential | |
| USA California | 5 min | 2.29 | 4 / 0.5 | plant fence-line | |
| Canada Ontario | 10 min | 1 | 0/5 | Any sensitive receptor | Ontario's Ambient Air Quality Criteria (2012) |

Peak-to-mean factor F depends on the distance and atmospheric stability (Piringer et al., 2007; Schauburger et al., 2000, 2013)

* Area sources: $F = 1.9$ applies to E, F stability in the far-field ($F = 2.3$ in the near-field) & $F = 2.3$ for A-D stability in the far-field ($F = 2.5$ in the near-field); Volume sources, $F = 2.3$ (McGahan et al., 2002)

‡ No guidelines are given to determine the peak-to-mean factor for an integration time, which deviates from the 1 h mean value.

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