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# Supplementary material

## 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 [1–3].

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 [4] and VDI 3940 Part 1 [5, 6–9]. 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 [10–12] 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 Schauberger et al. (2006), Figures 4–6) [13].

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

**Table 1.** Odour impact criteria (OIC) of various jurisdictions defined by the odour concentration threshold $C_T^*$ ($ou_E \cdot m^{-3}$) 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** $C_T$* / $p_T$ ($ou_E \cdot m^{-3}$ / %) | **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 $ou_E \cdot m^{-3}$ the hour is counted as an odour hour) | Limit values defined as odour hours per year (odour hours/8760)<br>0.02<br>0.10<br>0.15<br>0.15 | Irrelevance criterion<br>Residential and mixed areas | [14] |
| | 1 h | | Annoyance factors (Limit values to be multiplied by the annoyance factor) | Commercial and industrial areas<br>Villages (only for livestock odour) | |
| | | | 0.5<br>1.5<br>0.75<br>0.5<br>0.5<br>0.5 | Pleasant odours<br>poultry<br>fattening pigs<br>milking cows<br>Fattening bulls<br>horses | |
| Austria | 5 s | variable $^{\#}$ | 1/8 and<br>5 / 3 | residential areas | [15] |
| Ireland | 1 h | 1 | 4.3 / 2 | residential areas / pig | [16–18] |
| | | | 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 | [19] |
| | | | 10 / 2 | poultry | |
| The Netherlands | 1h | 1 | | Suggested limit values, to be approved locally | [20] |
| | 1h | 1 | 5 / 2<br>1.5 / 2<br>0.5 / 2 | Upper limit existing situations,<br>Upper limit new situations<br>Safe target for new sources | |
| | | | 1 / 0.5<br>2 / 0.1<br>10 / 0.01 | Suggested limit values for new (highly) intermittent sources | |
| | | | 0.5 / 2<br>1.5 / 2<br>1.0 / 2 | Specific Branche limit values, example: STP new facilities, densely populated | |

| | | | | | |
|---|---|---|---|---|---|
| | | | 3.5 / 2 | existing facilities, densely populated<br>new facilities, sparsely populated<br>existing facilities, sparsely populated | |
| Denmark | 1 min | 7.8 | 5 to 10 / 1 | residential areas | [21,22] |
| | | | 10 to 30 / 1 | industrial and rural areas | |
| Hungary | 1 h | 1 | 0.6 to 1.2 / 2 | | [23] |
| France | 1 h | 1 | Odour flow as a function of emission height | Food and beverage industries (previously different industries) | [24–26] |
| | | | 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<br>Solvent industries | |
| | | | C<5 at 500m if people are living in this area | Other authorized activities | |
| Italy (province of Trento) | 3 s | 2.3 | 1 / 2.0<br>2 / 2.0<br>3 / 2.0 | Residential areas<br>$x > 500$ m<br>200 m $\leq x \leq$ 500<br>$x < 200$ m | [27] |
| | | | 2 / 2.0<br>3 / 2.0<br>4 / 2.0 | Non-residential ar $x >$ 500 m<br>200 m $\leq x \leq$ 500<br>$x < 200$ m | |
| Australia Queensland | | 10 | 5 / 2.0 | stacks | [28] |
| | | 5 | 5 / 0.5 | ground-level or down-washed plumes | |
| Australia New South Wales | 3 s | * | $C_T$= f($D$) / 1 | $C_T$ (ou·m$^{-3}$) depends on the population density $D$ (1·km$^{-2}$); $C_T$ = −(log$D$−4.5)/0.6 | [29] |
| Australia West Australia | 3 min | ‡ | 2 / 0.5 | | [29] |
| | | | 4 / 0.1 | | |
| Australia Victoria | 3 min | ‡ | 4 / 0.1 | | [29] |
| Australia Queensland | | 2 | 2.5 / 0.5 | residential areas | [29] |
| Australia South Australia | 3 min | ‡ | CT= f(D) / 0.1 | $C_T$ (ou·m$^{-3}$) depends on the population density $D$ (1·km$^{-2}$); $C_T$ = −(log$D$−4.5)/0.6 | [29] |
| New Zealand | 1 h | 1 | 1 / 0.5<br>2 / 0.5<br>5 / 0.5 | high sensitivity /unstable and semi unstable<br>high sensitivity / stable | [30] |

| | | | | | |
|---|---|---|---|---|---|
| | | | 5 to 10 / 0.5 | moderate sensitivity<br>low sensitivity | |
| USA<br>Pennsylvania | 2 min | 2 | 4 / 0.57 | residential with highway | |
| USA<br>California | 1 h | 1 | 4/ 1.1 | industrial with some residential and highway | |
| USA<br>Pennsylvania | 1 h | 1 | 20 / 1.1 | residential | |
| USA<br>California | 5 min | 2.29 | 4 / 0.5 | plant fence-line | |
| Canada<br>Ontario | 10 min | 1 | 0/5 | Any sensitive receptor | [31] |

[#] Peak-to-mean factor *F* depends on the distance and atmospheric stability [32–34].

[*] 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, $F = 2.3$ ([35])

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

## References

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1. Miedema, H.M.E.; Ham, J.M. Odour annoyance in residential areas. *Atmospheric Environment **1988***, *22*(11), 2501-2507.
2. Miedema, H.M.E.; Walpot, J.I.; Vos, H.; Steunberg, C.F. Exposure-annoyance relationship for odour from industrial sources. *Atmos. Environ.* **2000**, *34*, 2927–2936.
3. Noordegraaf, D.; Bongers M. *Relationship between Odour Exposure and Odour Nuisance in the Neighbourhood of Livestock Farms*; PRA Odournet: Amsterdam, The Netherlands, 2007.
4. European Committee for Standardization CEN. *Ambient Air—Determination of Odour in Ambient Air by Using Field Inspection—Part 1: Grid Method*; EN 16841–1:2016 CEN: Brussels, Belgium, 2016. .
5. The Association of German Engineers. VDI. *Measurement of Odour Impact by Field Inspection—Measurement of the Impact Frequency of Recognizable Odours—Grid Measurement*; VDI 3940 *Part 1*; Beuth Verlag GmbH: Berlin, Germany, 2006.
6. Steinheider, B.; Both, R.; Winneke, G. Industrial odours as environmental stressors: Exposure-annoyance associations and their modification by coping, age and perceived health. *Journal of Environmental Psychology* **1993**, *13*, 353–363. .
7. Both, R.; Sucker, K.; Winneke, G.; Koch. E. Odour intensity and hedonic tone – important parameters to describe odour annoyance of residents. *Water Science and Technology* **2004**, *50(4)*, 83-92.
8. Sucker, K.; Both, R.; Bischoff, M.; Guski, R.; Winneke, G. Odor frequency and odor annoyance. Part I: Assessment of frequency, intensity and hedonic tone of environmental odors in the field. *Int. Arch. Occup. Environ. Health* **2008**, 671–682, doi:10.1007/s00420–007–0259-z.
9. Sucker, K.; Both, R.; Biscoff, M.; Guski, R.; Winneke, G. Odor frequency and odor annoyance Part II: Dose-response associations and their modification by hedonic tone. *Int. Arch. Occup. Environ. Health.* **2008**, 683–694, doi:10.1007/s00420–007–0262–4.
10. Hartmann, U. Odor assessment in agriculture -Determination of the pollution situation in NRW by model calculation, emissions from animal husbandry. *Board of Trustees for Technology and Construction in Agriculture Darmstadt* **2006**, *449*, 169–178.
11. Müller, F.; Riesewick, H. Odor problem in the context of land-use planning in rural areas (Geruchsproblematik im Rahmen der Bauleitplanung im ländlichen Raum). VDI Report 2195 **2013**, 137-148.
12. Ranzato, L.; Barausse, A.; Mantovani, A.; Pittarello, A.; Benzo, M.; Palmeri, L. A Comparison of Methods for the Assessment of Odor Impacts on Air Quality: Field Inspection (VDI 3940) and the Air Dispersion Model CALPUFF. *Atmospheric Environment* **2012**, *61*, 570–579.
13. Schauberger, G.; Piringer, M.; Petz, E. Odour Episodes in the Vicinity of Livestock Buildings: A Qualitative Comparison of Odour Complaint Statistics with Model Calculations. *Agriculture, Ecosystems & Environment* **2006**, *114*(2,4), 185-194.
14. Administrative Regulation. Determination and Evaluation of Odour Immissions—Guideline on Odour in Ambient Air GOAA (1994/1999/2004/2008). *Länderausschuss für Immissionsschutz GOAA* **2008**, LAI-Schriftenreihe No 5 Berlin (in German) revised version 1999.
15. ÖAW, 1994. Umweltwissenschaftliche Grundlagen und Zielsetzungen im Rahmen des Nationalen Umweltplans für die Bereiche Klima, Luft, Geruch und Lärm, in: Kommission für Reinhaltung der Luft der Österreichische Akademie der Wissenschaften (Ed.), Schriftenreihe der Sektion I . Band 17. Bundesministeriums für Umwelt, Jugend und Familie, Vienna, Austria, 1994; Volume 17.

16. Sheridan, B.A.; Hayes, E.T.; Curran, T.P.; Dodd, V.A. A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland. *Bioresource Technology* **2004,** *91*(2), 145-152.
17. Toner, P.; Bowman, J.; Clabby, K.; Lucey, J. McGarrigle, M.; Concannon, C.; Clenaghan, C.; Cunningham, P.; Delaney, J.; O'Boyle, S.; MacCárthaigh, M.; Craig, M.; Quinn, R. Water Quality in Ireland. *Environmental Protection Agency Ireland* **2001**. Available online: https://www.epa.ie/pubs/reports/water/waterqua/EPA_water_quality_2001-3.pdf (accessed on 03 February 2021).
18. Hayes E.T.; Curran, T.P.; Dodd, V.A. Odour and Ammonia Emissions from Intensive Poultry Units in Ireland. *Bioresource Technology* **2006**, *97*(7), 933-939.
19. Collart, C.; Lebrun, V.; Fays, S.; Salpeteur, V.; Nicolas, J.; Romain, A.C. Air survey around MSW landfills in Wallonia: Feedback of 8 years field measurements. In Proceedings of the ORBIT 2008, 6th Biomass and Organic Waste as Sustainable, Wageningen, The Netherlands, 13–15 October 2008. Available online: https://orbi.uliege.be/handle/2268/12829 (accessed on 28 July 2020).
20. Yang, G.; J, Hobson. Odour nuisance - Advantages and disadvantages of a quantitative approach. *Water Science and Technology* **2000,** *41*(6), 97–106.
21. Mahin, T. Comparison of different approaches used regulates odours around the world. *Water Science & Technology* **2001**, *44*(9), 87-102.
22. Olesen, H.R.; Lofstrom, P.; Berkowicz, R.; Ketzel, M. Regulatory odour model development: Survey of modelling tools and datasets with focus on building effects. NERI Technical Report No. 541, National Environmental Research Institute, Ministry of the Environment, Copenhagen, *Denmark* **2005**, *1-64*. Available online: https://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR541.pdf (accessed on 03 February 2021).
23. Cseh, M.; Nárai, K.F.; Barcs, E.; Szepesi, D.B.; Szepesi, D.J.; Dicke, J.L. Odor setback distance calculations around animal farms and solid waste landfills. Idojaras **2010**, *114*(4), 303-318.
24. Order of 12 February 2003 relating to the requirements applicable to classified installations subject to authorization under section 2730 treatment of by-products of animal origin, including debris, issues and corpses, excluding activities covered by other sections of the nomenclature, diagnostic, research and teaching establishments (Arrêté du 12 février 2003 relatif aux prescriptions applicables aux installations classées soumises à autorisation sous la rubrique 2730 traitement de sous-produits d'origine animale, y compris débris, issues et cadavres, à l'exclusion des activités visées par d'autres rubriques de la nomenclature, des établissements de diagnostic, de recherche et d'enseignement). *JORF* **2003**, *89*, 6654.
25. Order of April 22, 2008 setting the technical rules that must be met by composting facilities subject to authorization in application of Title I of Book V of the Environment Code (Arrêté du 22 avril 2008 fixant les règles techniques auxquelles doivent satisfaire les installations de compostage soumises à autorisation en application du titre Ier du livre V du code de l'environnement). *JORF* **2008**, *0114*, 8058.
26. Order of April 20, 2012 relating to the general requirements applicable to classified composting installations subject to registration under the heading nº 2780 (Arrêté du 20 avril 2012 relatif aux prescriptions générales applicables aux installations classées de compostage soumises à enregistrement sous la rubrique nº 2780). *JORF* **2012**, *0104*, 7794.
27. Guidelines for the Construction and Operation of Compost Production Plants. Revocation of the d.g.r 2003, n. 7/12764 (Linee Guida Relative alla Costruzione e All'esercizio Degli Impianti di Produzione di Compost. Revoca della d.g.r 2003, n. 7/12764). Regione Lombardia, Bollettino Ufficiale. Available online: https://www.territorioambiente.com/wp-content/uploads/2014/07/dgr_7_12764_esercizio_impianti_produzione_compost.pdf (accessed on 26 August 2020).
28. *Odour Impact Assessment from Developments*; Department of Environment and Heritage Protection, Queensland Government: Brisbane, Queensland, Australia, 2012. Available online: https://www.ehp.qld.gov.au/licences-permits/business-industry/pdf/guide-odour-impact-assess-developments.pdf (accessed on 27 July 2020).
29. Wallis, I.; Cadee, K. Odour Exposure Criteria and Odour Modelling in Western Australia. *Water* **2008**, *35*(2) 144-148.
30. New Zealand Ministry for the Environment. *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*; New Zealand Ministry for the Environment: Wellington, New Zealand, 2003.
31. Standards Development Branch. *Ontario's Ambient Air Quality Criteria*; (MOE) Standards Development Branch: Toronto, ON, Canada, 2012.
32. Piringer, M; Petz, E.; Groehn, I.; Schauberger, G. Sensitivity Study of Separation Distances Calculated with the Austrian Odour Dispersion Model (AODM). *Atmospheric Environment* **2007**, *41*(8), 1725-1735.
33. Schauberger, G.; Piringer, M.; Petz, E. Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM). *Atmospheric Environment* **2000**, *34*, 4839–4851.
34. Schauberger, G.; Piringer, M.; Petz, E. Corrigendum to "Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM)". *Atmospheric Environment* **2013**, *67*, 459–462.
35. McGahan, E.; Kolominskas, C.; Bawden, K.; Ormerod, R. Strategies to Reduce Odour Emissions From Meat Chicken Farms. Proceedings of the 2002 Poultry Information Exchange, ANA Hotel, Gold Coast Australia, Poultry Information Exchange Association Inc., Caboolture, Queensland, Australia, 14-16 April 2002.

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