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Assessment of odour in the vicinity of livestock installations – the new guideline VDI 3894

The guideline VDI 3894 enables to assess odour sensations caused by livestock installations on the basis of a distance regulation and according to the criteria of the Guideline on Odour in Ambient Air (GIRL). Distances are a function of the emission rate of the livestock installation, the spatial extension of the sources, the frequency of wind direction and the frequencies of odour hours being permissible according to GIRL. Sensitivity analysis shows that the determination of the immission limit values for odour sensation is more crucial for the assessment than the precise determination of the source strength or of the frequency of wind direction.

Keywords
Livestock installation, odour nuisance, separation distance regulation, odour assessment

Abstract
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The guideline VDI 3894/2 "Emissions from and impacts of livestock installations – Method to determine separation distances-Odour" was published in November 2011. For the first time this allows assessment of immission caused by farm animal housing odours based on a distance model with consideration of odour hour immission frequency and without having to carry out a dispersion calculation.

The guideline completely replaces the VDI guidelines "Emission reductions in farm animal production", published during the last 25 years and repeatedly applied up until now and including: VDI 3471 for pigs, VDI 3472 for poultry from 1986, VDI 3473 for cattle from 1994 and VDI 3474 – all animals – from 2001

Calculation and description of the distance model

The VDI 3894/2 distance calculation [1] is no longer based on the empirical approach of the former guidelines. Instead, a completely new separation distance model is applied on the basis of dispersion calculation results with the model AUSTAL2000 (in total around 8000 distance values) applied with the following framework conditions [2]:

- Simulation of the emission source as vertical line source from 0 to 6 meters over ground surface (near-ground level, disordered derivation)
- Calculation for eight different odour source strengths (500, 2000, 5000, 7500, 10000, 20000, 30000, 50000 GE/s)
- Calculation area 2000 m x 2000 m; a nested calculation grid (mesh size 16, 32 und 64 m), quality level 0
- Expansion over an area with an average roughness length of 0.2 m, representing landscape type "Agriculture and natural ground cover"
- Use of meteorological data (dispersion class statistics) from 23 countrywide selected German Meteorological Service measurement stations, offering a very wide coverage regarding wind direction frequency and average wind speed.

From the results of the regression analysis, the following functional relationships were calculated for the guideline separation distance R of VDI 3894/2:

$$R = a \cdot Q^b + d_r \qquad \text{Eq. 1}$$

The distance function described in the first part: a point or vertical line source as power of the source strength Q with the model parameters a and b. The second part is a correction term d_r, which takes account of source expansion. The factor a depends on the wind direction frequency h_W and the odour hour frequency h_G, the exponent b only from h_G:

$$a = (-0{,}0137 \cdot h_G + 0{,}689) \cdot h_W + 0{,}251 \cdot h_G + 0{,}0590 \qquad \text{Eq. 2}$$

$$b = \frac{1}{0{,}204 \cdot h_G + 1{,}79}$$

As well as calculation of the distance required for protection from substantial odour nuisance, the guideline distance model also allows estimation of odour immission frequencies for a particular distance or to calculate back to an odour substance emission corresponding to a certain frequency.

Input factors for calculation of guideline distances

Source strength *Q* (type and size of farm animal production unit)

Within the framework of the distance calculation, only the emissions from animal housing and associated buildings for silage and manure storage within a farm complex were considered in the first instance. This distance calculation cannot assess results for farm animals kept outdoors. For calculating the emissions VDI 3894 offers conventional values for emission factors.

The emissions from farm animal housing fitted with tested exhaust air cleaning systems [3] including biological end phases can be safely ignored if, between exhaust air cleaning plant and the residential/commercial areas to be protected certain distances are maintained [4].

These comprise:

- 100 m with near ground level area sources, e. g. biofilters, and
- 200 m in the case of central point sources, e. g. biotrickling filters.

Otherwise, 30 GE/m^3 or 10 % of the maximum pure gas concentration at a level of 300 GE/m^3, which is the maximum permissible under the DLG test procedure, should be applied as emission. Regarding average air volume rates these represent an odour substance flow of around 3–4 GE/(s GV) in pig feeding units [2].

The guideline distance model is – independent of type of odour source – universally applicable. Hereby, the distance calculation can also be applied to other types of odour substance emitters, e. g. biogas plants. The only requirement is that for each source there should be an odour emission rate being determined.

Additional distance d_r (expansion of source(s) – source geometry)

The additional distance d_r of the complete farm animal housing complex takes account of the influence on guideline distance of the horizontal expansion of the emission sources. This depends on the distances of the different sources between each other and on the expansion of the individual sources. This is to be measured in such a way that as a radius fixed at the main emission point of the complete farm animal complex (distance measuring point) it covers all emission sources (**Figure 1**). This prevents the guideline distance intersecting the source of the complex in question.

The distance measurement point, or emission focus, of a complex represents the centroid for an individual source. Where there are several separate sources, the coordinates x_i and y_i of the individual sources are weighted along with the appropriate source strengths Q_i:

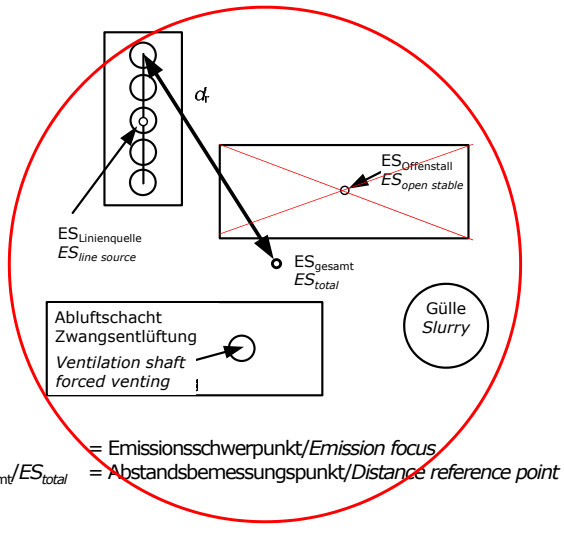
$$x_{ES} = \frac{\sum\left(x_i \cdot Q_i\right)}{\sum Q_i} \; ; \; y_{ES} = \frac{\sum\left(y_i \cdot Q_i\right)}{\sum Q_i} \qquad \text{Gl. 3}$$

This method represents the application of the old VDI 3471 and 3472 guideline distance measurements [5]. The additional distance has, however, the disadvantage that with long drawn-out sources (e. g. several exhaust air shafts distributed over the roof ridge axis of a barn) the immission situation in stall axis direction is strongly overestimated. This method is still accepted, however, in the interests of achieving a simple and conservative assessment. In the same way, sources with expanded areas from smaller neighbouring structures, e. g. silage pits for cattle, lead to a larger distance. In individual cases it can be estimated here using VDI 3894 how large and relevant the immission contribution of such an individual source is in the relevant immission areas. This particularly applies where such an individual source lies behind the main source (farm animal housing) when viewed from the immission site.

Wind direction frequency h_W

The site wind direction frequency distribution (36-point wind rose, i. e. 10° sectors) given in per mille (‰) has an important influence on the distribution and the frequency of odour impacts in the environment around a farm animal housing complex. Hereby it is important that the available wind directional data are always understood as indicating the compass direction from which the wind blows.

Fig. 1



Determination of the additional distance d_r for a farm with different sources (VDI 3894 Blatt 2 [1], modified)

The wind frequency is required for wind directions which, starting from the emission focus of the entire farm complex, influence the odour transport direction towards the location to be protected on the opposite side (+ 180°).

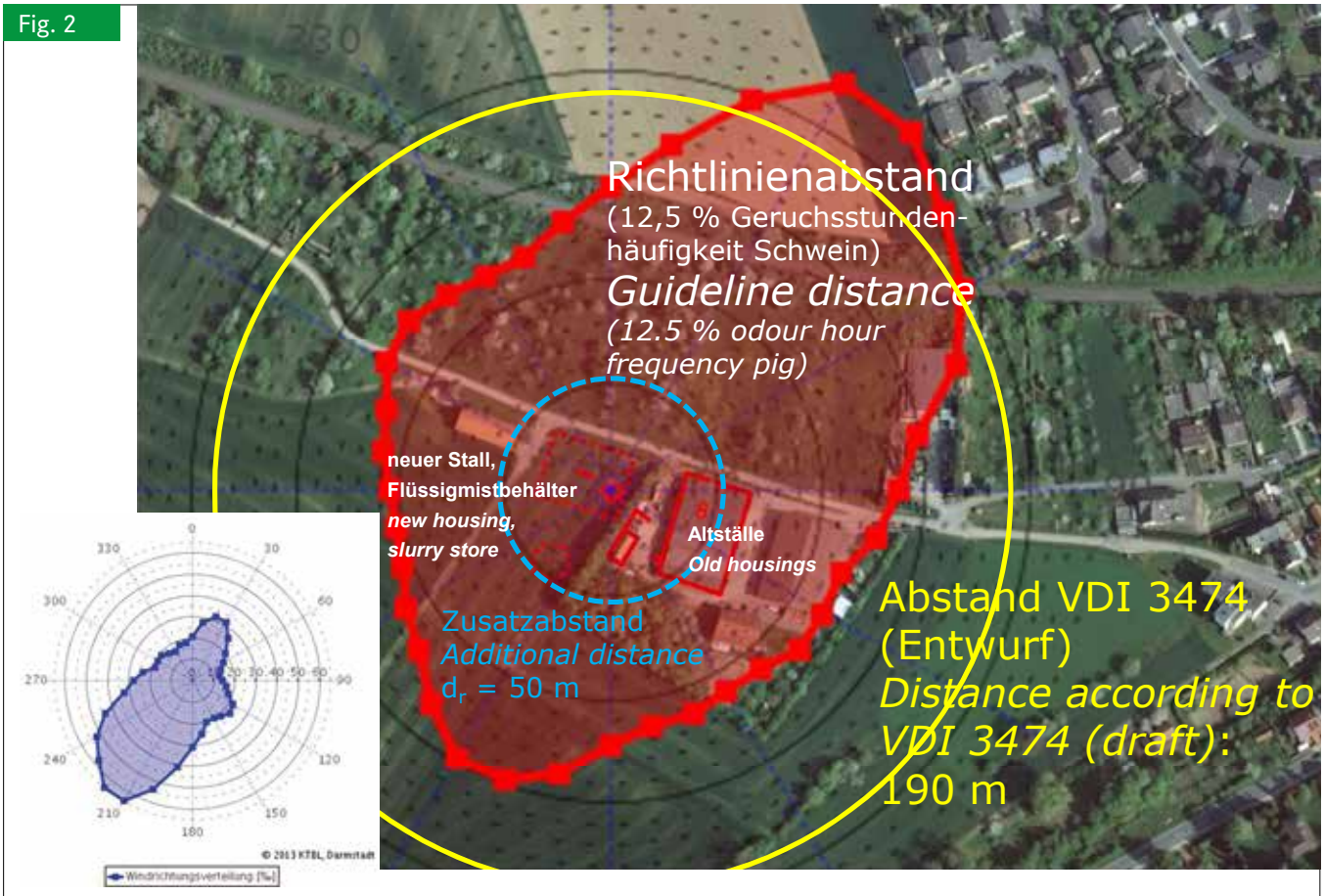
Appropriate data can be acquired from the German Meteorological Service, private services, or – in some federal states – from the Internet [6]. For the assessment of individual immission locations no complete wind direction frequency distribution is required, the frequency for the appropriate sector is sufficient. For first rough estimates of the guideline distance, a location-specific wind direction frequency can often be done without. Instead, a general frequency of 60 ‰ can be applied. This represents the upper limit of the applicable area of distance calculation, giving a separation distance circle that is known from the application of the old VDI guidelines.

However, should a wind rose be available for a neighbouring location, the largest wind direction frequency (in the main wind direction) of this location can then also be applied with a safety margin addition of 20 % for all wind directions [2]. This means, for instance, that the maximum wind direction frequency of 60 ‰ (main wind direction) of a neighbouring location is adjusted so that the wind direction frequency for all 36 directions is accepted with 72 ‰ (60 ‰ + 12 ‰, representing 20 % of the frequency).

If no data at all are available, it is possible, with a flat location and a broad valley position that a wind direction frequency of 70 ‰ can be applied and, with a narrow valley situation, a frequency of 150 ‰ [2]. In the latter case, valley locations are also covered where there is extreme channelling of wind direction frequency distribution. When applying this sort of procedure it must be realised that it does not represent a calculation conforming to guideline requirements. But it is still suitable as an estimation method. For a more secure assessment of the situation data collected at the location are indispensable.

Figure 2 presents the results of the immission assessment for a farm animal housing complex achieved with VDI 3894/2 distance calculations based on a local wind direction frequency distribution. As the main wind direction is from the southwest, the guideline distances in northeasterly (transport) direction are the greatest.

Fig. 2



Isopleth of the guideline distance of a pig breeding installation (odour emission 4,489 OU/s, additional distance d_r = 50 m) according to VDI 3894 Part 2 in the case of an odour hour frequency h_G = 12.5 % (h_b = 16.67 % for pig odour) for a residential area adjacent to undeveloped land (transient area). Calculation was done with the KTBL-distance calculator (http://www.ktbl.de/index.php?id=1066).The distribution of the wind direction frequencies of the site (left corner [6]) indicates a main wind direction from south-west; accordingly guideline distances are largest in north-east direction. For comparison the distance circle is shown, that can be derived according to the former guideline VDI 3474 (draft) based on comparable assumptions.

Permitted odour immission frequency h_G (exposure limit value)

The applications to be assessed regarding odour immissions are categorised according to planning legislation (e. g. residential/mixed usage, villages, commercial and industrial areas, undeveloped land) and these have different permitted levels for acceptable odours.

Unlike the previous guidelines VDI 3471-3474, VDI 3894 makes no requirements on distances required to avoid substantial odour nuisance. For assessment standards the guideline refers to the GIRL [7] and its exposure limits (**Table 1**). Court rulings issued on GIRL extend the breadth of evaluation possibilities for external undeveloped areas and for those areas with different usages converging on one another (**Table 2**).

Investigations from Sucker et al. [8] have shown that, with the exception of poultry, farm animal production odours have a less stressful effect than those from industry. Regarding farm animal odours, cattle have the lowest and poultry the highest nuisance potential, with pigs in between. With GIRL, these differences are taken account of through the animal-specific weighting factor *f* (**Table 3**). This also has an effect on the distances according to VDI 3894 in that the applicable odour hour frequency h_G is multiplied with the applicable weighting factor to give the so-called assessed odour hour frequency h_b that is applied for calculating distance. State-specific regulations also apply in such cases.

The animal-specific weighting factor has the effect that, in individual areas and according to planning legislation and animal category, more or less odour immissions are allowed. For instance in a residential area for which, according to GIRL, 10 % odour hour frequency is permitted this can comprise in fact up to 20 % odours from cattle production, (10 %/0.5) or up to

Table 1

Exposure limit values as per GIRL [7] for clearly perceptible ambient odours from installations and different areas which are populated not only temporarily

Gebietstyp ***Category of area***	**Immissionswert (IW) (Geruchsstundenhäufigkeit) [%]** ***Exposure limit value (frequencies of odour-hours) [%]***
Wohn-/Mischgebiete *Residential and mixed areas*	10
Gewerbe-/Industriegebiete *Commercial and industrial areas*	15
Dorfgebiete *Villages*	15 (bis 20 angrenzend zum Außenbereich)/*(up to 20 in the transient areas between the outskirts and undeveloped land)*
Außenbereich *Undeveloped land*	25

Table 2

Modification of the exposure limit values according to decisions of administrative courts [2]

Gebietskategorie ***Category of area***	**Geruchsstundenhäufigkeit** ***Frequencies of odour-hours [%]***
Kur-/Klinikgebiete *Spa areas/hospital areas*	max. 6 ≤ 10
Grenzbereich Wohnen-Außenbereich *Transient area residental zone/undeveloped land*	11–13 (Mittelwert/*intermediate limit value*)
Kerngebiete *Center zones*	10–15
Wohnnutzung „faktisches“ Dorfgebiet *Residential zone in rural villages*	15–17 bis ≥ 20
Gemengelagen *Mixed areas*	17–22 (Mittelwert/*intermediate limit value*)
Reines, nicht landwirtschaftsbezogenes Wohnen im Außenbereich *Living in external undeveloped areas with no agricultural context*	15–26; 30,5
Landwirtschaftsbezogenes Wohnen im Außenbereich/nebeneinander landwirtschaftlicher Betriebe im Außenbereich *Living in external undeveloped areas with agricultural context, different farms among each other*	42 – ≥ 50 nicht beurteilungsrelevant *not relevant for assessment*
Friedhof *Graveyard*	≤ 10
Sport-/Freizeitanlagen, Golfplatz *Sports and recreational facilities, golf course*	≤ 25

Table 3

Weighting factors for individual types of animals according to GIRL [8]

Tierspezifische Geruchsqualität ***Animal-dependent odour quality***	**Gewichtungsfaktor *f*** ***Weighting factor f***
Mastgeflügel (Puten, Masthähnchen) *Fattening poultry (turkeys, broilers)*	1.5
Mastschweine, Sauen (bis zu einer Tierplatzzahl von ca. 5 000 Mastschweinen bzw. unter Berücksichtigung der jeweiligen Umrechnungsfaktoren für eine entsprechende Anzahl von Zuchtsauen) *Fattening pigs, sows (up to a capacity of approx. 5,000 fattening pig places or for a certain number of sows, respectively, considering the pertinent conversion factors)*	0.75[1)]
Milchkühe mit Jungtieren (einschl. Mastbullen und Kälbermast, sofern diese zur Geruchsimmissionsbelastung nur unwesentlich beitragen) *Dairy cows including young cattle (also covering fattening bulls and calves, provided their contribution to the ambient odour exposure is negligible)*	0.5[2)]
Sonstige Tierarten (z. B. Legehennen) *Other animal categories (e. g. laying hens)*	1

[1)] UM Baden-Württemberg [10]: 0,6.
[2)] UM Baden-Württemberg [10]: 0,4.

13.3 % odours from pig production (10 %/0.75), while for broiler production the figures are only 6.7 % (10 %/1.5).

In practice, immission contributions from neighbouring buildings within the farm animal production complex (manure storage, silage clamps) are assessed with the same weighting factors as the farm animal production buildings.

In the case of different types of animal, a general maximum emission value can be applied as first assessment [2].

Application areas for the separation distance model

The application area of VDI 3894/2 guideline distance models result from the known method used in the calculation (dispersion calculation via model AUSTAL2000) and the thereby selected framework conditions. In general, therefore, where the standard dispersion model is not applicable VDI 3894 distance calculation should also not be used for assessment (e. g. for difficult topographical conditions).

The framework conditions are established on the basis of an error analysis so that the distance model delivers sufficiently conservative and legally secure results within the requirements of its application area [9].

The application area of the distance calculation in the guideline is limited to:

- Odour emissions of up to 50 000 GE/s, i. e. up to a headage of around 7 500 fattening pigs, 490 000 laying hens (low emission management system) or 3 500 dairy cows.
- Wind direction frequencies for the distance calculation of significant sectors of up to 60 ‰ with a 36-sector wind rose
- Immission odour hour frequencies of from 7–40 %,
- Any type of exhaust air channelling
- Distances of 50 m or more arising from this calculation, and
- On complexes of the same operator for the accumulated effects of neighbouring complexes can only be taken account of to a limited extent.

For simplification, VDI 3894 based its distance model on the most unsuitable case of ground-near surface emission (vertical lineal source). The type of discharge conditions for the emissions (high over the roof and ground level, exhaust air speed) are arbitrary.

The distance function also fundamentally applies for the adjacent areas of a source. In practice, however, the airflow conditions in such areas are greatly influenced by external airflows around the buildings. Hereby, distance calculations should only be used for distances over 50 m. The effect of higher discharge conditions (e. g. 10 m over ground surface and 3 m roof ridge) have to be taken into account via dispersion calculations.

Basically, the VDI 3894/2 distance model carries out a continuous function and thereby also leads to plausible results with input data outwith the application area [2]. Hereby, in individual cases, application of the distance calculation outwith the application area can appear both practical and suitable. This means in practice that the distance calculation can also be applied for, e. g., wind direction frequencies of over 60 ‰. However, in such cases there is an increased risk that the required distance for protection from substantial odour nuisance is underestimated compared to that arrived at through prognosis calculations. Thus the former should only be seen as an orientation guide.

Sensitivity analysis

Sensitivity analyses of the distance model [9] make clear that alterations or errors regarding the source strength have the least influence on the guideline distance. Relative alterations of the source strengths have an effect of up to a third on the distance. In comparison, relative alterations in wind direction frequency result in a guideline distance alteration of about the same size. The strongest effect comes from variations in odour hour frequency. Here, the relative alterations can even more than double the guideline distance.

In practice, this means that the establishment of exposure limit values for the assessment of odour hour frequency is much more important than precise determination of the size

of farm animal production complex, or source strengths. It can thus be assumed that even when the source strengths or the wind direction frequency exceed guideline application area, results can be acquired which are in the main reliable.

Conclusions

With VDI 3894 local conditions can be taken more into account than in the past for assessment of farm animal production odours, e. g. expanded area sources, wind direction frequency distribution and the protection requirement status of the surroundings. Yardstick for assessing distances that offer a particular odour hour frequency are GIRL exposure limit values.

Through the new VDI 3894 is to be expected that the importance of its guidelines in the context of regulation and legal interpretation will increase still more. This aims more clearly than the predecessor at basic concepts of protection in the Federal Immission Control Act and fits snugly into the evaluation framework for odour immissions created in Germany through GIRL. The results of immission assessment using the new distance calculations agree much better with those from the dispersion calculations than was the case with the older guidelines.

For a deeper understanding and the correct application of the guideline the KTBL publication 494 "Emissionen und Immissionen von Tierhaltungsanlagen – Handhabung der Richtlinie VDI 3894" [2] offers important and helpful background information. Additionally, simple application of the VDI guideline 3894/2 is possible with the help of the cost-free KTBL separation distance calculator at (http://www.ktbl.de/index.php?id=1066).

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