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ODOUR INTENSITY AND HEDONIC TONE – IMPORTANT PARAMETERS TO DESCRIBE ODOUR ANNOYANCE OF RESIDENTS?

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Abstract
For odour regulation in Germany the Guideline on Odour in Ambient Air is in use for many years. The main parameter the odour regulation authority has to take into account is the odour frequency expressed as odour hours per year. In the Guideline limit values are given for the maximum odour frequency per year.
These limit values are based on field investigations in which significant relationships between odour impact and odour annoyance was found. In these investigations odour intensity did not yield a better description of the annoyance degree of residents. The hedonic tone was not mentioned.
In a new research project finished in 2003 the influence of odour intensity and hedonic tone in addition to odour frequency has been assessed. Two installations emitting pleasant odours, two emitting neutral und two emitting unpleasant odours have been selected. In each case grid field measurements by a panel were carried out and the annoyance of residents was assessed by a special questionnaire.
The results of this project are: - A new method to measure odour intensity and hedonic tone in the field with data record forms was developed and validated. With this method reliable and reproducible results are obtained. - The parameter odour frequency based on the system of "odour hours" is suitable and sufficient to predict odour annoyance caused by unpleasant/neutral odours. - In the case of pleasant odours hedonic tone has an abundantly clear effect on the dose-response-relationship between odour frequency and annoyance. Pleasant odours have a significant lower annoyance potential than unpleasant/neutral odours. - The odour intensity has no additional influence on this relationship. If odours are recognisable they can cause annoyance.

Keywords
Annoyance; field measurements; immission limit values; odour impact, odour frequency

INTRODUCTION

Legal framework

The legal basis for any requirement with respect to ambient air quality is the German Federal Protection Act for Ambient Air (1974/1990) and the Technical Instruction on Air Quality Control (2002). According to § 3 Federal Protection Act for Ambient Air odours caused by installations are treated as a nuisance. The problem is to find out whether a nuisance has to be considered as significant. If odour emissions from installations occur this question has to be answered in every licensing or surveillance procedure. In cases of urban development planning evaluations of odours in ambient air are also required.

The Guideline on Odour in Ambient Air GOAA (1994, revised version 1999; in former times also called Directive on Odour in Ambient Air) is in nearly all these cases the odour regulation

instrument in Germany. In this Guideline, a complete system is designed, beginning with measurement methods of the initial odour impact and calculation of the additional odour impact and the total impact and concluding with ambient air quality requirements expressed as immission* limit values in terms of maximum permitted odour frequency in ambient air in certain areas (Both, 1996; Both, 2001). *(The word „immission“ is used in the sense of influence of air pollutants, in this case odour, on humans. This establishes an active view of air pollutants influencing receptors, in contrast to the passive view of receptors being exposed to air pollutants. If we neglect this more semantic difference, “immission” can be interpreted as exposure.)

Odour limit values

In the GOAA quality requirements are fixed as immission limit values as given in Table 1. These values limit the amount of recognisable odours related to installations. A difference is made between two types of areas, residential or mixed areas on the one hand and trade or industrial zones on the other hand.

Table 1. Limit values for odour in ambient air in different areas.

Residential, mixed area		Trade, industrial zones	
relative frequency	%	relative frequency	%
0.10	10	0.15	15

These limit values were developed on the basis of investigations (Steinheider et al. 1994, 1998) in which the initial odour impact measured as odour frequency (Guideline VDI 3940, 1993) and the degree of odour annoyance of residents assessed by questionnaires according to Guideline VDI 3883 Part 1 (1997) were correlated (Sucker, 2001). As a result odour frequencies between 10% and 20% were found to be the critical range where a significant nuisance according to the definition of the German Federal Protection Act for Ambient Air is recognised.

Odour intensity and hedonic tone

Furthermore the investigations of Steinheider et al. (1994, 1998) showed that increasing odour intensities did not necessarily lead to an increasing degree of annoyance. It was sufficient for the description of the odour situation on site (the odour impact) to determine recognisable odours expressed as odour frequencies (Steinheider, Winneke 1992). The hedonic tone of odours in terms of pleasant and unpleasant was not taken into account in these investigations.

In odour regulation in Germany hedonic tone of odours generally did not appear as a relevant parameter for the evaluation procedure. However, there are a few hints in literature that odour intensity and hedonic tone play a role in odour annoyance (Hangartner, Wuest 1994). But up to now there were no standardised methods to measure these parameters in ambient air in residential areas where they may cause complaints. Also, there is no elaborated system, which could be used for regulation.

Therefore the Ministry of the Environment, Conservation, Agriculture and Consumer Protection of the State of North Rhine-Westphalia, Ministries of the Environment and Traffic of the state Baden-Württemberg and the German Chemical Industry Association (VCI) have assigned a scientific investigation with the subject **INVESTIGATIONS ON THE EFFECT OF ODOUR INTENSITY AND HEDONIC TONE ON THE ANNOYANCE DEGREE OF RESIDENTS** in 1999.

The project started in 1998 and was finished in 2003. At the beginning a lot of time was spend to find installations, which cause pleasant, neutral and unpleasant odours in residential areas. A

sufficient preclassification based on the hedonic tone was essential to reach the project objectives. The objectives were:

- to develop and validate methods to assess odour intensity and hedonic tone in ambient air,
- to investigate the relationship between odour frequency, odour intensity and hedonic tone,
- to confirm the association between odour frequency and odour annoyance as found in former investigations,
- to investigate the influence of odour intensity and hedonic tone on the annoyance response of residents and finally
- to find out if statistically significant correlation probably assessed is strong enough to modify the proved system of the GOAA.

After preclassification six installations were selected: two with pleasant (goodies production, rusk bakery), two with neutral (textile and seed oil production) and two with unpleasant odour immissions (fat refinery, cast iron foundry).

METHODS

Assessment of odour impact - Field Measurements

In the investigation odour impact was measured by field inspections using trained and selected panel members (Guideline VDI 3940, 1993; Both, 1996; GOAA 1999). With such field measurements it is possible to record odours that are immediately recognisable under real field conditions. Thus, the result of field measurements directly depends on the initial odour impact (existing impact) in a certain area. Expressed in terms of odour frequency it represents what residents would perceive.

The quality requirements for panel members are listed in Table 2. If the tested person does not fulfil these criteria it could not be used as a panel member neither for olfactometry nor for field measurements. The minimum panel size according to the GOAA is 10. For the investigation presented about 15 panel members were involved.

Table 2. Quality requirements for panel members

Odourant	Lower limit [µg m^{-3}]	Odour threshold [µg m^{-3}]	Upper limit [µg m^{-3}]
n-butanol	60	123	250
Hydrogen sulfid	0.7	1.4	2.8

In a measurement plan, among other things, the assessment area, assessment squares, measuring points, the assessment period, the time of measuring during the day, the number of measurements and the code of relevant odour qualities are defined. The assessment area is defined as a circle with a radius of 30 times the height of the stack. The minimum distance from the border of an installation is 600 m. For measurement purposes, a grid of equidistant measuring points covers the area. According to the GOAA, assessment squares and measuring points are only required at places where people do not only stay temporarily, as for example residential neighborhoods. The standard distance between two measuring points (grid spacing) is 250 m. Figure 1 shows the specific adjustment to these requirements in case of the rusk bakery, including numbering of the measuring points and the assessments squares.

The assessment period takes at least half a year and covers cold and warm seasons in equal parts. During this period, 13 or 26 odour measurements are carried out at each measuring point. Hence, 52 or 104 records are carried out for each assessment square. To get reliable data for the existing conditions it is indispensable that measurements at the measuring points of one assessment square are taken at different days. In the case of the rusk bakery a number of 26 measurements per measuring point (104 per assessment square) was chosen. Therefore, odour measurements on site were taken 4 to 5 times per week at different hours during the day.

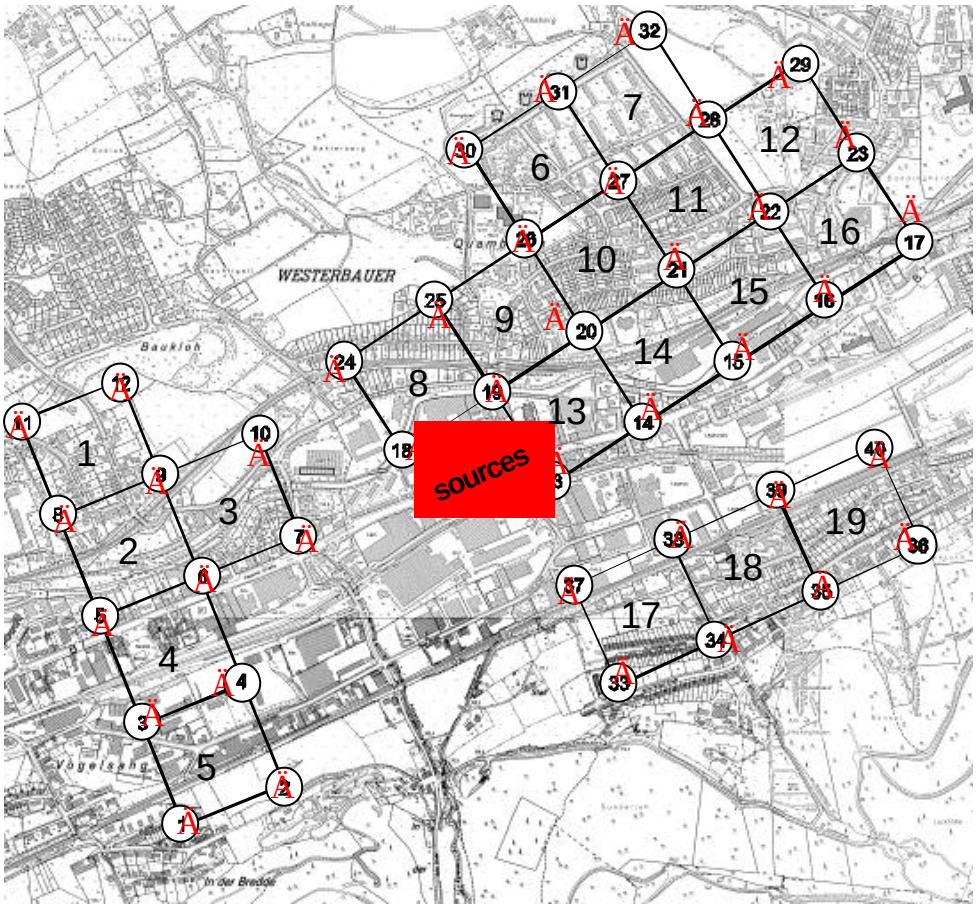

Figure 1. Asessment squares and measuring points in the vicinity of the rusk bakery

For a single measurement a data record form (Figure 2) and a stopwatch is required. Each measurement lasts 10 minutes. During the 10 minutes, the panel member who carries out the measurement is asked the question in intervals of 10 seconds whether the odour is recognisable or not. Hence, this YES - NO question has to be answered 60 times all together. If the answer is positive the panel member has to record his or her observation on the data record form, with respect to the odour quality code. As a result, the percentage of odour time per measurement duration can be determined for each odour quality.

In connection with this procedure an evaluation follows which is based on the definition of an "odour hour" given in the GOAA. One measurement carried out by one panel member is considered as an "odour hour" when the percentage of odour time is equal or exceeds 10 % of the duration of one 10 minutes-measurement. One basic effect of the definition of an "odour hour" is, that short

odour peaks can entail the same amount of "odour hours" as broader peaks over a longer time period. This convention takes into account that short but recurring odour peaks can be more annoying than broader peaks, which may allow adaptation.

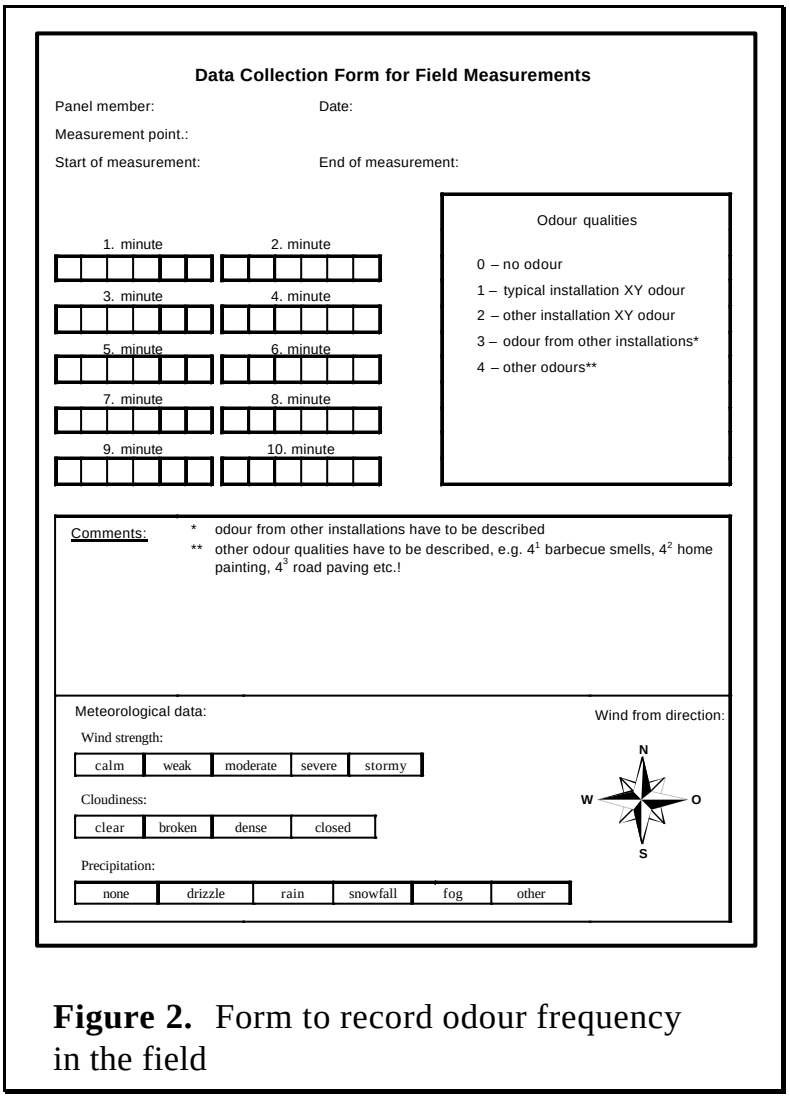

Figure 2. Form to record odour frequency in the field

Assessment of odour annoyance

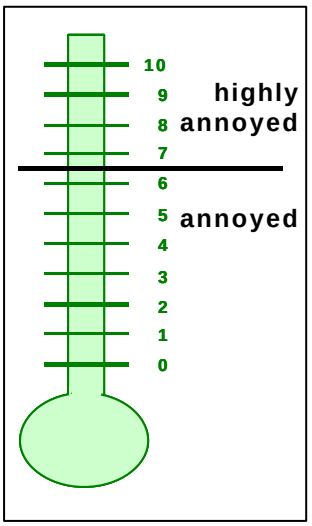

Figure 3. Annoyance thermometer

The assessment of odour annoyance was done by means of direct interviews using a modified questionnaire with respect to Guideline VDI 3883 Part 1 (1997) covering odour annoyance, symptom reporting and relevant covariates. The interview was introduced as an investigation on the working and living conditions of the population and as an appraisal of general air pollution and noise in the neighbourhood. In order to avoid attribution bias it is important not to draw too much attention to the odour situation. The annoyance response to odours (and noise) is directly measured as the degree of disturbance by means of an 11-point graphic scale (annoyance thermometer, Figure 3) and by the degree of annoyance using a 7-point verbal scale. In order to identify critical segments on the thermometer scale also inacceptability judgements are collected.

Multiple logistic regression analysis was used to establish dose-response associations between odour frequency, odour intensity and

hedonic tone on one hand and annoyance and somatic symptoms on the other hand. In the full regression model, other variables, such as gender, age, education, length of residence, residential situation, quality of the residential area and perceived health were included. Altogether 1456 residents living in the vicinity of the installations under investigation were interviewed. For more details in connection with the assessment of odour annoyance see Sucker 2001, Sucker and Winneke 2002, Sucker et al. 2003a and Sucker et al. 2003b.

RESULTS AND DISCUSSION

Assessment of odour impact

During the investigation in the vicinity of the rusk bakery 104 records were carried out by the panel (26 per measuring point) over half a year. The data of each single measurement were analysed according to the definition of the "odour hour" mentioned above. In Figure 4 the total amount of "odour hours" (A) and the odour impact expressed as relative odour frequency (B) are shown. The largest number of „odour hours“ per measuring point and per assessment square was investigated in the northeast of the emitter depending on the prevailing wind direction (south-west). Less "odour hours" were recorded in the other wind directions. Figure 4 (B) shows that in the residential areas the odour impact caused by the rusk bakery reached a level of approximately 0.30 relative odour frequency, respectively 30% (percentage of odour frequency).

For each of the six installations under investigation similar figures were created. Depending on the wind direction distribution and the distance to the odour source, the odour impact per assessment square varies between 0.00 and 0.55.

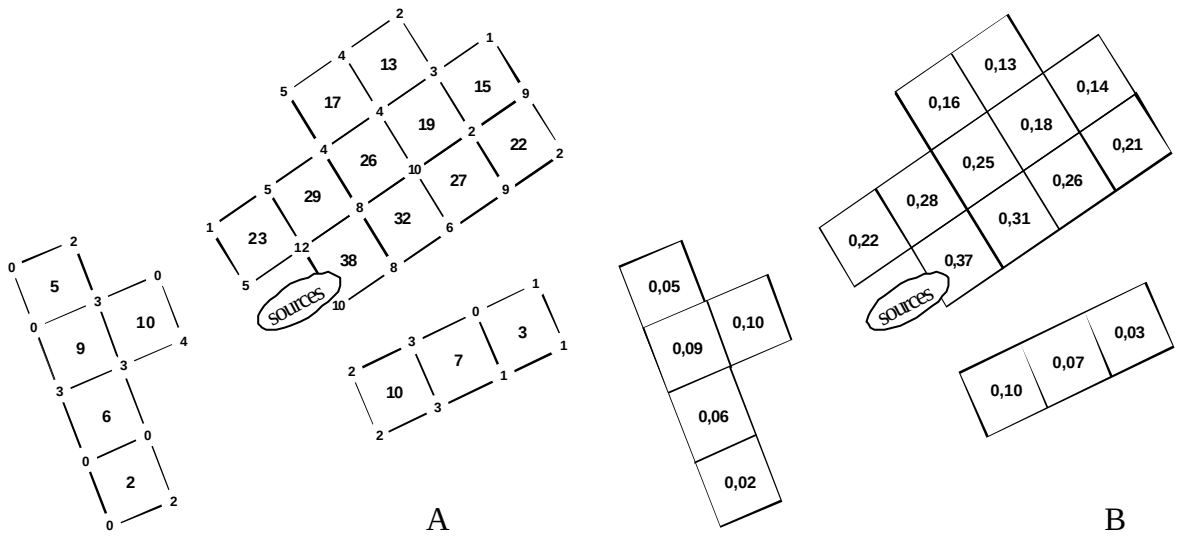

Figure 4. Total amount of odour hours (A) and odour impact (relative odour frequency) (B)

Assessment of odour intensity and hedonic tone

Please complete this data record form subsequent to the 10-minutes measurement duration!

Panel member: Date:

Measurement Point:

Data record form – odour intensity

Please describe your odour intensity impression for the quality ***odour source (e.g. backery odour)*** with the following scale:

strongest impression	**frequency of the strongest impression**	**mean impression**
6 ❍ extremely strong		6 ❍ extreme strong
5 ❍ very strong	5 ❍ always	5 ❍ very strong
4 ❍ strong	4 ❍ very often	4 ❍ strong
3 ❍ distinct	3 ❍ often	3 ❍ distinct
2 ❍ slight	2 ❍ sometimes	2 ❍ slight
1 ❍ very slight	1 ❍ seldom	1 ❍ very slight
0 ❍ not noticeable		0 ❍ not noticeable

Data record form – odour hedonic tone

Please describe your odour hedonic impression for the quality ***odour source (e.g. backery odour)*** with the following scale:

most pleasant impression

extremely unpleasant				neither unpleasant nor pleasant				extremely pleasant
❍	❍	❍	❍	❍	❍	❍	❍	❍
-4	-3	-2	-1	0	+1	+2	+3	+4

most unpleasant impression

extremely unpleasant				neither unpleasant nor pleasant				extremely pleasant
❍	❍	❍	❍	❍	❍	❍	❍	❍
-4	-3	-2	-1	0	+1	+2	+3	+4

mean impression

extremely unpleasant				neither unpleasant nor pleasant				extremely pleasant
❍	❍	❍	❍	❍	❍	❍	❍	❍
-4	-3	-2	-1	0	+1	+2	+3	+4

Figure 5. Form to record odour intensity and hedonic tone in the field

Up to now there was no method to measure odour intensity and hedonic tone in ambient air. Therefore a lot of attempts in the laboratory and in the field were carried out to develop a reliable method that leads to reproducible results. Especially the use of anchoring stimuli was tested to harmonise panel members' hedonic classifications. But the application of standardised stimulus leads to a wider distribution of panel answers.

After all the most successful method was the use of the data record forms for odour intensity and hedonic tone presented in Figure 5. The panel members have to fill out the form after the ten minutes measurement of recognisable odours. This leads to reliable and reproducible results.

As an example in Figure 6 the odour intensity and in Figure 7 the hedonic tone measured in the vicinity of the rusk bakery are shown. Odour intensity is strongly correlated with odour concentration and therefore decreases with increasing distance to the source. Hedonic tone is over a broad range independent from odour concentration and therefore does not show a differentiation with distance.

For all installations similar figures were obtained. Together with odour impact expressed as odour frequencies, odour intensity and hedonic tone data were the basis for the following investigations on odour annoyance.

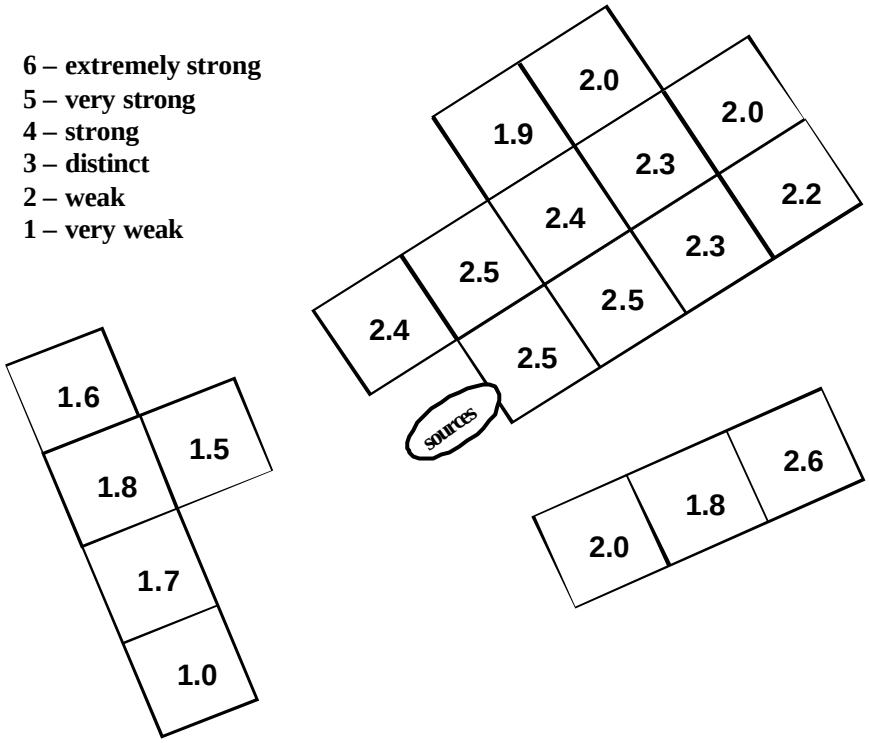

Figure 6. Odour intensity of perceived odour in the vicinity of the rusk bakery

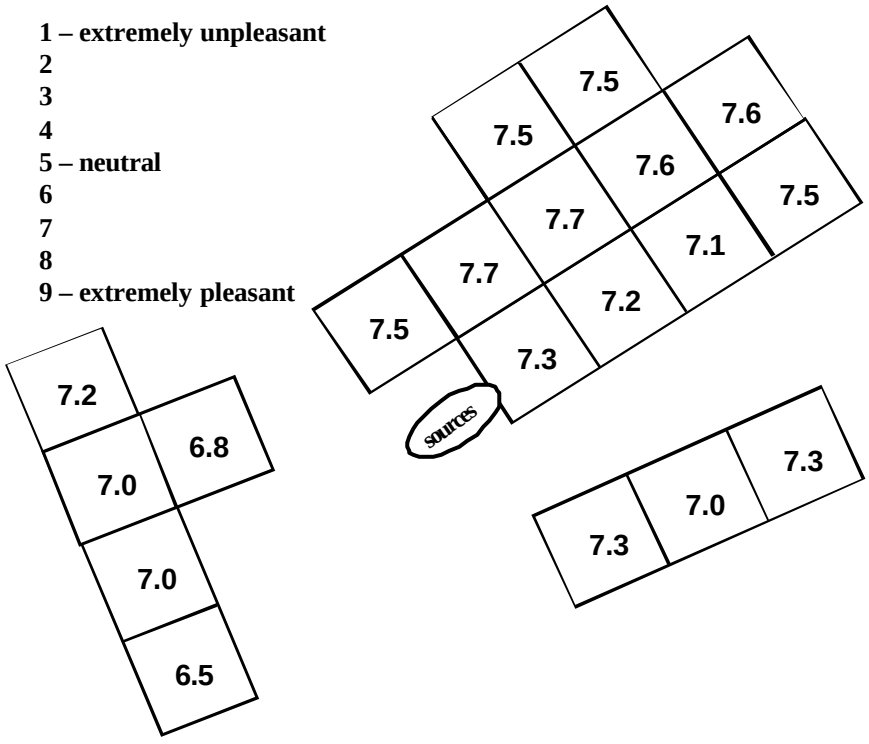

Figure 7. Hedonic tone of perceived odour in the vicinity of the rusk bakery

Assessment of odour annoyance

In this paper only the results in connection with the annoyance thermometer and the inacceptability judgements are taken into account. The complete results are presented in Sucker et al. (2003b).

In Figure 8 the connection between annoyance thermometer data and inacceptability judgements is shown. Two points are remarkable: a distinct increase of inacceptability judgements in connection with thermometer values of four and higher and a dramatic increase for thermometer values of seven and higher. These two protruding points are taken as the basis to distinguish between different annoyance degrees of residents: from 1 to 10 on the annoyance thermometer scale – *annoyed*; from 4 to 10 – *distinct annoyed*; form 7 to 10 - *(very strong or) highly annoyed*.

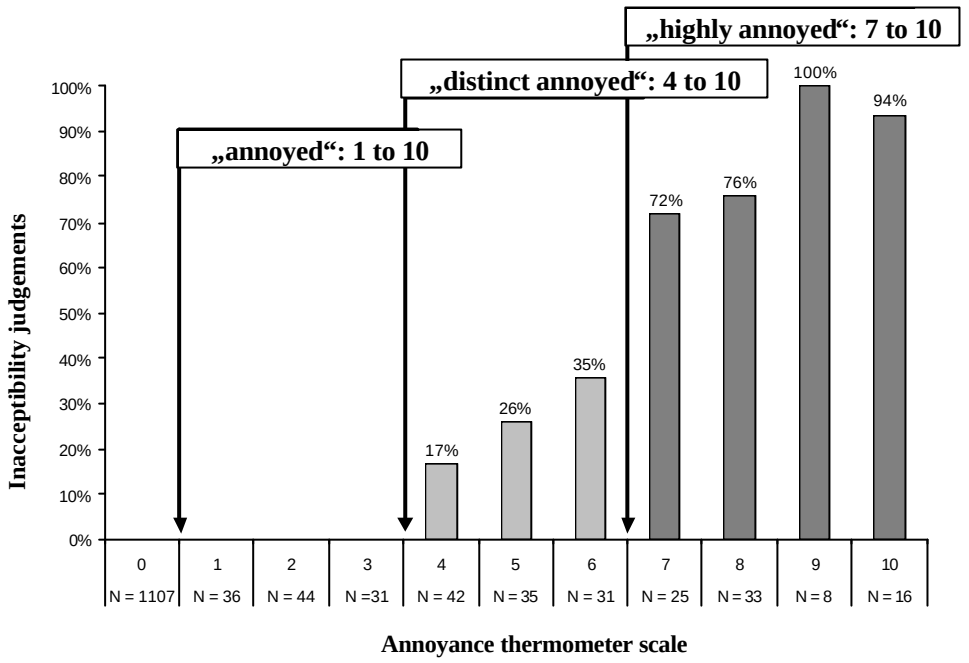

Figure 8. Frequency [%] of inacceptability judgements of residents in dependence on annoyance degree (neutral and unpleasant odours only).

In Figure 9 the correlation between odour frequency and the percentage of highly annoyed residents and in Figure 10 the effect of hedonic tone expressed as unpleasant/neutral on the one hand and pleasant on the other hand is pointed out. It is obvious that hedonic tone in the case of pleasant odours has an abundantly clear effect on the dose-response-relationship between odour frequency and annoyance. Pleasant odours have a significant lower annoyance potential than unpleasant/neutral odours.

The parameter odour frequency based on the system of “odour hours” is suitable and sufficient to predict odour annoyance caused by unpleasant/neutral odours in the cases under investigation. Odour intensity has no additional influence on this relationship. If odours are recognisable they can cause annoyance.

Looking at the upper limit of the 90% confidence interval for unpleasant/neutral odours the range of the immission limit values is confirmed. In the case of pleasant odours the dose-response-relationship is different as shown above. Therefore at present considerations are ongoing how to handle unpleasant odours in odour regulation in the future.

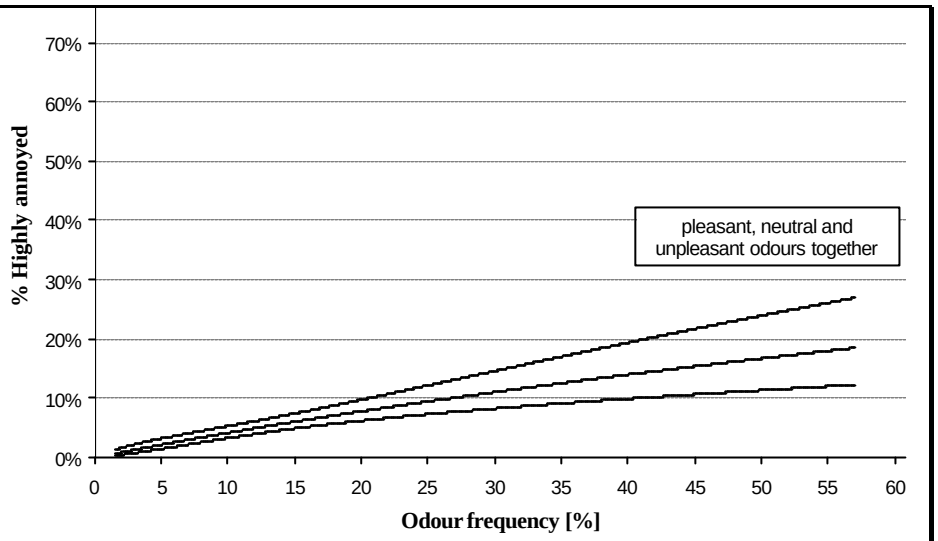

Figure 9. Percentage of highly annoyed residents in dependence on the odour frequency and on the hedonic tone including 90% confidence interval

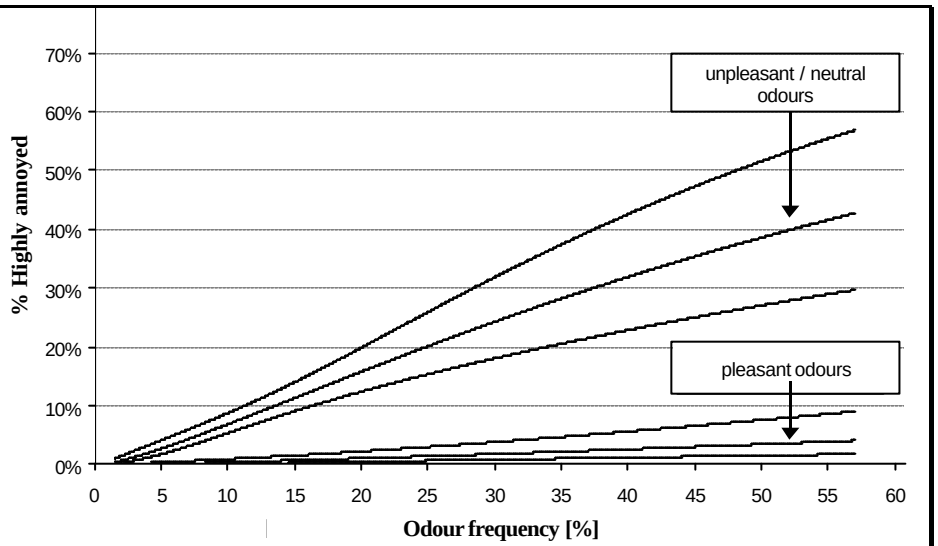

Figure 10. Percentage of highly annoyed residents in dependence on the odour frequency and on the hedonic tone including 90% confidence interval

SUMMARY

- Field measurements with panels to assess the odour impact and interviews using a standardised questionnaire to assess odour annoyance of residents were carried out in the vicinity of six installations with different hedonic characteristics.
- A new method to measure odour intensity and hedonic tone in the field with data record forms was developed and validated. With this method reliable and reproducible results are obtained.
- The parameter odour frequency based on the system of “odour hours” is suitable and sufficient to predict odour annoyance caused by unpleasant/neutral odours.
- In the case of pleasant odours hedonic tone has an abundantly clear effect on the dose-response-relationship between odour frequency and annoyance. Pleasant odours have a significant lower annoyance potential than unpleasant/neutral odours.
- The odour intensity has no additional influence on this relationship. If odours are recognisable they can cause annoyance.

Note: Part of the data and concepts used in this paper were produced by Kirsten Sucker in partial fulfilment of her PhD-requirements.

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