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Exposure-annoyance relationships for odour from industrial sources

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Abstract

Existing data from field surveys have been reanalysed in order to establish relationships between odour annoyance and odour exposure concentrations caused by (bio) industrial odours in a community. The percentage of highly annoyed persons (%HA) was found to have a simple relationship with the logarithm of the 98 percentile of the odour exposure concentrations (lgC98). Pleasantness ratings of the odours were obtained through a supplementary laboratory study with samples from the sources concerned. It was found that the prediction of %HA improves if the pleasantness of the odour is taken into account. The %HA at a certain level of lgC98 is found to be higher when the odour is less pleasant. This indicates that odour standards may improve if they take the odour pleasantness into account. Before doing so the possibility must be ruled out that the effect of pleasantnees on %HA was caused by factors confounded with the pleasantness of odours. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Odour concentration is an indicator of the strength of environmental odour. It was found to be an important determinant of the annoyance caused by environmental odour. Miedema and Ham (1988) and Miedema (1992a) published curves for predicting the percentage of persons who are highly annoyed by odour in the surrounding community (%HA). The curves give %HA as a function of the 98 (or 99.5) percentile of the distribution of the odour concentrations ($C98$ or $C99.5$) to which persons are exposed.

Quality or pleasantness is another aspect of odour. This is what makes the odour from a pastry factory very different from the odour from a rendering plant. The pleasantness of an environmental odour is defined here as the pleasantness of the emitted odour rated in the laboratory after dilution to a certain fixed odour concentration. Consequently, by definition, odour from one source has only one degree of odour pleasantness.

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The above-mentioned results in Miedema (1992a) are based on field surveys around six very different types of odour sources. With one exception the data for the individual sources followed a consistent pattern and could be described with a single curve. Based on these findings, it was suggested to use a single curve for all types of odour sources. The results were taken to indicate that the differences in pleasantness of odours that would be found with short exposure times in the laboratory are relatively unimportant for persons exposed to these odours in their living environment. The higher annoyance found for the one exception could be explained by previous accidents that may have sensitised the community to the odour of the factory concerned, as a possible indicator of danger.

However, the results did not lead to consensus among those involved in the regulation of environmental odour in the Netherlands. Many felt that pleasantness is an important determinant of annoyance from environmental odour in the surrounding community and that a single curve does not give an adequate description for all (bio) industrial sources. This is an important issue because environmental odours can have very different degrees of pleasantness, and the overall odour quality

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Table 1
The studies (year in which they were conducted[a]) and the types of odour source included in the analyses, with the number of respondents and the non-response rates

Source type	1984/85	1988a	1988b	1990	1995a	1995b	1996	Total
Oil extraction	354							354
Chemical		310	359					669
Rendering plant				98				98
Pig farm	174							174
Sugar blending		222	247					469
Grass drying					600			600
Chips							984	984
Wire coating	722							722
Pastry						515		515
Cacao		355	352					707
Tobacco							984	984
Total	1250	887	958	98	600	515	1968	6276
Non-response rate	20%	14%	37%	40%	46%	47%	32%	

[a] References:
1984/85: Miedema and Ham (1988), Miedema (1991).
1988a: Verschut et al. (1991), Miedema (1991).
1988b: Verschut et al. (1991), Miedema (1991).
1990: Miedema (1992b).
1995a: Smit (1995).
1995b: Krist-Spit (1995).
1996: Walpot and Boom (1996).

may change after odour abatement measures have been taken.

Therefore, the relationship between $C98$ and %HA, and the hypothesis that %HA is independent of the odour pleasantness is further investigated here. The number of different odour sources for which data on exposure and annoyance are available has increased, and a method has been developed to quantify the pleasantness of odour (Miedema and Walpot, 1997).

2. Data

As many existing relevant data sets as possible have been used in the present analyses. An available data set from a field survey on odour annoyance was used, provided it contained the odour annoyance responses from the survey so that %HA could be derived, and $C98$ for the exposure of the respondents. This annoyance measure (%HA) was chosen because it has been used in publications on relationships between environmental noise exposure and annoyance (see e.g. Schultz, 1978; Miedema and Vos, 1998), which is a subject closely related to the present subject, and because it is less sensitive to certain methodological differences between studies than other possible annoyance measures (see Section 3). The exposure measure ($C98$) has been chosen because it is commonly used in practice in the Netherlands, where all available studies were conducted. The measures of exposure and effect are further discussed in Section 3. An additional requirement for studies to be usable was that the same type of odour still was emitted so that samples could be taken for rating the pleasantness. This requirement was needed because $C98$ and annoyance responses were determined in the original studies and included in the data sets from these studies, but pleasantness ratings had not been carried out.

Table 1 gives an overview of the studies used and the source types that were investigated in these studies. Also the number of respondents and the non-response rates are given. The number of respondents in each study is smaller than the number of respondents whose address was selected for an interview, because some persons could not be contacted or refused to cooperate for various reasons. The number of such non-respondents is expressed as a percentage of the number of persons whose address had been selected, and this percentage is called the non-response rate.

With the exception of the potato chips factory and the tobacco factory, each source was the only important environmental odour source for the respondents. Even though such a single-source situation was preferred, the chips factory and the tobacco factory were included to increase the diversity of odour types and because most likely respondents were able to distinguish the odours emitted by these factories. No significant changes had

Table 2
The annoyance questions and the way of interviewing

Study	Annoyance question	Type of inter viewing
1984/85 and 1988a	Q16: How often do you smell an odour from industry in your house or its surrounding? Thus, we are not concerned here with e.g. odour of exhaust from cars or aircraft, or odours from stables or dung. (never, seldom, sometimes, often, always) Q17: To what degree does this odour or do these odours annoy you? (very annoying, annoying, just annoying, just not annoying, not annoying) Q18: Can you describe the annoying odours or tell where they come from? If a respondent answered "never" to Q16, then Q17 and Q18 were skipped. These respondents were assumed to be not annoyed by the odour source concerned. Respondents who were annoyed but reported to Q18 another source as the cause of the annoyance were assumed not to be annoyed by the investigated source. One of the sources in the 1984/85 study was a pig farm. In the survey conducted around that source, stables were mentioned in Q16 as the source of interest instead of being excluded.	Face-to-face
1988b	Q18: Taking everything into account, how much annoyance due to odour from industry (thus not from exhaust) do you experience? (definitely no annoyance, very little annoyance, little annoyance, some annoyance, quite some annoyance, much annoyance, very much annoyance) Q23E: How much annoyance do you experience from odours of industries? (definitely no annoyance, very little annoyance, little annoyance, some annoyance, quite some annoyance, much annoyance, very much annoyance) The annoyance responses to both questions were averaged.	Mail
1990	Q16: And the following possible odour sources, how often do you smell them in your house or its immediate surrounding? [industrial site] (never, seldom, sometimes, often, always) Q17: To what degree does this odour annoy you? (not annoying, just not annoying, just annoying, annoying, very annoying) If a respondent answered "never" to Q16, then Q17 was skipped. These respondents were assumed to be not annoyed by the odour source concerned.	Face-to-face
1995a and 1995b	Q10: Now I am going to mention some things that can cause annoyance or that influence the quality of life. I would like to know how often during the last years you were bothered by industrial odour. (never, sometimes, often) Q11: If you were annoyed by industrial odour, how annoyed were you? I would like to know if, during the last years you were not annoyed, annoyed or highly annoyed. If respondents answered "never" to Q10, then Q11 was skipped. These respondents were assumed to be not annoyed by the industrial odour concerned.	Telephone
1996	Q10 and Q11 were the same as in the 1995 studies. Other pertinent questions were: Q12: You just mentioned that you are sometimes or often annoyed by industrial odours. Do you know which company is the cause? (if a respondent couldn't give a name then Q13 was asked; otherwise Q13 was skipped). Q13: Can you describe the odour? Respondents who were annoyed but answered Q12 or Q13 by identifying another source as the cause of the annoyance were assumed not to be annoyed by the investigated source.	Telephone

occurred in the sources within the year preceding the interviews. The 11 odour sources involved are all located in the Netherlands.

Table 2 gives for each study the annoyance questions that have been used, and it indicates the way of interviewing. The topic of the interview mentioned in the introductions of the interviews was not odour, but a more general topic such as the quality of the residential area. Table 3 gives an overview of what is known about the sampling procedures. The study area was defined in all cases on the basis of information concerning the area where the odour from the factory concerned could be noticed. The information used was diverse, e.g. preliminary dispersion calculations on the basis of estimated or available emission data, information from the management about the most distant houses from which complaints were received, and observations (smelling) in the field by researchers. This information was only used to define the study area. A more precise determination of the odour exposure was a part of the studies (see Section 3), and these exposures were used in the analyses.

Table 3
Sampling procedures

Study	Sample procedure	Conditions
1984/85 and 1988a	Respondents were selected in three steps: 1. First areas at different distances from the source were selected. The distance ranged from as close to the source as possible to a distance where odour was expected to be hardly detectable. 2. Within an area households were selected with a random procedure. 3. One person of at least 18 years of age was at random chosen from a selected household for the interview. When a selected person could not be interviewed, the interview was continued with the person contacted in the first place.	Limited traffic No other odour source Age $\geqslant 18$ years Residence > 3 months
1988b and 1990	Households were selected at random from the area where the odour was supposed to be detectable at least sometimes. Respondents were selected in three steps: 1. First three areas at different distances from the source were selected. 2. Within an area households were selected with a random procedure. 3. One person of at least 18 years of age was at random chosen from a selected household for the interview. When a selected person could not be interviewed, the interview was continued with the person contacted in the first place.	No streets included in 1988a Residence > 3 months Age $\geqslant 18$ years
1995a and 1995b and 1996	Respondents were selected in two steps: 1. First three (1995a) / four (1995b) / an unknown number of (1996) areas were selected at different distances from the source. 2. Within each area a random sample was drawn from the addresses having a telephone. Prior to a contact a household received a letter in which the telephone interview was announced. The interview was conducted with the person who answered the telephone, unless he or she was younger than 13 years.	Age $\geqslant 13$ years

3. Exposure and annoyance measures

The strength of the odour to which a respondent was exposed is described with *C*98. This measure was determined by combining emission measurements and dispersion calculations as follows.

Samples were taken from the emitted air at the source. With an apparatus called an olfactometer these samples were diluted and presented to a panel of 5–10 persons. The odorous sample is presented to each person at a randomly varied position together with clean air at one or two other positions. Each individual must choose the diluted odour from the two or three air flows that are presented to him or her. From the percentage of correct responses at different dilution levels, the dilution level is estimated at which 50% of the population just cannot discriminate the odour from clean air. This dilution level is called the odour concentration of the sample and is expressed in odour units per m^3.

Olfactometric procedures are standardised in the Netherlands in document NVN 2820 (1995) and on a European level in document CEN TC264/WG2 (1997). The Netherlands and the European standards fully agree so that results of the methods can be directly converted. The method used was the same in all studies in Table 1 and complies with the Netherlands and European standards.

After having determined the odour emission (ou m^{-3}) and the volumetric flow ($m^3\ s^{-1}$), these were multiplied to obtain the odour emission rate (ou s^{-1}). The odour emission rate together with source characteristics (stack release height, temperature of the air), meteorological data from the year preceding the interviews, and the position of each respondent relative to the source were the input for dispersion calculations. The meteorological data were obtained from a nearby airport. The Long Term Frequency Distribution Model (LTFDM) was used as a dispersion model (Werkgroep Verspreiding Luchtverontreiniging, 1983). LTFDM is a Gaussian plume model which calculates the 1-h average concentration level of a position for various meteorological situations. From these results and the distribution of the meteorological conditions the 98 percentile ($C98$) of the odour concentrations is derived. In this way, the 1-h average odour concentration that is exceeded during 2% of the year preceding the interviews is calculated for each respondent.

Two methods (pairwise comparison, rating with a reference scale) were used in the laboratory to scale the pleasantness of the odours (see Miedema and Walpot, 1997). The data on pleasantness were not collected in the original studies, as is the case for the annoyance responses and $C98$, but the experiments were carried out with a panel of 12–14 persons especially for the present analyses. For one of the 11 odour sources (grass drying) two subsources that emitted different types of odour were evaluated separately in the experiments, so that 12 types of odour were judged. The average of the scores obtained for the two subsources were used in the further analyses corresponding to grass drying.

With the pairwise comparison method a subject is presented with two odours, and must choose the most pleasant one. Subjects judged a combination 3 times, and in a few cases less often. The percentage that preferred odour A to odour B is calculated by first determining per person the average number of times that odour A is preferred, and thereafter averaging these values. Only 15 of the 66 ($= 12 \times 11/2$) possible pairs were evaluated by the panel. Gulliksen's (1956) method for paired comparisons with incomplete data was used to find scores for the odours on the basis of the preference judgements. The experiment was carried out three times with different odour concentration levels (10, 25, and 50 ou m^{-3}), so that three sets of scores were obtained for the pleasantness of the odours (see Fig. 1a).

The second method uses a 9-point rating scale with H_2S as a reference at the one but most unpleasant category, and amyl acetate as a reference at the one but most pleasant category. Subjects had to place each of the 12 odours on this scale, taking the positions of the two reference odours into account. The odours were presented to the panel in three clusters on different dates. Two successive clusters had one odour in common. Cluster 1 consisted of the odours oil extraction, chemical, rendering plant and pig farm, cluster 2 consisted of pig farm, sugar blending, grass drying ($2\times$) and wire coating, and cluster 3 consisted of chips, wire coating, pastry, cacao and tobacco. To calculate pleasantness scores the rank numbers from 1 to 9 are assigned to the categories ($1 =$ very unpleasant and $9 =$ very pleasant) of the rating scale. Then the score of an odour is calculated by first determining the average score per person, and thereafter averaging the results. The scores from separate clusters were not combined so that two odours (pig farm, wire coating) had two scale values after this procedure. The difference between the two scale values for the pig farm odour was added to the scores in the second cluster, and this difference plus the difference between the two scale

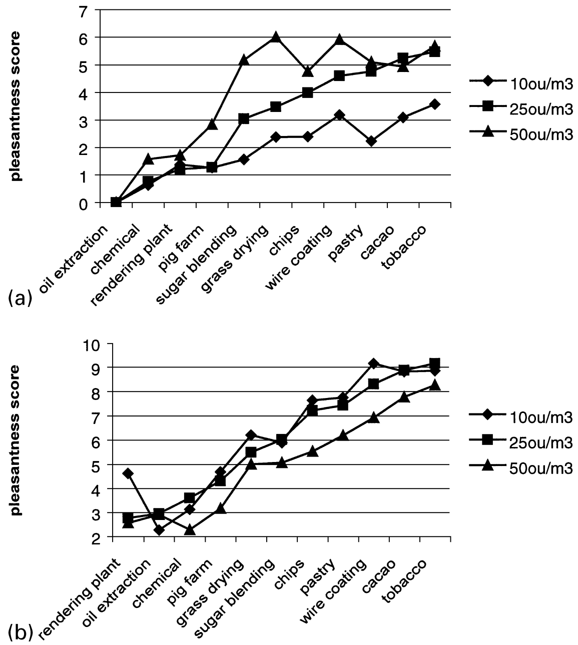

Fig. 1. (a) Odour pleasantness scores based on pairwise comparisons between these odours. The odour concentrations of the compared odours were all equal to 10, 25, or 50 ou m^{-3}, respectively; (b) Odour pleasantness scores based on ratings of these odours with the aid of a reference scale. The odour concentrations of the rated odours were all equal to 10, 25, or 50 ou m^{-3}, respectively.

values of the wire coating odour was added to the scale values in the third cluster. In this way the scores were corrected for context effects, i.e., the influence of the other odours rated at the same occasion. This experiment was also carried out three times with odour concentration levels of 10, 25, and 50 ou m^{-3}, so that three additional sets of scores were obtained for the pleasantness of the odours (see Fig. 1b).

The relative position of the pastry odour with all six procedures is remarkable. In advance, it was expected to be the most pleasant odour. A possible explanation for the outcome is that the sample has been taken inside the oven, where the character of the odour may be different from the odour emitted afterward when the pastry is cooling. The odour emitted in this latter phase is most important for the total emission of the factory, and causes the exposure in its surrounding. This would mean that the pastry odour to which people in the surrounding are exposed is more pleasant than suggested by the results in Fig. 1. However, because there is no evidence concerning this conjecture, the result for pastry as shown in Fig. 1 is used in the analyses.

Annoyance questions in different studies do not use the same number of response categories (see Table 2). Some questions have only three response categories while

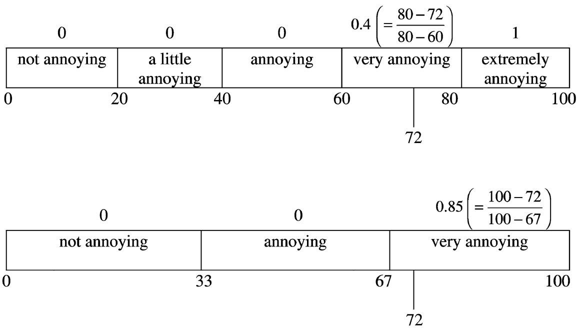

Fig. 2. Two illustrations of the transformation of annoyance categories to a scale form 0 to 100, and the determination of the indicator variable for 'high annoyance' (= an annoyance response above 72).

others use as many as seven categories. In order to obtain comparable annoyance measures for different studies, different response scales were translated into a scale from 0 to 100, and a cutoff point is chosen on that scale (see Fig. 2, where the cut-off is equal to 72). Then an indicator variable is determined that is equal to 1 for a respondent whose annoyance level exceeds the cut-off, and 0 if the annoyance level is lower than the cut-off. That is, the value is equal to 1 for a respondent who chose an annoyance category that lies completely above the cut-off, 0 if the category chosen lies completely below that cut-off, and between 0 and 1 if the annoyance category chosen contains the cut-off. In the latter case the value of the indicator is equal the probability that the 'exact' annoyance level of the respondents exceeds 72, assuming that all values within the category are equally likely. This means that the value of the indicator variable is equal to the proportion of the category above the cut-off. If the cut-off is 72 on a scale from 0 to 100, then (100 times) the average of the indicator variable is called the percentage highly annoyed persons (%HA) (see Miedema and Vos, 1998).

An important advantage of the indicator for high annoyance over other annoyance measures is its relatively low sensitivity to the following methodological differences between studies. In some studies respondents who never or only seldom notice an odour had to skip the odour annoyance questions, while other studies present the annoyance question to all respondents. In the former studies, the respondents who had to skip the annoyance question are assumed not to be annoyed. Actually, some of them would have reported a low level of odour annoyance if they had to answer the annoyance question. Thus, skipping the annoyance question affects annoyance measures that are sensitive to differences in low degrees of annoyance. In contrast, unless a respondent who did not or only seldom notice the odour would have reported high annoyance (>72 on a scale from 0 to 100), skipping the annoyance question does not affect his value of the indicator of high annoyance. In a similar way, the difference between correcting or not correcting the annoyance response on the basis of a subsequent question on the cause of the annoyance will affect annoyance measures that are sensitive to differences in low degrees of annoyance more than the indicator for high annoyance. Therefore the focus is on analyses with %HA.

4. Analyses and results

Fig. 3 shows for each odour source %HA as a function of the logarithm of $C98$ (lg $C98$). To obtain these curves lg $C98$ was divided into intervals of 0.1 wide. If an interval contained less than 30 respondents, then it was combined with an adjacent interval until each interval contained at least 30 respondents. The %HA per interval is plotted at the mean lg $C98$ within that interval, and then the points for a single source are connected.

A synthesis curve based on the combined data from all odour sources except the chemical factory was obtained with regression analyses in which each point was weighted according to the number of observations on which it is based. The chemical factory was excluded because the curve for this source lies isolated from the rest, i.e. it is an outlier. The relatively high annoyance at low exposure levels is possibly caused by a history of external safety problems of that factory, which were known in the local community.

Four models were fitted. One model is $\%HA = a0 + a1 \lg C98 + a2 (\lg C98)^2$, and three other models are obtained by setting parameters ($a0$, $a1$, $a2$) in the equation equal to zero (see Table 4). The correlation coefficient of quadratic model 1 (0.897) is substantially larger than the correlation coefficient of the linear model 2. The correlation coefficients of models 3 and 4 are equal, and only a little lower than the coefficient of model 1. Model 4 is preferred above model 3 because it is simpler (one less parameter), while it represents the data equally well. This means that models 1 and 4 are better than models 2 and 3.

The curves for models 1 and 4 are shown in Fig. 3. In model 4 the curve is forced through the origin, while in model 1 %HA increases if lg $C98$ decreases below approximately 0.5. Possibly the high annoyance reported by some respondents at very low exposure levels is incorrectly attributed to the source studied. Model 1 has the flexibility to capitalise on this supposedly incorrect attribution and this probably causes the slightly higher correlation of model 1. The curves for model 1 and model 4 almost coincide at higher levels and the effect of the difference above 1.5 on the correlation coefficient must be small because there are only a few datapoints in that high range. Therefore, it is concluded is that model 4 gives an optimal representation of the data.

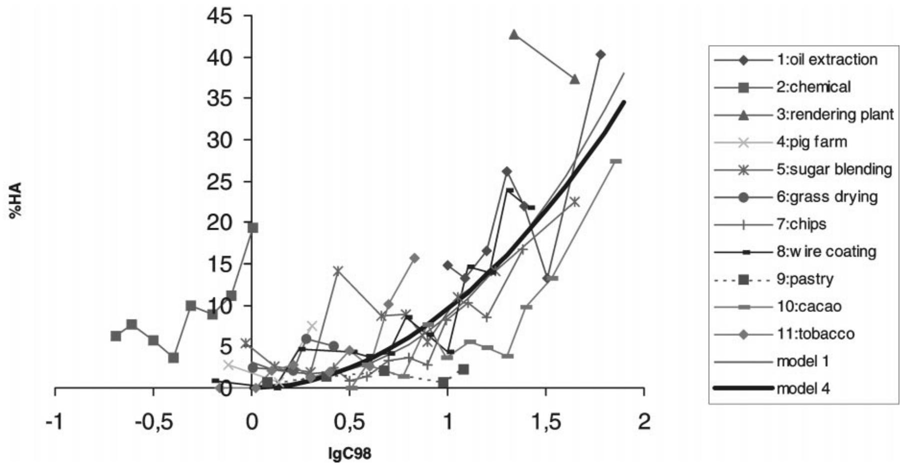

Fig. 3. Percentage highly annoyed (%HA) as a function of the logarithm of the 98 percentile of the odour concentrations in the year preceding the interviews (lg *C*98): datapoints and curves fitted with two models (1 and 4).

Table 4
The four models fitted to the combined data (except the data for the chemical factory), the values found for the parameters with a regression analysis, and the resulting correlation coefficients *r*

Model	*a*0	*a*1	*a*2	*r*
1: $\%HA = a0 + a1 \lg C98 + a2 (\lg C98)^2$	3.07	− 8.63	14.2	0.897
2: $\%HA = a0 + a1 \lg C98$	− 1.67	12.61		0.838
3: $\%HA = a0 + a2 (\lg C98)^2$	0.736		9.05	0.889
4: $\%HA = a2 (\lg C98)^2$			9.55	0.889

To investigate the influence of the pleasantness of the odour, a series of six similar regression analyses was carried out. In each analysis one of the six ($= 2$ methods $\times$ 3 concentration levels) pleasantness scales was incorporated into model 4 ($\%HA = a(\lg C98)^2$). The extended models have the following form: $\%HA = [a + b\,K] (\lg C98)^2$, where K is one of the six odour pleasantness scales, the values of which are shown on the vertical axis in Fig. 1 (in the present analysis standardised so that the mean is equal to zero). K is equal for all respondents exposed to the same odour source. Thus, $C98$ and K are the independent variables of the model, and a and b are the parameters of the model that must be estimated. When the pleasantness score of an odour is equal to the average of all pleasantness scores, i.e. $K = 0$, then the value added to a is equal to zero. However, with $b > 0$, a positive value bK is added to a for odours that have a positive pleasantness score K, and a negative value bK is added for odours that have a negative pleasantness score K. The effect of the added term bK is that the rate of increase of %HA as a function of lg $C98$ can vary with the pleasantness of the odour. If a large value of b is found, then this means that pleasantness score K has a stong influence on the %HA. The range of lg $C98$ was restricted to values > 0.5 ou m^{-3} (see discussion above) when the values of a and b were estimated.

The correlation coefficients presented in Table 5 are all substantially higher than the correlation coefficient of model 4, which is equal to 0.901 if the range of lg $C98$ is restricted to values > 0.5. The increase of the correlation coefficient r is statistically significant at the 0.01 level (F-test of the r square change). This means that the extension of the model with an odour pleasantness score increases the accuracy. Part of this increase in accuracy may be an indirect effect of taking into account variables associated with odour pleasantness, in particular study site variables and study characteristics, by incorporating odour pleasantness in the model. These factors are associated with the pleasantness score because different sites have different pleasantness scores, and each site was investigated in only one study (with the exception of the three sites that were investigated in the 1988a and the 1988b study).

In Table 5 the correlation coefficients obtained with the reference scale are higher than the correlation coefficients obtained with paired comparisons. Furthermore,

Table 5
The correlation coefficients for six models which have the following form: %HA = $[a + b.K]$ $(lg\ C98)^2$, where K is one of the six odour pleasantness scores (standardised so that the mean is equal to zero). The range of lg$C98$ is restricted to values > 0.5

Odour-scale	Concentrations (in ou m^{-3})	r
Reference method	10	0.934
	25	0.945
	50	0.943
Pairwise comparison	10	0.921
	25	0.935
	59	0.925

the correlation coefficients obtained at an odour concentration of 25 ou m^{-3} are higher than the correlation coefficients at 10 or 50 ou m^{-3}. Therefore, the predictions of the model extended with odour pleasantness measured at 25 ou m^{-3} with the reference scale are shown in Fig. 4. The bold curve is predicted by model 4. This curve is the same for all types of odour. The thin curves are predicted by the extended model. These curves depend on the odour pleasantness score for the type of odour concerned. It may be noted that the improvement of the prediction of %HA would have been larger if the pleasantness rating of the pastry odour would have been higher and more in accordance with the expected rating of the pleasantness (see the previous section).

5. Conclusion and discussion

The form of the relationship between the percentage of highly annoyed persons (%HA) and the logarithm of the 98 percentile of the odour concentration (lg $C98$) is simple: %HA increases as a quadratic function (without constant or linear term) when lg $C98$ increases. The accuracy of the prediction of %HA is improved if both the pleasantness of the odour and the odour concentration are taken into account. The rate of increase of %HA as a function of lg $C98$ is found to be higher if the odour is less pleasant. It is possible, however, that factors confounded with the pleasantness of the odour, such as site variables or study characteristics, are partly responsible for this dependency of the rate of increase of %HA on odour pleasantness. The results were obtained with sources that emit in all periods of the year. It is not known whether the results generalise to seasonal sources, which emit odour only in a limited period.

The simple overall curve presented in this paper (Fig. 3: model 4) can be used to predict %HA in a given situation as follows. First the odour emissions of the factory concerned are determined through odour emission measurements. Then the odour exposures in the surrounding of the odour source are calculated with a dispersion model using the odour emission as one type of input. With the dispersion calculations the concentration level that is exceeded 2% of the year, i.e. $C98$, is determined for each point. The simple overall curve presented in this paper can be used to find the probability that someone living at that point is highly annoyed (estimated probability = %HA : 100). These probabilities themselves can be used as a basis for the evaluation of the odour, or they can be combined with data about the coordinates of dwellings and the number of their inhabitants to find the percentage highly annoyed persons in the surrounding of the source.

Of course, deviations from the predicted percentage must be expected at individual sites because random factors and local circumstances affect the odour annoyance. However, in many cases the prediction on the basis of a "norm" curve is a more suitable basis for policy than the actual annoyance. The predicted annoyance is the annoyance that would have been found if a sufficiently large sample of the general population would have been exposed to the odour and no significant changes in the exposure would have occurred, assuming that the samples on which the norm curve is based represent the general population.

For example, a norm curve is useful when exposure limits for dwellings in the vicinity of an odour source and odour abatement measures are discussed. It also can be used to estimate the number of highly annoyed persons in the vicinity of a factory for different scenarios concerning emission reductions. That the norm curve does not take local circumstances or reactions to a change in exposure itself into account is considered to be an advantage for many purposes. Equity and consistency of policy would not be served if in each case the actual annoyance is taken as the (only) basis for these evaluations.

An important point that is not fully settled by the results presented in this paper concerns the need for separate curves for different types of odour. The prediction of annoyance improved when the pleasantness of the odour was taken into account. This may indicate that it is important to take pleasantness into account in odour standards. On the other hand, however, it is possible that factors confounded with the pleasantness of the odour are partly responsible for this improvement. A disadvantage of taking the pleasantness of the odour into account is that this complicates the evaluation of odour exposures in practice and will increase the costs for the assessment of the exposure. Instead of conducting odour pleasantness measurements in every specific case, the following approach may be practical. In principle, odours are evaluated on the basis of a single curve such as the one presented here (Fig. 3: model 4). In addition to that curve two separate curves are established for very unpleasant

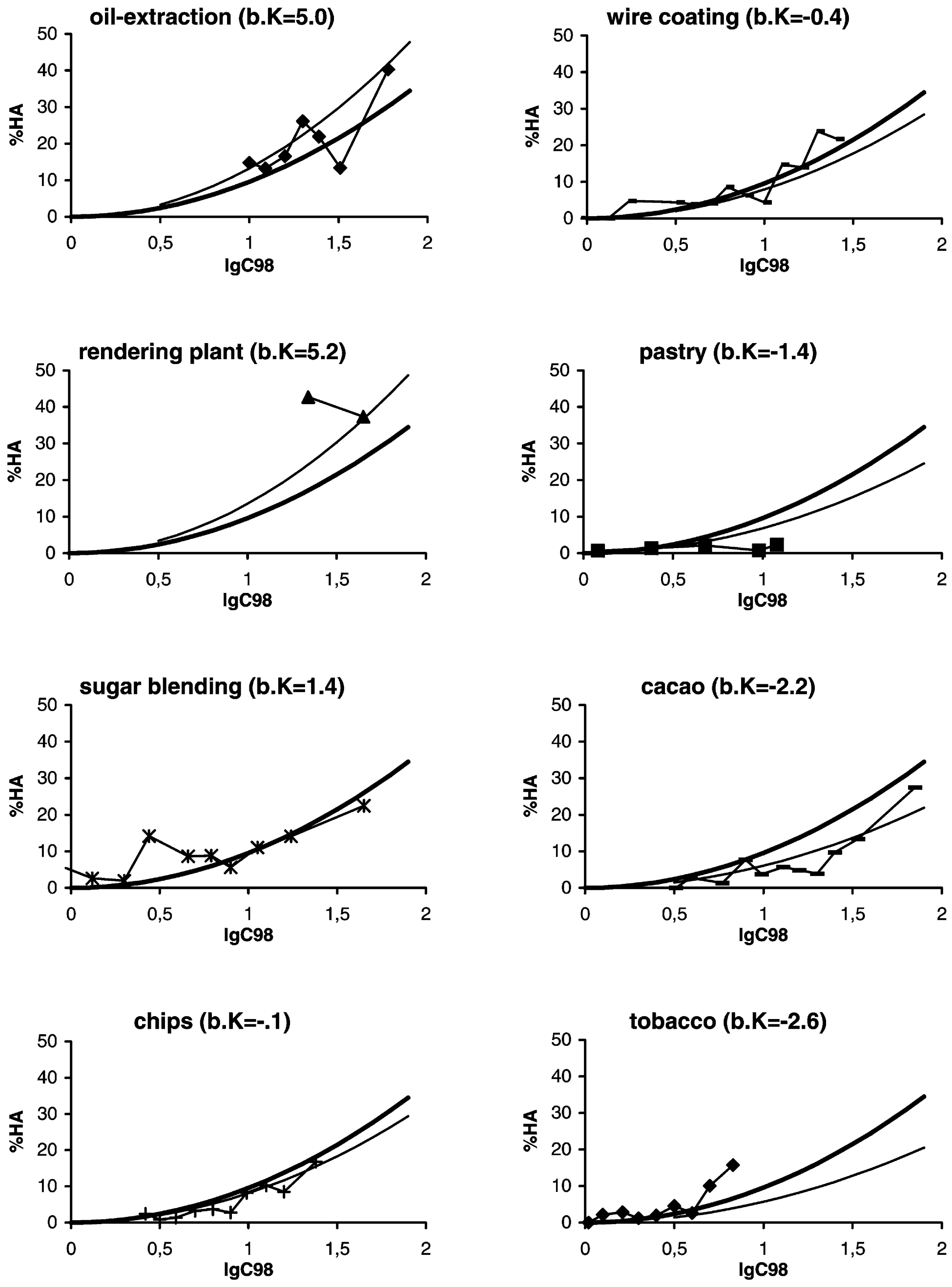

Fig. 4. Percentage highly annoyed (%HA) as a function of the logarithm of the 98 percentile of the odour concentrations in the year preceding the interviews (lg $C98$). For each source the datapoints are shown, and the curves fitted with model 4, i.e %HA $=$ a(lg $C98$)^2 (bold), and the extended model 4, i.e., %HA $=$[a $+$ b.K]. (lg $C98$)^2. The two curves for sugar blending coincide. Here K is a score for the pleasantness of the odour.

odours and for very pleasant odours, and a list is made of the odour sources for which these two additional curves apply. Establishing the two additional curves and making the corresponding lists of odour sources requires additional research.

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