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TNO-rapport

RESPONSE FUNCTIONS FOR ENVIRONMENTAL ODOUR IN RESIDENTIAL AREAS

NIPG-publicationnumber
92.006

April 1992

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Nederlandse organisatie voor
toegepast-natuurwetenschappelijk onderzoek

TNO-Gezondheidsonderzoek stelt zich ten doel bij te dragen aan de verbetering van preventie en behandeling van ziekten en afwijkingen door het toepasbaar maken van kennis op medisch biologisch, psychosociaal en epidemiologisch gebied ten behoeve van de volksgezondheid en de gezondheidszorg.

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CONTENTS

PREFACE

The present study is the second of three related studies about environmental noise and odour. They are reported under the titles:

I. Response functions for environmental noise in residential areas;

II. Response functions for environmental odour in residential areas;

III. Quantification of environmental quality.

In the first and second study the original data from a number of investigations are analysed together to find functional relations between annoyance and exposure. These relations can be used to find for *individual* sources the exposure levels which correspond to limits with respect to annoyance. These relations also make it possible to find for various noise and for odour sources the levels which have equally adverse effects.
The third is a study into the foundations of the description of environmental quality. An environmental quality measure is described. It can be used to find for *combinations* of noise and odour sources the levels which correspond to limits with respect to annoyance. Moreover, the index can be used to find the (combinations of) exposure levels for noise and odour sources which are equally adverse.

This study, as well as the two others, have been carried out under contract of the Ministry of Housing, Physical Planning and Environment. Research bureau OP&P was so kind to provide us with their original data and communicated with us about some data analytical topics. For all studies in this compilation, the division Environment and Energy of our organization did the olfactometric work and carried out the dispersion calculations.

1. INTRODUCTION

For environmental odour far less studies about the relation between exposure and effects are available than for noise. The first field studies relating noise annoyance to noise exposure measures were carried out in the fifties. As far as we know, our study carried out in 1984/85 (Miedema & Ham, 1988) was the first comparable study for environmental odour. One explanation for this difference is that problems due to environmental odour are less widely spread than problems due to environmental noise. Another factor is that for noise useful exposure measures are more easily determined.
There are some studies which relate annoyance to distance from the source (e.g. Deane, Sanders & Jonsson, 1977; Kastka 1982; Langenhove et al., 1988). But in these studies the influence of the emission of the sources is unknown. Miedema & Ham (1988) reported a study (in the sequel referred to as the 1984/85 study) where annoyance is related to odour exposure determined with olfactometric emission measurements and dispersion calculation. A single curve was found to describe the relation adequately for all three included sources. A follow up of this study was carried out by Miedema and Verschut (referred to as 1988a study) around three other types of odour sources (Miedema, 1991; Verschut 1991). Punter and Verschut carried out another part (referred to as 1988b study) of the same project (Punter, 1991; Verschut 1991). They used a Dutch translation of the questionnaire from Winneke & Kastka in a survey around the same sources.

Here we report the analysis of the compiled data from the 1984/85, 1988a and 1988b studies, which all included information about both odour exposure and annoyance. The main purpose is to determine the relation between odour annoyance and exposure to (bio-)industrial odour in residential areas. An important question is whether a single relation can be used for different types of sources. Also the influence of non-olfactory factors on response curves for odour is studied.
The questions are treated in chapter 4, and followed by a discussion in chapter 5. But first measures to characterise odour exposure and annoyance are described in chapter 2 and the studies in the present compilation in chapter 3.

2. EXPOSURE AND EFFECT MEASURES

Exposure measures were already determined in the same way in the three studies in this compilation. For the annoyance there are differences between the 1984/85 and 1988a studies on the one hand, and the 1988b study on the other hand. Special attention is given to the problem of defining *comparable* annoyance measures.

2.1 Exposure measures

Since odour exposure or immission is characterized in terms of odour concentration, this concept is clarified first.

The odour concentration for an odorous air sample (a smell can be detected) is the number of times the sample has to be diluted with clean air to arrive at the detection threshold. The detection threshold may be roughly defined as the point where 50% of the persons can detect odour. It is perfectly legitimate to conceive of odour concentration as the ratio between the mass of the odorous substance in a sample and the volume of that sample, with as unit that ratio for a sample with the same odorous substance but at detection threshold. To put it in another way, it is just the ordinary concentration of the odorous substance, but with the unit depending on the type of substance. There are good pragmatic as well as theoretical reasons for this dependency of the unit on the type substance (for a deep, measurement theoretic analysis see Miedema, 1992b).

There is considerable agreement to express odour concentration in odour units per cubic metre (ou m^{-3}). One odour unit of a *particular* substance or compound then is that mass of the substance which, when mixed with one cubic metre clean air, can just be smelled, i.e. the sample is precisely at the detection threshold. Those opposed to the idea of odour unit conceive of odour concentration as a dimensionless number.

In the compiled studies the TNO olfactometer is used for odour concentration measurements of emitted air. In separate sections of a mobile room eight persons simultaneously judged a series of triples, one containing diluted emission air and the two others clean air. From each triple one had to be selected as containing odour.

Odour immission is determined with dispersion calculations (LFTD-model, 1981) using averages per hour as input. Input data are: the odour concentrations in emitted air, the emission rate, the emission height, the distance between emission point and a receiver (respondent), and meteorological data as atmospheric stability class, wind velocity and wind direction. The output consists of odour concentrations at receptor points.

Due to fluctuations in the operation conditions of the source and in the meteorological conditions, the immission fluctuates over time. When the joint distribution of operation and meteorological conditions is known, the distribution of the odour concentration at each receptor point can be found. For this latter distribution e.g. percentiles can be determined. The odour concentration that is exceeded during (100 - P)% of period T is denoted by $C_P(T)$, the log of it by $L_P(T)$. Since here we use only the one year period preceding the interviews, we agree to write C_P or L_P for the level exceeded (100 - P)% of time in that year. C_{98} and $C_{99.5}$ are the concentrations exceeded during 175, respectively 44 hours in that year. $C_{99.99}$ is the maximum concentration for an hour in that year.

For sources with a constant emission in climatologically similar areas (as within the Netherlands) the shape of the log odour concentration distribution is nearly constant. Thus, the differences between e.g. L_{98} on the one hand and $L_{99.5}$ or $L_{99.99}$ on the other are nearly fixed. In the Netherlands these differences are about .3 respectively .6 - .9, depending somewhat on the effective emission height and the distance of the receptor to the source. However, for intermittent or fluctuating sources this is not the case. For a source that emits only a fraction F of the year and is constant within the emission period, the differences between L_{98} on the one hand and $L_{99.5}$ or $L_{99.99}$ on the other depend on F. If F > .5, then differences are about the same as those mentioned above for constant sources (F = 1), but for smaller fractions these differences become larger (Eggels and Duijm, 1989). However, the difference between $L_{99.5}$ and higher percentiles changes much less with variation of F than do the differences between L_{98} and higher percentiles. We will find that for sources with different F $L_{99.5}$ is a better

single predictor of odour annoyance than L_{98}, indicating that persons base their evaluation especially on the highest levels.
It may be stressed that for all studies in the compilation the olfactometer as well as the calculation procedures used were the same. Therefore, similar exposure measures from these studies are directly comparable. Unfortunately, olfactometers are not (yet) standardized, so that exact numerical values for exposure measures depend on the (sensitivity of) the olfactometer used.

2.2 Effect measures

Apart from nonspecific odour annoyance (i.e. not concentrating on disturbance of particular 'activities') there are reports of annoyance related to specific functional effects as sleep disturbance and specific somatic effects as nausea. Odour is also hypothesized to have social consequences as a decreased inclination to invite people at home. However, based on the analysis of their data, Miedema & Ham (1988) conclude that the influence of odour immission on specific effects is weak. These effects may occur, but above exposure levels for which nonspecific annoyance already demonstrates a severe adverse effect. Hence, nonspecific odour annoyance is the most relevant effect for the evaluation of odour situations.

In the compiled studies respondents rated (nonspecific) odour annoyance by choosing one of several categories. Usually there is considerable dispersion in the categories chosen by respondents with similar exposures. One possibility for summarizing the data is to describe the *percentages* of respondents reporting at least a certain level of annoyance as a function of the exposure. Another possibility is to describe the annoyance *scores* as a function of the exposure, after having assigned in a certain way scores to categories. Using the percentage approach the problem is to determine for different category systems a boundary that dichotomizes the annoyance continuum at approximately the same place. Using the scoring approach the problem is to assign to categories from different systems scores that represent their midpoints on the annoyance continuum. Finding a cut off point as well as assigning scores is simplest when the following two assumptions can reasonably be made:

- Equal intervals: each category from a single system occupies an equal portion of the annoyance continuum;
- Equal extremes: the lower and upper outer category boundaries from different category systems coincide.

When these assumptions are met, the cut off points and scores given in chapter 3 can be used.

Thus cut off points and scores are based on two assumptions. These assumptions have been checked for nonspecific noise annoyance in Miedema (1992a) with a procedure known as optimal scaling. The responses of the same person to two similar annoyance questions, but one with four and the other with ten categories, were compared with each other. Categories were chosen as would be expected on the basis of the above assumptions. That is, equal scores were obtained for both questions, using the scoring procedure for the categories based on these assumptions, described in the next chapter.

3. STUDIES IN THE COMPILATION

In each study locations were sought where a single odour source determined the exposure of the neighbourhood and where no significant changes within the preceding year had occurred.
There are six odour sources involved, all located in the Netherlands. They all produced a different type of odour, ranging from an odour (from a food industry) that will in the proper context be judged by many people to be pleasant to odours (from the electric wire insulation and chemical industry) that are unpleasant in any context. Table 1 gives an overview of the sources and the number of respondent at the locations.

Table 1 Number of respondents per location

	study		
	1984/85	1988a	1988b
rapeseed oil extraction	353		
electric wire insulations	728		
pig farm	172		
food industry		355	352
food industry		222	247
small chemical industry		310	359

In the 1984/85 and 1988a studies questionnaires were used in face-to-face interviews. Respondents were selected in three steps. First, areas were selected at different distances from the source. The range was from as close as possible to the source to a distance where, based e.g. on information from the company, odour was expected to be hardly detectable. Important criteria for selection were a limited amount of traffic and absence of other odour sources.
Within an area households were selected by a random procedure. From a selected household one person was chosen for the interview. For this purpose the interviewee started with making a list of the household members. From those at least 18 years old one was selected at random for the interview. When not possible with that person, the interview was continued with the person contacted in the first

place. A condition for an interview was that the respondent lived at least three months at the present address.

In the 1988b study questionnaires were sent by mail. Households were selected at random from those that were expected to at least sometimes detect the odour. However, streets included in the 1988a study were excluded. Questionnaires from respondents that lived three months or less at their present address were not used.

The non-response percentages were 20% for the 1984/85 study, 14% for the 1988a study and 37% for the 1988b study. Remember that the first two percentages are for face-to-face interviews, where the interviewer called at the door, while the latter percentage is for mail interviews.

The odour annoyance was determined in the same way in the 1984/85 study and the 1988a study. In the latter an abbreviated questionnaire was used, but up to and including the questions of interest here, they were the same. The questionnaire was used in face-to-face interviews. In the introduction only evaluation of the residential environment was mentioned as topic. The core questions, concerning the perception, annoyance and source of annoyance are:

How often do you smell in your house or its surroundings an odour from industry? So we are NOT concerned here with e.g. odour of exhaust gasses from cars or aircraft or odours from stables or dung?

	upper category boundary	score
never (next questions skipped)	20	10
seldom		
sometimes		
often		
always		

To what degree does this odour or these odours annoy you?

very annoying	100	90
annoying	80	70
just annoying	60	50
just not annoying	40	30
not annoying (next question skipped)	20	10

Can you describe the annoying odours or tell where they came from?

In the 1984/85 study one of the sources was a pig farm. In the odour question stables were added as a source of interest instead of being excluded.

The questionnaire used in the 1988b study was sent by mail. The questionnaire was said to be about the quality of the residential area. There were three questions dealing with nonspecific (i.e. not concentrating on disturbance of particular 'activities') odour annoyance. One question did not focus on industrial odours and is therefore not used here. The others are:

Taking everything into account, how much annoyance due to odour from industry (thus not from exhaust gasses) do you experience?

	upper category boundary	score
definitely no annoyance	14	7
very little annoyance	28	21
little annoyance	43	36
some annoyance	57	50
quite some annoyance	71	64
much annoyance	86	79
very much annoyance	100	93

How much annoyance do you experience from odours of industries?

definitely no annoyance	14	7
very little annoyance	28	21
little annoyance	43	36
some annoyance	57	50
quite some annoyance	71	64
much annoyance	86	79
very much annoyance	100	93

The most important difference in questions and method probably are the difference in number and labels of the response categories and the lack of a identification of the annoying source in the 1988b study.

4. RESPONSE FUNCTIONS

Two different types of response functions are determined, one involving annoyance scores, the other percentages annoyed. Both scores and percentages are related to L_{98}, $L_{99.5}$ and $L_{99.99}$. Since the latter measure was not determined in the 1984/85 study, results for $L_{99.99}$ are based only on data from the 1988a and 1988b studies. In plots C_{98}, $C_{99.5}$ and $C_{99.99}$ are shown on a logarithmic axis instead of L_{98}, $L_{99.5}$ and $L_{99.99}$ themselves, because the former are the common measures in this field. Quantities as correlation coeficients for the relation with annoyance scores are presented as triples, with at the first place the quantity for L_{98}, etc..

For the analyses of the *scored annoyance* often linear regression is used. When there are indications for nonlinear trends, higher order polynomial regression can be used. A disadvantage, however, is that data at one point also influence the fitted polynomial at distant points. To put it another way, changes in annoyance at a certain exposure level would change the fitted polynomial also at different exposure levels: local changes have global influence.

A procedure which brings out nonlinear trends when present, but which does not have the above mentioned disadvantage is polynomial spline regression. The polynomial spline used consists of several polynomial pieces of order r. With $r \geq 2$ pieces are so connected, that together they constitute a continuous function. Furthermore, when $r \geq 3$ connections are such that i^{th} left and right derivatives are equal, $i=1,...,r-2$. As a consequence the function is smooth. Finding the best fitting piecewise polynomial of the above type is called spline regression.

For the analyses of *percentage annoyed* as a function of exposure, the exposure continuum is often partitioned in intervals. For each exposure interval the percentage respondents with annoyance above a cut off point is plotted as a function of the midpoint or average of the exposure values in that interval. By linear interpolation a function is obtained for the range of exposures involved.

A disadvantage is that this function usually exhibits variations due to random error. In order to get a clearer picture of the main trend smoothing can be applied.

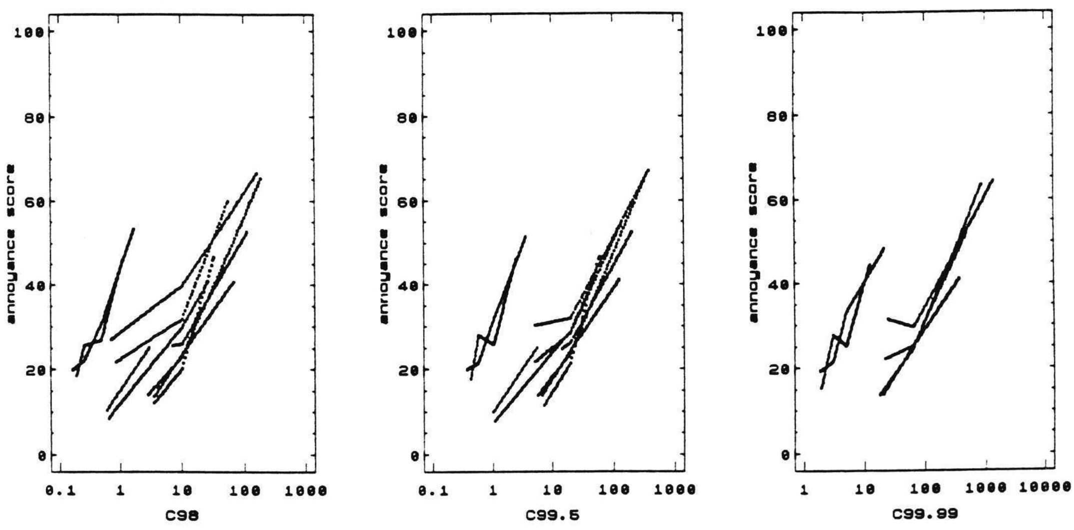
One way of smoothing derives from the observation that a percentage annoyed for an exposure interval is (100 times) the average score in an interval, when respondents are assigned score 1 when their response is above the annoyance cut off point and 0 when it is below it. A result with less meaningless variation can be obtained by determining the weighted average of these 0's and 1's. A set of unimodal weight functions is used. Each is nonzero on a limited exposure interval and the values of these fuctions (the weights) add to 1 at each exposure level. In the present case tent shaped weight functions are used, the nonzero part of which consists of an increasing linear piece and a connected decreasing linear piece. With some appropriate set of weight functions w_k, k=1,..,n, response function f is then defined at

$$\overline{x_k} = \frac{\sum_{i=1}^{n} w_k(x_i)\, x_i}{\sum_{i=1}^{n} w_k(x_i)}$$

by

$$f\left(\overline{x_k}\right) = \frac{\sum_{i=1}^{n} w_k(x_i)\, y_i}{\sum_{i=1}^{n} w_k(x_i)}$$

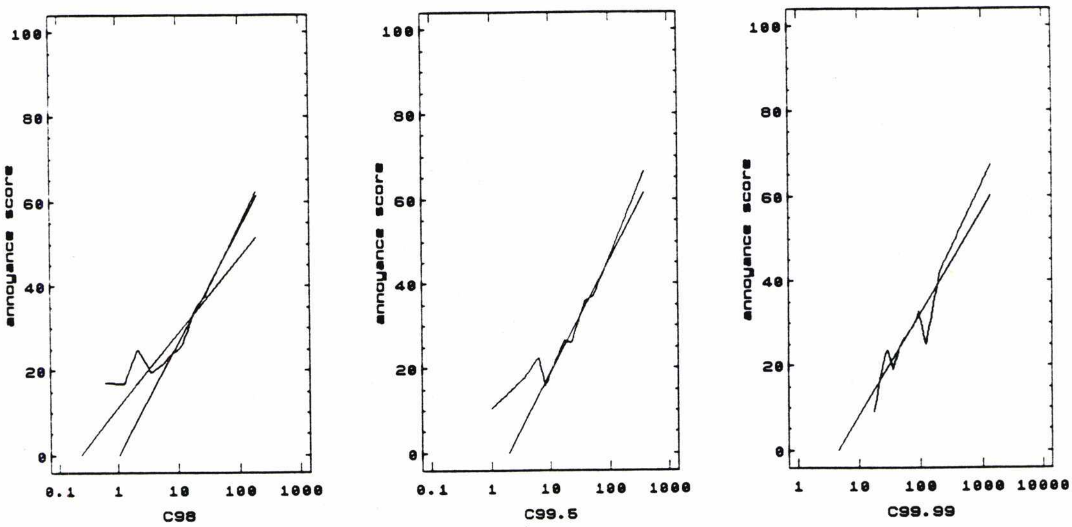
Figure 1 Annoyance score as function of exposure measures per location and study.



where x_i is the exposure level of respondent i and y_i equals 1 if his annoyance is above the cut off point and 0 if it is below. n is the number of respondents. Note that this procedure gives the common percentages when for each interval a weight function is chosen that is 1 on that interval and zero outside it.

In figure 1 annoyance score is plotted per location as a piecewise linear function of the exposure measures. The two curves that are separated from the rest in all three plots are for the chemical factory in the 1988a and in the 1988b study. The overall correlation coefficient for the other curves together is r = .39 .39 .39.

Figure 2 Annoyance score as piecewise linear and linear function of exposure measures. For explanation of the two straight lines in the left panel see text.

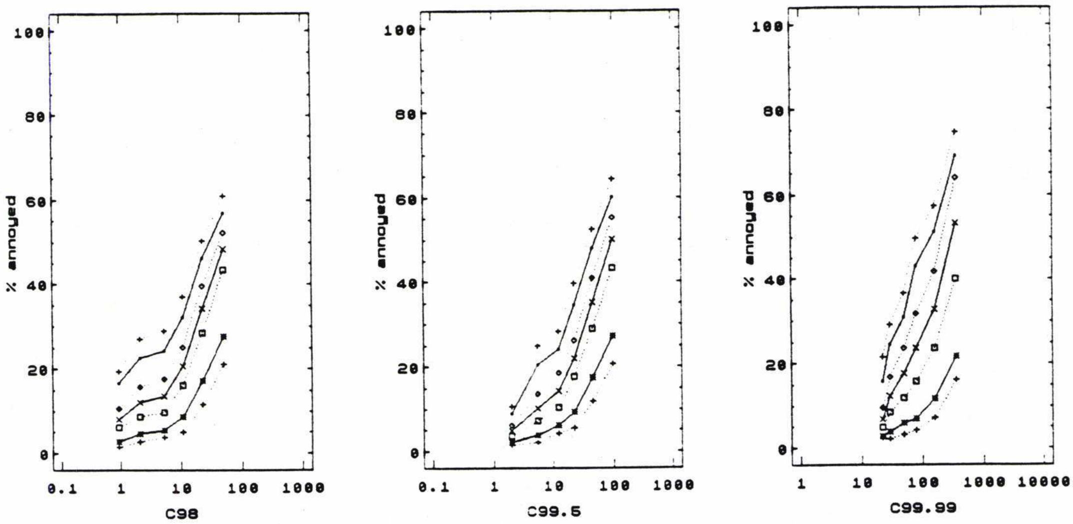


In figure 2 piecewise linear relations (r = .32 .36 .38) for the combined data, excluding the chemical factory, are shown. Since there are ten pieces, the function has considerable flexibility to take different shapes. The curve for $L_{99.99}$ exhibits more oscillations than the other two, presumably because it is based on less cases. The decrease of the correlation coefficient compared to the previous analysis, with separate curves for different locations and studies, is largest with L_{98}. An explanation for this could be that persons base their annoyance judgement on the highest levels, so that C_{98} would predict too little annoyance for sources with short emission periods ($F < .5$) relative to the annoyance predicted for sources with constant emission ($F = 1$) (see section 2.1). This explanation is supported by the following fact. For a source with considerably shorter emission periods than the others, included in the 1988a and 1988b study, the two curves are above the other curves when C_{98} is used but move towards them when $C_{99.5}$ or $C_{99.99}$ is used.

When above some threshold the true relation of annoyance with an exposure measure is linear, a somewhat 'distorted' picture will actually be found due to the fact that annoyance is categorized. The lowest annoyance score that can be attained is 7 - 10, depending on whether five or seven response categories were used. So below this threshold the annoyance *score* is expected to be constant at 7 -10 (or somewhat higher since errors can only go in one direction). Above the threshold the score increases with increase of exposure. When the true relation is indeed linear the rate of increase becomes constant at some point above the threshold. The true relation just above the threshold can then be found by extrapolation of this linear relation at higher levels.

In figure 2 straight lines ($r = .29$ .32 .36) are shown which are determined by linear regression restricted to cases with $L_{98} \geq 6$ ou m^{-3} and subsequent extrapolation to lower levels. For L_{98} two straight lines are shown. The least increasing one is obtained in the way just described, as are the straight lines for the two other exposure measures. The other is the straight line obtained for $L_{99.5}$ shifted about .3 to the left. For sources which emit at least about half of the time with a constant level the shifted line gives the best prediction of annoyance based on C_{98}. The shifted line is based on all data except for the chemical factory, using $C_{99.5}$ as exposure measure, and the shift of about .3 derives from the fact that for sources with $F < .5$ and meteorological condiditions as in the Netherlands $L_{98} \approx L_{99.5} - .3$.

Figure 3 Percentage annoyed as function of exposure measures. The cut off points for the curves are, from the bottom to the top, 80 72 60 50 40 28 and 20. Verbal labels for the percentages exceeding cut off points 72 50 and 28 (solid curves) are highly annoyed, annoyed respectively (at least) moderately annoyed.



In figure 3 the percentage annoyed is plotted as function of the exposure measures. The cut off points for the lines from the bottom to the top are 80, 72, 60, 50, 40, 28 and 20 (see chapter 3 for the scores of the annoyance category boundaries). The lines for 72, 50 and 28 are solid and the percentages are called the percentage highly annoyed, annoyed and (at least) moderately annoyed respectively.

The cut off points are the same as used in a large compilation study with respect to noise annoyance (Miedema, 1992a). The cut off at 72 is used because it was also used in a prior influential noise compilation study (Schultz, 1978). Schultz identified percentage highly annoyed with this percentage.

The percentages were calculated from the percentages obtained from the 1984/85 and 1988a study (all with five annoyance categories) and the percentages for each of both annoyance questions in the 1988b study (two responses with seven alternatives from same respondent). First the cumulative percentage for the successive category boundaries were determined. Where necessary the cumulative percentages for the above 'standard' cut off points were determined by linear interpolation. Then the percentages for both questions in the 1988b study were averaged with the number of responses on which they were based as weight. Finally, this was averaged with the percentages obtained from the 1984/85 and 1988a study, using the number of respondents on which percentages were based as weight.

It may be stressed that for sources which emit at least about half of the time with a constant level, the best way to obtain a percentages at a C_{98} level is by using the $C_{99.5}$ curves, shifted .3 to the left. The reasons for this are the same as discussed in relation to figure 2.

Figure 4 Road traffic noise (non-highway) that is equally annoying as an exposure to environmental odour.

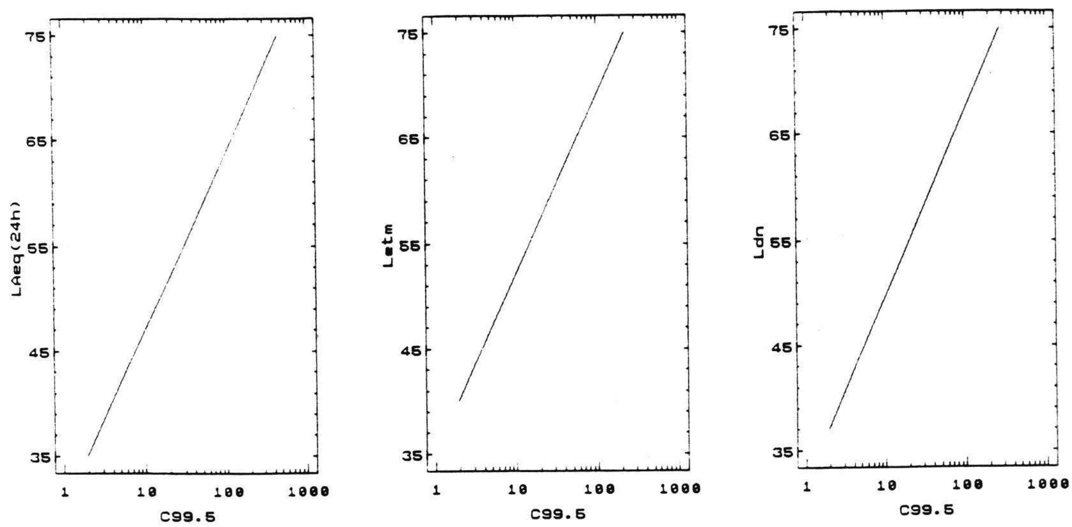


Figure 4 requires some introduction. In Miedema (1992a) the annoyance for several environmental noise sources is related to noise exposure measures L_{Aeq}-(24h), L_{etm} and L_{dn}. L_{Aeq}(24h) is 10 times the log of the average sound energy in a 24 hour period, with the contribution from different frequency bands weighted according to the sensitivity of the ear to that frequency. L_{etm} and L_{dn} are related measures, but with penalties for contribution in the evening and especially the night, when noise is believed to be more harmful. These are used in noise standards, the former in the Netherlands, the latter e.g. in the U.S.A..

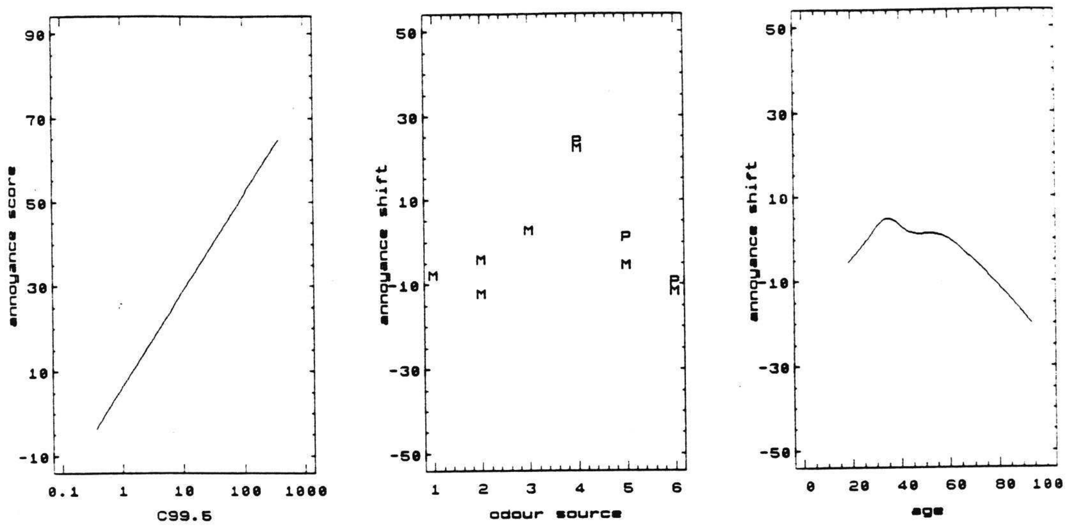
In Miedema (1992c) respondents rated the annoyance with similar categories for noise and odour sources separately, and they compared the annoyance from noise and odour sources. It was found that similar noise annoyance and odour annoyance ratings on separate questions indeed imply noise and odour are considered to be equally annoying when explicitly compared. It was concluded that similar categories represent the same degree of annoyance, irrespective of whether odour or noise is judged.

The results from these two studies and the straight line for annoyance score versus $L_{99.5}$ in figure 2 were used to make figure 4.

Vos (1992) explored the effect of several non-olfactory variables on the relation between exposure and annoyance. He used the data from the 1988a study. Factors as sex, perceived healthiness of the air, purity of the air or the amount of smoking in the living room did not influence the relation. But age and perceived risk did. Higher risk goes with higher annoyance. Contrary to the earlier expectations however, this did not explain the difference as evident in figures 1 between the chemical factory and the other sources. The earlier expectation was based on only chemical factory having a history of external safety problems.

The other studies did not include information on perceived risk, but the age of respondents is known. Figure 5 shows the effect of age. The analysis shown is similar to that in figure 1 with the curves per location and study. To reduce the number of parameters, an additive model and best fitting straight lines are used.

Figure 5 Linear relation of annoyance score with $L_{99.5}$ in an additive model with location and age (left). Shift per location and study (middle) and shift depending on age (right). M = 1984/85 and 1988a study, P = 1988b study. Sources are in the same order as in table 1. Source 2 was studied twice, in 1984 and 1985.



That is, curves per location and study are assumed to be obtainable from a single straight line by adding or subtracting a constant to (a piece of) that line. The single line is shown in the left panel, the constants to be added or subtracted per location/study in the middle. The values to be added or subtracted depending on the age are shown in the right panel. With constant exposure annoyance increases from 18 to about 35 years old, then decreases to a level that is stable until about sixty, where a sharp decrease starts. These result is similar to that found by Vos for the limited data set.

5. CONCLUSIONS AND DISCUSSION

The data analysed here all come from studies where annoyance is determined with a questionnaire and exposure with emission measurements combined with dispersion calculations. The main result is that for five, widely different types of odour sources the relation between $L_{99.5}$ and annoyance can be described by a single curve. For a sixth source a deviating relation is found.
There are differences in questionnaires (differently formulated questions and alternatives; used face-to-face versus by mail) and different measures for annoyance are employed (annoyance scores and percentages annoyed). The main result is robust with respect to these differences.
At present we do not have an explanation for the single deviation. The source was special in two ways. Different products were made in batches, each time with different odour emission. But the time fraction and emission measurements for each product were determined and combined in the immission calculations. And there had been some external safety problems in the past. But perceived risk as reported by the respondents could not explain the difference with the other sources.
The fact that $L_{99.5}$ is a somewhat better single predictor of annoyance than L_{98} is consistent with the hypothesis that persons base their annoyance judgement especially on the hours with maximal exposure.
An interesting result is the relation of annoyance with age. The trend found may be an indication for changes of the focus on environmental quality with age. The decrease at higher ages may be the result of deterioration of the odour sense.

An important issue is which relation can best be used to derive odour concentration immission standards from limits on the intensity and prevalence of annoyance. It appears most reasonable to use the straight line for annoyance score versus $L_{99.5}$ in figure 2 and the percentage versus $L_{99.5}$ curves in figure 3. They give a satisfying description for five of the six sources and can be applied to constant as well as intermittent sources. The deviation of the sixth source tells that in this way for some sources the adverse effect of odour exposure may be underestimated.

Results as figure 4 can be used to arrive at consistent evaluations of exposures to environmental factors, in this case (non-highway) road traffic noise and odour. For example, with figure 4 a rating system for odour exposure can be based on that proposed for noise in Miedema (1992a). However, there is a danger here that noise standards, which in a number of countries are already formulated, are translated via such figures to odour standards. But noise standards are, for pragmatic reasons, very permissive. Such a degree of permissiveness is from the health perspective undesirable.

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Projectnumber: 5114